On the Road to Stewardship

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Message from the Conference Chair

C. Leroy Irwin

As I reflected on what to say in this message I reminisced back several years ago to the beginnings of this conference. We, in Florida, were struggling with the issues of maintaining connectivity for wildlife habitat in a rapidly urbanizing state. As we began to search for information on the subject, we did not find much available. We learned that some activity was happening in Europe. As a result, in 1996 the first International Conference on Wildlife Ecology and Transportation (ICOWET) was held in Florida with international participation. About the same time, the Washington State Department of Transportation and the Center for Transportation and the Environment began a similar national conference on Transportation, Wetlands, and the Natural Environment (Connections '96). These two conferences joined together in 2001 in Keystone, Colorado, as the International Conference on Ecology and Transportation (ICOET).

Shortly after the 2001 ICOET meeting, AASHTO and FHWA sponsored an International Technology Scan Tour on Wildlife Mortality. Representatives of state DOTs, FHWA, federal resource agencies, and non-governmental organizations toured five countries in Europe to see first hand what was being accomplished in Europe to address wildlife mortality and the re-connecting of habitats there. The reports of that scan tour and several presentations at ICOET 2003 in Lake Placid communicated those findings to you in 2003.

In September 2005, nine years after the first ICOWET meeting in Florida, we opened the third ICOET in San Diego, California. The theme for ICOET 2001 was "A Time for Action," and the theme for ICOET 2003 was "Making Connections," and I have no doubt those objectives were achieved. The theme for ICOET 2005 was "On the Road to Stewardship." The stewardship theme emphasized that we have learned many things about the importance of maintaining habitat connectivity, but now, how do we protect and maintain the all-important habitats? I hope that you took away from the 2005 conference a desire to continue to work together to enhance the vital links between ecosystems and transportation systems.

It is gratifying to know that we had far more requests for presentations for this conference than could be accommodated in the agenda. I am sorry that some of you were not chosen to present. We wish to thank the planning committee for their hard work in selecting the best papers. It was not an easy task. I would also like to thank the sponsors — governmental, non-profit, and private — for without your support, this conference could not have taken place. Many environmental agencies, research institutions, public interest groups, and the transportation industry have shared their expertise. It is hoped that by this cross-functional sharing of information a better understanding of the ecological and social relationships will result.

Your hosts, the California Department of Transportation (Caltrans) and the University of California-Davis Road Ecology Center, organized two spectacular field trips that highlighted two types of ecological communities in Coastal and Inland San Diego County. Caltrans and the Road Ecology Center were also integral to developing two new special sessions on acoustics ecology, of which the papers or abstracts are contained in these proceedings.

As chairman of the conference I would like to express my appreciation to the Center for Transportation and the Environment for their assistance with organizing and co-sponsoring this conference and to Caltrans and the UC-Davis Road Ecology Center for their hospitality as conference co-hosts.

We met in beautiful Southern California, to share our thoughts, knowledge, and even to celebrate our successes, but let us remember that although we have come far, we still have much to learn and do. The conference has truly become an international, multi-disciplinary event with representatives from 15 nations. I hope that you enjoy these proceedings and use them to move forward to promote the conservation of our natural resources as we develop our transportation systems for the 21st century throughout the world. Make your plans now to join us at The Peabody Hotel and Convention Center in Little Rock, Arkansas, for ICOET 2007 (see www.icoet.net for more information). We hope to see you there!

C. Leroy Irwin
ICOET 2005 Conference Chair
Former Manager (Retired), Office of Environmental Management
Florida Department of Transportation

Special Sessions Overview

This year's conference included several new sessions and special events worth noting.

Acoustics Ecology

For the first time, ICOET addressed acoustics ecology issues as they relate to aquatic wildlife and birds. California has championed much work in this specialized area. The California Department of Transportation (Caltrans) was recognized by the Federal Highway Administration in 2005 for environmental excellence in ecosystems, habitat, and wildlife due to its "Fisheries-Hydroacoustics Mitigation for San Francisco Bay Bridges Work Group" initiative. This proceedings includes eight technical papers and abstracts from two sessions, organized by Caltrans and UC-Davis in cooperation with FHWA, on transportation and acoustics ecology advances in the U.S. and Europe. This subject will become a regular ICOET track in future conferences.

High-Speed Rail

As communities consider the implementation of high-speed rail corridors, the ecological implications are becoming increasingly challenging to identify and assess. ICOET 2005 included a high-speed rail session, organized and facilitated by Defenders of Wildlife, a long-time ICOET co-sponsor, to help states begin to investigate the general ecological impacts of high-speed rail, focusing on both positive elements and drawbacks, and also including an overview of the California high-speed rail proposal.

Integrating Transportation and Resource Conservation Planning

In keeping with the stewardship theme, ICOET 2005 included four sessions that explored approaches for integrating resource conservation issues earlier in the transportation planning process. Conservation banking, conservation planning, landscapes and road networks, and science and partnerships comprised the four session titles that featured initiatives from the U.S. as well as Switzerland and Taiwan. In addition, Defenders of Wildlife hosted an evening workshop, titled "Conservation and Transportation Planning in California," with a facilitated discussion on barriers to integration, solutions to these barriers, and proposed recommendations. The report and the presentations given at the workshop are available on Defenders' website: http://www.defenders.org/california/icoet.html.

Keynote Presentation

"Beauty and the Beast – Human Dimensions in Ecology and Transportation"
Dr. Bruce Leeson, senior environmental assessment scientist (retired) for the Parks Canada Agency, Western Service Center - Calgary, provided an outstanding keynote address on the evolution of and challenges associated with the human perceptions tied to the 30-year highway twinning project in Banff National Park. The project involved the construction of an unprecedented number of wildlife crossing structures, which have generated an exceptional body of research data on effective crossing structure planning, placement, and monitoring. Dr. Leeson discussed how the human factors associated with this project ultimately posed far greater challenges than the ecological or engineering factors. He encouraged attendees to consider carefully how to successfully engage the public throughout the course of transportation projects that have significant ecological impacts, as well as the importance of educating the public on the complex and dynamic relationship between wildlife and transportation issues.

ICOET Steering Committee Member Recognitions

At the conference closing session, ICOET 2005 Chair Leroy Irwin recognized two of ICOET's "founding fathers," who recently retired from Federal service: Fred Bank, team leader for the Water and Ecosystems Team, Office of Natural and Human Environment, FHWA Headquarters, and William (Bill) Ruediger, ecology program leader for highways, USDA Forest Service – Washington Office. Mr. Bank and Mr. Ruediger helped to construct the vision for ICOET and to mobilize the agency resources necessary to achieve that vision throughout the conference's nine-year history. Throughout their careers, they have shown leadership, foresight, and an unwavering commitment to achieving environmental excellence in transportation.

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Chapter 1

Overview of Federal and International Activities

Overview of Select Provisions from SAFETEA–LU

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Abstract

The new transportation bill was passed in August 2005. It is a 5-year bill with new environmental provisions that are directly related to the areas of interest addressed at ICOET. Below are quick summaries of the key provisions. Some require regulations and guidance to be prepared by the Federal Highway Administration. Since the bill is still so new, work is still underway to get this guidance out.

Title 1 Subtitle A – Authorization of Programs

- Sec. 1113: Changes the State's Transportation Enhancement set aside to the greater of 10 percent of State STP apportionment or the amount set aside for FY2005. Transportation Enhancements projects which may include reduced vehicle-caused wildlife mortality while maintaining habitat connectivity.
- Sec. 1119:
  - Not to exceed $ 10 million per fiscal year. Shall be used for the costs of facilitating the passage of aquatic species beneath roads in the National Forest System.
  - Wildlife Vehicle Collision Reduction Study

Title 1 Subtitle D – Highway Safety

- Sec. 1401: The addition or retrofitting of structures or other measures to eliminate or reduce accidents involving vehicles and wildlife (may use safety funds).

Title 1 Subtitle H – Environment

- Sec. 1805: Use of Debris from Demolished Bridges and Overpasses. May involve the beneficial use of debris to construct features such as artificial reefs and other marine habitat creation or ecological restoration work in general.

Title V Research

- Sec. 5201: Exploratory Advanced Research. $14 million per year for 2005-2009 is authorized for an exploratory advanced research program to address longer-term, higher risk research, including environment.
- Sec. 5203: Technology Deployment. Innovative Pavement research and Deployment Program. One of the stated goals of this program is to, under subpart (H), develop designs and materials to reduce stormwater runoff.

Title VI – Transportation Planning and Project Development

- Sec. 6001: Transportation Planning.
  - Metropolitan Planning – Development of Long Range Statewide Plan must include "a discussion of potential environmental mitigation activities and potential areas to carry out these activities in consultation with Federal, State, and Tribal wildlife, land management, and regulatory agencies.
  - Statewide Planning — Development of Long Range Statewide Plan must include "a discussion of potential environmental mitigation activities and potential areas to carry out these activities and potential areas to carry out these
- Sec. 6002: Efficient Environmental Reviews for Project Decision Making.
  - Mandates a new environmental process for highway projects advanced with EISs.
  - Describes the USDOT's role as lead agency.
  - Creates a new category of "participating agencies."
  - Bars filing claims for judicial review of a permit, license, or approval by a Federal agency unless it is filed within 180 days after publication of a notice in the Federal Register.
  - Authorizes States to assume the Secretary's authority for determining that projects are categorically excluded from requirements for EIS or EA.

    - Allows State to assume other environmental review responsibilities of the Secretary on categorically excluded projects.
- Sec. 6006 – Environmental Restoration and Pollution Abatement: Control of Noxious Weeds and Aquatic Noxious Weeds and Establishment of Native Species.
    - The first portion (pollution abatement and restoration) extends the existing STP eligibility to the NHS.
    - The second portion is a new eligibility item that promotes the detection and eradication of noxious weeds and establishes a preference to the extent practicable for the planting of native plant species.

Biographical Sketch: Mary E. Gray has been with the Federal Highway Administration for 15 years. She currently works for the headquarters of the Office of Natural and Human Environment, specializing in the Endangered Species Act and wildlife crossings. She has also worked in California, Idaho, and Washington. Her responsibilities have included right-of-way, engineering, and the environment. Because of her responsibility as state environmental program manager, she has worked in almost every environmental area. Mary has degrees in environmental studies and geography from the University of California, as well as a master's degree in civil engineering from Stanford University.

Reducing Habitat Fragmentation by Roads: A Comparison of Measures and Scales

Organized Oral Session at the INTECOL-ESA 2005 Joint Meeting in Montreal, August 7th to 12th, 2005

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Abstract

Introduction

Concern is growing over the fragmentation of habitats by roads and other transportation infrastructure. A number of measures to avoid, minimize, mitigate, or compensate for the detrimental effects of such fragmentation have been suggested.

These are geared to specific scales, from culverts at the scale of a single road to plans for re-connecting habitats across entire countries or continents. They include the removal of roads, building of overpasses and underpasses at roads and railways to increase permeability for animals, restoration or creation of wildlife corridors and networks of wildlife corridors across transportation infrastructure, and the design of less fragmenting road network patterns, e.g., the bundling of traffic lines.

However, it is still unknown which measures are the most effective in terms of restoring ecological processes. The investigation of their effectiveness, therefore, is an important and most urgent task because the most effective measures should be applied predominantly in order to use resources most efficiently.

How can the effectiveness of such measures be evaluated (criteria and methods)? For example, possible criteria for the effectiveness of crossing structures are the reduction of road-kill frequencies, increased passage frequencies, presence of species on both sides of the road, genetic exchange across the road, recovery of lowered reproductive rates and skewed sex ratios, re-colonization success, recovery of skewed foraging intensities among foraging areas on either side of the road, and recovery of skewed predation rates. More generally, the measures should enhance landscape connectivity and restore ecological processes among habitat patches and across landscapes.

During the last three years, considerable progress on measuring the effectiveness of such measures has been made in both Europe and North America. This session brought together the “Father of Road Ecology” Richard Forman with researchers from Europe (Austria, The Netherlands, etc.) and North America working at different scales and in different locations. They presented current methods and results on the success of various mitigation measures to foster cross-scale comparison and synthesis on this topic. The presentation included empirical studies, synthetic overviews, modeling studies, and conceptual studies.

List of abstracts and talks

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1. Forman, R. T. T. 2005. Integrating traffic, network location, and surrounding habitat to create a connected landscape. Harvard University, Cambridge, Massachusetts.

   Using simple spatial models, three key variables (traffic, location in network, and habitat arrangement relative to roads) are evaluated for their effects on habitat loss, degradation and fragmentation. Although the overall approach may be new, parts of the picture have been successfully applied in, e.g., Germany, Netherlands, Massachusetts, Florida and New Jersey.

   First, the values of large patches (natural habitat), high connectivity, and small patches are used to ecologically evaluate a road segment, plus a road network, relative to the spatial arrangement of large patches, small patches, wide corridors and narrow corridors. Overall, a gradient emerges from the best arrangement (small habitat patch in center of a network enclosure) to the worst (large patch dissected by network). The best location for a road passing between two large patches is part way between the mid-point and a patch edge.

   Second, the curvilinear relationship between road traffic and wildlife crossing, as well as between traffic (noise) and effect distance on wildlife, are added to the analysis, along with spatial differences between natural and agricultural or suburban landscapes.

   Based on habitat loss, degradation, and fragmentation, the ecologically worst situations are high and medium traffic in a natural area and high traffic alongside a large natural patch in an agricultural/suburban landscape. For a given traffic flow, the best network form has a few large enclosures and is characterized by a few busy roads.

Further modeling of network forms, traffic, and habitat arrangements, plus empirical field studies, should convert the patterns uncovered into principles for transportation, ecology and society.

Keywords: ecological effects of traffic, ecology of network form, habitat arrangement relative to roads, roads and habitat loss, degradation and fragmentation.

2. Bissonette, J. A. 2005. Taking the road less traveled: The importance of scaling indirect road effects allometrically. United States Geological Survey Utah Cooperative Fish and Wildlife Research Unit, College of Natural Resources, Utah State University, Logan, Utah.

The roaded landscape has both direct and indirect effects on ecological patterns and processes. In particular, animal movement is especially hindered as road density increases. Although barrier effects are not similar across all roads, the effects of road geometrics (e.g., road type, width, presence of fences) present significant problems to animals, resulting in fragmented habitats and often isolated populations.

Mitigation to decrease barrier effects includes, among other things, the construction of crossing structures of two general types; those that cross over the road, and those that provide passage underneath. The number, type, configuration, and placement of crossing structures will determine whether permeability is restored to the roaded landscape.

By permeability, I refer here specifically to the ability of species of all kinds to move relatively freely across the roaded landscape. By my definition, landscape permeability differs from the term connectivity: permeability implies the placement of crossing structures allometrically scaled to the organism; connectivity as I define it here refers to the human perception of how connected the landscape matrix is, irrespective of organism scaling.

As Wiens pointed out (*1989 Functional Ecology 3:385-397*), scale dependency in ecological systems may be continuous or not. I suggest that whether it is or not, it may be possible to find domains of scale for groups of species for which animal movement scaling functions can be identified and used to guide the placement of appropriate types of crossing structures. Early work has suggested a relationship between metabolism rate and home range size. Bowman et al. (*2002 Ecology 83(7):2049-2055*) argued that dispersal distance of mammals is proportional to home range size.

To the extent that these arguments hold, it may be possible to identify allometrically scaled domains of movement that presumably include similar sized animals. If this is possible, the placement of appropriate types of crossing structures can be accomplished in a scale informed and sensitive manner, resulting in a permeable roaded landscape. In this paper, I explore these ideas with evidence and analyses.

Keywords: scaling, roads, permeability, connectivity.

3. Beier, P., K. L. Penrod, C. Luke, W. D. Spencer, and C. R. Cabañero. 2005. The Missing Linkages Project: Restoring wildland connectivity to southern California. Northern Arizona University, Flagstaff, Arizona.

In Fall 2001, the groundbreaking Missing Linkages report identified 232 wildlife linkages in California. South Coast Wildlands immediately spearheaded an effort to prioritize, protect, and restore linkages in the South Coast Ecoregion.

We first forged a partnership with 15 federal and state agencies, conservation NGOs, universities, county planners, and transportation agencies. By partnering from the start (rather than developing a plan on our own and asking others to “unite under us”), we garnered spectacular support and are making rapid progress. With our partners, we (1) selected 15 priority linkages (out of 69 linkages in the ecoregion) on the basis of biological importance (size and quality of core areas served) and vulnerability; (2) held workshops to identify 12 to 20 focal species per linkage; (3) researched the needs of focal species, obtained high-resolution spatial data, conducted GIS analyses, and collected field data to develop a linkage design; and (4) presented the design to partners who are now procuring easements and land, changing zoning, restoring habitat, and mitigating transportation projects.

Our collaborative, science-based approach provides a template for creating a green infrastructure in even the most human-dominated landscapes. A more recent effort in Arizona is being led by state and federal transportation agencies. These efforts promise not to merely slow down the rate at which things get worse, but rather to create projects that will improve connectivity for wildlife.

Keywords: corridors, wildlife linkages, reserve design, habitat fragmentation by roads.

4. Jaeger, J. A. G. and L. Fahrig. 2005. Effects of bundling of roads on population persistence. Swiss Federal Institute of Technology ETH, Zurich.

Roads act as barriers to animal movement, thereby reducing the accessibility of resources on the other side of the road. They also increase wildlife mortality due to collisions with vehicles, and reduce the amount and quality of habitat. The strength of these effects depends on the amount of traffic. To minimize these effects, the bundling of roads and traffic has been suggested because it keeps as large areas as possible free from disturbances due to traffic.

This can be done in two ways: avoiding the construction of new roads by upgrading of existing roads and placing new roads close and in parallel to existing roads. However, this suggestion has been criticized because the accumulated effects of several roads bundled together, or an upgraded road with more traffic on it, may create a stronger overall barrier effect that may be more detrimental to population persistence than the even distribution of roads across the landscape. We used a spatially explicit individual-based simulation model of population dynamics to evaluate the effectiveness of road and traffic bundling. We compared the probability of population persistence and the time to extinction for three different road configurations and different types of animal behavior at the road, when traffic volume was varied.

Our results support the bundling concept. Population persistence was generally better when all traffic was put on one road than when it was distributed on several roads across the landscape. If traffic cannot be combined on one road, our results suggest it is better to bundle the roads close together than to distribute them evenly across the landscape.

Keywords: barrier effect, road effects, spatially explicit population model, traffic mortality.

5. Zink, R., R. Grillmayer, F. Reimoser, F. Völk, and M. Woess. 2005. Reducing habitat fragmentation: Strategies, scales, and implementation in Austria. University of Veterinary Medicine, Research Institute of Wildlife Ecology, Vienna, Austria.

In Europe nowadays, migration and genetic interchange for wildlife species crucially depend on the location and distribution of barriers such as motorways. We illustrate the emergence of wildlife passageway concepts, their legislative implementation in Austria and present some case studies.

In addition to an increase of transit, the central, geographic characteristics and position of Austria combined with extended road construction has impacted the ability for wildlife to migrate. Especially in Alpine valley regions, residential areas and highways are concentrated, and they often irreversibly prohibit wildlife passage. Although historical migration routes and corridor areas for wildlife were not appreciated in the past, this topic is intensively studied today.

Substantial lobbying has led to better public understanding and resulted in legislative changes. Authorities and transport planning officials, regional planners, game managers, farmers, foresters, hunters and conservationists cooperated to put the results into practice. A federal directive (RVS 3.01, FSV 1997) to reduce traffic accidents and road-kills began a series of measures to restore landscape connectivity in Austria. Passageways and migration corridors are an inherent part of wildlife ecological spatial planning (Reimoser 2002) and have been included in regional land-use regulation.

In order to provide an overview about potential migration corridors in Austria, a GIS-model at the University of Natural Resource and Applied Life Sciences was developed. This model is based on land-cover data and spatial resistance for wildlife mobility (Grillmayer et al. 2002). The outcome provides information about habitat fragmentation and potential migration routes for the umbrella species red deer and brown bear.

Additionally, terrestrial surveys have been undertaken and more than 3,500 bridges have been evaluated for passage possibilities (Volk et al. 2001). We combined potential migration routes and dividing road networks to determine high-value, key patches for migration. The construction of several 'green-bridges' in cooperation with the Austrian highway operator ASFINAG has occurred. It is also partly financed by the European Union and is only one example that proves our effort to succeed on national and international levels.

Keywords: habitat fragmentation, wildlife corridor, modeling, spatial planning.

6. van der Grift, E. A. and J. Verboom. 2005. Patch-based monitoring to assess the effect of wildlife passages on the viability of metapopulations. Alterra, Wageningen University and Research Center, Wageningen, Netherlands.

It has been proven that wildlife crossing structures, such as badger pipes, amphibian tunnels, or wildlife overpasses, are frequently used by a variety of species. However, it is not clear yet if these defragmentation measures affect population viability. Transport corridors, as well as accompanying mitigation measures, affect populations in a complex way. Wildlife passages may improve reproductivity, reduce mortality, and increase both immigration and emigration. Wildlife fences prevent mortality, but increase, at the same time, the barrier effect of transport corridors, resulting in a decline in gene flow or a reduced recolonization probability.

Considering these complex relations between mitigation measures and population dynamics, monitoring the effectiveness of defragmentation measures is not an easy task. Based on metapopulation theory, we suggest a so-called patch-based monitoring to measure the effects of wildlife crossing structures at transport corridors on the survival of populations.

In this method, the presence or absence of a species is assessed in all spatially distinct habitat patches suitable for the species. Presence in a habitat patch is as important as absence, based on the characteristics of metapopulations that not all suitable patches are inhabited simultaneously at a certain moment in time and that over time, populations become locally extinct and habitat patches become recolonized again.

Survey results can be statistically compared with model predictions of the probability that a species occurs in each habitat patch, based on differences in patch size, isolation, and patch quality, as well as characteristics of the species itself such as dispersal capacity. In such predictive models, the barrier effect of infrastructure as well as the defragmentation effect of wildlife crossing structures can be included.

To prove an effect of defragmentation measures on population viability, both study species and study sites should be carefully selected. Study species should, among others, be sensitive to both fragmentation impacts by transport corridors and defragmentation impacts by mitigation measures. Study sites can be best chosen at locations where defragmentation measures will result in a considerable shift in population viability. Surveys should preferably be conducted over many years.

Keywords: population viability, wildlife passages, defragmentation, patch-based monitoring.

7. Reck, H., M. Böttcher, K. Hänel, and A. Winter. 2005. German Habitat Network: Effects of fragmentation in Germany and solutions to preserve, restore, and develop functioning ecological interrelationships. Christian-Albrechts-University, Kiel, Germany.

The ecological and legal situation is that Germany's traffic is the densest worldwide: 1.8 km road/km2, 4.9 percent traffic areas; traffic density is 1.750.000 km driven by car/a km2. Less than 23 percent of Germany consists of areas least 100 km2 in size which are undivided by heavy traffic. Urban areas cover 6.5 percent of land. Agriculture and forestry is intensive.

As a consequence, we find extreme deficiencies of up to 80 percent in ground beetle communities in isolated habitats and similar effects in other taxa as well as deficiencies in genetic diversity, and we find that road kills are a threat even to fast-moving mammals.

Therefore, in 2002 a new article was added to the Federal Nature Conservation Act, covering at least 10 percent of the total area, a network of interlinked biotopes must be designed and every new project has to undergo an impact-regulation procedure if it may impair the ecosystem.

Draft of the German Habitat Network. For execution of the law, a first sketch of a network was carried out as an integrated approach to preserve, restore, and develop functioning ecological interrelationships, not only for maintaining species diversity, but also for human use.

The lecture reviews the aims and methods used in setting up this draft in the scale of 1:750.000. It is basic information to identify priorities for minimizing ecological barriers and to identify priorities for mitigation or compensation of future impacts; so it is essential information in impact assessment procedures. The draft is also a request to improve landscape data and knowledge necessary for developing landscape corridors and stepping stones in more detailed scale.

Current activities: In order to improve motivation, design and execution, especially research on ecological needs and capabilities for migration of representative target and keystone species (plants, insects, mammals) is in demand. At present, four approaches supported by the Federal Agency for Nature Conservation shall enhance knowledge: 1. Identifying most-important habitats and best-fitting corridors within Germany using new land cover data and GIS algorithms, 2. Compiling ideas for international linkages, 3. Metaanalysis for an integrative assessment of barrier effects (connected with a combination of metapopulation models with movement modeling of target species) 4. Assessment of the benefits of undivided areas with low traffic.

Keywords: impact assessment, mitigation, habitat corridors, modeling migration.

8. Adriaensen, F. and E. Matthysen. 2005. Using least-cost models to plan and evaluate measures reducing habitat fragmentation by roads. University of Antwerp, Department of Biology, Campus Drie Eiken, Antwerp.

The growing awareness of the adverse effects of habitat fragmentation on natural systems has resulted in a rapidly increasing number of actions to reduce current fragmentation of natural systems, as well as a growing demand for tools to predict and evaluate the effect of changes in the landscape on connectivity in the natural world. Recent studies have used least-cost modeling (available as a toolbox in GIS systems) to calculate effective distance, a measure for distance modified with the cost to move between habitat patches based on detailed geographical information on the landscape as well as behavioral aspects of the organisms studied.

We will discuss the modeling technique, as well as some results of the application of the method to a small-scaled agricultural system subject to different scenarios (e.g., tree lines along road sides) and to the construction of a wildlife bridge across a highway. Least-cost modeling is not a tool to measure effectiveness of mitigating measures. The key role for least-cost models is in the planning phase, in modeling the potential effects of measures given that these measures will function as predicted.

There are some very important aspects on restoring connectivity that may be modeled using least-cost models. Different locations for mitigating measures can be evaluated for their effect on a local as well as on a larger scale, taking into account other corridors and barriers even if they are located at some distance . Different locations can be evaluated for their accessibility from source populations of the target species. Especially in complex landscapes, the evaluation of different scenarios may become a very complex problem. Least-cost models are able to generate more integrated landscape-wide 'pictures.'

The model is shown to be a flexible tool in scenario building and evaluation in wildlife protection projects and applied land/infrastructure management projects. (F. Adriaensen et al. 2003. The application of 'least-cost' modeling as a functional landscape model. *Landscape and Urban Planning* 996, 1-15).

Keywords: least-cost, modeling, landscape connectivity.

9. Strein, M., R. Suchant, and M. Herdtfelder. 2005. Aggregated wildlife road kills as indicator for wildlife corridors at different scales: Modeling for practical application. Forstliche Versuchs und Forschungsanstalt, Baden-Wuerttemberg, Freiburg, Germany.

Annually more than 200,000 larger mammals are killed through traffic in Germany, of which 20,000 are counted for the federal state of Baden-Wuerttemberg. These accidents cause about 3,000 injuries and kill about 50 people. The direct damages without the costs of the peoples economy amounts to more than 400,000,000 Euro.

For most wildlife in Germany road mortality ranks among the main causes of death; respectively the populations of rare species suffer from landscape fragmentation by traffic infrastructure and substantial impairment of ecological functions that are especially contradictory to the ranges of larger mammals. However, large mammals are among the decisive indicators for the functionality of wider ecological relations in cultivated landscapes.

Our actual work is based on research about potential wildlife corridors in Baden-Wuerttemberg, where we found out that many wildlife road kills are concentrated over long time periods in very short traffic sections of maximal 500 meters. For that reason, foresters, hunters and road-maintenance personnel all over Baden-Wuerttemberg were questioned for the location of short traffic sections with aggregated road kills, number and concerned species of annual wildlife road kills and possible installed measurements of prevention.

Surprisingly, about 40 percent of the total of 20,000 wildlife road kills in Baden-Wuerttemberg is concentrated in about 1,000 short road sections. The analysis of the landscape ecology in the environment of these road sections allows us to differentiate between different causes, as well as to calculate or predict collision risks at already-existing or planned traffic infrastructure. Therefore, we will identify and describe landscape parameters of these road sections with aggregated road kills that locate wildlife corridors on a regional landscape level and higher. These results are directly used in modeling for the parameterization of wildlife corridor models and compared with traditional wildlife routes, as well as with the results of the former project Wildlife Corridors in Baden-Wuerttemberg.

Therefore, the number of wildlife collisions does not only correlate with the abundance of a certain species and a given traffic volume, but under certain circumstances it is beyond dependent on wider functional landscape ecological relations.

Keywords: wildlife road kills, fragmentation, road ecology, modeling.

Biographical Sketch: Jochen A. G. Jaeger is a postdoctoral fellow in the Department of Environmental Sciences at the Swiss Federal Institute of Technology Zurich (ETH Zurich), Switzerland, with Prof. Dr. Klaus Ewald. He studied physics at the Christian Albrecht University in Kiel, Germany, and at the ETH Zurich. He received his Ph.D. from the Department of Environmental Sciences at the ETH Zurich. He has held a position at the Center of Technology Assessment in Baden-Württemberg in Stuttgart, Germany, and has lectured at the University of Stuttgart, Germany. In 2001, he won a two-year research grant from the German Academy of Natural Scientists Leopoldina and went to Carleton University in Ottawa, Ontario, Canada, as a postdoctoral fellow with Dr. Lenore Fahrig in her Landscape Ecology Laboratory (Department of Biology). Dr. Jaeger is currently working on his habilitation thesis, funded by a research fellowship from the German Research Foundation (DFG). His research interests are in landscape ecology, quantification and assessment of landscape change, assessment of the suitability of landscape metrics, environmental indicators, road ecology, modeling, urban sprawl, and novel concepts of problem-oriented transdisciplinary research.

Stewardship on the Horizon: Integrated Planning in the 21st Century

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Abstract

Currently, highway projects are planned, funded, and designed before considering the potential impacts to wildlife and habitat. Often, this can lead to expensive delays, lawsuits, and unnecessary loss of habitat. Streamlining project delivery and reducing unnecessary delays is important to state transportation agencies. By utilizing natural-resource data in early stages of planning, state transportation agencies can avoid, minimize, and mitigate early and avoid costly delays later in the life of their projects.

As part of the federally funded State Wildlife Grants Program, all state fish and wildlife agencies have recently completed comprehensive, wildlife conservation strategies, called State Wildlife Action Plans. These Action Plans will prioritize efforts and maximize investments to protect the state's natural resources. While fish and wildlife agencies are leading the charge, the aim is to create a strategic vision for conserving the state's wildlife–not just a plan for the agency.

Each Action Plan includes eight required elements, including "distribution and abundance of wildlife species" and "descriptions of locations and relative condition of key habitats and community types." Many states produced maps of prioritized habitat throughout the state. Correspondingly, the new transportation bill, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) included provisions that integrate consideration of wildlife conservation into the transportation planning process.

Under the new law, each metropolitan planning organization (MPO) and state department of transportation (DOT) will consult with resource agencies in developing long range transportation plans and compare the transportation plan with conservation maps or natural resource inventories–such as the new State Wildlife Action Plans.

The State Wildlife Action Plans are an opportunity for states to adopt a proactive approach to habitat conservation and an effective tool for transportation planning. For the first time, transportation agencies will have access to comprehensive natural-resource data at the planning stage, rather than waiting until environmental review.

Biographical Sketch: Trisha White is the Director of Defenders of Wildlife's Habitat & Highways Campaign at their national headquarters in Washington, D.C. The Habitat & Highways Campaign seeks to reduce the impact of surface transportation infrastructure on wildlife and encourage state and local authorities to incorporate wildlife conservation into transportation and community planning. In partnership with the Surface Transportation Policy Project (STPP), Trisha authored a best practices report, *Second Nature: Improving Transportation Without Putting Nature Second*, which has since been awarded the 2004 Natural Resource Council of America Award of Achievement for best publication. White is also:

- International Conference on Ecology and Transportation (ICOET) sponsor and member of steering and program committees
- Member, Federal Highway Administration's Europe Scan tour on wildlife mortality
- Member, Transportation Research Board Task Force on Ecology and Transportation
- Board Member, Southern Rockies Ecosystem Project

Prior to Defenders, Trisha spent three years with World Resources Institute's Biological Resources program and one year as environment policy consultant to the U.S. Agency for International Development's Global Environment Center. In 2000, she received her Masters degree in environment & resource policy from the George Washington University.

Update IENE and Other New European Actions

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Abstract

The following contains general information about some important issues concerning habitat fragmentation due to linear infrastructure and measures taken to counteract this phenomenon.

COST 341

At the International Conference on Ecology and Transportation (ICOET) 2003, I presented an overview of COST 341. This European action, ordered by the European Union (EU), was initiated by the Infra Eco Network of Europe (IENE). The action concluded in November 2003 with a well-attended international conference in Brussels. At this conference, we appreciated it very much that several ICOET representatives attended. As the official chairman of the conference, I gave a piece of the jigsaw to Mary Gray to remind the Federal Highway Administration (FHWA) to continue with the subject and to use the information.

At the conference, the products of the COST 341 action were presented. These products include the *European Review*, the handbook, the national state-of-the-art-reports, and the database.

The Handbook of Cost 341 was translated to national versions for several countries. In each version of the handbook, specific, nationally oriented comments and questions were added. This was done in the Czech Republic, France, the Netherlands, Norway, Sweden, and Switzerland. In several of the 18 connected countries inside the action, the national working groups still exist as groups of well-informed people concerned about habitat fragmentation due to linear infrastructure.

Also very important is that the network of people at the international level is still vital. When there is a need for information, a second opinion, or advice, a COST 341 colleague is willing to give assistance. This is only possible because there is a network of capable and involved people.

The information gathered in COST 341 was the basis of several contributions at conferences concerning environmental issues in general or habitat fragmentation specifically. At the World Road Association (PIARC) 2003 World Congress in Durban, the results of COST 341 were presented as well. Habitat fragmentation now is included in the work of PIARC in Technical Committee (TC) 2.1, Sustainable development and road transport. I am responsible for the action mitigation of the environmental impact of road transport, one of several actions under this TC. This technical committee sent out a questionnaire to contacts all over the world, and we will hope to have enough feedback to produce some practical recommendations on how to handle fragmentation in our report to the next World Congress in Paris 2007.

At conferences in France, Italy, the Netherlands, and Poland this information was given to other people for use in other situations.

Some general developments with big impact in Europe

Previously, there were several EU directives concerning environmental issues around transport. Four of note include: the Habitat and Bird Directive, Soil Directive, Noise Directive, and Air Quality Directive. These directives must be implemented in the national legislation of each country that signed such a directive.

These EU directives have a big influence on policy and legal aspects concerning nature protection and environmental issues along roads and rail lines. For example, the Air Quality Directive, which is already implemented in Dutch legislation, was enforced in this year and caused reconstruction plans to be stopped. A Dutch high court decided that the expected pollution levels would be too high. That means that the reconstruction was postponed until the expected impact has been measurably decreased. This court decision gave an enormous push to the research and measures involving air pollution due to traffic.

Since 2004, there have been 10 new member nations added to the EU. The bilateral contacts intensified rapidly. There is an enormous increase of travel and cargo trade to and from these countries. And with this increasing amount of movement, there is a big need for new motorways and improvement of roads. This urgent need demands knowledge and for a new set of cooperation tools.

These new countries must fulfill the regulations for road-building activities ordered by the EU directives. That is an important reason for several bilateral contacts, projects, and programs to exchange knowledge and information. So at this moment (September 2005), there is a conference in Poland where the 10 new EU countries are discussing the possibilities and tools for environmental impact assessments and strategic environmental assessments.

Some developments in the Netherlands

In the new handbook (Leidraad aunavoorzieningen; see http://www.rwsnatuurenlandschap.nl), there is a lot of information about approaches, procedures, and ideas for defragmentation measures.

The Long-Term Defragmentation Program has been launched and has been accepted by Parliament. In this program three ministries (Agriculture, Nature Protection and Food; Transport, Public Works and Water Management; Spatial Planning and Housing) give their intentions, including work schemes and money to counteract fragmentation due to national infrastructure (motorways, canals, and rail). This program is to solve the problems in the ecological main structure, including the robust zones inside that main structure. The approach in this long-term program is area-oriented, integrated, and based on cooperation between involved parties in the region.

Biographical Sketch: Hans Bekker graduated from the Agricultural University of Wageningen as an engineer. He works at the Road and Hydraulic Engineering Institute (DWW), an inside advisory unit of the Ministry of Transport, Public Works and Water Management in the Netherlands. Bekker is a program leader working mainly with wildlife, roads, and traffic. He functions as a bridge between civil engineers and ecologists. He was chair of the European project COST 341: Habitat Fragmentation due to Transport Infrastructure. He is program leader for the Dutch Long-Term Defragmentation Program. He is a member of the steering committee of the International Conference on Ecology and Transportation (ICOET), where he represents the Infra Eco Network Europe (IENE).

Chapter 2

Acoustics Ecology

Aquatics Issues

Assessing the Impact of Pile Driving Upon Fish

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Abstract

Pile driving associated with the removal and reconstruction of a jetty was monitored at a busy harbor in the North East of Scotland, adjacent to an important Atlantic salmon river. The main concern was with the impact of noise upon salmon migrating through the lower part of the river estuary. Pile driving was allowed to proceed subject to an agreed program of works to monitor sound levels and ensure least disturbance to salmon.

Both percussive and vibratory pile driving took place. Sound-pressure levels from both were measured. Percussive pile driving involved the repeated striking of the head of a steel pile by a double-acting hydraulic hammer, with a 5 tonne ram weight operated with a mean stroke of about 1 m. Vibratory pile driving was achieved by means of a variable eccentric vibrator attached to the head of the pile.

The majority of piles were initially driven into the substrate by vibration, over a period of several minutes. Each pile was then subsequently driven to its full depth with a sequence of repeated hammer blows. Steel facing piles were inserted adjacent to the quayside and subsequently backfilled to provide a new frontage to the quay. Diagonal-bearing piles were also inserted well behind the quay to strengthen the adjacent roadway.

Sound pressure levels generated by pile driving in water were measured using a calibrated hydrophone suspended 1 m above the bottom. The hydrophone was connected to a low-noise amplifier, which controlled the signal gain and bandwidth. The output was connected to a laptop PC by a digital audio interface. When recording at close range, where sound levels were especially high, a less-sensitive hydrophone transducer was used, connected directly to the audio interface. All sound recordings were made as 16-bit WAV files. For some of the piles, particle-velocity amplitudes were measured by means of an assembly of three orthogonally mounted, calibrated geophones placed on the seabed.

The sound-pressure levels (SPL) of the background noise and vibro-piling noise were measured as a root-mean-square (rms) level expressed in decibels relative to a reference level of one micro Pascal (dB re 1μPa). The shorter-duration impulsive sounds generated by the individual blows of the pile-driver hammer were measured in several different ways: the peak pressure reached during the impulse, the rms pressure measured over the time period that contained 90% of the sound energy (rms impulse), and as the sound-exposure level (SEL) expressed in dB re 1μPa2-s. The latter was defined as the constant sound level of 1s duration that would contain the same acoustic energy as the original sound. Sound levels were converted to source levels (SL), i.e., normalized to an equivalent noise level at a distance of 1 m. In all SL calculations, it was assumed that the spreading loss was represented by the expression 15 log R where R was the distance in meters.

Received sound level in water may be expressed in terms of sound pressure, particle velocity, or intensity, all of which can vary with time over the duration of the sound. In this study, the majority of measurements were expressed in terms of sound pressure. However, it was recognised that it was really necessary to determine the particle velocities as this is the stimulus which is received by the ear of a fish like the salmon. On a few occasions, the particle velocities were measured and the acoustic intensity calculated.

Background-noise levels within the harbor and even within the river itself were high, within the range 118 – 149 dB re1μPa rms over a bandwidth of 10 Hz-10 kHz. Much of the noise derived from manoeuvring and stationary ships. The sound-pressure levels generated in water by percussive pile driving were very high, but variable depending on the pile type, the substrate being penetrated, the distance from the source, and whether the bubble curtain was in operation. Within the harbor, they ranged from 142-176 dB re 1μPa peak, with sound exposure levels (SELs) of between 133-154 dB re 1μPa2-s, without the bubble curtain in operation. Estimated source levels ranged from 177-202 dB re 1μPa peak. Within the river, more than 220 meters away from the pile driver and separated from it by a spit of land, the sound-pressure levels reaching the fish ranged from 162-168 dB re1μPa peak, with SELs of between 129-145 dB re 1μPa2-s. Sounds measured at a distance from the source within the harbor consisted of a low-frequency pre-pulse, followed by the main sound pulse. In this case, and in the river itself, the sound was propagated through the substrate, as well as the water, perhaps accompanied by flexural waves at interfaces between strata. Particle velocities within the harbor and in the river reached 110 dB re 1 nms-1, mainly in a vertical direction, and intensities of up to 0.023 Wm-2 were registered.

The main energy generated by the percussive pile driver extended up to and above 10 kHz close to the source, with most of the energy below 2 kHz. By the time the sound reached the river the higher frequencies had been removed and the predominant frequencies were below 1 kHz, still with considerable energy within the hearing range of salmon (which declines above 250 Hz).

Vibro-piling also generated high sound levels in water, with sound-pressure levels within the harbor ranging from 142-155 dB re1μPa rms and source levels between 173-185 dB re 1μPa rms. Levels in the river ranged from 140-143 dB re 1μPa rms.

A bubble curtain was successful in reducing the peak amplitude of the sound from the pile driver by up to 5 dB and in reducing the high-frequency content of the sound. The bubbles therefore reduced the likelihood of damage or injury to fish. However, they did not reduce energy at the lower frequencies to which fish are sensitive, especially at a distance from the source.

The principal purpose of monitoring the pile driving was to assess the impact upon salmon. There is some controversy and uncertainty about the actual levels of pile-driving sound which affect fish adversely. It is evident that sound affects different species to a differing degree. Thus, although in some instances a level of 180 db re1μPa has been adopted as a standard, above which sounds are likely to kill or cause damage to fish, this is a very uncertain figure which is open to question. It was concluded that the sound pressure levels (SPLs) and sound exposure levels (SELs) generated by percussive pile driving within the harbor were not likely to have killed fish, whether the fish were within the river or the harbor itself. However, the sound levels were high enough close to the pile driver to injure or induce hearing loss in some species of fish. The noise from pile driving in the harbor was certainly high enough to be detected by salmon in the river at considerable distances from the source. The levels of sound from both percussive and vibro-piling were well above the hearing thresholds of the fish. As salmon could not be observed during this exercise, it was not possible to determine whether salmon reacted adversely to the sounds. However, there was a risk that their upstream migration may have been delayed or prevented with consequent effects upon spawning populations. The measurements indicated that any pile driving within the river itself would have the potential to injure or induce hearing loss in salmon and might have adverse effects upon their behavior.

During this exercise, trains of low frequency ‘thumping’ sounds were recorded within the River Dee, similar to those made by fish. The sounds may be emitted by European eels, which are common at the location.

Biographical Sketch: Tony Hawkins is the managing director of Loughine Limited and an honorary professor at the University of Aberdeen in Scotland. His research interests include underwater acoustics and the sounds made by fish. He is a former director of fisheries research for Scotland and is currently chair of the North Sea Commission Fisheries Partnership, which brings scientists and fishermen together from around the North Sea.Loreetue molor sum zzrit praestrud ent lametum zzrit lore ming ectet ex er sit alisl doloreetue consed exeril utat adignisl duisit lummolore modolorem in ut dolortis acilis elit, con vel dolore min eugiatu sandre mod erit in endigna adip el dolenis odipsum dolenim doluptat.

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BAROTRAUMA INJURY OF PHYSOSTOMOUS AND PHYSOCLISTOUS FISH BY NON-EXPLOSIVE SOUND AND PRESSURE CYCLING

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Abstract

Barotrauma injury has historically been a concern for fish exposed to underwater explosions and passage through hydroturbines. Recently this concern has been extended to include underwater sound generated by pile driving, particularly that generated during impact driving of larger-diameter steel casing. Description of the characteristics of sound impulses generated by impact pile driving that are a threat to fish is lacking and current protective criteria that rely on simple peak overpressure do not have a clear scientific basis and appear too restrictive. This paper considers the mechanisms for barotrauma injury to both physostomous and physoclistous fish as a function of acclimation depth and the criteria developed for protection of fish from barotrauma pressures generated by explosions and passage through hydroturbines. These mechanisms and criteria are discussed within the context of observations of impact pile driving generated pressure time histories and observations of barotrauma injury to fish made during pile driving projects on the West Coast of the United States. Also considered are the results of recent sound-mitigation efforts, including driving of steel casing pile in the dry, the use of both confined and unconfined bubble curtains, and the success of these mitigation efforts as measured by comparison with fish-protection criteria.

Pile Driving and Bioacoustic Impacts on Fish

How Did We Get Into This Mess? Where Do We Go From Here? Status of Developing Best Available Science to Improve Decision-Making Processes

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Abstract

How did those of us in the transportation industry suddenly find ourselves in need of knowing about underwater pressure waves and fish barotrauma? On October 17, 1989, a portion of the East Span of the San Francisco Oakland Bay Bridge collapsed. That event was the catalyst for the State of California to institute a comprehensive seismic retrofit program for its bridge structures. The bridge is considered a “vital lifeline structure” to San Francisco. Therefore, the bridge was to be designed to withstand the maximum expected credible quake with a design-life of 150 years. The criticality of the structure, the design life, and the soil conditions in San Francisco Bay precipitated the need for an innovative foundation design that was the nexus to use steel piles as the preferred structural support material. Ultimately, there was no structural alternative. When we began driving the steel piles, we realized that underwater pressure waves were being generated that caused stunning and even death to fish near the pile.

Pressure waves are generated when the hammer strikes the pile, imparting a flexural wave that moves down the pile at approximately 5000 feet per second. As the wave does this, it interacts with the air, creating a localized pressure perturbance, resulting in airborne noise. It then moves through the water column creating compressional waves. This results in what we refer to as a hydroacoustic pulse. Finally, the energy moves down into the more-resistant substrate, where it is dissipated through the physical displacement of soil particles. A wave travels down, then back up, and it continues to reverberate until all of the energy has been dissipated, into the air, water, and soil.

Our efforts to develop a better understanding of the acoustic properties of pile driving and its effects on fish began with examining the findings from past research for their relevance and applicability while looking at a variety of wave forms. The U.S. Army Corp of Engineers, Canada’s Department of Fisheries, the US Navy, and others have done many studies on the effects of explosive blasts on fish. There is a relatively small, but high-quality, body of literature that exists for effects of long-term continuous noise exposure on fish, such as that found in active sonar arrays. There is almost no information on pile driving impacts.

We have also been designing and testing various noise-attenuation technologies. The bubble-tree attenuation device used to surround piles being driven for the Benicia-Martinez Bridge Project successfully reduced peak noise levels to an approximate 20m radius around the pile. This equated to a 99.8% reduction in radiated energy compared to an unattenuated pile.

What are some of the lessons we have learned so far? First, one needs to understand the ramifications of permit terms and conditions for these types of projects. These have to be meaningful and measurable criteria. They need to be biologically relevant and technologically possible conditions. For instance, underwater noise-monitoring equipment needs to be able to measure the target frequencies committed to within the permit. Second, one needs to develop and follow monitoring protocols with specific objectives and study controls. In other words, don’t go out and collect a bunch of data and then try and make something of it. Third, one needs to obtain incidental take authorization to avoid unanticipated work stoppages. Last and most important, avoid jeopardy and avoid and minimize the incidental effect of take to the extent practicable.

What else have we learned? This is a highly complex issue, and we need to be very careful to ensure we base decisions on credible and relevant information. Just because it is in print does not mean it is useful, credible, or relevant. As the Endangered Species Act (ESA) clearly states: “The best available information is to be used in the implementation of the ESA and this information must be reliable, credible, and represent the best scientific and commercial data available.”

We soon realized other states and industries were struggling similarly with this issue and that by working together we could be more effective in our efforts. Therefore, two years ago we formed the Fisheries and Hydroacoustic Working Group. The three key goals of the Fisheries and Hydroacoustic Working Group are to summarize: 1) what we currently know (what is the best available science); 2) what we need to know (define future research needs); and, 3) what is the best application of current information for consistent interim standards. As new information is developed, the cycle repeats itself, and we will continue to update our summary of current understanding, re-evaluate further research needs, and re-evaluate and possibly modify noise-criteria standards based on what we have learned. In support of this effort, Caltrans funded preparation of the report titled “Effects of Sound on Fish” by Mardi C. Hastings, Ph.D., and Arthur N. Popper, Ph.D., that was completed in January 2005. The final report constitutes a comprehensive literature review and analysis of relevant research, recommendations for preliminary guidance, areas of uncertainty, and recommended research.

Caltrans also submitted a proposal to the Transportation Research Board, National Cooperative Highway Research Program to fund a national research study to evaluate hydroacoustic impacts on fish from pile installations. That proposal was accepted and is underway. It is Project 25-28, Hydroacoustic Impacts on Fish from Pile Installation.

The Federal Highway Administration has also sponsored a pooled-fund project titled "Structural Acoustic Analysis of Piles." The study's goals are to develop and validate models of sound fields and the effects of attenuation systems, to develop and validate acoustical source models of pile driving, to synthesize information from this project with other pertinent research, and to develop a guidance document for practitioners.

The three most recent efforts that Caltrans has underway are: 1) the development of an Interim Guidance Manual that identifies procedures for assessing and mitigating effects of pile driving sound on fish; 2) the development of an underwater sound-pressure compendium; and, 3) development of a methodology for measuring and reporting underwater sound pressure.

Biographical Sketch: Deborah McKee is a senior environmental planner, aquatic resource biologist for the California Department of Transportation (Caltrans). Ms. McKee oversees research, regulatory compliance, and inter-agency coordination for aquatic resources including fisheries bioacoustics.

What Do We Know About Pile Driving and Fish?

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Abstract

There are growing concerns about the potential effects of in-water pile driving on aquatic organisms. These concerns arise from an increased awareness that high-intensity sounds have the potential to harm both terrestrial and aquatic vertebrates (e.g., Fletcher and Busnel 1978; Kryter 1984; Richardson et al. 1995; Popper 2003; Popper et al. 2004). The result of exposure to intense sounds may extend over a continuum running from little or no effects to the death of the ensonified organism. This paper is a brief review of what is known about the effects of pile driving on fish. It also provides some ideas about the design of future experiments that can be used to test these effects. The conclusions and recommendations presented here are explored in far more detail in a recent review on effects of pile driving on fish (Hastings and Popper 2005). In addition, a broader examination of the general effects of sound on fishes can be found in Popper (2003) and Popper et al. (2004).

It is widely believed that fish close to pile-driving activities may be killed by exposure to very intense sounds. There is also some evidence that fish at some greater (but undefined) distance may survive exposure to pile-driving activities. However, experimental data are very limited. Moreover, nothing is known about non-life-threatening effects on fish of some (undefined) distance from the pile-driving operation. Such effects may include (a) non-life threatening damage to body tissues, (b) physiological effects including changes in stress hormones or hearing capabilities, or (c) changes in behavior (discussed in Popper et al. 2004). These effects could be temporary (e.g., a temporary loss of hearing that recovers over time) or of sufficient length to lower long-term survival and/or reproductive potential of individual animals or communities. There are also no data on effects of cumulative exposure to pile-driving sounds.

The concerns about currently available pile-driving data arise because there is very little quantification and replication of experiments and because the investigators were not able to control the stimulus to which the fish were exposed. Thus, little is known about the stimulus actually received by fish during experiments. It therefore becomes difficult to evaluate the effects of pile driving on fish that are at different distances from the source. Moreover, there are no studies to date that included observations of the behavior of fish during exposure to pile-driving signals (but see paper by Hawkins in this volume).

Because of the dearth of data on effects of pile driving on fish, it has been suggested that data from other types of experiments involving intense signals be extrapolated to pile driving. A problem, however, is that the sounds used in other studies, such as the effects of sonar (Popper et al. 2005a), seismic air guns (Pearson et al. 1992; Engås et al. 1996; Wardle et al. 2001; McCauley et al. 2003; Popper et al. 2005b), and pure tones (Enger 1981; Hastings et al. 1996) differ greatly from sounds produced during pile-driving activities. Moreover, there are also concerns about extrapolating effects between species, and particularly between species that have different life styles, sound-detection capabilities, and responses to adverse stimuli (see Hastings et al. 1996; McCauley et al. 2003; Popper et al. 2005b). Furthermore, there is some evidence to suggest that it may not always be possible to generalize the effects of high-intensity sounds between different age classes of the same species (e.g., Popper et al. 2005b).

Since there are issues with the way pile-driving experiments have been done to date, it is worth considering how one might design an experiment that would provide the data needed to understand the effects of pile driving or, for that matter, any intense sound, on fish. One caveat with these suggestions, however, is that they require that fish be kept in a limited locale (e.g., a cage or tank) so that they can be observed before, during, and after the sound exposure, and that the fish can be retrieved for physiological and morphological analysis. Such requirements preclude direct observations on how fishes might behave if they were free from constraints or confinement during the exposure to pile driving, as has been done in one study on the effects of seismic air guns on fishes on a reef (Wardle et al. 2001).

In bullet form, the characteristics of an appropriate experiment should include:

- Sound fully under control of the investigator to ensure that the sounds to which the fish are actually exposed are calibrated and of known duration and intensity.
- Detailed analysis of the received sound, with calibration not only in terms of RMS and peak pressure levels, but also in terms of exposure over time (sound exposure level) and, where appropriate, in terms of particle displacement (see Popper et al. 2005b).
- Healthy fish from known sources that are carefully acclimated to the experimental site and situation prior to start of sound exposure.
- Recording of fish behavior during the whole experiment by video from multiple angles to enable later analysis.
- Quantitative design of the experiments to ensure statistically valid results.
- Multiple test groups to replicate results.

- Control and baseline animals, with control animals being subject to precisely the same paradigm as exposed animals, other than the presence of sound. Baseline animals serve as “controls for the controls” in that they are subject to all of the same conditions as control and exposed animals, other than for being placed into the experiment itself.
- Use of standard procedures to determine loss of hearing, both immediately after exposure and then over several days post exposure to determine if there is late onset hearing loss and/or recovery from hearing loss (e.g., Hastings et al. 1996; Scholik and Yan 2001; Smith et al. 2004; Popper et al. 2005).
- Necropsy and histopathology of a variety of organ systems done by experienced fish pathologist to determine if the ear and/or other organ systems are affected by the sound (e.g., Marty 2004; Popper et al. 2005a).
- “Blind” analysis wherever possible so that the experimenters do not know whether the fish being analyzed were exposed, control, or baseline animals. It should be recognized that this is often not possible due to the need to do experiments in a limited time frame, which often requires constant feedback to maximize the data obtained. However, when blind experiments are not possible, it is important to have more than one person independently analyze the data.

While this paradigm has yet to be used in any pile-driving study, it has been employed, with appropriate modifications for specific experimental sites and experimental questions, at least twice, once for investigation of the effects of seismic air guns on fish in northern Canada (Popper et al. 2005b) and in examining effects of high-intensity, low-frequency sonar (Popper et al. 2005a, in prep.). In the air-gun study (Popper et al. 2005b), three species of fish were exposed to air guns at a received mean level of 207 dB re 1 μPa (peak) (or 197 dB re 1 μPa (RMS); 177 dB re 1 μPa2·s sound exposure level (SEL)). Results showed no mortality and no damage to the fish (though it should be noted that a pathologist was not involved in this study due to costs and logistics). There was some hearing loss in some, but not all, of the species, and full recovery from hearing loss within 24 hours after exposure.

The sonar study (using SURTASS LFA sonar) exposed caged fish to 324 seconds of sound at frequencies below 500 Hz. The received level of the sound was 193 dB re 1 μPa and the experiment was done in a very deep lake where the fish were well into the acoustic far field of the sound source. The acoustic conditions were very similar to those that a fish might encounter if exposed to this low frequency sonar in the ocean. The results showed no mortality or adverse pathology in any organ system (examined by a trained fish pathologist) to two species, rainbow trout and channel catfish. There was some hearing loss. Preliminary data suggests recovery within 96 hours. Behavioral effects, as observed by video, were minimal for both species.

However, there is still the question as to whether these two studies can be extrapolated to pile driving for reasons discussed above. At the same time, the levels of the sounds to which the fish were exposed in these two studies was well above the 180 dB re 1 μPa (RMS) “criteria” that is now being promulgated for pile driving. Since the exposure in both the air gun and sonar tests were substantially longer than it is likely any fish would be subject to in pile driving (assuming the fish survives the first exposure and can swim away), it may be tentatively suggested that the 180-dB criteria is far too conservative.

Finally, there are a range of questions that need to be answered before the effects of pile driving can be understood and fully effective criteria be applied to protect animals. These can be divided into: (a) obtaining information about the pile-driving sounds and (b) determining the responses of fish to the exposure.

It is important to analyze pile-driving sounds from different types of piles and then construct “standard” sounds for use in fish experiments. This is critical since it is impossible to define every type of sound produced by every type of pile in every water depth and in every substrate. Thus, an appropriate group of acousticians and pile-driving experts need to develop a set of “representative” sounds that will fulfill the characteristics of the broadest possible set of pile-driving activities.

Once a set of sounds is developed, there needs to be a set of studies that examine the sounds’ effects on a small and manageable set of species that are generally representative of the fishes that are most likely to be exposed to and most affected by pile-driving activities. To obtain the necessary data, there needs to be a set of studies, most of which will have to be conducted at different levels of pile-driving signals (in order to simulate fish at different distances from the source). These studies include:

- Measures of hearing sensitivity of selected species that are potentially exposed to pile driving (to serve as a baseline for effects of exposure).
- Mortality of exposed fish.
- Effects on hearing capabilities (e.g., temporary or permanent).
- Effects on eggs and larvae of select species (e.g., Banner and Hyatt 1973).
- Behavioral responses to pile driving of exposed fishes (swimming activities, etc.).
- Long-term behavioral and physiological effects on fish.

- Effects on the structure of the ear, lateral line, and non-auditory tissues and whether these repair over time or ultimately lead to death.
- Cumulative effects of exposures on fish to pile-driving sounds.

In all cases, sufficient amounts of data are needed to enable the development of “models” to “predict” the effects of particular pile-driving operations on fish (e.g., Smith et al. 2004 for responses to narrow bands of noise). Thus the work must be done using a very highly quantified sound field with specific knowledge of the stimulus, and the stimulus must be controlled by the investigator.

Clearly, the studies described need to be done with animals in cages or in the laboratory where the fish can be closely observed and retrieved for study. These results, however, do not provide insight into the behavior of fish that are able to respond to pile driving by showing normal behaviors such as swimming away from the source. Thus, while studies of non-captive fish are substantially harder to do than controlled experiments, data on “natural” behaviors are of great interest since they provide needed insight into whether fish would actually be impacted in any significant way by pile driving.

Biographical Sketch: Arthur N. Popper is professor of biology at the University of Maryland, where he is also co-director of the Center for Comparative and Evolutionary Biology of Hearing. He served as chair of the Department of Biology for 10 years and, after that, as director of the Neuroscience and Cognitive Science Program at the University. His research interests are in mechanisms of sound detection and processing by fish, the evolution of vertebrate hearing, and the effects of sounds on fish hearing. He is co-editor of the Springer Handbook of Auditory Research, a series of 27 volumes (to date), each of which is a comprehensive treatment of one aspect of hearing.

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Chapter 2

Avian Issues

Bioacoustic Profiles: Evaluating Potential Masking of Wildlife Vocal Communication by Highway Noise

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Abstract

Highway noise can mask vocal communication and natural sounds important to wildlife for mate attraction, social cohesion, predator avoidance, prey detection, navigation, and other basic behaviors. This acoustic interference can potentially result in the reduced ability of individuals to acquire mates successfully, reproduce, raise young, and avoid predation. Because different species have evolved unique vocal repertoires, they are differentially susceptible to the masking effects of highway noise. No single noise-level criteria can be used to accurately define impact thresholds for all species. Here we show the utility of using bioacoustic profiles of bird vocal signals to identify and describe the range and variability of acoustic-masking thresholds. Variation in noise load, source amplitude, and signal frequency are modeled to illustrate the dynamic nature of each species' critical acoustic space.

Biographical Sketch: Dr. Edward West specializes in applied ecological research and management of rare, threatened, and endangered wildlife; ecosystem conservation; and mitigation planning. He is a senior environmental scientist with Jones & Stokes in Sacramento and a research associate in the John Muir Institute of the Environment at UC-Davis. His current research focuses on bioacoustics analysis of highway noise impacts on wildlife, particularly how noise impacts vocal communication and associated behaviors in birds. Dr. West is a member of the Bioacoustics Working Group at the UCD Road Ecology Center where he teaches courses in bioacoustics ecology.

Estimating Effects of Highway Noise on the Avian Auditory System

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Abstract: Our own common experience suggests that the adverse effects of noise on birds can be considered with regard to four potentially overlapping categories. First, noise might be annoying to birds. This may cause them to abandon a particular site that is otherwise ideal in terms of food availability, breeding opportunities, etc. Second, noise which lasts for very long periods of time can be stressful. Such noise levels can raise the level of stress hormones, interfere with sleep and other activities, etc. Thirdly, very intense noise (acoustic overexposure) can cause permanent injury to the auditory system. Finally, noise can interfere with acoustic communication by masking important sounds or sound components. The first two categories of investigation are probably best addressed by field experiments. The second two categories of effects are probably best addressed by laboratory experiments where precise control can be obtained. The results of some of these experiments are described in this paper.

Experimental Design

A series of behavioral experiments in the laboratory examined the effect of intense noise on the peripheral auditory system of birds and the effect of less-intense masking noise on the ability of birds to detect and discriminate bird vocalizations. In all, these experiments involved four species of birds (budgerigars, canaries, Japanese quail, and zebra finches) with similar audiograms. All birds were trained by behavioral conditioning methods and were tested in the same behavioral apparatus using exactly the same procedures. Birds exposed to intense noise were also exposed under identical conditions to the same exact noises. These conditions minimized differences that might be due to different non-experimental conditions or methodologies. Thus, any differences that emerged are differences between species.

Acoustic Overexposure

In spite of very similar audiograms, budgerigars and quail respond quite differently to exposure to an intense pure tone. When exposed to a 2.86-kHz tone at 112 dB for 12 hours, budgerigars show an initial threshold shift (hearing loss) of about 40 dB, which is completely recovered by 1-2 days following the exposure. Quail, on the other hand, show an initial hearing loss of 70 dB and never fully recover their hearing, even after a year following this exposure. In another experiment, budgerigars, canaries, and zebra finches were all exposed to the same band noise (2-6 kHz) at a level of 120 dB for 24 hours. Again, species differences emerged. All three species showed an initial hearing loss of about 50 dB. Canaries and zebra finches recovered their hearing to within 10 dB of normal by about two weeks. Budgerigars never fully recovered their hearing and still showed a permanent hearing loss of over 20 dB several months following the exposure. These comparative results show that in spite of similar audiograms, different species of birds show considerable variation in their response to hearing damage from acoustic overexposure.

Masking of Vocalizations by Noise

Previous work has also shown that, in spite of similar audiograms, there can be considerable species differences in how well birds can hear against a background of noise. In recent work by Lohr and his colleagues (Lohr et al, 2003), two species of birds were trained by behavioral conditioning methods to detect and discriminate both their own species vocalizations and the vocalizations of the other species. Moreover, these experiments were conducted with two different kinds of noises having similar overall levels: one noise with a relatively flat spectrum over a broad range, and the other noise with a traffic-spectrum-shaped noise with the peak energy shifted to lower frequencies. Results show that both species required a better signal-to-noise ratio, by a few dB, to discriminate between two vocalizations than they did simply to detect whether a vocalization was presented or not. This fits well with our common-sense experiences listening to speech in noisy environments. The results comparing flat-spectrum noise to traffic-spectrum-shaped noises were also clear. Given the same overall level, birds could hear and discriminate vocalizations better in noise that resembled the spectrum of traffic noise than they could in a flat noise with energy evenly spread across frequencies. These results show that even with acoustically complex communication signals like vocalizations, it is the energy that is in the frequency region of the vocalizations that is most effective in masking the vocalizations. In their natural habitat, it is likely that birds, like humans listening to speech, can offset some of the masking effects of noise by turning their heads, raising their voices, and using various other strategies.

Conclusions

These results show that there are considerable species differences in how birds respond to noise. While generally birds are fairly resistant to auditory-system damage from intense-noise exposure, there are large species differences. A noise exposure that barely affects one species could cause serious anatomical damage and permanent hearing loss in another. When listening to vocalizations in a background of noise, it is the energy that falls within the spectral region of the vocalizations that is most effective in masking the vocalizations. Since many bird vocalizations contain most of their energy at frequencies above 1 kHz or so, traffic-like noise is less effective in masking bird vocalizations than is broadband noise if both are at the same overall level. These findings should have relevance for predicting the effects of noises on bird-communication systems and for the design of abatement strategies.

Biographical Sketch: Robert J. Dooling (Professor), received his Ph.D. in Physiological Psychology from St. Louis University in 1975. After postdoctoral studies at Rockefeller University in New York, he moved to the University of Maryland, College Park. Currently he is the co-director of the Center for the Comparative and Evolutionary Biology of Hearing at the University of Maryland. His Laboratory of Comparative Psychoacoustics is aimed at understanding how animals communicate with one another using sound and whether there are parallels with how humans communicate with one another using speech and language. Much of the work involves comparing the auditory systems of humans and different animals to gain insight into function. Other work seeks to understand vocal learning especially in birds such as songbirds and parrots, which, like humans, rely on hearing and learning to develop a normal vocal repertoire. There are currently ongoing projects on vocal learning and vocal development in budgerigars, the regeneration of auditory hair cells and recovery of hearing and the vocalizations following hearing damage, and the effect of masking noise on hearing and communication.

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Evaluating and Minimizing the Effects of Impact Pile Driving on the Marbled Murrelet (*Brachyramphus marmoratus*), a Threatened Seabird

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Abstract

The purpose of this paper is to describe the methods used to evaluate the potential adverse effects of underwater sound from impact pile driving on the marbled murrelet (a seabird that is federally listed as threatened), and to introduce measures that have successfully minimized adverse effects. The U.S. Fish and Wildlife Service has evaluated the effects of pile driving on the marbled murrelet through several recent Endangered Species Act consultations. Over the past few years, there has been increased attention to the potential for impact pile driving to adversely affect fish species. When foraging, marbled murrelets dive in pursuit of prey and can be exposed to the same elevated sound pressure levels that adversely affect fish. Exposure to these sounds could result in mortality, injury, and/or modification of normal behaviors.

Marbled murrelets forage in the marine waters throughout Puget Sound. Recent transportation projects that have occurred in Puget Sound include replacement of the Hood Canal Floating Bridge and multiple Washington State Ferry terminal-maintenance and preservation projects. These projects typically use 36-inch and 24-inch hollow steel piles. Impact installation of these piles can produce sound pressure levels of 210 dB peak. Physical injury, including death, may occur in aquatic organisms at sound-pressure levels above 180 dB peak. Sound-pressure levels above 153 dBrms are expected to cause temporary behavioral changes that may negatively affect foraging efficiency.

These projects were evaluated by determining the area where sound pressure was expected to exceed the above levels and then estimating the potential for marbled murrelets to be exposed to those sound-pressure levels. When exposure was likely to occur, the U.S. Fish and Wildlife Service anticipated adverse effects in the form of harm (physical injury) and harassment (modification of normal behavior patterns). Minimization measures focused on reducing that potential exposure. Sound-attenuation devices (bubble curtains) were used to reduce the extent of the geographic area where adverse effects could occur. A hazing program was used to move murrelets out of the area where physical injury was expected.

We present the analysis used to evaluate adverse effects to marbled murrelets from pile driving, discuss the method used to estimate the extent of effects, and introduce measures to minimize adverse effects. Finally, we recommend future research needed to better understand and to reduce further these impacts.

Biographical Sketch: Emily Teachout is a fish and wildlife biologist with the U.S. Fish and Wildlife Service in Lacey, Washington, and is a member of her office's Transportation Planning Branch. As a transportation liaison, Emily reviews transportation projects through the National Environmental Policy Act, Endangered Species Act, Fish and Wildlife Coordination Act, and other regulations. Emily provides technical expertise on the conservation of bull trout, marbled murrelets, Northern spotted owls, bald eagles, and other sensitive species. As her office's lead on evaluating potential impacts of underwater sound on aquatic species, Emily develops risk assessments, effect analyses, and policy guidance on pile installation related to ferry operations and bridge projects.

Synthesis of Noise Effects on Wildlife Populations

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Abstract: This report contains a partial summary of a literature review dealing with the effect of noise on wildlife emphasizing the effects on birds. Beginning with studies in the Netherlands and, later, in the United States, a series of studies have indicated that road noise has a negative effect on bird populations (particularly during breeding) in a variety of species. These effects can be significant with 'effect distances' (i.e., those within which the density of birds is reduced) of two to three thousand meters from the road. In these reports, the effect distances increase with the density of traffic on the road being greatest near large, multilane highways with high densities. A similar effect has been reported for both grassland and woodland species. It is important to note that 1) not all species have shown this effect and 2) some species show the opposite response, increasing in numbers near roads or utilizing rights-of-way. It is important to determine the cause of this effect and to utilize additional or alternative methods beyond population densities as the sole measure of effect distance, because the latter is susceptible to variation due to changes in overall population density. Recommendations for further study are given, including alternative measures of disturbance in birds.

Introduction

This presentation summarizes part of a larger report that reviewed literature dealing with the effect of noise on wildlife on a wide variety of species (Kaseloo and Tyson 2004). Here, the responses reported for bird species are summarized, because they have been reported to show the most dramatic negative response to road noise of any group and this response appears proportionate to the level of traffic on the road. According to a recent estimate, 20% of the land area of the United States may be ecologically affected by public roads (Forman 2000). This estimate is based, in part, on findings of the effect of road noise on the density of bird populations. In these studies "effect distance" is defined as the distance from the road to the point at which reduced density was no longer recorded.

Effect of Road Noise on Bird Species

In an early study (a re-analysis of previous work), avoidance of roads was found for at least two species (lapwing and black-tailed godwit) of grassland birds (van der Zande et al. 1980). A subsequent study of grassland birds found seven of 12 species had reduced breeding densities near roads and that the effect distance increased from 20-1,700 m at 5,000 vehicles/day to 65-3,530 m at 50,000 vehicles/day (Reijnen et al. 1996). A longer-term (five-year) study near Boston found that, at least for two species of grassland birds studied (bobolinks and meadowlarks), the effect distances increased from no effect at 3,000-8,000 vehicles/day to 1,200 m at traffic densities of 30,000 vehicles/day or more (Forman et al. 2002).

In a study of woodland species, 26 of 43 (60%) were found to show a decrease in population densities with effect distances that also increased with the amount of traffic. The effect distances ranged from 50-1,500 m at 10,000 vehicles/day and increased to 70-2,800 m at 60,000 vehicles/day (Reijnen et al. 1995b). A further, multi-year study found that 17 of 23 species showed a reduction in breeding bird density in at least one year of the study (average 40,000-52,000 vehicles/day) (Reijnen and Foppen 1995a). This effect was reduced in years of high overall population density. The authors concluded that high overall population densities led to an underestimation of the quality of the habitat as the numbers of birds were forced into poorer-quality areas under these conditions (Reijnen and Foppen 1995a; see also Reijnen et al. 1997, figure 1).

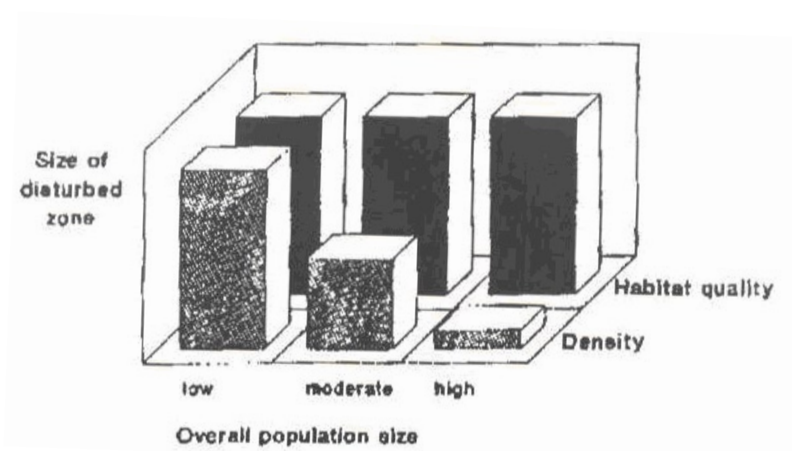

Figure 1. Schematic representation of the effect of disturbance by traffic on habitat quality (solid) and density (hatched) of breeding birds in relation to overall population size. (Reprinted with the kind permission of Springer Science and Business Media from Reijnen et al. 1997.)

Based on these results, sound levels above 50 dB(A) could be considered potentially deleterious, and the effect distance was estimated to be an average of 1,000 m (Reijnen et al. 1997). The existing model of the effect on birds assumes that noise is the presumptive major causative factor (see figure 2) because of the distances involved in the effect. However, it is important to consider that no multi-species study has found all species to be sensitive. In several studies that cover a wide range of habitat types it has been shown that while some species become less common near the road, others show the opposite effect, and the importance of these (ecotonal) species may also need to be considered in evaluating the impact of roads (Michael et al. 1976; Clark and Karr 1979; Ferris 1979; Adams and Geis 1981). It should be noted that noise was not the focus of these studies, but the fact that population densities vary dramatically between species merits consideration. Other species have been shown to breed in exceptionally noisy environments such as near roads and airports (e.g., Awbrey et al. 1995). Finally, a number of studies have found that rights-of-way can provide breeding habitat for some species and that management of this area can be important, particularly in areas where disturbance (e.g., from agricultural activity) farther from the road may preclude the use of alternative areas (Oetting and Cassel 1971; Voorhees and Cassel 1980; Laursen 1981; Warner and Joselyn 1986; Warner 1992). Again, it should be noted that noise was not the focus of these studies, but the close proximity of significant numbers of breeding birds of various types (pheasants, ducks, passerines) to the road (interstate highways) indicates that noise from the road is not an absolute barrier to breeding, particularly if alternative areas are not readily available.

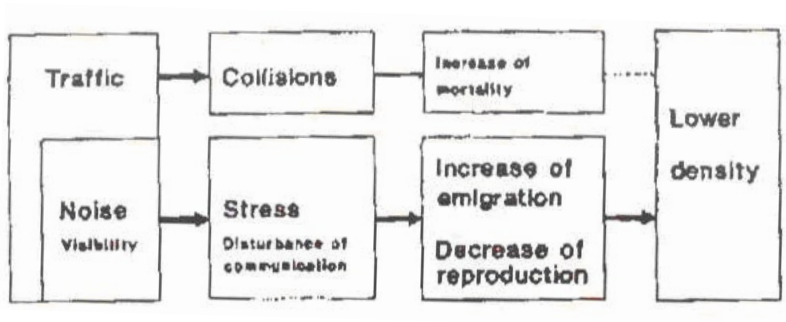

Figure 2. Probable relationship between traffic and density of breeding birds. (Reprinted with the kind permission of Springer Science and Business Media from Reijnen et al. 1997.)

The fact that the reduction in density of some species is proportional to traffic density supports the idea that noise is having a significant effect on these species. However, the effect is not universal and needs to be considered in terms of the surrounding habitat as well as species in question.

Recommendations for Future Study

Because the effect attributed to road noise can be extremely significant and has been shown to occur in a number of studies and across a wide variety of species, this effect must be investigated further. One central question that has yet to be resolved is whether noise in isolation is sufficient to cause this effect. To this point it has been assumed that noise is the cause because of the large effect distances and because other potential sources (e.g., visual disturbance, pollution, etc.) are unlikely to have an influence at such distances (Forman et al. 2002). If noise can be established as the cause of this effect, then mitigation efforts that are able to reduce noise alone can be expected to produce the desired response (i.e., may make habitat more attractive to species that had been avoiding these areas). In addition, the time for such a response to occur needs to be evaluated (i.e., over what time frame does a study need to be conducted to see a response). Because birds can be territorial it may take some time for them to reoccupy an area, even if acoustic conditions are more favorable.

The proximate effects of traffic noise on avian physiology have not been quantified. Since density alone can be a misleading indicator as to habitat quality (see also van Horne 1983), additional measures need to be employed to evaluate the stress the bird is experiencing. Such factors could include physiological measures of stress such as hormone levels or behavioral or activity measures that would indicate a bird is experiencing less or more favorable conditions. In breeding birds, the fecundity or fledging success might be useful indicators as well. Finally, areas of noise mitigation exist, and, although many of these may be near heavily populated regions, careful examination of these areas may reveal test sites that can be used for comparison to other (non-mitigated) areas so long as sufficient similarities (e.g., community composition, patch size, etc.) for comparison remain. These areas may present an opportunity for study without the need to construct or modify existing roads for such comparisons, although creation of controlled sites with high and low noise levels may ultimately prove necessary.

An accurate assessment of the impact of road noise will only be possible once the nature of the effect of road noise on birds is determined so that predictions as to the magnitude of the disturbance can be made.

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Biographical Sketch: Dr. Paul Kaseloo is currently an assistant professor in the Biology Department at Virginia State University. He has a Ph.D. in zoology and physiology from the University of Wyoming, where his research involved the energy costs of diving and digestion in ducks. His broader research interests include the physiological ecology of vertebrates. He authored a review of the effects of noise on wildlife through the Federal Highway Administration Minority Institutions of Higher Education Competitive Assistance Program.

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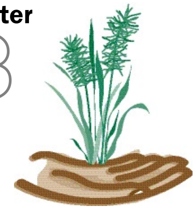
Chapter 3



Aquatics and Marine Ecosystems

Culvert Test Bed: Fish-Passage Research Facility

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Abstract

The passage of juvenile salmonids and other fish through culverts is a significant Endangered Species Act (ESA) issue throughout the Pacific Northwest and now in other areas of the nation. Much of recent research and engineering has focused on increased passage of returning adult salmon; however, juvenile-salmonid movement both up and downstream throughout the year is now recognized as substantial and is a key area in which future research promises practical returns. Because a large percentage of the culverts beneath roads in the Pacific Northwest are judged as blocking juvenile salmon from thousands of miles of habitat, determining appropriate hydraulic and fish-passage designs for retrofitted culverts before installation has both substantial cost and environmental implications.

To address these issues, the Washington State Department of Transportation (WSDOT) leads a partnership that includes the Washington Department of Fish and Wildlife (WDFW), Alaska Department of Transportation, Alaska Department of Fish and Game, Oregon Department of Transportation, California Department of Transportation, the Federal Highway Administration, and the Pacific Northwest National Laboratory (PNNL). The partnership has undertaken a phased program conducted by an interdisciplinary team of scientists and engineers from PNNL to address the hydraulic and behavioral issues associated with juvenile-salmonid fish passage through culvert systems. This program addresses the testing and assessment of full-scale physical models of culvert systems deployed in an experimental test bed. Experiments in the test bed have begun and will measure the hydraulic conditions (mean velocity, turbulence, and water depth) associated with various culvert designs under various slopes and flow regimes, and then relate these measures to repeatable, quantitative measures of fish-passage success.

The culvert test-bed program is a one-of-a-kind capability designed to provide scientifically sound information that can be used to develop better designs for retrofitted culvert installations. Compared with field studies or temporary installations, the facility promises fast results, scientific and statistically controlled evaluations, an ability to quickly discern optimum engineering principles, and elimination of expensive trial-and-error approaches of field installations.

Biographical Sketches: Dr. Walter H. Pearson is associate director of the Marine Sciences Laboratory in Sequim, Washington, which is a part of the Pacific Northwest National Laboratory, operated for the U.S. Department of Energy by Battelle Memorial Institute. His bachelor's and master's degrees are in biology from Bates College and the University of Alaska. His doctorate is in oceanography from Oregon State University. Dr. Pearson's primary area of expertise is the study of the effects of pollution and human activities on marine and estuarine environments, especially on the fisheries these environments support. He has expertise in ecotoxicology and the behavioral ecology of fish and shellfish. Working for the Marine Sciences Laboratory for over 20 years, Dr. Pearson has gained extensive experience leading large multidisciplinary, multi-organizational studies to address environmental and fisheries issues. From 1993 through 1997, Dr. Pearson was founding program director of the innovative offsite program of Huxley College of Environmental Studies in Port Angeles, Washington, as part of Western Washington University's extended education program. In 1998, Dr. Pearson joined the newly formed Environmental Research and Wildlife Development Agency (ERWDA) in Abu Dhabi in the United Arab Emirates (UAE). He served as head of the Marine Environmental Research Center (MERC) until August 2000. Dr. Pearson led MERC as its staff developed programs for sea turtles, dugong, sea grasses, fisheries, water quality, oil-spill contingency planning, coastal-sensitivity mapping, and other marine issues. He returned to the Marine Sciences Laboratory in 2000. Dr. Pearson's current research at the Marine Sciences Laboratory addresses the effects of dredging on Dungeness crab, oil-spill impacts on marine fisheries, and juvenile fish-passage through culvert systems.

Dr. Christopher May is a senior research engineer at the Marine Sciences Laboratory in Sequim, Washington, which is a part of the Pacific Northwest National Laboratory, operated for the U.S. Department of Energy by Battelle Memorial Institute. Dr. May works to extend existing ecosystem assessment and restoration capabilities in the marine and near-shore environment into freshwater ecosystems with a focus on watershed analysis, stormwater management, non-point-source pollution issues, and salmonid-habitat assessment. Dr. May has served as a researcher and adjunct faculty member at the University of Washington and Western Washington University, as a private consultant, and as a technical advisor to the U.S. Navy and Department of Defense for stormwater and watershed-management issues. Dr. May has been principal investigator on projects ranging from a study to evaluate the impacts of urbanization on aquatic ecosystems and the effectiveness of stormwater best-management practices for the Watershed Management Institute and Environmental Protection Agency to the Kitsap and Jefferson County Salmonid Refugia Projects to identify and evaluate potential salmonid habitat-conservation areas for endangered salmon. Dr. May holds a Ph.D. in environmental science and engineering from the University of Washington, an M.S. in industrial engineering and management from the University of Minnesota, and a B.S. in marine engineering from the United States Naval Academy.

Engineered Logjams: an Alternative Bank-Protection Method for US 101 Along the Hoh River, Washington

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Abstract

The Washington State Department of Transportation (WSDOT) has repetitively made emergency scour-damage repairs along US 101 at the location on the outside of a meander bend in the channel-migration zone of the Hoh River near Forks, Washington. Four emergency projects that involved armoring the bank with large volumes of rock occurred at this location in the past few years, yet erosion continued and US 101 remained in imminent danger of being washed out.

Engineering analysis conducted by WSDOT indicated that relocation of the highway further from the channel-migration zone was economically infeasible. Therefore, bank-stabilization and river-deflection measures to protect the roadway were the only viable option. Because the “traditional” repairs were not effective, WSDOT developed an alternative solution for the site using engineered logjams (ELJs) in place of armoring bank-stabilization methods. The project has the added benefits of restoring salmon habitat and proving that sustainable engineering is not only possible, but can at times provide the most practical long-term solution.

ELJs emulate historic conditions and natural processes to rehabilitate aquatic and riparian habitat; provide erosion control, flood diffusion, and grade control; and increase sediment retention. Engineered logjams are an emerging technology based upon the premise of applying rigorous scientific and engineering principles to the design and construction of structures to protect infrastructure in a manner that emulates natural systems.

The Hoh River engineered-logjam project is the largest engineered-logjam project in the Pacific Northwest, and possibly the world. A series of 12 mid-channel and bank structures were installed. This action was intended to deflect and diffuse river flows to reduce the erosive forces acting upon the bank adjacent to the highway, as well as provide greater separation of the river from the highway shoulder.

The mid-channel logjam structures each include more than 100 logs (many with rootwads) with key log diameters of 36 to 48 inches. The core of each structure consists of steel H-piles, 65 logs, and 2,200 tons of rock. Each mid-channel structure is approximately 30 feet in height, 75 feet wide, and 70 feet long, with approximately 15 feet of the structure buried below the riverbed level. The structures include several large protruding logs that are used to hold smaller racked logs in place forming irregular faces. Exterior racked logs and naturally accumulating woody debris are key for complex habitat formation.

The design life of the engineered logjam structures is expected to be a minimum of 50 years. These structures will provide stable hard points that deflect river flow and provide a medium for the growth of native vegetation on logjam islands in the channel, while emulating natural logjams in many pristine river reaches in the Pacific Northwest.

The project was designed in the spring of 2004 and constructed from early July through mid-October 2004. Significant difficulties with the temporary river diversion, water-quality maintenance, and fish handling occurred during construction. Although winter flows have been lower than normal in this first year, indications are that the structures are performing as desired.

Biographical Sketch: Carl Ward received a B.S. in wildlife and fisheries biology from the University of Vermont (1987). He has been the WSDOT regional biologist/Olympic Region biology program manager since 1991. He manages a staff of biologists and an environmental-restoration work crew. Ward leads the team in the identification and evaluation of the effects of transportation design, construction, and operations on plants, wildlife, fisheries, threatened and endangered species, and associated habitats. The team also prepares and implements restoration, enhancement, and replacement mitigation plans for unavoidable impacts to natural resources. Prior to joining WSDOT, Carl worked in the private environmental-consulting field for four years in the assessment of wetlands, fish, and wildlife.

Environmental Retrofit for Highways: Making Wildlife a Priority

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Abstract

The environmental aspects of transportation projects have typically focused on the avoidance and minimization of impacts and compensatory mitigation for unavoidable impacts. Recently, progressive transportation agencies have been expanding beyond the primary focus of project effects and evolving toward a more thorough integration of environmental stewardship in their actions. Agencies are beginning to integrate environmental factors into transportation planning and are also providing environmental enhancements as part of projects when opportunities arise.

Transportation agencies have traditionally prioritized their work to meet the typical infrastructure needs for addressing deficiencies and making improvements for safety, capacity, and system efficiency, as well as upgrading aging facilities. Significant environmental improvements can be reached using good stewardship practices in planned transportation projects. However, sometimes areas with ecological needs do not coincide with areas needing transportation-infrastructure improvement.

How can transportation programs move beyond the project and permit perspective and work to address ongoing ecological issues and thus provide larger environmental gains?

One approach is the Environmental Retrofit Program developed by the Washington State Department of Transportation (WSDOT). This program is designed to identify environmental deficiencies within the highway system and address them both as parts of planned transportation projects and also as stand-alone environmental-retrofit projects. These stand-alone retrofit projects may be conducted not only where the transportation needs are currently satisfied, but where significant ecological impacts exist. The focus areas for this program are based on the ecological priorities, including fish-passage correction, stream-habitat restoration, and water-quality improvements.

An example of the benefits of this program can be seen in fish passage retrofit activities. Culverts at road crossings that block fish movement are recognized as a significant conservation issue, particularly for anadromous salmonids, many of which are listed under the federal Endangered Species Act (ESA).

Since 1991, the Fish Passage Retrofit Program has been managed cooperatively between WSDOT and the Washington State Department of Fish and Wildlife (WDFW). Over 5,000 stream crossings have been inspected on the state highway system. As a result, over 800 culverts have been identified that block significant habitat upstream and are targeted for correction. Over $26 million has been invested in inventory, design, and construction for stand-alone retrofit projects that restore fish passage at 59 high-priority sites.

As a result, access to over 400 linear miles of salmonid habitat, once blocked, has been improved. This presentation will discuss how the program operates, as well as specific examples of the projects that have been implemented.

The main components for operating this program include: Definition of the problem and parameters; Field Inventory and survey; Statewide prioritization, based on ecological gain; Scoping of project corrections; Design development; Permitting; Construction; Monitoring; Research; and Coordination and partnerships

The concepts of this program are now being expanded to address other types of aquatic-habitat issues though identification of what is termed chronic environmental deficiencies (CED) and stormwater treatment needs. Future applications of this program are being developed to address priorities for terrestrial habitat-connectivity improvement. This is a successful program with tangible benefits on the ground that demonstrates how transportation agencies can play a meaningful role in ecological-restoration efforts.

Biographical Sketch: Paul Wagner is a wildlife biologist with over 20 years experience in the field, including work with red-wolf reintroduction in North Carolina and studies of seabirds in Alaska's Pribilof Islands and ice-age mammals in Arctic Alaska. He is currently the biology branch manager for the Washington State Department of Transportation and manages programs responsible for policy and interagency coordination related to wetlands, fish, wildlife, and habitat issues statewide. He has a B.S. degree in natural history from Juniata College and graduate coursework in salmon ecology at Evergreen State College. He has served on committees of the National Academies of Sciences, involved in assessing the ecological effects of roads, and has been a steering committee member of ICOET since 1998.

Restoration of Aquatic Habitat and Fish Passage Degraded by Widening of Indian Highway 58 in Garhwal Himalaya

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Abstract: Sustainable approaches to the construction and widening of roads and highways are essential to offset negative influences on aquatic habitat and fish passage in the fragile ecosystem of the Himalayan Mountains in northern India. Evidence is growing that the expanding, poorly designed network of roads and trails in mountain areas, without giving due considerations to natural processes such as geological processes and climatic severity, such as heavy monsoon precipitation, is a major cause of habitat fragmentation and degradation of both terrestrial and aquatic habitats.

These effects have been quantified for aquatic primary producers (periphyton), aquatic benthic insects, and Snow Trout, a Himalayan teleost (Schizothorax richardsonii, Gray; Schizothoraichthys progastus, McClelland) that dwells in the upper Ganges River, following Indian National Highway 58 (NH-58) in the mountain region of Garhwal Himalaya, India (latitude 29 degree 61 minutes -30 degree 28 minutes N; longitude 77 degree 49 minutes -80 degree 6 minutes E). Indian Highway 58 is one of the most important highways, is 300-km long, and passes along the Alaknanda River (230 km), which is one of the parent streams of the Ganges (70 km) in the fragile mountain ecosystem of Garhwal Himalaya of northern India. Keeping in mind the heavy traffic on the highway, a RS 450 million (US $100 million) widening project was launched in 2001.

The widening of Highway 58 through massive cutting of mountain slopes, the disposal of tons of the cut material downhill into the waterways in an uncontrolled manner, and the improper water management of the slopes has resulted in intensive accumulation of soil and woody debris into the aquatic ecosystem from accelerated erosion, gulling, and landslides, resulting in drastic changes in the physico-chemical and biological profile of the aquatic habitat. Detrimental effects on transparency, current velocity, conductivity, bottom-substrate composition, dissolved oxygen, periphytonic production, and the production of benthic insect communities have been documented. Feeding, spawning, and the passage of the Snow Trout cold-water fish have been degraded or destroyed.

Subsequent to the widening of Highway 58, the annual gross primary production (Pg) of periphyton declined from 8771 g C m-3yr-1(96.48 k. cal m-3yr-1) to a value of 5952 g C m-3yr-1 (65.47 k cal m-3yr-1), a 32-percent decrease in aquatic habitat. The maximum biomass (standing crop) of aquatic insects declined from a mean monthly biomass of 4.926 g m-2 (February) to 1.848 g m-2, a 62-percent decrease, and a minimum monthly mean biomass of 0.408 g m-2 (August) to 0.126 g m-2, a 69-percent decrease. Subsequent to widening of the highway, the standing crop estimate of Snow Trout declined from a maximum mean monthly biomass of 2.955 g m-2 (February) to 1.201 g m-2, a 59-percent decrease, and a minimum monthly mean biomass (August) of 0.244 g m-2 to 0.082 g m-2, a 66-percent decrease. Annual productivity of Snow Trout declined from 1.309 g m-2 to 0.448 g m-2, a 66-percent decrease.

This decline is believed to have been caused by increased turbidity accompanied by a decline in depth and dissolved oxygen, accumulation of fine silt and suspended solids, a decrease in primary productivity, a decrease in general benthic-aquatic insects productivity, depletion of the food supply, and loss of cover.

We have recommended the following measures to restore habitat quality and connectivity of Snow Trout:

- Stream restoration and stream bank stabilization using these structures:
  - Toe walls
  - Retaining walls
  - Stone layers
  - Stone arches
  - Terraces
- Bioengineering methods by
  - Planting fast-growing plant species in combination with wire netting, gravel mining, and dredging in the impacted sites
  - Protecting riparian vegetation
  - Monitoring of water quality
  - Enhancement of fish food reserves
  - Sustainable approaches to road construction and widening
  - Proper drainage of water-saturated mountain slopes and spring runoff during monsoon season (July-August)
  - Sealing of side drains against underground water penetration alongside endangered sections of the highway
  - Construction of check dams for protection of steep gullies and side erosion of the river bed

We also recommend establishment of a strong partnership among experienced, expert

- Geologists
- Civil engineers
- Structural engineers
- Environmental biologists

Introduction

It is undisputed that the existence of roads is an imperative requirement for mobility, accessibility, and smooth development in Himalayan Mountains. Due to the young geology of the Himalayas and instability of their slopes, the region is prone to recurrent and often devastating landslides triggered by construction and widening of roads and highways.

Garhwal Himalaya is an important part of Himalaya located in the state of Uttaranchal of North India. The major Indian rivers (Ganges and Yamuna) and their tributaries (Alaknanda, Bhagirathi, Bhilangana, Mandakini, Pindar, and Nayar) have their origin in Garhwal Himalaya. Most of the roads in Garhwal Himalaya have been constructed in the valleys along the rivers. Therefore, any activity related to the construction and widening of roads has detrimental effects on the aquatic ecosystem and the organisms dwelling in it. Geology and the fragile nature of the region make this relationship of roads and the aquatic ecosystem more vulnerable.

Evidence is growing that the expanding, poorly designed network of roads and trails in mountain areas, without giving due consideration to natural processes such as geological processes and climatic severity, such as heavy monsoon precipitation, is a major cause of habitat fragmentation and degradation of both terrestrial and aquatic habitats. Massive cutting of the mountain slopes and disposal of the cut material downhill in an uncontrolled manner, uncontrolled blasting of rock in large quantities for road cutting, and improper water management in mountain terraces has resulted in intensive soil loss from accelerated erosion, gullying, and landslides.

Therefore, sustainable approaches to the construction and widening of roads and highways are essential to offset negative influences on the aquatic habitat and fish passage of the fragile ecosystem of the Himalayan Mountains of Northern India. Considerable work has been done on the impact of the transportation network on aquatic ecosystems and fish life in America and Europe. However, except by Sharma (2003), no sincere effort has been made so far on the restoration of aquatic habitat and fish passage degraded by roads and highways in India.

The present paper attempts to provide manifestation of the negative impact of Highway 58 on water quality and to quantify the impact on primary production (periphyton), secondary production (aquatic insects), and production of Snow Trout, an important Himalayan teleost. For Snow Trout, several remedial measures for restoring the habitat quality and connectivity degraded by the widening of NH-58 in Garhwal Himalaya have been suggested and tried on many stretches of the Alaknanda River.

The Snow Trout is an important coldwater fish distributed along the Himalayas in India, Pakistan, Bhutan, Nepal and Bangladesh. It contributes more than 65 percent of the total fish catch of Garhwal Himalaya. This is an important indigenous teleost dwelling in snow-fed hill streams of the Himalayas. Members of the subfamily Cyprininae pertaining to the family Cyprinidae are commonly known as Snow Trout. Snow Trout comprise mainly two genera: Schizothorax with a suctorial lower lip and Schizothoraicthys with a non-suctorial lower lip. The most important species of Snow Trout dwelling in Garhwal Himalaya streams are Schizothorax richardsonii (Gray) and Schizothoraichthys progastus (McClelland). The fish weigh up to 2.5 kg with a maximum total length of 45 cm. Snow Trout are surface feeders. They are local migratory fish and prefer temperatures between 5° to 20° Celsius (Singh and Sharma 1998, Sharma 2003).

Materials and Methods

Physiography of the study area

The study area is located in the Garhwal Himalaya, an important zone of the Himalayas and a part of the new state of Uttaranchal of North India (latitude: 29 degrees 26 minutes -31 degrees 28 minutes N; longitude: 77 degrees 49 minutes -80 degrees 6 minutes E). It encompasses six districts (Dehradun, Tehri, Pauri, Uttarakashi, Chamoli, and Rudraprayag) and covers an area of 30,029 km^2.

The area is very rich in biodiversity (animal, plants, and microbes). The entire region of Garhwal Himalaya is bestowed with tremendous freshwater resources in terms of major fluvial systems of Ganges and Yamuna and their tributaries. Due to the rich freshwater resources, Garhwal Himalaya is known as the ‘tower of freshwater resources.’ Two major parent streams, the Alaknanda and Bhagirathi, form the Ganges after confluences at Deoprayag.

A thick network of roads and highways has been launched in the region to cater to the needs of the heavy influx of tourists. Most of the roads and highways in Garhwal Himalaya have been constructed in the river valleys along the rivers.

Geology of the study area

The study area is characterized by a flat-topped ridge, steep slopes, and a wide valley. The area is covered by three types of rocks of the upper Proterozoic to lower Paleozoic ages (Valdiya 1984). The area is represented by huge, thinly foliated, highly folded, fractured, and joined phyllite rock traversed by quartz veins and few basic intrusions in the form of a sill and dykes. The phyllite is called Pauri phyllite (Kumar and Agrawal 1975). Vertically folded, highly fractured, pinkish ripple, and current-bent quartzite rocks, intercalated with a massive intrusion of meta volcanic rocks, are under the Garhwal groups of rocks. The tectonic features generally control the landform of an area; slopes of a drainage pattern are more sensitive to recent neotectonic activities.

The wide valley of the Alaknanda River is characterized by the set of terraces formed by the river shifting and reducing the water discharge. The river flowing in the area was assumed to have heavy water discharge with laminar flow that reduced to its present level. Therefore, the sediments and load deposited along the riverside in the form of terraces. Most of the lowest terraces are in contact of the river.

The whole stretch of the Alaknanda River covers a distance of about 250 km and flows across the different lithotectonic units of Garhwal Himalaya. The river can be conveniently divided into three zones: Mana to Vishnu Prayag (highest gradient-I grade), Vishnu Prayag to Karanprag (moderate gradient-II grade), and Karanprayag to Devprayag (low gradient-III grade). National Highway 58 runs along the Alaknanda River from Badrinath to Devprayag (230 km) and Deoprayag to Rishikesh (70 km) along the Ganges.

Natural preconditions for road construction and widening in Garhwal Himalaya
Road construction and widening are very much dependent on the natural preconditions (climate, geology, topography, and environment) in mountainous areas. Favorable preconditions generally result in modest construction/widening volume per km, whereas unfavourable preconditions can bring enormous work volume and be very expensive. The climate of Garhwal Himalaya is mainly dependent on the altitude and varies from subtropical to alpine and temperate. The annual rainfall differs from place to place, ranging from less than 250 mm to 3500 mm. Most of the precipitation (80 percent) occurs during the monsoon period (July-August), creating tremendous problems for the road builders.

Garhwal Himalaya is affected by a constant tectonic uplifting accompanied by a down cutting of the river systems. The results of these natural forces are slopes which become steeper and steeper and therefore unstable. It is evident that such conditions make road widening a difficult task. The hilly belt of Garhwal Himalaya generally consists of rugged topography with a tremendous difference in elevation ranging from 350 m above mean sea level (m.s.l.) to 3,500 m above m.s.l. The resulting steep slopes are divided into many gullies and small valleys, and the valley floors are extremely narrow.

Such extreme conditions demand very careful road construction and widening activities. Forest and vegetation cover is a must for a balanced ecosystem. Depletion of forest resources by cutting of trees for firewood (the source of energy) and the extension of farmland into steep and unstable areas has made the entire mountain area of Garhwal Himalaya vulnerable. Such deforested and abandoned land has accelerated water runoff in volume and speed and is prone to slides. These four natural preconditions have a negative influence on road construction and widening in Garhwal Himalaya.

Salient features of the Indian Highway 58
Highway 58 is one of the most important highways and is 300 km long, passing along the Alaknanda River (230 km) and the Ganges (70 km) in the fragile mountain ecosystem of Garhwal Himalaya of northern India. NH-58 caters to the needs of heavy traffic (0.5 million people per year) and is used by people visiting the world-famous Indian shrines of Badrinath, Kedarnath, and Kemkunth Sahib, in addition to world-heritage sites (Nanda Devi Biosphere Reserve and Valley of Flowers).

Keeping in mind the heavy traffic on NH-58, in 2001 a project costing over Rs 450 million (US $100 million) for widening the highway was launched. The basic objective of widening NH-58 is to make it double lanes for the smoother running of traffic. This project is expected to be completed in March 2007. The details of the widening work on different stretches of NH-58 are presented in Table 1.

Table 1. Details of widening works of NH-58.

Stretch	km	Activity	Expected Completion
Byasi-Kodiyala	08	Cutting Work	March 2006
Bagwan-Srinagar-Srikot	20	Hotmix	April 2005
Pharasoo-Kaliasaur-Rudraprayag	21	Cutting Work	April 2005
Bugwan-Rudraprayag	60	Construction of culvert and Hotmix	March 2006
Gauchar-Karnaprayag	32	Cutting Work	March 2006

Methodology
Physico-chemical analysis of the water quality of the aquatic habitat of the Alaknanda River was made following the methods outlined in Wetzel and Likens (1991) and APHA (1998). Primary productivity of periphyton was determined by incubating substrates in a 1.93-liter molded-polystyrene chamber (Rodgers et al. 1978) for a four-hour incubation (0800-1200 hrs). A submersible pump (powered by an attached battery pack) supplied water circulation in the chamber. A variable resistor allowed variable flow in the chamber. Black-plastic tape was used to cover the dark (opaque) chambers. For the oxygen produced over a given time period, calculations were made after running modified Winkler's test on each of the samples.

Calculations for gross primary productivity (Pg) were made as follows:

Gross Primary Productivity (Pg): Total oxygen produced = Oxygen at end, light chamber not covered (minus) oxygen at end, black-taped chamber

The values obtained in mg. l-1 oxygen were converted to milligrams of carbon per cubic meter (mg C m-3) multiplying the value by 375.36 (Strickland and Parsons 1960). The values in mg Cm-3 can be converted to grams of dry weight by multiplying the milligrams of carbon by two and dividing by 1000. The values of dry weight were converted to calories of energy multiplied by 5.5 (Benton and Warner Jr. 1972).

The productivity of aquatic insects (secondary productivity) was determined by the biomass method (Winberg 1971, Downing and Rigler 1984). For the study of density, biomass, and production of the Snow Trout, the three small seine nets (TSSN) methods of Penczak and O'Hara (1983) were employed. The value for instantaneous growth (G) was estimated, when growth is considered to exponential:

$$G = \frac{\log_e \overline{w}_2 - \log_e \overline{w}_1}{t}$$

Where and = mean weight of the fish at times t1 and t2, respectively.

To estimate monthly production, mean biomass () was multiplied by the instantaneous growth rate (G): P= G (Chapman 1978). The annual production (g.m-2.yr-1) was estimated for Snow Trout.

Results and Discussion

Morphometric transformation of fish habitat

A large-scale morphometric transformation of the habitat of Snow Trout in a large section of the Alaknanda River has taken place due to widening activities on NH-58. As a consequence of these construction activities accompanying the road widening, a large stretch of the fluvial system has been transformed into a trench and a dammed pool of sluggish currents of water from rapids, cascades, and part of the high water from riffles. The other section of the river has been converted into narrow, turbulent, and turbid riffles from white and clear water pools as a result of the large scale of disturbances caused by disposal of tons of cut material downhill into the waterways of the Alaknanda River (figure 1).

Figure 1. Disposal of cut material downhill into the Alaknanda River caused by the widening activities on NH-58.

The composition of bottom substrates has been drastically altered by the widening activity of NH-58. Improper management of the slopes has resulted in intensive accumulation of soil, woody debris into the aquatic ecosystem from accelerated erosion, gullying, and landslides.

Degradation of physico-chemical aquatic environment

Degradation in the mean physico-chemical parameters of the aquatic environment of the Alaknanda River caused by the widening of NH-58 over a three-year period (January 2002-December 2004) is presented in Table 2.

Table 2. Degradation in the mean physico-chemical parameters of aquatic environment of the Alaknanda River caused by widening of NH-58 during a three-year period (January 2002-December 2004)

Parameter	**Standard Site** (S1) (± SD)	**Impacted Site** (S2) (± SD)
Air temperature (°C)	21.42 ± 6.50	21.78 ± 6.53
Water temperature (°C)	13.35 ± 2.51	14.02 ± 2.21
Hydromedian depth (m)	2.34 ± 1.34	1.51 ± 1.20
Conductivity (µScm-1)	80.56 ± 24.67	82.09 ± 25.18
Relative humidity (%)	46.21 ± 5.58	41.65 ± 5.75
Water velocity (m.sec-1)	1.375 ± 0.685	1.15 ± 0.702
Turbidity (NTU)	85.21 ± 78.37	121.65 ± 84.73
Transparency (m)	1.581 ± 0.637	1.20 ± 0.416
Photoperiod (LH day-1)	11.76 ± 1.20	11.76 ± 1.20
TDS (x 102 mg.l-1)	4.90 ± 4.80	5.94 ± 4.94

Table 2 (continued)

Parameter	Standard Site (S1) (± SD)	Impacted Site (S2) (± SD)
pH	7.45 ± 0.05	7.65 ± 0.07
Dissolved oxygen (mg l-1)	13.8 ± 3.12	8.54 ± 0.68
Free carbon dioxide (mg l-1)	0.92 ± 0.31	1.01 ± 0.16
Total alkalinity (mg l-1)	39.54 ± 6.54	37.51 ± 5.10
Phosphates (mg l-1)	0.030 ± 0.011	0.036 ± 0.012
Nitrates (mg l-1)	0.023 ± 0.012	0.30 ± 0.013
Silicates (mg l-1)	0.039 ± 0.34	0.043 ± 0.038
Sulphates (mg l-1)	1.576 ± 0.486	1.545 ± 0.612
Chlorides (mg l-1)	3.104 ± 1.112	3.281 ± 0.765

Analysis of the data revealed that a slight change in the water temperature in year 2004 (14.02 ± 2.21 °C) was noticed in comparison to the temperature recorded before the project (13.35 ± 1.34 °C). The drastic change in hydromedian depth (HMD) was recorded at the impacted site (1.50 ± 1.20 m) in comparison to the depth at the reference site (2.34 ± 1.34m). Conductivity was also influenced from the natural condition (80.56 ± 24.67 µmho cm-1) by the widening activities at the impacted site (28.09 ± 25.18 µmho cm-1).

The water velocity has been altered to a great extent at the impacted zone (1.15 ± 0.072 m sec-1-) versus the water velocity at the unaltered site (1.375 ± 0.685 m sec-1). A considerable change in the suspended material in the water at the impacted section (121 ± 84.73 NTU) was recorded versus the reference site (85.21 ± 78.37 ± NTU). A reduction in dissolved oxygen was also recorded at the impacted site (8.54 ± 0.68 mg l-1) versus the reference site (13.8 ± 0.12 mg l-1). A minor change in other chemical parameters (free CO2, phosphates, nitrates, sulphates, chlorides, and silicates) was also noticed at the impacted zone of the Alaknanda River in comparison with the study made before the initiation of the NH-58 project.

Trophic depression in the aquatic environment

The biotic profile of the aquatic environments of the Alaknanda River is characterized by the presence of periphyton and macrophytes at the primary trophic levels and zooplankton and aquatic benthic insects at secondary trophic levels. These biotic components act as food for hill stream fishes. The natural composition of these organisms was also drastically influenced by the widening activities of NH-58. The percentage of aquatic insects was reduced from 50.83 percent to 30.06 percent over a period of three years (figure 2) as a consequence of the degradation of aquatic environment caused by the NH-58 widening activities.

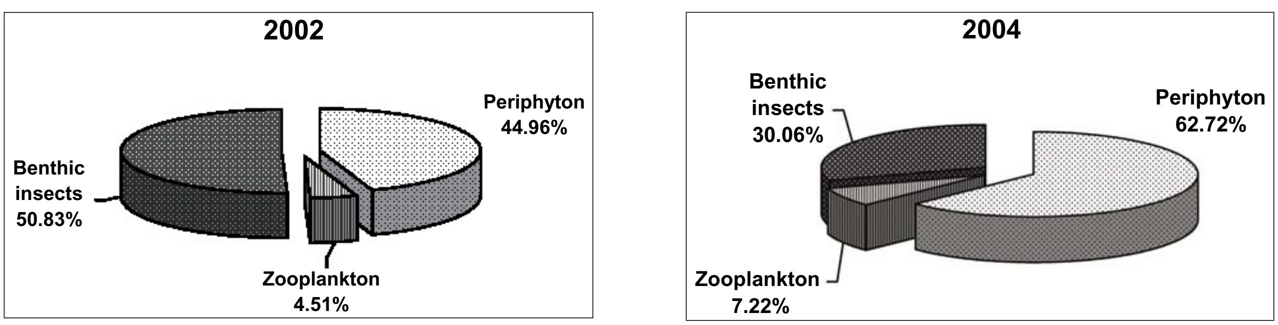

Figure 2. Impact of widening activities of NH-58 on the percentage composition of aquatic organisms of the Alaknanda River, Garhwal Himalaya, over a period of three years.

The road-widening activities of the Alaknanda River drastically influenced the primary production of the aquatic environment contributed by aquatic plants. The annual gross primary production of periphyton was reduced from 8771 g C m-3 yr-1 (96.48 k. cal. m-3 yr-1) to a value of 5952 g C m-3 yr-1 (65.47 k. cal. m-3 yr-1), a 32-percent decrease in aquatic primary production over a three-year period (figures 3 and 4) The peak in primary production was recorded during November-December (winter months), when the transparency of the water was recorded to be very high.

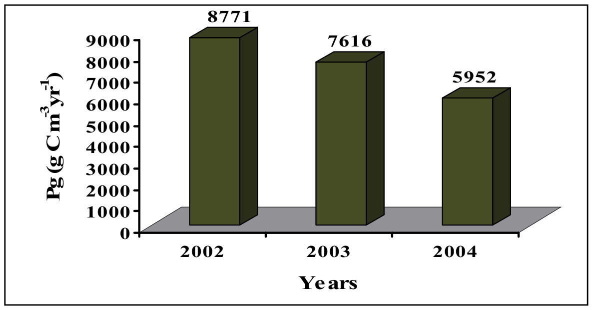

Figure 3. Impact of NH-58 widening on the annual carbon value of aquatic environment of the Alaknanda River.

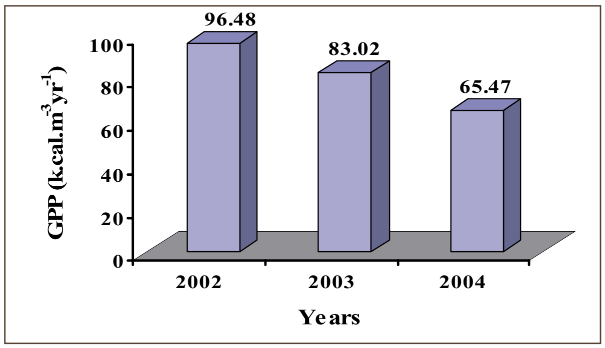

Figure 4. Impact of NH-58 widening on gross primary production (Pg) over a period of three years (32 percent decrease).

The maximum biomass (standing crop) of aquatic insects declined from a mean monthly biomass of 4.926 g m-2 (February) to 1.848 g m-2, a 62 percent decrease and a minimum mean monthly biomass 0.408 g m-2 (August) to 0.126 g m-2), a 69-percent decrease (table 3).

Table 3. Impact of widening of NH-58 on the mean monthly biomass (g m-2) of aquatic insects

Month	2002 (g m-2)	2004 (g m-2)
January	3.342	1.062
February	4.926	1.848
March	4.788	1.812
April	3.624	1.362
May	2.052	0.708
June	0.672	0.258
July	0.420	0.138
August	0.408	0.126
September	1.092	0.408
October	1.632	0.606
November	2.022	0.738
December	2.400	0.846

Impact of widening of NH-58 on the life of Snow Trout

Inundation of Spawning and Feeding Grounds of Snow Trout
The inundation of spawning and feeding grounds of Snow Trout inhabiting the Alaknanda River was observed at the impacted site of the river. As a result of the road-widening activities of NH-58 and a phenomenal change in turbidity and silting pattern, the failure of spawning or ineffective spawning of Snow Trout was observed. The presence of gravel, pebbles, sand, and bank-side vegetation is a prerequisite for Snow Trout to build their spawning nests (redds).

Choking of breeding grounds and fish passage
Environmental degradation brought about by intensified road-widening activities in the Alaknanda River catchment has adversely affected the local migratory fish species (*Schizothorax richardsonii*, Gray; *Schizothoraichthys progastus*, McClelland). Due to land slides, slope failures, sliding of the retaining wall, and disposal of tons of cut material downhill into the waterways, substantial morphometric transformations have resulted in the fish habitat that obstruct the free movement of Snow Trout into the breeding grounds. To spawn, both species of Snow Trout need clean, stable, and well-oxygenated gravel habitats, shaded with riparian vegetation. After the eggs are laid in the gravel, well-oxygenated water must pass over the eggs (Sharma 1991).

Impact on Production of Snow Trout
As a consequence of the massive scale of road-widening activities in the entire valley of Alaknanda, the Snow Trout (an important food fish of Indian Himalaya) is facing a lot of survival problems in the degraded and stressed habitats. Various stages of the life cycle (migration, spawning, incubation, and rearing) of Snow Trout are drastically influenced (figure 5).

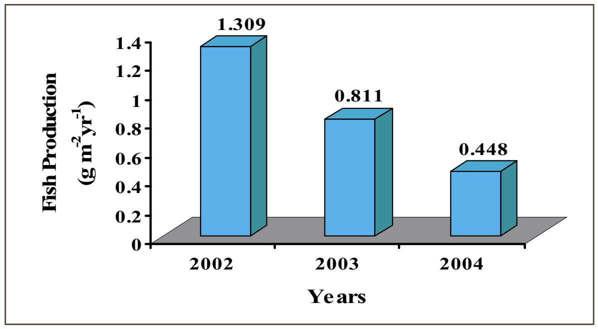

Figure 5. Impact of widening of NH-58 on the annual production (g m-2yr-1) of Snow Trout of the Alaknanda River.

Mountain ecosystems play a key role in providing forest cover, feeding perennial river systems, conserving genetic diversity, and providing an immense resource base for livelihood to local inhabitants. However, the mountain ecosystems are among the most fragile ecosystems in terms of susceptibility to natural and anthropogenic shocks. There has been a significant adverse impact on the mountain fluvial ecosystem caused by construction and widening of roads and highways. In order to protect and restore the aquatic ecosystem for fish survival, the complex inter-relationships between fish and their habitat must be understood.

All cold-water fish species, including Snow Trout dwelling in Himalayan water, need relatively unaltered or pristine freshwater habitats during part or all of their life-cycle stages. Fish migration, spawning, incubation, and rearing are examples of life-cycle stages.

The successful completion of each of these stages is dependent on one or more of the following environmental conditions of the fresh water habitat:

- Water temperature
- Depth
- Velocity
- Turbidity
- Dissolved oxygen
- Bottom substrates
- Cover
- Food supply

Different aquatic communities are broadly associated with habitat features based on the following (Wetzel 1983, Cole 1994):

- Water temperature
- Salinity
- pH
- Flow velocity
- Plant nutrients
- Bottom substrates
- Water clarity
- Dependability of oxygen concentration
- Concentration of toxic material (Wetzel 1983, Cole 1994)

Early work on the influence of inorganic sediment on aquatic life has been reviewed by Cordone and Kelley (1961). The effects of construction of the M11 motorway in Essex, Greta Britain, were studied by Extence (1978). The macro-invertebrate communities above and below the entry of motorway run-off became progressively dissimilar over the study period. Certain groups (such as stone flies, may flies, and cased caddis flies) were largely absent at the outset. These studies show that the high suspended solids carried by runoff during civil-engineering operations can have a marked effect on the ecology of the received stream. Their long-term effects could, however, prove to be small since, once the works are completed and winter spates have carried the bulk of the material away, recolonization can occur from upstream.

This view finds support in the studies of Barton (1977) who noticed that the reduced fish population (24 to 10 kg. ha-1) immediately below the site of highway construction returned to the original level after the work had been completed. Duvel et al. (1976) reported that modification of streams had a direct deleterious effect on the trout population, and large trout were denied suitable natural hiding places (holes, undercut, and bank vegetation).

The relationship between fish life and suspended solids was the first to be considered by the European Inland Fisheries Advisory Commission in their Technical Paper Series (EIFAC 1964). This relationship has since been reviewed by Alabaster (1972) and Alabaster and Lloyd (1980). Trout population in stream sections affected by high suspended solids had lower densities than in unaffected stretches (Scullion and Edwards 1980).

The long linear ecosystems (rivers and streams) are particularly vulnerable to fragmentation. There is a growing concern about the role of road crossings in altering habitat and disrupting river and stream continuity. Little consideration has been given to the ecosystem processes such as natural hydrology, sediment transport, fish and wildlife passage, or the movement of woody debris (Jackson 2003).

According to Mann and Penczak (1986), productivity levels of fish are affected by both biotic and abiotic influences, with the latter being of prime importance. Biotic variables (cover, food, and predation) have more influence in stable environments. Zaleswaki and Naiman (1985) demonstrated that abiotic factors (fluvial geomorphology, geology, and climate) were of primary importance in many situations. Zaleswki et al. (1985) stressed that growth rates in headwaters (low-order streams) are primarily restricted by abiotic factors, especially temperature and trophic status. Egglishaw (1970) demonstrated a relationship between fish production and availability of water flow and feeding sites. According to Power (1973), the presence of cover in the form of boulders and large stones greatly enhances the holding capacity of the river for fish and hence influences the production level. A deleterious effect of turbidity on fish production was noticed by Starrett and Fritz (1965). According to them, turbidity probably affects the procurement of food by sight-feeding fish. It also affects production of plankton and other food resources of fish.

The production level of fish is also dependent on light access and the amount and quality of autochthonous and allocthonous organic matter (Naiman 1983, Minshall et al. 1983) and temperature and its range (Elliot 1976, Edward et al. 1976). Thomas (1998) studied the effects of highways on western cold-water fisheries of North America. Highway network activities have an adverse impact on cold-water fish through loss of fish habitat, changes in habitat quality, isolation of populations, reduction, and invertebrate food supplies. Sheehy (2001) reported that roads are the major sources of sediment deposited in streams. This is especially critical when roads are adjacent to streams with sensitive species, where any sediment deposited into streams could have adverse effects.

Management of aquatic habitat may be as simple as adding a bottom structure, such as artificial reefs or spawning gravel for protective cover on reproduction (Kohler and Hubert 1993). Many degraded habitats can be cost-effectively aerated to increase oxygen concentration, fertilized to increase productivity of aquatic plants, or dredged to remove sediments. Habitat management integrates the management of entire watersheds. Sustaining an optimum balance of surface water and groundwater contributes to aquatic habitats by controlling erosion of sediments and nutrients.

The negative effects of environmental change in fish have been cumulative and interactive. Predictive understanding and effective management requires more holistic ecosystem approaches. The concept of recovery of ecosystem ‘integrity’ as the most appropriate means for obtaining optimum sustained benefits has gained considerable credence.

Restoration of Aquatic Habitat and Fish Passage

Efficiently protecting and restoring aquatic habitat and fish passage degraded by the transportation network is one of the most-needed management actions for natural resource managers throughout the world (Forman and Sperling 2002). Aquatic-habitat enhancement should be undertaken integrating natural channel-design techniques, aquatic-vegetation restoration techniques, and more traditional hydraulic and channel-design engineering practices (Welsche 1985; Nyman 1998, 2003). Successful treatments or techniques that directly protect or restore aquatic habitat impacted by roads are wildlife and fish passage improvement, channel and floodplain structure placements, and reconnecting water bodies (Doyle 2003). The utilization of passive treatment systems to mitigate the effects of acid mine drainage and acidic leachate discharge is a recent innovation in the restoration of aquatic ecosystems (Brookens et al. 2003).

Development of mountain-specific and sustainable infrastructures in mountainous areas requires multi-disciplinary inputs (Deoja 1994). Protecting and restoring aquatic habitat and fish passage of Snow Trout in the Alaknanda River along NH-58 in Garhwal Himalaya has become a priority. Therefore, the following measures have been recommended to restore habitat quality and connectivity for the Snow Trout.

Stream restoration and stream bank stabilization

Stream restoration and stream bank stabilization of the Alaknanda River can be made by improving the stability of a slope or to regaining stability of a slope after failure. Three different measures can be applied: improving the slope by making it as dry as possible (drainage system), supporting the slope by structures, or stabilizing by bioengineering methods. These three methods should be combined to achieve the optimum success. Stream-bank stabilization can be made through the protection structures (toe walls, retaining walls) to retain soil masses, other structures like stone layers, systems of stone arches, and terraces for preventing slope-surface erosion caused by the widening of NH-58. All these methods (improving the slope, support of the slope by structures, and bioengineering) have also been recommended by Schaffner (1987).

Bioengineering erosion-protection measures will be very effective in stabilizing unstable slopes at several locations on NH-58. Bioengineering measures consist mainly of planting fast-growing nonpalatable (Alnus spp.) species suitable to the climatic conditions of the site. Most important is the plant's capacity for deep rooting, thus increasing the soil surface and water-absorption power (drainage effect). There should be proper drainage of water-saturated slopes and spring runoff during monsoon seasons (July- August).

Another surface erosion protection measure is the combination of planting and mini-terrace construction out of wood. Finally, mini toe walls made of wood were also constructed. It has to be emphasized that areas with new plant cover have to be fenced off or watched by a watchman to avoid foraging by free-grazing animals, causing an eventual failure of the protective measure. The best method to prevent erosion on the uphill of NH-58 would be not to touch the mostly unstable slopes. They should be left uninhabited with their original forest cover.

Slopes drainage system

The activity of widening of NH-58 is a massive interference with the environment. Therefore, it should be handled with the utmost care. Thus 'kid-glove' approaches to road construction and widening should be applied, which include automatically the principle of preventing and minimizing erosion. Following this concept, slope failures have to be immediately repaired to prevent further extension and avoid the possibility that they become uncontrollable. Where the water runoff is not tightly checked, the system has to be improved to prevent creeps and slides. Early failures of the toe walls due to heavy precipitation during monsoon season (July-August) are very common in Garhwal Himalaya (figure 6). Therefore, several big culverts and check dams have been constructed for proper drainage throughout the length of NH-58 along the Alaknanda River in Garhwal Himalaya (figure 7).

Figure 6. Early failure of toe wall due to heavy precipitation during monsoon (July-August) on NH-58.

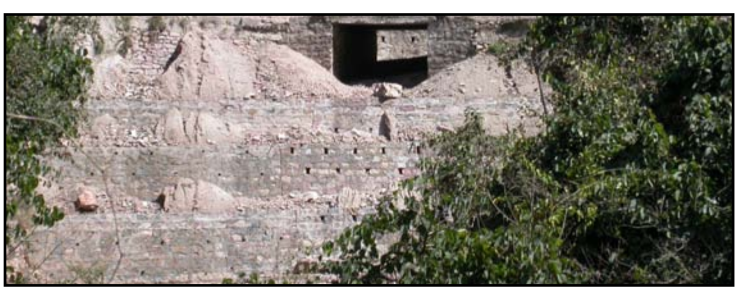

Figure 7. Construction of big culverts and check dams along NH-58 for proper drainage.

Sealing of side drains
Sealing of side drains should be made immediately against water penetration into the underground alongside endangered sections. Site drains should be discharged only into natural brooks, rivulets, and rivers. Steep gullies carrying increased water volume due to road-water discharge should be protected by check dams as far down as necessary to avoid depth and slide erosion of the river bed.

Gravel mining and dredging in the impacted sites
Fine silt and suspended solids are accumulated in the riverine ecosystem of the Alaknanda River. Snow Trout have difficulty in respiring, and their eggs are smothered. Turbidity reduces plant productivity to the extent that photosynthesis is impaired by reduced sunlight. Recreational opportunities are also lost.

Sediments usually refer to soil particles that enter the water column from eroding land. Sediments consist of particles of all sizes, including fine clay particles, silt sand and gravel. Suspended sediments can be traced to the road-construction source. Restoration of the impaired ecosystem of the Alaknanda River caused by the activities of widening NH-58 can be done in different ways to improve the aquatic habitat. Dredging and gravel mining are among the important ways to restore the impaired ecosystem. Dredging involves widening and/or deepening river channels to facilitate migration of fish. Dredging also maintains the flow of water and prevents clogging caused by silt.

Protecting the riparian vegetation
Riparian vegetation, stream bank morphology, overhanging vegetation, undercut banks, aquatic vegetation, and deep-water pools of the Alaknanda River are drastically altered by the debris generated by the widening of NH-58. These natural structures provide adult and juvenile cold-water fish with shade, resting areas, and protection from predation.

Riparian management is extremely critical for fish and wildlife populations (Thomas 1986). Riparian vegetation provides habitat cover for fishes and other wildlife, moderates stream temperatures, serves as a food source, and helps in stabilizing embankments (Welsch 1992). Riparian zones of the Alaknanda River received an inappropriate amount of the impact of the road cutting and widening of NH-58.

Riparian zones often are the most productive sites in a region because floodplains frequently have rich soils with plentiful moisture. They have a greater diversity of plant and animal species than adjoining ecosystems. Healthy riparian systems purify water as it moves through the vegetation by retaining sediments and by retaining water in aquifers beneath the floodplain. Riparian zones often are a diverse mix of wetland and upland vegetation, all of which are linked closely with the floodplain groundwater.

Maintaining proper amounts of herbaceous vegetation is a critical part of increasing sediment deposition and enhancing channel restoration in a hill stream system (Clary et al. 1996). Conversion of shrubland or woodland to herbaceous vegetation can greatly increase water yields. This is because grasses and forbs generally transpire much less water than do woody plants.

Recovery of ecosystem integrity
The negative effects of environmental change in fish habitats have been cumulative and interactive. Predictive understanding and more effective management require a more holistic ecosystem approach. Recovery of ecosystem 'integrity' is the most appropriate means for obtaining optimum sustained benefit and has gained considerable credence.

Monitoring of water quality
Monitoring of water quality of the Alaknanda River ecosystem is a prerequisite for maintaining the optimum physico-chemical conditions for Snow Trout. Monitoring of water quality will provide base data for improving the water quality for successful completion of different stages of life cycle (migration, spawning, incubation, rearing) of Snow Trout.

Sustainable approaches to the construction and widening of roads and highways
Development of mountain-specific and sustainable roads and highways in Garhwal Himalaya requires multidisciplinary inputs. An integrated development strategy based on geological, engineering, socioeconomic, and environmental factors is required for the construction and widening of roads and highways in mountainous areas. Mountain-specific design and approaches for construction of roads and their widening require access to comprehensive knowledge of geology, geotectonic, engineering, and economic analysis. Traditional civil engineers must be trained in mountain-specific skills.

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Biographical Sketch: Professor Sharma has a distinguished academic career. He graduated with zoology honors and obtained a master's degree in zoology in freshwater fishery biology. He obtained his doctorate (Ph.D.) in the environmental biology of fish and his doctor of science (D.Sc.) in environmental biology. For more than thirty years, he has had a wide experience teaching and researching environmental monitoring, bioenergetics, limnology, resource management, aquatic biodiversity, hyporheic biodiversity, microbial diversity, and transportation and environmental issues in the Himalayas. More than 12 research projects have been completed on these aspects. Under his supervision, 18 doctoral-research students have earned doctoral degrees and seven more students are engaged in research. He has sufficient professional experience and exposure by way of visiting and working at different research laboratories in India and abroad

(Canada, the Czech Republic, Poland, Sweden, and the United States.). He has published more than 104 research articles in journals of international repute. He has received several awards and gold medals (NATCON Environment Gold Medal 2001, Zoological Society of India Gold Medal 2001, Environmentalist of the Year Award 2003, Recognition Award Gold Medal 2004, and Indira Gandhi National Environment Award 2005). He is a fellow of many national and international societies. Currently, he is the professor and chairman of the Department of Environmental Sciences, H. N. B. Garhwal University, Srinagar-Garhwal, Uttaranchal, India.

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The Role of Geomorphic River Reach Assessments in Developing Environmentally Beneficial Highway-Protection Measures

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Abstract

Historic highway placement within river valleys has commonly occurred within flood and erosion hazard areas. Traditional maintenance of highways and other infrastructure in these environments can be costly, result in significant environmental impacts, and exaggerate risk elsewhere. Many rivers are subject to frequent changes in position as they migrate within their valleys. This channel migration is not limited to low-lying land subject to frequent flooding, but can consume new areas where the river has not historically been.

Changes in channel geometry alter flow conditions that can lead to either degradation (down-cutting) or aggradation of the river. Degradation can undermine road grades and bridge abutments and piers. Aggradation can increase flood frequency. Chronic maintenance and emergency repair are expensive and often do not address the source of the problem, but rather address the effect the flooding and erosion is having on the highway and related infrastructure. Furthermore, these measures rarely address impacts to habitat or how habitat can be improved from a proposed project.

Conducting a “geomorphic reach assessment” of a river’s processes and dynamics can be a valuable management tool for highway maintenance and operations managers to better understand why maintenance measures are chronically failing and to minimize emergency response by assessing potential near-term river hazards that may pose a threat to a highway and infrastructure. Geomorphic assessments evaluate historic channel dynamics, current river conditions, and hydrologic characteristics of the river system.

These assessments can also include conceptual designs and recommendations describing how to protect the highway from flooding and erosion, as well as improve existing habitat that may have been historically compromised because of highway placement and maintenance.

The results of a geomorphic assessment provide useful scientific information that is used in developing effective design solutions that address the flooding and erosion problems associated with a highway in a manner that does not compromise habitat, but instead actually improves current habitat conditions.

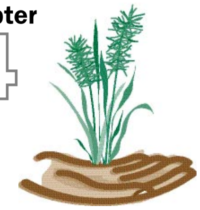
One such emerging technology that was developed in the Pacific Northwest is the use of “engineered logjams” for highway and infrastructure protection with the secondary benefit of improving aquatic habitat. Logjams can increase pool frequency, channel length, and riparian cover, as well as provide necessary bank protection for highways located along actively eroding banks. However, these technologies reintroduce natural complexity and variability to the river system. An analysis of how these structures could potentially alter flooding and erosion within a reach needs to be assessed for individual site scenarios.

We present several examples of reach assessments conducted for the Washington Department of Transportation to provide a better understanding of highway segments with chronic problems and outline better long-term maintenance strategies that enhance habitat recovery. This approach was utilized in the implementation of a complex engineered logjam (ELJ) project that has successfully protected U.S. Highway 101 and created valuable new aquatic habitat in the Hoh River of western Washington.

Biographical Sketches: Jennifer Black Goldsmith is a senior scientist with Herrera Environmental Consultants in Seattle. Ms. Goldsmith has 14 years of experience conducting natural-resource assessments throughout the Pacific Northwest. Her professional expertise includes water resources, water quality, geomorphology, and forestry. Ms. Goldsmith has extensive experience preparing water-resource analysis documentation for a variety of environmental impact statements, reach analysis, environmental assessments, and permit applications for a variety of projects.

Timothy B. Abbe, Ph.D., L.E.G., L.H.G., director of River Science and Geomorphology, Herrera Environmental Consultants. Tim Abbe has 17 years of experience in geology, geomorphology, environmental restoration, applying engineering principles in environmental project design, and solving problems in urban fluvial and coastal environments. He has pioneered the development of engineered logjams, which are artificial structures that emulate naturally occurring stream structures to achieve particular purposes (e.g., bank protection, grade control, and sediment trapping). His work on engineered logjams has offered new technology to professionals who must comply with environmental regulations while solving traditional problems such as runoff and bank erosion.

Chapter 4



Context Sensitive Solutions: Integrating Community Values with Conservation Objectives

A Case Study in Context-Sensitive Design in Transportation Planning

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Abstract: This abstract examines the use of context-sensitive design on the Blue Ball Properties Project in Wilmington, Delaware. The project addressed existing traffic flow and safety concerns; projected traffic generated by 5,000 new or relocated AstraZeneca employees; recreational needs; historic preservation; storm-water management problems; and community land-use concerns.

Overview and Methodology

A collaborative effort utilized a context-sensitive design approach that satisfied the goals of AstraZeneca, the local community, and each federal and state agency.

Traditional traffic criteria were used to determine acceptable alternatives for the overall shape of the project in the 1990s. The Delaware Department of Transportation (DelDOT) developed transportation improvements for the area based on those criteria. This plan is known as the "Spaghetti Plan" for its numerous loop ramps and multi-level overpasses. Roundly opposed by the local residents, the plan also utilized much of the land now proposed for AstraZeneca and for recreational and environmental-enhancement purposes.

Therefore, rather than establishing the traditional minimum level of service as the measure of effectiveness, a "No Degradation" approach was undertaken, meaning that traffic operations of the proposed design should operate no worse in the design year than existing conditions. This nontraditional guideline led to a significantly reduced transportation footprint. In keeping with the community's wishes, the smaller footprint allowed for re-allocation of right-of-way to be used for recreational and environmental purposes.

Fostering an intense public involvement effort is another hallmark of context-sensitive design. During the Master Planning process, 125 stakeholders were divided into a Transportation Committee and a Recreation and Historic Preservation Committee. The committees included private citizens and representatives from area businesses and civic organizations and local, state, and federal government agencies. Their task was to review information and analyze natural features, historic structures, travel patterns, public transit, and community recreational needs.

Results

In this manner, over 260 transportation and land-use alternatives were analyzed. Ideas from civic leaders, local legislators, and the public ranged from broad concepts to specific details. As the committees agreed on the preferred environmental, transportation, recreation, and historic-preservation concepts, these concepts were presented for public consideration through workshops, newsletters, and an interactive website (www.blueball.net) until the Final Master Plan was adopted. Ongoing public involvement efforts include frequent presentations to local civic groups, regular public workshops, monthly construction working-group meetings, project videos, and historic site tours.

One goal was to improve the environment in the study area, not simply avoid environmental features or mitigate for impacts. Previous studies fully documented natural, cultural, and social resources within the study area, which allowed the project team largely to avoid features such as wetlands and historic properties. After the Master Plan was approved, a formal Environmental Assessment was conducted.

Specific environmental enhancements include:

- Existing storm-water management systems are being significantly improved and designed to address long-term, systemic problems.
- Three historic standing structures have or will be improved, including the Weldin Ruins Archaeological Site, which is being developed into an interpretive site.
- Extensive stream stabilization and restoration of a local stream is being performed.
- Wetlands mitigation will comprise 1.92 acres to rebuild 1.23 acres impacted by the project.

The community was also concerned that two large open tracts of land (150 acres) in the study area would be developed, further worsening traffic problems. As part of the agreement between the AstraZeneca, the county, and the state, both tracts of land are being developed as county or state parks. Following the Recreation Committee's recommendations, the western tract will be maintained as "passive" recreation (uses that fit in with the existing natural and cultural characteristics of the land), while the eastern tract will be oriented toward "active" recreation (e.g., multipurpose playing fields, playgrounds, picnic areas etc.).

The park and adjacent network of trails will be accessible by all modes of transportation. Walkers, hikers, and cyclists will be linked to the City of Wilmington by extending the Northern Delaware Greenway from the Brandywine River. All major park facilities will be interconnected with paved park paths providing ADA accessibility and accommodation of occasional service and emergency vehicles. All park paths will link to the Greenway system and facilitate accessibility from abutting neighborhoods to all parts of the park.

Recommendations for Future Research

- Lower design speeds are being evaluated on park and local roads to encourage slower traffic and minimize environmental impacts. Future additional traffic-calming measures may also be evaluated.
- AstraZeneca is implementing an aggressive effort to reduce peak-hour trips to its site. This may determine the need for a transportation center at the campus.

Biographical Sketch: Bert Cossaboon, AICP, is a vice president with McCormick Taylor and an experienced land-use and transportation planner. He plays a key role as project manager or principal-in-charge for many planning and environmental projects in Delaware, New Jersey, and Pennsylvania. Mr. Cossaboon holds primary responsibility for defining project scopes and schedules, determining staff priorities and interfacing with all requisite regional, state, and federal agencies. Additionally, he is responsible for the overall management of the environmental staff in all of McCormick Taylor's Pennsylvania offices. He has been with McCormick Taylor since 1983. Most recently, Mr. Cossaboon was instrumental in establishing McCormick Taylor's Land Use Planning and Urban Design Group. His education includes a B.S., Environmental Studies, Richard Stockton College, 1976 and a Master of Regional Planning degree, University of Pennsylvania, 1983.

Bayview Avenue Extension, Richmond Hill, Ontario, Canada Habitat Creation and Wildlife Crossings in a Contentious Environmental Setting: A Case Study (September 2005)

Proponent and Project Funder: York Region Transportation and Works, Regional Municipality of York, Newmarket, Ontario, Canada

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Abstract: Bayview Avenue is an important north-south arterial road link in the road network of the York Region, Ontario, Canada. The roadway passes through a portion of the Oak Ridges Moraine (ORM), one of Ontario's most significant landforms as recognized through the Oak Ridges Moraine Conservation Act (2001) and Plan (2002).

McCormick Rankin Corporation (MRC) and its subsidiary, Ecoplans Limited, were retained by the proponent, York Region, to plan and design the 4.5-km missing-link Bayview Avenue extension from Stouffville Road north to Bloomington Road. This two-lane rural roadway was planned and designed to support the Region's growth (within the Greater Toronto area) while being sensitive to topography and natural-environmental features. Forest, wetland, and kettle features; Lake St. George Conservation Field Center uses; and wildlife habitat/movements were key resource issues and challenges recognized by the project team throughout the planning, design, and construction work.

Accordingly, an innovative environmental-management and enhancement program was developed and implemented during the project. The objectives were to reduce and mitigate effects on the natural environment, provide habitat creation and wildlife passage, advance the body of environmental research and education, and secure agency approvals.

The wetland-habitat creation project was developed in consultation with Education Centre field staff, and incorporated the following: a) creation of a three-cell experimental wetland complex outdoor "laboratory" located in a cultural meadow and connecting existing natural areas well removed from Bayview Avenue; b) protection of archaeological finds that were integrated in the wetland creation project; c) provision of trail and lookout zones; and d) provision of added habitat diversity in what was a cultural meadow.

The planning and design of the roadway also integrated an amphibian-migration study and detailed literature review on wildlife crossings. In response to this work, recognition of the reported presence of the rare Jefferson Salamander in the area, and the desire to maximize roadway permeability for wildlife, dedicated amphibian tunnels were located and installed under the roadway. In addition, a three-span 81-meter bridge was installed across an open dry ravine to maintain the ORM landscape character and provide a 14-meter vertical clearance for wildlife movement.

The Individual EA for the road project was successfully delivered in 1998 and the design was completed in 2001. The road was opened to traffic in 2002.

Post-construction monitoring at the amphibian tunnels (spring 2003, 2004) and recent observations (2005) have confirmed use by a variety of species including small mammals, Wood Frog, American Toad, Leopard Frog, and Spring Peeper. Use by target salamanders has not yet been confirmed. Challenges encountered include water ponding in some tunnels and some landscape changes from residential development. Outdoor education uses of the created wetland area have been very positive and will likely expand in the future.

In conclusion, the environmental-management program for the roadway was instrumental in securing agency approvals for the project. These efforts were also acknowledged by the naturalist community. The science of wildlife-crossing mitigation has been advanced and some challenges associated with tunnel design and landscape changes have been noted. Further tunnel monitoring has been recommended. Tangible environmental and educational benefits have been realized with the wetland-habitat creation project. The undertaking received the Canadian Consulting Engineers Award of Excellence in 2003.

Introduction

Bayview Avenue is an important north-south arterial road link in the road network of the York Region, Ontario, Canada. The roadway passes through a portion of the Oak Ridges Moraine (ORM), one of Ontario's most significant landforms as recognized through the Oak Ridges Moraine Conservation Act (2001) and Plan (2002). The moraine is a glacial-deposition feature about 100 miles in length with rolling topography and characterized by a mix of agricultural lands, forest, wetland, thicket, and rural residential areas. Total forest cover on the moraine is about 30 percent. The general site location is shown in Figure 1.

Figure 1. Site Location–Oak Ridges Moraine
(Graphic Courtesy of Ontario Nature–Federation of Ontario Naturalists)

McCormick Rankin Corporation (MRC) and its subsidiary, Ecoplans Limited, were retained by the proponent, York Region Transportation and Works, to plan and design the 4.5-km missing-link Bayview Avenue extension from Stouffville Road north to Bloomington Road.

The ORM landscape in this area consists of agricultural lands, forest and wetland blocks, kettle lakes, Toronto Region Conservation Authority (TRCA) lands, and areas of existing and approved development. This two-lane rural roadway was planned and designed to support the Region's growth (within the Greater Toronto area) while being sensitive to topography and natural environmental features. Figure 2 shows the moraine features and topography during road construction.

Given the high environmental profile of the undertaking, the project went through both the Class Environmental Assessment (EA) and Individual EA study processes. The Jefferson Forest, Wilcox-St. George provincially significant wetland (PSW), kettle lakes, the Lake St. George TRCA Outdoor Education Center uses, and wildlife habitat/movements were key resource issues and challenges recognized by the project team throughout the planning, design, and construction work.

Construction Photographs

Figure 2. Local Moraine setting and Bayview Avenue construction (2002)

Accordingly, an innovative environmental-management and enhancement program was developed and implemented during the project. The objectives were to reduce and mitigate effects on the natural environment, provide habitat creation and wildlife passage, advance the body of environmental research and education, and secure agency approvals.

The Individual EA for the road project was successfully delivered in 1998 (Ecoplans Limited and McCormick Rankin Corporation, 1997a) and the design was completed in 2001. The road was opened to traffic in 2002.

This case-study paper focuses on the design and delivery of two key facets of the environmental-management program for the roadway: 1) the wetland-habitat creation project and 2) wildlife-crossing mitigation. An overview panel of this environmental-management program is shown in Figure 3.

Figure 3. Bayview Avenue Extension–Environmental-Management Program Summary

Environmental-Management Program

Wetland creation pilot project

There is an existing section of Bayview Avenue bordering the Lake St. George TRCA Conservation Field Centre lands. However, widening of this road section was not feasible because of existing road geometry and the condition, traffic safety and sightlines, and impacts that would be incurred on numerous existing homes. Consequently, the road extension had to "thread the needle" between two key constraint areas: 1) the existing residential area to the west and 2) the Lake St. George Conservation Field Centre lands to the east (mosaic of agricultural fields, cultural meadow, thicket, forest, wetland, and the Lake St. George kettle lake).

The adopted environmental-management approach was careful roadway routing through this area, buffer measures through contour grading and planting, invasive-species removal (buckthorn management), wetland-substrate salvage, and wetland-habitat creation (Ecoplans Limited and McCormick Rankin Corporation, 1997b). Figure 4 shows the roadway routing through this area, along with the various environmental-management measures.

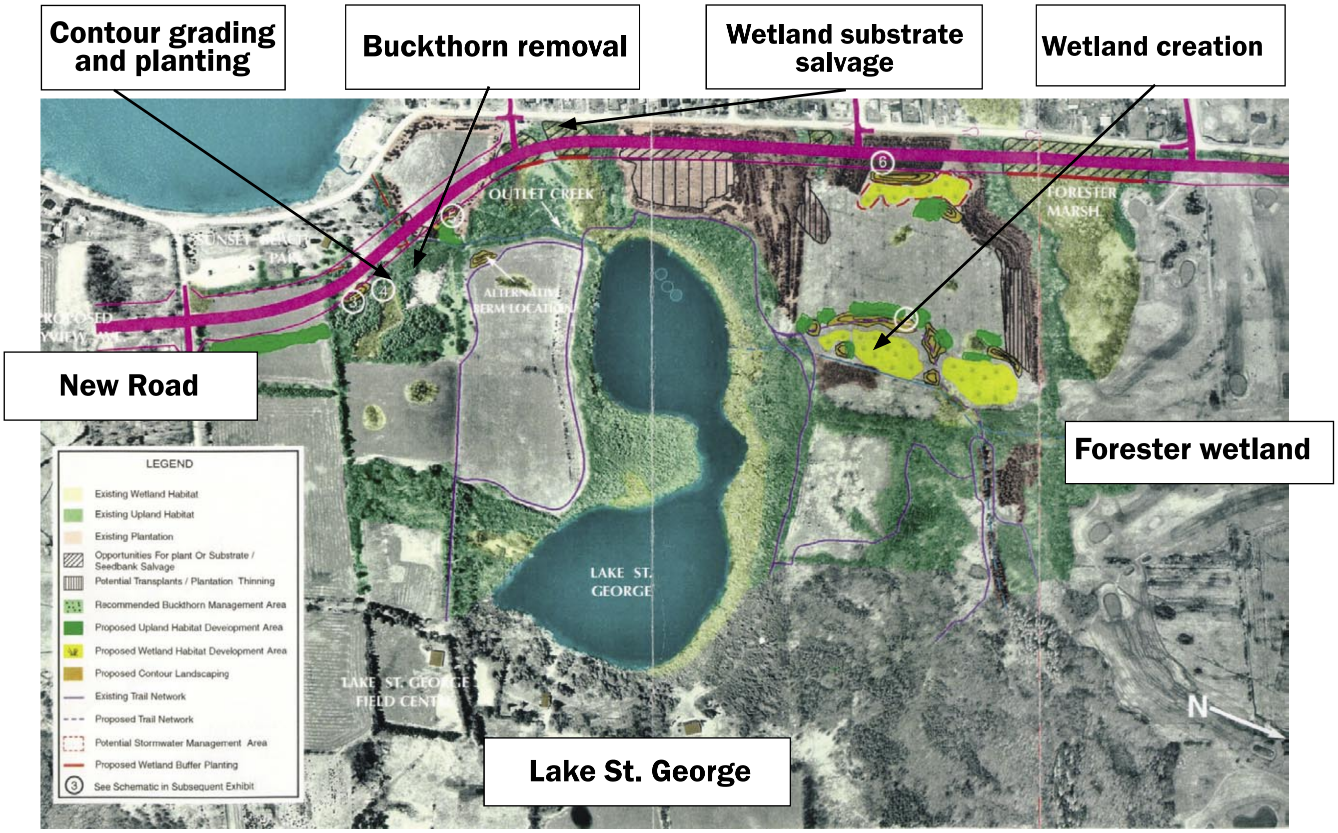
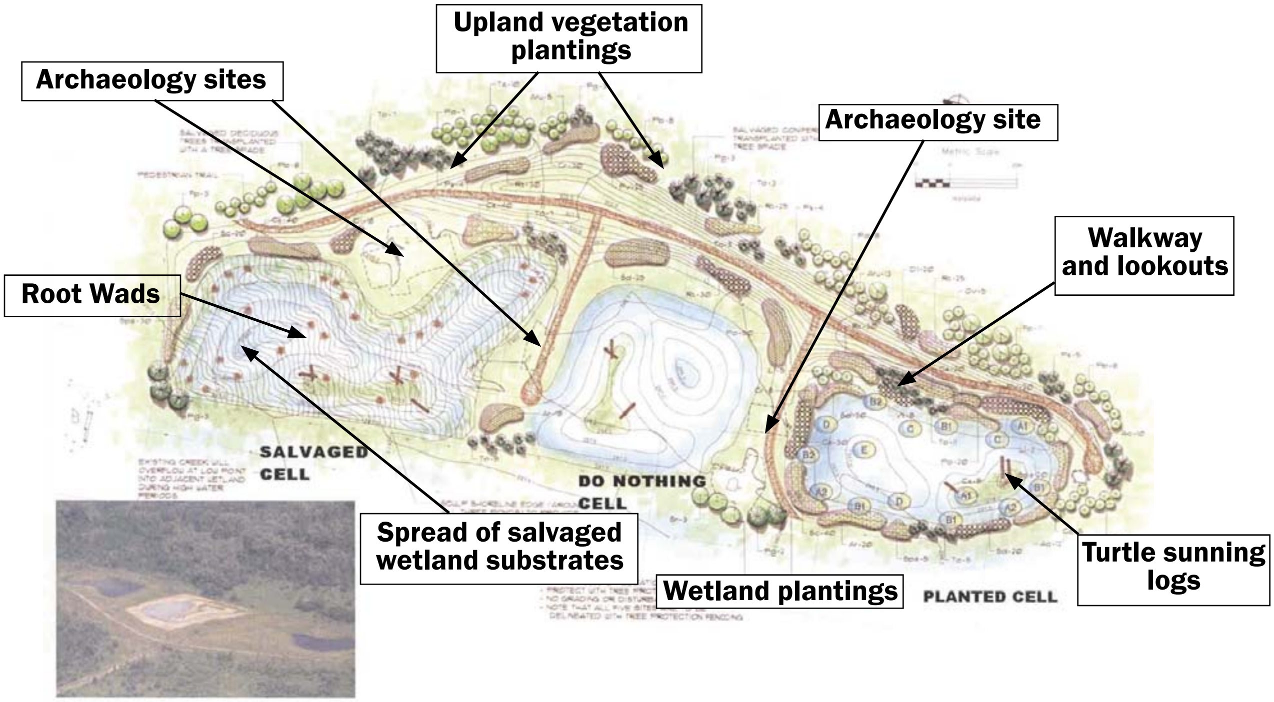


Figure 4. Lake St. George Conservation Field Centre lands–Environmental Management and Enhancement

Considerable effort was made to avoid all wetlands, not just the PSW, during the roadway routing, while also conserving ORM topography and buffering the TRCA Lake St. George Conservation Field Centre lands. However, some wetland removal was unavoidable (about 1.5 ha) and the roadway had to cross a portion of the Conservation Field Centre land close to a small wetland pond and forest used for outdoor education (Frog Pond for calling amphibians and outdoor survival skills program in adjacent forest).

In recognition of these effects, a wetland-habitat creation project was developed in consultation with TRCA Conservation Field Centre staff, incorporating the following (See Figure 5):

- Creation of a three-cell wetland habitat complex (a "do-nothing cell," a planted cell, and a cell with salvaged wetland substrates) located between a natural wetland (Forester Marsh/Swamp) and Lake St. George on the TRCA property and buffered (300 m) from Bayview Avenue
- Protection of archaeological finds that were integrated in the wetland-creation project
- Provision of trail and lookout zones for outdoor education and cultural heritage experiences
- Provision of an "outdoor laboratory" where wetland and upland vegetation development and wildlife colonization can be tracked by Conservation Field Centre staff and students
- Provision of more diverse wildlife habitat in what was a cultural meadow and improved habitat connections between Forester Wetland and Lake St. George



Pilot Wetland Habitat Creation Area

Figure 5. Pilot Wetland Habitat Creation Landscape Plan–Bayview Avenue Project

The wetland creation site was a cultural meadow with the groundwater table located relatively close to the surface. A small drainage channel follows the east side of the site, with seasonal flow eventually reaching Lake St. George. The excavations for the wetland pools created adjacent upland mounds. The wetland depressions were graded to provide a range of water depths, a variety of sculpted edges, and therefore a diversity of microhabitats. The upland areas accommodate trails and lookouts. Wetland construction was undertaken and completed in 2000.

North planted cell
Figure 6 is a series of photographs showing construction and planting of the north wetland cell in September 2000 and wetland conditions in July 2002 and August 2005.

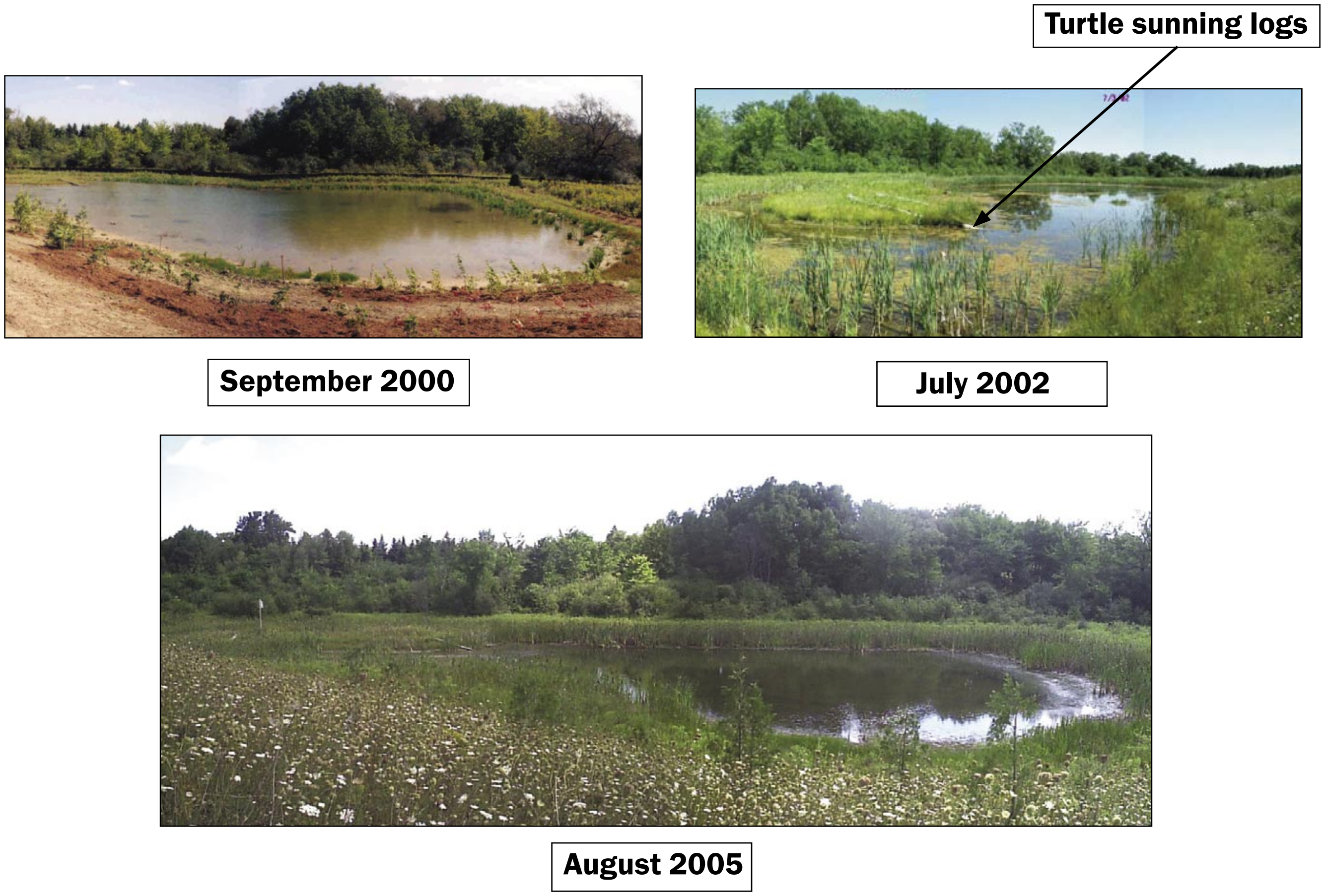


Figure 6. North Wetland Cell (Planted)–Stages of Development

An overview of the planted wetland cell development is as follows:

- The wetland cell was developed following a traditional design approach. Topsoil from the area was salvaged, stockpiled, and then spread over the graded depression and upland areas.
- Turtle sunning logs were obtained from woody material cut during roadway construction. The logs were strategically placed extending from the shoreline into the pond.
- Upland zones were seeded using a standard MTO (Ministry of Transportation Ontario) Type 1 seed mix. Nodal plantings of a variety of tree and shrub species were installed throughout the upland zone.
- The wetland portion of the cell was planted with the following associations: shoreline wet meadow plants, grassy wet meadow plants, shallow emergents (up to 15-cm high sun-tolerant and shade-tolerant species), emergent plants (up to 30-cm high), deep-water emergent plants (up to 60-cm high), and floating/submerged plants. A complete list of all vegetation installed in the planted cell is provided in Appendix A.

General observations stemming from this work were as follows:

- A good growth of cultural-meadow vegetation developed in the surrounding upland zone (see Figure 6, August 2005 photo). This developed in part from the Type 1 MTO seed mix that included native and non-native cover species. Use of a native seed mix would have been preferable.
- Wildlife browse of planted vegetation material was an ongoing challenge (Canada Goose, ducks, Cottontail Rabbit, Raccoon, Porcupine, White-tailed Deer). Planted upland nodes still persist to varying degrees.
- Although not planted, Cattail (*both Typha latifolia and T. angustifolia*) quickly colonized portions of the wetland. Occasional overflow from the adjacent drainage channel provided the source of cattail material (dispersing seed).

- Nevertheless, observations in August 2005 revealed a good quality wetland system with the following conditions:
    - A good mix of shoreline wet meadow and grassy wet meadow species, including *Eupatorium maculatum*, *Eupatorium perfoliatum*, *Scirpus cyperinus*, *Glyceria striata*, *Juncus effusus*, *Scirpus acutus*, *Scirpus atrovirens*, *Carex hystericina*, and *Carex vulpinioidea*.
    - The presence of emergent wetland plants including *Sparganium eurycarpum*, *Alisma plantago aquatica*, and *Sagittaria latifolia*, as well as *Eleocharis palustris* (thriving colony in the southwest portion of the wetland).
    - The presence of submerged Canada Waterweed (*Elodea canadensis*) and floating pondweed (*Potamogeton pectinatus*) along the west and southwest wetland margins.
    - Numerous tracks of White-tailed Deer, Raccoon, Muskrat, numerous Leopard Frogs observed, Great-blue Heron and Green-back Heron observed, and reports of periodic waterfowl use.Numerous water striders were observed.
    - A Wood Duck nest box has been erected by Field Center staff at the north end of the wetland. No confirmed nesting at present.

Central "do-nothing cell"
Figure 7 is a series of photographs showing initial construction of the "Do-Nothing" wetland cell in September 2000 and wetland conditions in July 2002 and August 2005.

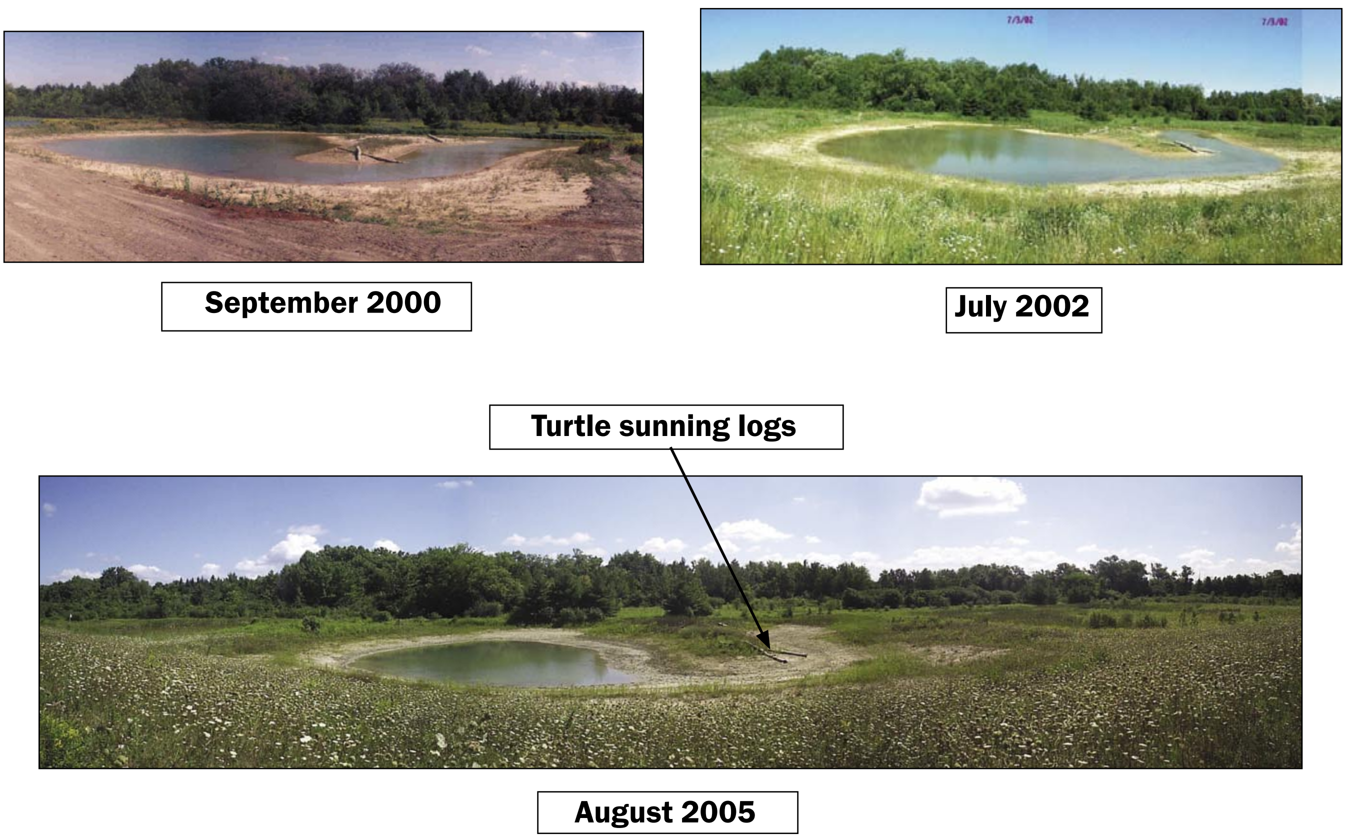


Figure 7. "Do-Nothing" Wetland Cell–Stages of Development

An overview of the "Do-Nothing" wetland cell development is as follows:

- The wetland cell was excavated down to the clay substrates below the water table. No additions of topsoil, planted vegetation, or any organic material were made in the wetland depression.
- An upland promontory was provided to increase the shoreline extent and provide a location for turtle sunning logs.

General observations stemming from this work were as follows:

- Other than a small cluster of shrub willow in the upper south margin of the wetland, riparian vegetation growth, and colonization has been negligible in this cell.
- The summer of 2005 has been very dry in southern Ontario and probably accounts for the limited amount of standing water present in the August 2005 photo (compared with the September 2000 and July 2002 photos).
- Cultural meadow vegetation has developed around the dry upper margins of the facility.
- Submerged and floating aquatic plant growth has been negligible.
- There are a few isolated clusters of spike rush (*Eleocharis sp.*), rush (*Juncus sp.*), and bulrush (*Scirpus validus*) present in the upper damp margin of the southwest corner.
- A few Water Striders were observed, but in limited numbers. Waterfowl have been occasionally observed loafing on the pond and a single Spotted Sandpiper was observed during the August 2005 site visit. A few tracks of White-tailed Deer and Raccoon were evident in the 2005 site check. A few Leopard Frogs were observed during the August 2005 site check, but overall habitat quality for amphibians in this cell is very limited.
- This wetland cell was nicknamed “The Beach” by Field Centre staff since its development. Sterile, barren, beach-like conditions persist today as evident in the August 2005 photo.
- The very limited habitat, wetland vegetation, and wildlife diversity in this cell are attributed to the sterile conditions provided by the clay substrates, with an absence of inoculation materials (such as topsoil or organic material) that would contribute plant-seed sources and a suitable rooting medium for colonizing species. Even cattail, an aggressive colonizing wetland plant, is absent from this wetland cell;

These observations confirm the importance of providing a suitable rooting medium environment in wetland-cell development to ensure some level of wetland plant colonization and growth. Without these conditions, even proximity to more-productive wetland cells (such as the Planted Cell and the Wetland Salvage Cell) as well as other natural seed sources (surrounding landscape) is no guarantee of successful wetland development.

Wetland salvage cell–south
Figure 8 is a series of photographs showing initial construction of the wetland substrate salvage cell in May 2000, and subsequent wetland conditions in July 2002 and August 2005.

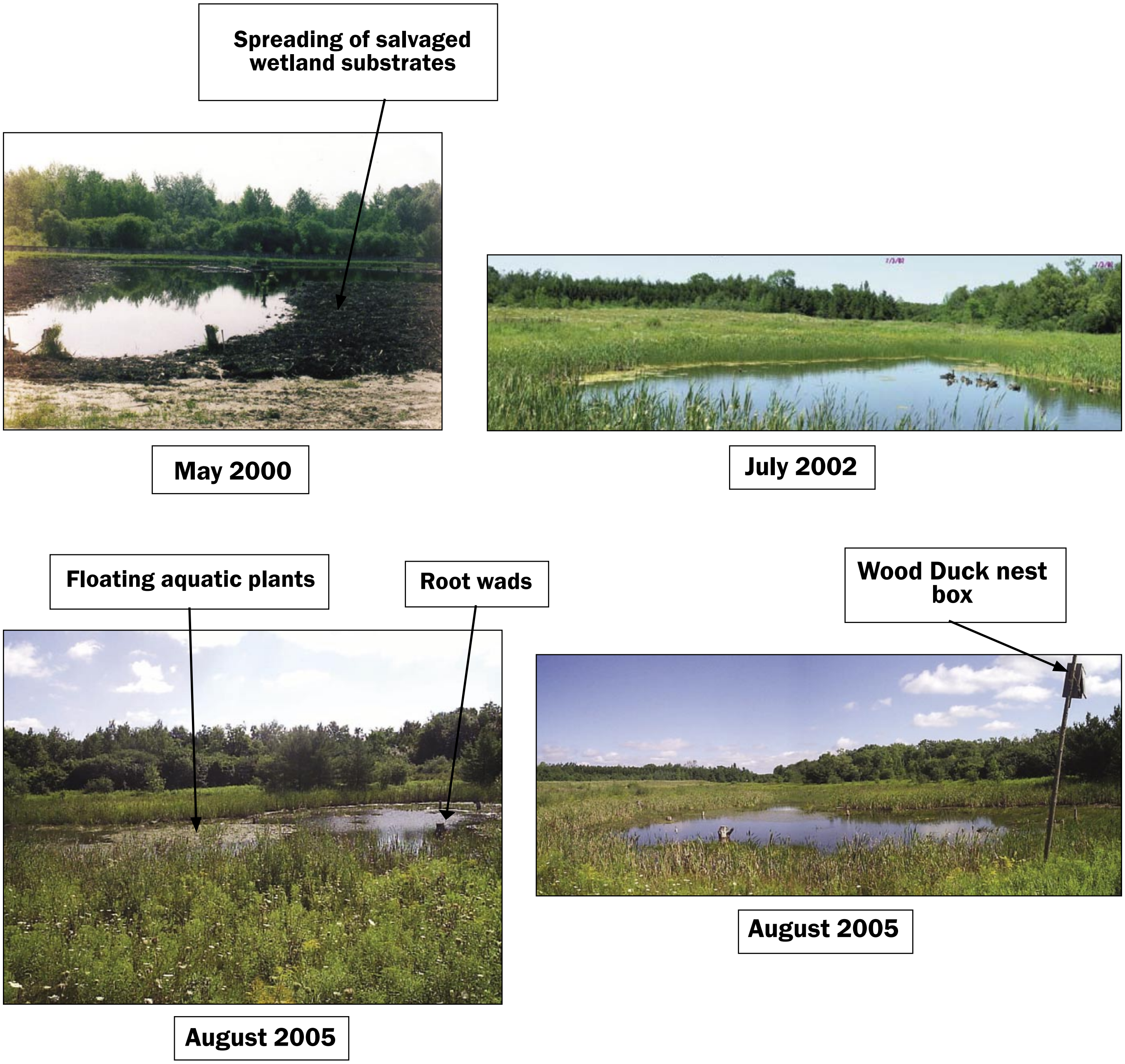


Figure 8. Wetland Substrate Salvage Cell–Stages of Development

An overview of the wetland salvage cell development is as follows:

- The wetland cell was excavated below the water table and raised upland mound zones were developed during the grading.
- Wetland substrates and organic material were salvaged from wetland pockets removed by the roadway and subsequently spread throughout the graded wetland depression. Willow root wads were also salvaged from the construction area and placed throughout the wetland cell. Turtle sunning logs were strategically placed extending from the shoreline into the wetland.

General observations stemming from this work were as follows:

- This was the fastest-developing wetland cell. It exhibited natural wetland characteristics within 3 months of construction.

- Wetland plants such as various sedges (*Carex sp.*), Nodding Bur-marigold (*Bidens cernua*), and Water Plantain (*Alisma plantago-aquatica*) developed first. Cattail (*Typha latifolia and T. angustifolia*) colonized parts of the wetland subsequently via seasonal overflow contributions from the adjacent drainage swale.
- The willow root wads initially exhibited leaf-out and then eventually died. However, the root wads continue to provide aquatic habitat, perches, and habitat for colonizing plants.
- The seed bank salvage placement was thicker than anticipated. Consequently, wetland pond depths were shallower than planned. Nevertheless, wetland water levels persisted throughout the summer, with minimum water depths of 25 to 30 cm present during the August 2005 site visit (following a very dry summer in southern Ontario, as noted previously).
- The wetland has developed with a variety of habitats–open water, meadow marsh, tall grass meadow marsh, cattail marsh, shrub thicket, and floating and submerged wetland. There is remarkably little invasive plant colonization (a few Purple Loosestrife stems noted) and a good diversity of wetland types and plant species has developed. A variety of rushes, sedges, bulrushes, spike rushes, broad-leaved herbaceous plants, and shrubs are present. Examples include *Scirpus atrovirens*, *Bidens cernua*, *Glyceria striata*, *Scirpus cyperinus*, *Eupatorium maculatum*, *E. perfoliatum*, *Asclepias incarnata*, *Carex hystericina*, *Carex stricta*, *Juncus effusus*, *Scirpus acutus*, *Eleocharis palustris*, *Carex vulpinoidea*, *Alisma plantago-aquatica*, *Sparganium eurycarpum*, *Sagittaria latifolia*, *Elodea canadensis*, *Potamogeton pectinatus*, *Scirpus validus*, and *Euthamia graminifolia*.
- Game trails (Muskrat, Raccoon, and White-tailed Deer) frequent the wetland. Leopard Frogs are abundant. Numerous Water Striders were observed during the August 2005 site visit as well as numerous baitfish. In addition, Great Blue Heron, Green-backed Heron, Mallard, Red-winged Blackbird, American Goldfinch, 12-spotted Skimmer (Dragonfly), and White-tailed Skimmer (Dragonfly) were observed.
- A Wood Duck nest box has been erected by Field Center staff at the south end of the wetland. To date, no nesting has been confirmed.
- Discussions with Lake St. George Conservation Field Centre staff (August 17, 2005) confirmed that this wetland cell has been the fastest to develop of the three cells and supports a good diversity of both plant and animal life.

Wetland Pilot Project–Field Centre Perspective

An interview with a Lake St. George Conservation Field Centre staff member (Mr. Jake Elkert) on August 17, 2005 yielded the following perspectives on the integration of the wetland-creation project with the outdoor-education program:

- Field Centre pond studies and the watershed program now involve about eight visits to the wetlands each year (four visits in the summer/fall period and four visits in the spring period). Observation activities include water sampling, assessing pond life (aquatic invertebrates), noting differences between the wetland cells, and wildlife presence.
- An Oak Ridges Moraine group has an annual visit to the wetlands. In addition to checking the various wetland cells, the ORM group has a particular interest in the archaeology sites that were integrated in the wetland creation project.
- Night hikes are held to listen to calling frogs (particularly Spring Peepers). While the existing Frog Pond site nearest Bayview Avenue is still used for this purpose (with vigorous frog calling), there is also good Spring Peeper calling at the constructed wetlands. The wetland creation area provides an alternative amphibian calling area for Outdoor Education uses because it is further removed from the traffic noise on Bayview Avenue (about 300 meters away).
- Weekend visits are made by groups such as the Girl Guides and Brownies, who have done some supplementary planting (cedar and dogwood) in the upland areas bordering the wetlands.
- The Field Centre has in the past provided a high-school environmental-science credit program. The addition of the created wetland complex on site provides an opportunity to re-initiate the science credit program if desired.

Wildlife-Crossing Mitigation

Overview of issues

The wildlife-crossing mitigation for the roadway developed in recognition of the following features and issues:

- The presence of kettle ponds and lakes, wetlands, forest blocks, and ravine topography in the area all provide wildlife habitat and wildlife movement opportunities.
- Frog movements were identified as an issue during the EA study process.
- Confirmation of Jefferson Salamander in the area (a provincially rare and nationally threatened species) by the Richmond Hill Field Naturalists. This occurred late in the design phase of the project.
- A desire to increase roadway permeability for wildlife.

Accordingly, a detailed amphibian-migration study was undertaken with the following objectives:

1. Assess Jefferson Salamander presence and movements in the area.
2. Assess movements by other amphibian species in the area.
3. Determine appropriate mitigation measures for incorporation in roadway design and construction.
4. Identify a post-construction monitoring strategy.

Amphibian migration study

Mole salamanders (such as the Jefferson Salamander and Spotted Salamander) emerge from overwintering sites and migrate in the spring during rainy or very humid nights to breeding ponds. After eggs have hatched, salamander larvae develop for three to four months in the breeding pond. Thereafter, the larvae move from the pond to surrounding forest areas to feed through the summer and fall, prior to the fall dispersal to overwintering sites (Rye and Weller 2002).

Anticipated amphibian movement areas were determined in the field in consultation with Ministry of Natural Resources staff and Dr. Jim Bogart. This determination guided the location and extent of drift fencing (paige wire fence with sediment fence attached and heeled into the ground) that was to be installed for amphibian capture and release. A study protocol was subsequently developed (Ecoplans Limited, 2002) and approved. Finally, a detailed literature review of wildlife-crossing mitigation was undertaken.

Drift fencing 2.2-km long was installed bordering both sides of the road right-of-way (ROW) in the selected movement areas. Pitfall traps were installed at 10-to-30-meter intervals along both sides of the drift fencing. Each pitfall trap consisted of a new four-liter paint can buried in the ground adjacent to the drift fence. A drainage hole was drilled in the bottom of each can. In each pail, a damp sponge was placed within an open plastic bag to provide a moist area for captured amphibians. In addition, a 3/8-inch diameter wooden dowel was placed in each pail to provide an escape route for small mammals. Pail lids were secured between sampling events and then offset with a brick on top to provide a capture entrance for moving amphibians. Figure 9 shows an example of the drift fencing and pitfall pail.

Figure 9. Amphibian Migration Study–Drift Fencing and Pitfall Pail Setup

The migration study and amphibian-processing protocol were completed under a Wildlife Scientific Collector's Authorization provided by MNR. Captured Jefferson Complex Salamanders were measured, sexed, toe-clipped (for genetic DNA analysis), and released in the original direction of movement following protocol procedures. Figure 10 shows an example of salamander capture (pitfall pail) and processing.

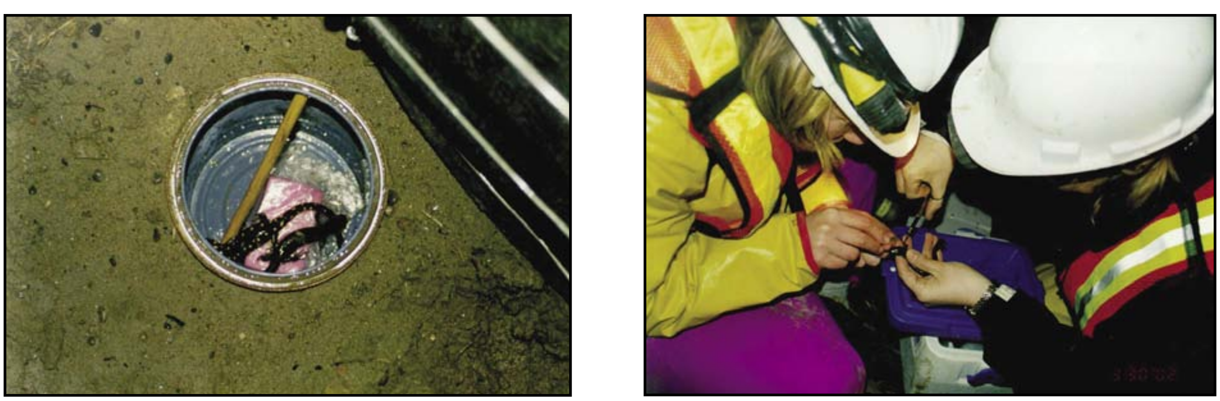


Figure 10. Amphibian Migration Study–Salamander Capture and Processing

Figure 11 summarizes the capture locations of Jefferson Complex Salamander and Spotted Salamander relative to Stouffville Road and the new Bayview Avenue Extension.

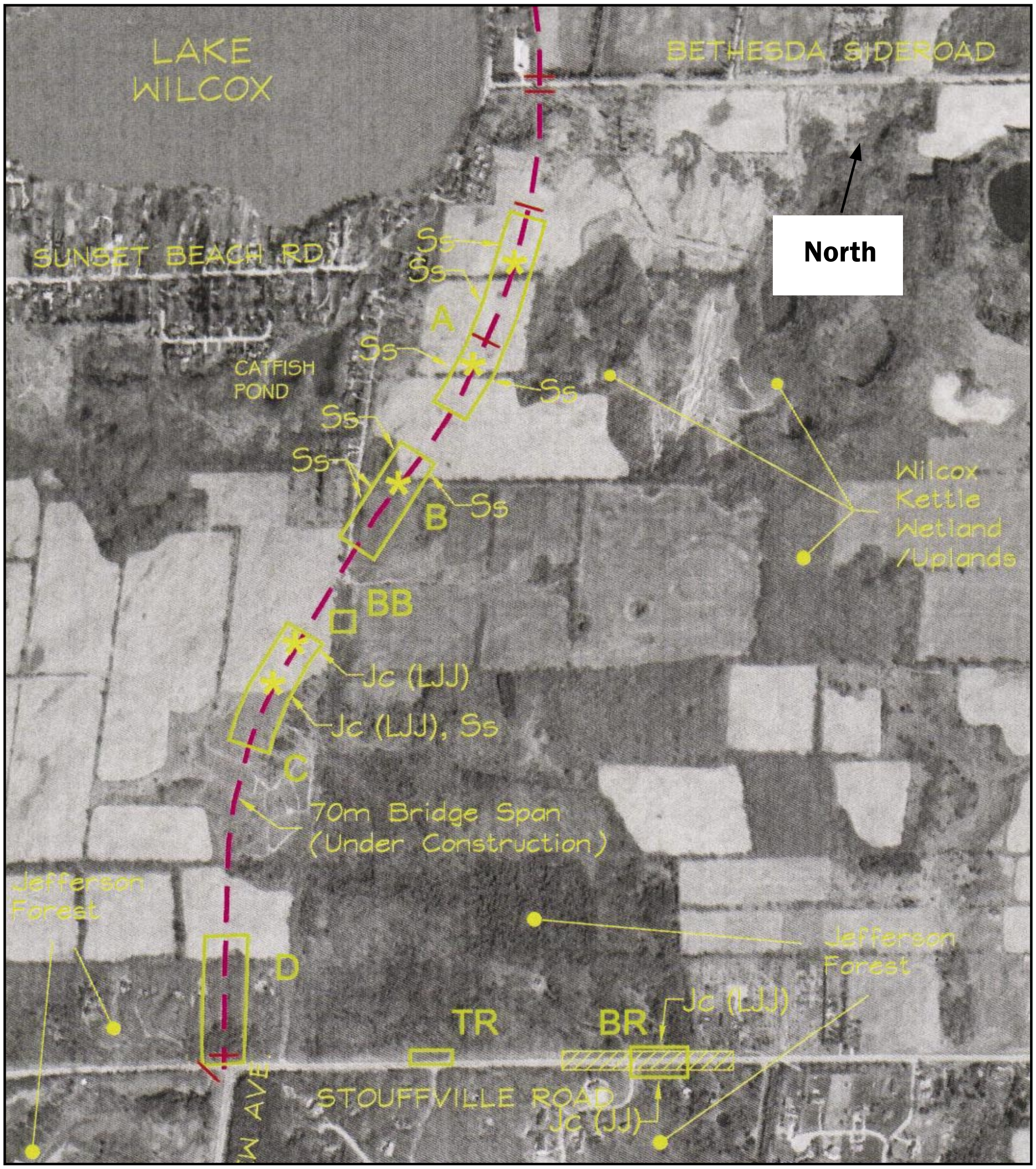


Figure 11. Amphibian Migration Study–Salamander Captures (2002). Jefferson Complex Salamander = Jc; Spotted Salamander = Ss; A to D, TR, and BR are Survey Zones where drift fencing was installed.

Key study activities and findings are highlighted below:

- 220 working pitfall traps were checked through the night by a two- or three-person field crew during 11 sampling events between March and May 2002. With this sampling approach, about 22,000 trap night hours were available for capture during the survey events.
- There were 147 captures/observations of the following eight species: Jefferson Complex Salamander (15), Spotted Salamander (30), Leopard Frog (63), Wood Frog (19), Spring Peeper (14), American Toad (four), Redback Salamander (one), and Northern Redbelly Snake (one).
- Of the 15 Jefferson Complex Salamanders recorded, one was the True Jefferson species (JJ) and the remainders were the Silvery Salamander (LJJ), a strong indicator of the presence of True Jefferson Salamander populations in this area. However, the number of captured/observed individuals is small relative to the survey effort. This may reflect a combination of a small population size and other dispersed breeding ponds in the landscape that do not require salamander movements across Bayview Avenue.
- Inferred movements by Jefferson Complex Salamanders were north and south across Stouffville Road and west (small numbers) towards Bayview Avenue.

- Inferred movements by Spotted Salamanders (in greater numbers) were predominantly west to east across the ROW from the Lake Wilcox area following agricultural fields to breeding sites in the Wilcox kettle wetlands to the east of Bayview Avenue.
- Moderate numbers of Wood Frog, Leopard Frog, and Spring Peeper were observed/captured in similar activity zones (Figure 11, Zones A, B, and C) as recorded for the salamanders.
- There never were mass migration movements of hundreds of amphibians at a time in very focused areas during this study. Movements involved smaller numbers of animals (about 150) in a more dispersed pattern. This number is (of course) conservative and does not include amphibians lost due to road mortality and not detected during road mortality surveys. In addition, the presence of Jefferson Complex Salamanders, as well as moderate numbers of several other amphibian species, led to a decision to provide some dedicated amphibian tunnels. The movement observations and capture information summarized in Figure 11, coupled with the detailed capture information (10-to-30-meter pitfall trap spacing) provided good guidance for tunnel placement.

Based on the capture data from the amphibian migration study, five dedicated amphibian tunnels were added to the design and located as shown in Figure 12. Tunnel-design characteristics were developed through the findings of the detailed literature review, knowledge of site-specific conditions, and discussions with knowledgeable professionals, including Dr. Bogart.

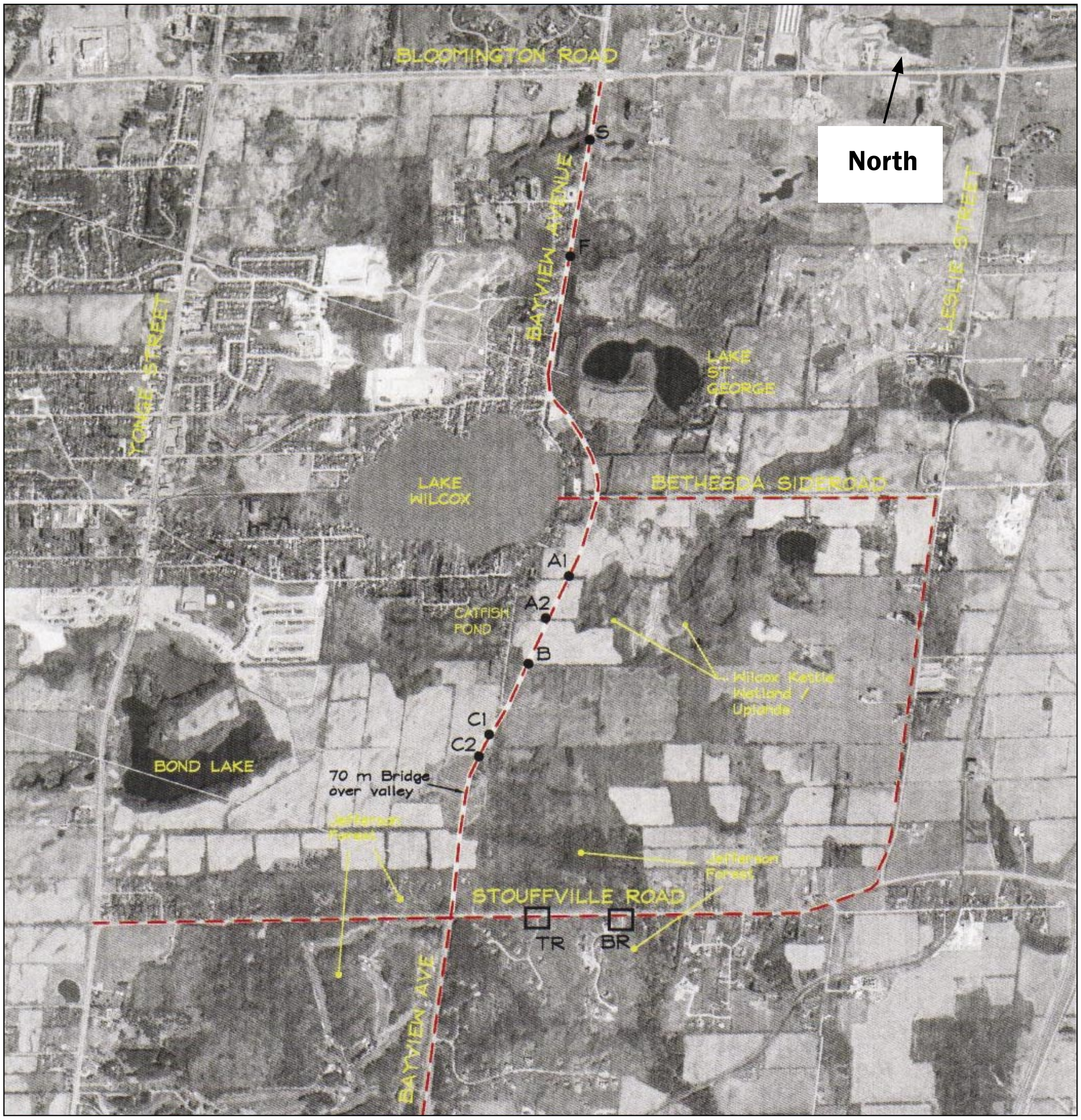


Figure 12. Bayview Avenue Extension Amphibian Tunnel Locations. (Tunnels A1, A2, B, C1, and C2)

The five dedicated amphibian culverts/tunnels were installed under the Bayview Avenue extension between Bethesda Side Road and Stouffville Road within zones A, B, and C (2002 study). The tunnel locations, dimensions, materials, and other characteristics were based on the findings and recommendations of the 2002 salamander study and are highlighted in Table 1 below (north to south from Bethesda Side Road). A sample tunnel cross section is provided in Appendix B.

Table 1. Characteristics of Amphibian Tunnels Installed under the Bayview Avenue Extension

Location	Tunnel Characteristics	Rationale
Tunnel A1	• 1.2-meter concrete pipe with two manhole tees and grates • About 25 meters in length • 50 meters of funnel fencing on each side of tunnel • On-site sandy substrates placed in tunnel	• Capture area for Wood Frogs, Spotted Salamanders, and Leopard Frogs moving towards Wilcox Kettle wetland/uplands • Meets basic size and multi-species use guidelines • Inlet grates for comparison with A2
Tunnel A2	• 1.2-meter circular CSP (corrugated steel pipe tunnel) • About 25 meters in length • 50 meters of funnel fencing on each side of tunnel • On-site sandy substrates placed in tunnel	• Capture area for Wood Frogs, Spotted Salamanders, and Leopard Frogs moving towards Wilcox Kettle wetland/uplands • Meets basic size and multi-species use guidelines
Tunnel B	• 1.2-meter circular CSP (corrugated steel pipe tunnel) • About 31 meters in length • 50 meters of funnel fencing on each side of tunnel • On-site sandy substrates placed in tunnel	• Capture area for Wood Frogs and Spotted Salamanders moving to/from adjacent wet area • Tunnel size supports suite of small to mid-size wildlife-species movements
Tunnel C1	• 1.0 x 1.7 meter elliptical concrete culvert • About 25 meters in length • 30 meters of funnel fencing on each side of tunnel • On-site sandy substrates placed in tunnel	• Located where LJJ Jefferson polyploid and Spotted Salamander crossing • Provides larger opening for tunnel exit brightening, no grates, for comparison with nearby Tunnel C2
Tunnel C2	• 1.2-meter concrete culvert with two manhole tees and grates (each end) • About 25 meters in length • 30 meters of funnel fencing on each side of tunnel • On-site sandy substrates placed in tunnel	• Located where LJJ Jefferson polyploid and Spotted Salamanders crossing • Addresses reasonable diameter guide-line for “see-throughness” • Supports multi-species movements • Grates to provide supplementary light and drainage

The photos in Figure 13 show examples of tunnel construction, tunnel interior (with natural substrates), and one of the finished tunnels (road under operation).

Figure 13. Bayview Avenue Extension–Examples of Amphibian Tunnel Construction, Interior, and Finished Look

Tunnel monitoring (2003/2004)
Tunnel monitoring was undertaken during the spring amphibian migration period in 2003 and 2004 as follows:

- A desire to increase roadway permeability for wildlife.
- Monitoring conducted by a two- or three-person survey crew with radios.
- Six to eight monitoring visits were undertaken each spring (March and April, 2003 and 2004).
- Solar-powered Moon Ray lights were installed at some tunnels to collect anecdotal information on possible attractiveness for amphibians moving through tunnels;
- A tunnel pitfall trap system was installed at each tunnel. The system consisted of a v-shaped plastic fence held in place by wooden stakes (See photo in Figure 14). Amphibians migrating through the tunnel from the opposite end would be directed by the plastic fence (which was still transparent) at the tunnel exist to a pitfall trap. In addition, pitfall traps were installed at each junction of the tunnel end and the funnel fence wall. Amphibians moving along the funnel wall toward the tunnel would be directed to these pitfall traps. In this manner, amphibian movements toward or through the tunnel could be observed/inferred. In addition, the survey crew slowly walked the funnel walls leading to all tunnels, and recorded/observed any amphibians noted. The survey crew also slowly drove the road through the study area looking for amphibian activity.
- Repeat checks following the above survey procedure were made along the road, at each tunnel, and along the funnel walls throughout each survey night.

Silt from manhole grates collecting in tunnel (ponding)

Figure 14. Bayview Avenue Extension–Tunnel Monitoring

Summary findings and conclusions of the monitoring work were as follows:

- Spring weather conditions in 2003 were very poor for amphibian movements because of very cool temperatures, rapid cooling during evenings, and bouts of snow/freezing rain. As a result, amphibian activity in 2003 in this study area was very limited. Limited tunnel passage by Spring Peeper and American Toad was confirmed. Observational data for amphibians were too limited to draw any conclusions about the role of additional artificial light (Moon Ray lights) or variations in tunnel characteristics on amphibian use of tunnels.
- Spring weather conditions in 2004 were better for amphibian activity. There was good calling frog activity in the area during the surveys and road mortality surveys showed moderate levels of amphibian activity.
- There was subdivision and sewer work in the area during the spring of 2004. This may have influenced some animal movements during the construction phase. However, migrating amphibians, particularly mole salamanders, are fairly persistent when moving to breeding ponds, as attested by periodic observations of salamanders (and frogs) in residential pools, basement window sills, and backyards.
- In 2004, 22 amphibians and three mammals were recorded in the vicinity of the tunnels (captures, movement along funnel walls, or movement through tunnels). There was confirmed tunnel use by Raccoons, American Toads, Wood Frogs, Spring Peepers, Leopard Frogs, and Meadow Voles. Observations were generally evenly spread across tunnels A1, A2, B, and C1. Raccoon tracks were noted in all tunnels. Both Meadow Vole use (visual sighting) and other small mammal tracks (possibly *Microtus* or *Peromyscus*) were observed in Tunnel C1.
- There was no recorded tunnel use by Jefferson Salamander or Spotted Salamander in either 2003 or 2004. In 2003, one Jefferson Complex Salamander was observed walking past the entrance to tunnel C1 to the end of the funnel wall, where it then attempted to cross the road. This animal was subsequently carried to the west side of the road and then released. Salamanders may need to "learn" to find and use the tunnels. We are hopeful this may occur over time.
- Most tunnels maintained damp sandy substrate conditions as desired (free draining with roadside stormwater bypassing the tunnels as designed). The exception was tunnel C2, which had persistent ponded water throughout the tunnel during the surveys and may have impeded or restricted animal use. The reason for the poor drainage of this tunnel is under review.

During a recent check of the tunnels in August 2005, two observations were made:

- Dispersing and foraging Leopard Frogs were active in the area. A few adults and one juvenile were observed using tunnels A1, A2, and B.
- In tunnel C2 (manhole tees and grates), silt material had fallen through the grates, resulting in silt piles under each manhole, with water ponding evident in between. Grates in this instance may therefore introduce some management challenges in the future.

Environmental Management Overview

Project summary/costs

- The Individual Bayview Avenue EA was successfully delivered in 1998.
- The road design was completed in 2001 and the road was opened to traffic in 2002.
- Total cost of the project (road works, wetland creation, and other mitigation, engineering, amphibian migration study and tunnels, and approvals) was about $10 million (US).
- The environmental management and wetland creation (pre-stressing of forest zones, protection fencing, clearing and grubbing, transplanting, berm construction (two berms + wetland berm), seed bank salvage, and landscaping costs totaled about $820,000 (US). Of this total, the wetland construction costs were about $330,000 (US).
- The cost of the 81-meter three-span bridge was about $1.2 million (US).
- The amphibian migration study cost (2002) was $71,000 (US).
- The cost of the five amphibian tunnels totaled $360,000 (US).
- Amphibian tunnel monitoring costs for 2003/2004 were $14,500/year (US).
- The project was awarded the Award of Excellence by the Consulting Engineers of Canada in 2003.

Landform Conservation–Oak Ridges Moraine

Conservation of landform topography has been identified as an important objective in the Oak Ridges Moraine Conservation Plan. One of the relevant transportation policies in the Plan deals with minimizing construction disturbance in natural linkage areas and allowing for wildlife movement. In addition to the provision of the dedicated amphibian tunnels, the project also installed a major three-span 81-meter bridge across ravine topography near the south end of the road extension (see Figure 15). This bridge maintains a good valley openness and clearance above the ravine bottom. Numerous White-tailed Deer tracks were observed in the sandy soils during the August 2005 site check.

Figure 15. Landform Conservation–Three-span 81-meter Bridge

Conclusions

- The environmental-management program was instrumental in securing agency approvals for a contentious project.
- The Project Team efforts were acknowledged by the naturalist community. At the completion of the amphibian migration study and design, a positive letter was received from the Richmond Hill Field Naturalists.
- The science of wildlife-crossing mitigation was advanced. Some challenges were noted with tunnel drainage (one tunnel) and subdivision/sewer work. There are answers and questions. Further tunnel monitoring has been recommended.
- The pilot wetland-habitat creation project provided tangible environmental and educational benefits and holds much promise for future Field Centre uses, as well as an example for other habitat-creation projects.

Acknowledgements: We wish to acknowledge the Region of York, Ontario, which was the proponent and funder of the project and who provided ongoing support throughout the planning, design, and construction of this challenging project. Mr. Ian Buchanan of the Aurora District Ministry of Natural Resources (now with York Region) provided helpful input during the amphibian-migration study portion of the project. Dr. Jim Bogart of the University of Guelph, a recognized expert on the Jefferson Salamander, gave freely of his time and knowledge in providing technical assistance to the project team. Mr. Jake Elkert of the Lake St. George Conservation Field Centre provided valuable input on the Field Centre programs in the context of the wetland-creation site. Finally, the positive response to the amphibian-migration study report and its implementation (dedicated amphibian tunnels) forwarded by the Richmond Hill Naturalists is acknowledged.

Biographical Sketches: Geoff Gartshore (B.Sc., M.Sc.) is a senior Ecologist and Partner with Ecoplans Limited, the independent environmental division of McCormick Rankin Corporation. Mr. Gartshore has been a key participant in a wide range of environmental projects encompassing terrestrial and aquatic-resource assessments for many public and private-sector clients throughout Ontario. He also helped prepare the Environmental-Management Plan for a major highway in New Brunswick. His expertise has been applied to highway and utility corridor studies, resource-management studies and plans, urban-development impact studies, and rehabilitation and restoration projects. Mr. Gartshore's special interest is in wildlife and transportation mitigation strategies for highways and urban developments. He has been working as an Ecologist since 1981 and has been with Ecoplans Limited since 1984. He has presented various research and case-study papers before bodies such as the International Road Federation, Environment Canada, Ontario Good Roads Association, Municipal Engineers Association, the University of Windsor, and the International Conference on Ecology and Transportation. He has participated in projects that received awards from the Consulting Engineers of Canada and the Transportation Association of Canada.

Michelle Purchase, B.E.S., M.L.A., Landscape Architect, has over five years experience working on environmental projects and is a Full Member of the Ontario Association of Landscape Architects. Ms. Purchase assists with the completion of environmental inventories and impact assessments, as well as the preparation of landscape designs and site-supervision services for numerous projects. She has recently been managing landscape design, environmental impact, and tree-management projects. Ms. Purchase conducts detailed botanical inventories (she is formally trained in the Ecological Land Classification System for Southern Ontario), prepares conceptual plans, research, graphic presentations, detailed designs, reports, construction drawings and specifications, cost estimates, and post-construction rehabilitation and monitoring. She has addressed arboricultural and ecological design challenges as they relate to a wide variety of projects including stream restoration, forest management, transportation, trail design, public park design, natural-heritage planning, and residential-estate design.

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Appendices

Appendix A. Bayview Avenue Extension, York Region, Ontario Canada. Wetland Creation Project–List of Planted Vegetation.

Seed Mix
MTO Type 1

Species planted in Planted Cell:
Speckled Alder, *Alnus rugosa*
Serviceberry, *Amelanchier sp.*
Gray Dogwood, *Cornus racemosa*
Red Osier Dogwood, *Cornus sericea*
Bush Honeysuckle, *Diervilla lonicera*
Ninebark, *Physocarpus opulifolius*
Chokecherry, *Prunus viginiana*
Staghorn Sumac, *Rhus typhina*
Pussy Willow, *Salix discolor*
Black Elderberry, *Sambucus canadensis*
Meadowsweet, *Spirea alba*
American Cranberry, *Viburnum trilobum*
Tamarack, *Larix laricina*
White Spruce, *Picea glauca*
White Pine, *Pinus strobus*
White Cedar, *Thuja occidentalis*
Red Maple, *Acer rubrum*
Musclewood, *Carpinus caroliniana*
Green Ash, *Fraxinus pennsylvani*
Ironwood, *Ostrya virginiana*
Balsam Poplar, *Populus balsamifera*
Eastern Cottonwoo, *Populus deltoides*
Black Willow, *Salix nigra*
Basswood, *Tilia Americana*

wet meadow mix (Shoreline) (28 plants per zone covering 5 sq. meters)
Swamp Milkweed, *Asclepias incarnata*
Spotted Joe Pye Weed, *Eupatorium maculatum*
Wool Grass, *Scirpus cyperinus*

grassy wet meadow (Shoreline)
Redtop, *Agrostis alba (stolonifera)*
Canada Blue-joint, *Calamagrostis canadensis*
Fowl Mannagrass, *Glyceria Striata*
Rice Cutgrass, *Leersia oryzoides*

shallow emergents - up to 15 cm
Nodding Bur-marigold, *Bidens cernua*
Porcupine Sedge, *Carex hystericina*
Wooly Sedge, *Carex Lanuginosa*
Tussock Sedge, *Carex stricta*
Soft Rush, *Juncus effusus*
Hardstem Bulrush, *Scirpus acutus*

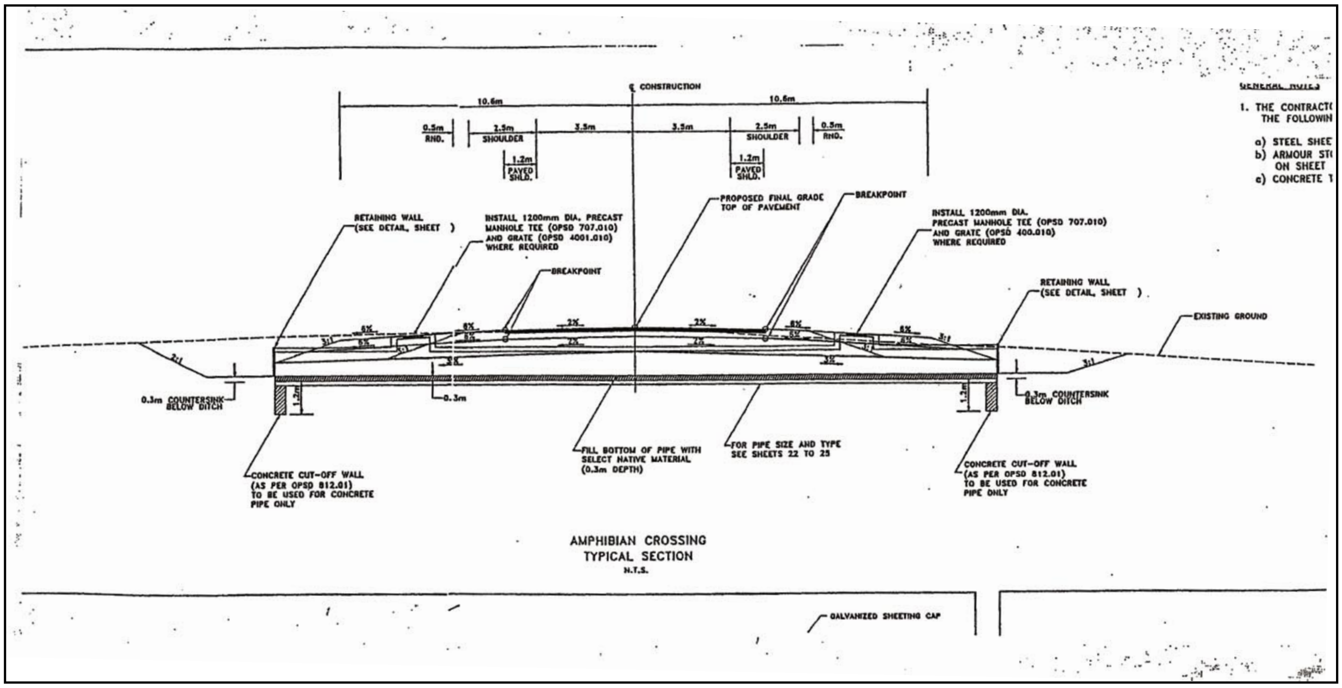
shallow emergents - up to 15 cm (shade tolerant)
Marsh Spike Rush, *Eleocharis palustris*
Retrorse Sedge, *Carex retrorsa*
Fox Sedge, *Carex vulpinoidea*

emergents - up to 30 cm
Water Plantain, *Alisima plantago-aquatica*
Giant Bur-reed, *Sparganium eurycarpum*

deep water emergents - up to 60 cm
Lake Sedge, *Carex lacustris*
Water Smartweed, *Polygonum amphibium*
Arrowhead, *Sagittaria latifolia*

submerged and floating,
Waterweed, *Elodea canadensis*
Sago Pondweed, *Potamogeton pectinatus*

Appendix B. Bayview Avenue Extension, York Region, Ontario Canada. Amphibian Tunnel–Sample Cross Section.



Connecting Values, Process, and Project Design: Twinning the Trans-Canada Highway in Banff National Park in Canada

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Abstract

Extending from coast to coast, the Trans-Canada Highway (TCH) plays an integral role in Canada's social and economic wellbeing. For geographic and historical reasons, 83 of its 7,500 kilometers bisect Banff National Park, Canada's first and most popular park. Part of the UNESCO Canadian Rocky Mountains World Heritage Site and known worldwide for this park's spectacular landscapes and exceptional natural resources, Banff has long been considered a harbinger for the future of other parks and protected areas across the country.

Parks Canada is the federal agency responsible for managing national parks in Canada. Under its mandate, Parks Canada must preserve and protect the ecological integrity of national parks for future generations while fostering public use and appreciation of these areas. And while not truly part of the mandate, major highways that run within and through federal park lands have also fallen to Parks Canada to manage.

Between 1979 and 2005, in response to rising traffic volumes and public safety concerns, 43 of 83 kilometers of the Trans-Canada highway in Banff National Park were converted in phases from two to four lanes. Each of these phases sparked national public interest, the first two in particular becoming flashpoints for the many divergent views about development and conservation in protected areas. These divergent views were not limited to external stakeholders, as highway twinning was seen internally to compete with and divert limited Parks Canada's resources away from direct mandate-related needs. Adding to the complexity of the situation is the unique governance context with Parks Canada as land manager, decision-making authority, and project proponent.

This paper offers a 25-year perspective on Parks Canada's approach to developing context-sensitive solutions; specifically use of a collaborative, interdisciplinary approach for developing a transportation facility that preserves scenic, aesthetic, and environmental resources while maintaining safety and mobility. Through four separate phases of the Trans-Canada Highway Twinning Project, this paper details how the nature and substance of public participation has changed over time and how public input can be reconciled with scientific information, project objectives, a challenging agency mandate, and engineering and financial considerations. Lessons learned in earlier phases have been applied to the most recent phase, resulting in improved stakeholder relationships and satisfaction, as well as leading-edge highway and mitigation design.

Biographical Sketch: Terry McGuire graduated in 1975 from the University of Calgary with a civil engineering degree. He is currently the Director of the Western Asset Management Service Center for the West and North Region of Parks Canada. Within this position, his duties include responsibility for highway operations, maintenance, and reconstruction within the Canadian Rocky Mountain Parks of Canada. He is a professional engineer. Of prime concern to McGuire is the mitigation of impacts highways have on ecological integrity within these national parks, as well as highway safety for both through traffic and park visitors.

Environmental Imperatives and the Engineering Interface: How to Make Hard Decisions

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Abstract

Parks Canada has been engaged in upgrading the Trans-Canada Highway in Banff National Park since 1979. A severe wildlife/vehicle collision problem existed and was predicted to worsen unless mitigation measures were employed. Permission to twin the highway from two lanes to four lanes was granted in phases, subject to exceptional environmental protection measures. Forty-five kilometers of highway have been twinned with 2.4-m-high fences and 24 large crossing structures. Parks Canada now is planning a 33-km continuance of the highway twinning project, with a 12-km segment presently under construction. Innovative environmental protection measures, based on the successes of earlier initiatives, are being employed.

The most obvious of these measures have been fences and wildlife crossing structures to safeguard the rich assembly of wildlife resident or transient in the Bow River Valley. Valued ecosystem components include 12 species of large, highly transient Rocky Mountain wildlife, all subject to habitat fragmentation and vehicle collision. The species include protected native fish, Harlequin ducks, and a rich biodiversity in a high profile World Heritage Site. Parks Canada has a legal duty to maintain or restore ecological integrity in such undertakings.

Research, planning, and design have high visibility in the presence of a motivated public who vigorously express divisive viewpoints. This presentation will explain:

- How new designs respond to scientific imperatives
- Science and social lessons learned
- How to manage the confrontation of rhetoric and reality
- How the future looks different than the past

Biographical Sketches: Martin Jalkotzy is a Senior Wildlife Ecologist with Golder Associates in Calgary, Alberta. Martin will be the senior reviewer and will provide on-going strategic direction throughout the project. He has authored or co-authored nine refereed publications and over 40 technical reports and papers and has filled the role of technical and quality assurance editor for several environmental assessments. During his 27 years as a wildlife biologist, he has specialized in the effects of human development on wildlife. He recently acted in a senior role during Golder's environmental assessment of twinning the Trans-Canada Highway from Castle Junction to the Continental Divide, which included a review of the effects of the project on grizzly bears, black bears, harlequin ducks, and boreal toads. Over the last two years, he coordinated a review of the cumulative effects of development on the Castle Carbondale region of southwestern Alberta. He was an invited wildlife specialist on the East Kootenay wildlife winter-range committee, which included the assessment of the effects of development on moose, elk, bighorn sheep, mountain goats, and caribou0. He completed an exhaustive review of the effects of linear corridors on wildlife, which included an examination of the effects of recreational development. His species-specific research in Banff National Park examined the effects of front and backcountry recreational use on habitat effectiveness for grizzly bears. Most projects involved the application of GIS to deal with spatially complex issues. His experience integrating GIS into complex projects will be an asset to this project.

Dr. Bruce Leeson has lived and worked in the Rocky Mountains since 1969. After graduating from Montana State University in 1972, Bruce took a position as an environmental scientist with Parks Canada, where he has since worked, primarily in the National Parks of western and northern Canada, most of them World Heritage Sites. Bruce's work has focussed on environmental planning, impact assessment, and stewardship issues inherent in managing protected areas. Bruce has worked on highways and wildlife issues since 1972, with responsibility for the environmental-planning elements of the Trans-Canada Highway through Banff National Park. Forty-seven km of highway have now been twinned and fenced with 23 wildlife-crossing structures. Positive results for wildlife and people have been exceptional. Dr. Leeson recently was Director of Environmental Affairs for the 2002 Kananaskis G8 Summit. Although Bruce has returned to his position as Senior Environmental Assessment Scientist for Parks Canada—Western, his involvement with G8 continues as Senior Environmental Advisor to undertake the Kananaskis G8 Environmental Legacy projects to enhance wildlife-habitat connectivity.

Improving Mobility for Wildlife and People: Transportation Planning for Habitat Connectivity in Washington State

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Abstract

Washington State's Snoqualmie Pass area supports many native habitat types and provides important linkage for wild lands between the North and South Cascades. The fragmented state of habitats in this area has made it a focal point for efforts by agencies and other organizations concerned with protecting and restoring natural habitats and wildlife populations.

Interstate 90 crosses the Cascade Mountains at Snoqualmie Pass. The Washington State Department of Transportation (WSDOT) is currently developing plans for adding lanes to Interstate 90 east of Snoqualmie Pass between Hyak and Easton. Planning for this transportation project includes consideration of the ecological needs of the area. In addition to transportation objectives, this project design also involves a major emphasis to construct the new roadway so as to improve and restore connectivity for terrestrial and aquatic species through the roadway corridor. This is a true multi-species approach which takes into consideration high- and low-mobility species, mountain terrain and climate, and landscape-level habitat linkages, as well as very localized special habitats.

This effort involves extensive coordination and partnership with state and federal agencies, as well as with environmental groups. Numerous scientific studies and inventories have been conducted in the area to provide a sound foundation and a special planning process specifically for the connectivity elements. Larger structures are planned at stream crossings to not only provide for hydrologic functions and processes, but also to allow for wildlife passage in riparian areas.

Additional upland wildlife crossing structures are planned to allow movement of terrestrial species. Seven emphasis areas, called Connectivity Restoration Areas (CRA's), have been identified in the 13-mile project. These improvements form a comprehensive approach in conjunction with compatible land management by the U.S. Forest Service and land acquisition and protection by environmental organizations. Together, these efforts represent a public investment in the hundreds of millions of dollars and constitute one of the largest restoration efforts of its kind in the country.

This presentation will discuss how the many issues related to habitat connectivity come together in the development of a large and complex transportation project. This involves the process for assessing planning aspects of the project that will improve connectivity for terrestrial and aquatic species hydrologic processes including baseline studies, GIS modeling, multidisciplinary groups for mitigation planning, analysis of connectivity needs for various species groups, and stakeholder coordination.

Future direction for habitat connectivity at the state or regional scale will also be discussed, including new Department Policies relating to connectivity, agency, and stakeholder coordination.

Note: The following posters scheduled for presentation at ICOET 2005 are related to this abstract and project:

- Combining Transportation Improvements and Wildlife Connectivity on Freeway Rebuild in Washington's Cascade Mountains (Charlie Raines, I-90 Wildlife Bridges Coalition)
- I-90 Snoqualmie Pass East Project: Linking Communities in the Natural and Built Environment (Jason Smith and Randall Giles, Washington State Department of Transportation)
- Landscape Ecology in Transportation Planning (Patricia McQueary, Washington State Department of Transportation)

Biographical Sketch: Paul Wagner is a wildlife biologist with over 20 years experience in the field, including work with red-wolf reintroduction in North Carolina and studies of seabirds in Alaska's Pribilof Islands and ice-age mammals in Arctic Alaska. He is currently the Biology Branch Manager for the Washington State Department of Transportation and manages programs responsible for policy and interagency coordination related to wetlands, fish, wildlife, and habitat issues statewide. He has a B.S. degree in Natural History from Juniata College and graduate coursework in salmon ecology at Evergreen State College. Wagner has served on committees of the National Academies of Sciences, been involved in assessing the ecological effects of roads, and has been a steering committee member of ICOET since 1998.

Integrating Community Values and Fostering Interagency Collaboration Through Outreach With Interactive GIS Models

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Abstract: The Merced County Association of Governments (MCAG) was chosen by the Federal Highway Administration, U.S. Environmental Protection Agency, and the California Department of Transportation to pilot a new program, Partnership for Integrated Planning (PIP), which aimed to: streamline planning and the project-delivery process; avoid environmental impacts; foster collaboration among planning, transportation, and environmental agencies; and engage the public at the beginning of long-term transportation planning.

Merced County provides a challenging test case through rapid population growth, cultural diversity, high unemployment, and increasing conflicts between stewardship of sensitive habitats and prime farmland and demands for transportation improvements and housing.

The Partnership for Integrated Planning (PIP) included the development of geographic information system (GIS) tools for modeling growth and environmental impacts to produce real-time maps and tables resulting from policy choices at public meetings. PIP engaged all regionally relevant planning, natural resource, and regulatory agencies in data-sharing exercises to integrate data important to each agency into the scenario testing and planning process. Most importantly, the Merced County Association of Governments (MCAG), which is the coordinating partner in PIP, led an extensive outreach program to engage the community in PIP.

To project land-use changes, we adapted UPlan, a rule-based land-use model developed at the University of California at Davis. UPlan incorporates user-controlled policy inputs ranging from general plan map choices, housing densities, and household labor rates to the ranking of environmental amenities. These are combined with user-settable infrastructure growth attractors to distribute population-growth estimates into spatially explicit land-use scenarios. UPlan stores all user-specified assumptions so many scenarios may be tested against one another in a transparent fashion. We evaluated information needs by asking planning agencies which features (such as roads and urban service boundaries) they considered attractions and discouragement factors for growth. Resource agencies were asked what environmental factors should discourage or constrain growth. All agencies were asked to provide all available and relevant data.

This shared information resulted in an Environmentally Sensitive Areas (ESA) map and a Prime Agricultural Lands map. These two maps were evaluated at a workshop attended by resource agencies' representatives, elected officials, and city and county planners. Contributors included over 20 federal, state, and non-governmental organizations.

Like most public agencies, MCAG has historically solicited public input for regional transportation planning from a few community workshops. For example, in 2001 the agency held seven workshops for its previous plan. Under PIP, MCAG held 20-32 meetings each quarter, for a total of 100+ public meetings in 18 months. In addition, MCAG replaced the previous narrow focus on transportation by asking county residents to develop a vision for land use, natural resources, and transportation throughout their community. MCAG mastered the use of UPlan and accompanying environmental data and improved substantially on both throughout the course of these public meetings.

Historically, transportation-plan approval has run into considerable public and agency opposition. Federal officials in the last decade have attempted to streamline the National Environmental Policy Act (NEPA), California Environmental Quality Act (CEQA, which is California's NEPA equivalent), and other permitting procedures. A goal of PIP was to find a method for responsibly arriving at a consensus plan with less conflict, particularly in the environmental-review phase. The Regional Transportation Plan was approved by the MCAG Governing Board and received no opposition during the CEQA Environmental Impact Report (EIR) public-comment period.

Results of the Partnership for Integrated Planning model include:

- 800 percent increase in public participation in the transportation-planning process
- 89 percent of participants said they enjoyed the PIP project
- 89.1 percent of participants said they learned more about transportation issues
- 30 percent increase in awareness of the Regional Transportation Plan (RTP) among all county residents
- New issues brought to the surface from county groups who had not previously participated in the process
- Better relationships were built at both the county and city level among civic organizations, agencies, and residents
- RTP was approved by the MCAG Governing Board and received no opposition during public-comment periods
- Development of an Environmentally Sensitive Areas map based on shared information from a variety of resource- agency databases
- Development of a Prime Agricultural Lands map based on input and information from a variety of agricultural interests

Further research is needed on the portability of this information and this tool-centered collaborative approach. Adjacent counties with similar needs are prime candidates for study. In addition, future projects should include measures of the social and political planning decision network structures existing before and after the conduct of such projects.

Background

The history of transportation and other project permitting in California is a study in "step-by-step" planning. The California Environmental Quality Act initial (scoping) filings for projects with potentially significant environmental impacts comprise over 15,000 EIRs filed for private and public construction projects since the inception of the act in 1972. Most of these projects concluded the need for one or more mitigation efforts (CEQAnet Database 2004).

This stepwise approach to planning, review, and mitigation has been costly and time-consuming and has led to a failure to appreciate the cumulative impacts of projects on such things as agricultural land loss, biodiversity, and wildlife-movement corridors (Landis et al. 1996). This practice has also missed the opportunity to provide more meaningful biological conservation through large area, multi-project planning.

The California Department of Transportation (Caltrans) has recognized this failing in single project planning and permitting. Caltrans management has long held an interest in finding methods to provide better management of cumulative impacts while streamlining the permitting process. In 1999, Caltrans convened the U.S. Environmental Protection Agency (EPA) and the Federal Highway Administration in a University of California, Davis facilitated dialog on the possibilities for innovative new approaches to planning.

These discussions resulted in the "Mare Island Accord," which committed the agencies to seek methods for cooperative, comprehensive planning and pledged the partners to creating a pilot project testing the principles of the Accord. A pilot project location was agreed to in Merced County, California, because of rapid regional growth pressure there and because GIS expertise was available and local leadership was willing to accept the challenge of creating a collaborative planning process. The result was the Partnership for Integrated Planning in which the Merced County Association of Governments led agencies to seek methods for cooperative, comprehensive planning.

Method

Agency partners

The first step in the process of establishing a collaborative, comprehensive framework for regional planning was to seek partners from among interested regulatory and resource agencies. Agencies were asked to provide two levels of input. One level was the provision of service on an administrative advisory board. The other level was contribution of personnel to a GIS and data technical-advisory board. It was necessary to insure that all interested agency partners have input to the process and the ability to review and comment on all data that would be used in a comprehensive regional-planning program.

Towards this end, 18 state and federal agencies were contacted and asked to participate in a series of technical and administrative meetings establishing the process, guidelines, and technical specifications for a planning process that would involve all parties in developing, understanding, and supporting a description of the natural resource and transportation context in which regional planning and project planning would take place in the future. Over 70 one-to-one and group technical and administrative meetings were held over a three-and-a-half-year period as agencies and institutions worked out their differences regarding the acceptability of data and the development of administrative agreements.

The first eye-opener was the realization that agencies did not even know what each other's mission statements were and if they conflicted with their own. A spreadsheet of participating agency mission statements was developed to help establish a foundation of understanding and appreciation. A second hurdle was asking reviewing agencies for a major shift in thinking from the project to the planning level. A third hurdle was, frankly, the level of trust among participants. Everyone recognized that only time and continuous communications could build this trust, and these activities, over time, proved to be productive. The one goal that was readily embraced by all participants was the desire to streamline the workload, especially in the face of reduced staff and other budget cuts. The challenge was in combining divergent expectations and processes.

What began as a slow "forming and storming" process gathered momentum as the result of relationship building and active listening over a period of time–and time should be stressed here. This is not an easy, readily agreeable, short-lived process. Eventually, agreement over a joint planning process, the nature of institutional relations, and the quality and usability of data were all issues that were significantly resolved.

The UPlan model tool

Overlapping and supporting the process of group consensus building was a process of urban-growth model development which supported the discussions and continued to bring a sense of urgency to the need for resolution of concerns on a regional scale. UPlan (an open source add-in for ArcView) was selected as the modeling tool for this project.

The UPlan urban-growth model was developed by Johnston, Shabazian, and Gao (2003). The model permits the user to identify a series of urban-growth attractors and discouragement factors which are then applied to the study region to direct the location of new households and employment according to local land-use plans. Two versions of UPlan are available, one in ArcView3.2 that uses Spatial Analyst and one in ArcGIS9 (ESRI, 2004). We used the Arc View 3.2 version for this project.

The UPlan urban-growth model is a rule-based grid model. It allocates the projected area needed by each land-use type to available areas through a set of rules based on projected population increases, local land-use plans, existing cities, and existing and projected roads

UPlan projects urban growth in seven land uses including four residential densities, industrial, and two densities of commercial development. The model is not calibrated on historical data because it is intended for use in long-range scenario testing. UPlan allocation rules simulate land markets broadly by using infrastructure and other features as surrogates for economic activity. UPlan assumes that population growth can be converted into demand for land use by estimating employment ratios and household sizes. It projects growth only into general plan uses which allow each type of land use unless otherwise instructed.

UPlan uses an additive model of weighting growth attraction and discouragement. Cells have different attraction weights because of accessibility to transportation and infrastructure or other features. Other cells, such as sensitive habitats and floodplains, will discourage new development. (See Figures 1 and 2.)

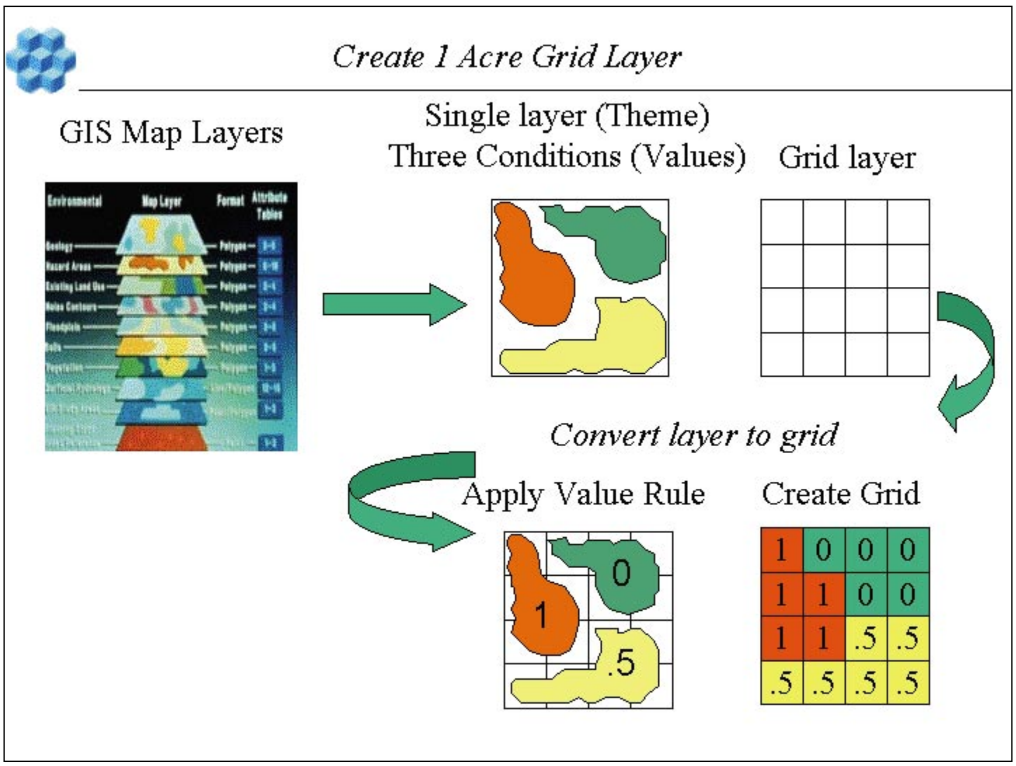

Figure 1. Create 1 Acre Grid Layer

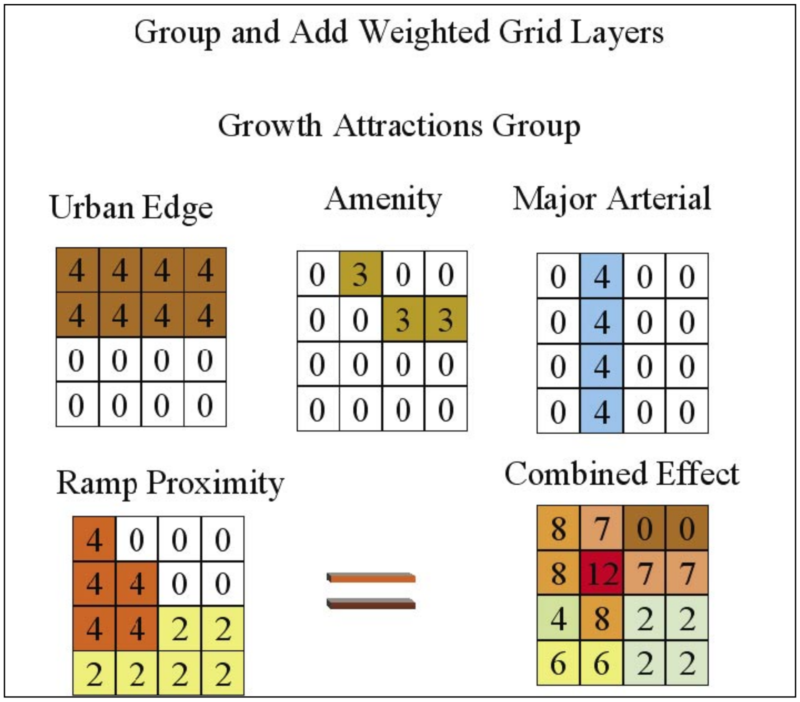

Figure 2. Uplan has a robust user interface which encourages non-GIS professionals to explore a variety of policy choices and value expressions that allow user control over everything from lot sizes to the value of vernal pools. Examples of planning variables and resource "discouragements" to development are given in Figures 3 and 4. The program is designed to run quickly to allow users to test many choices.

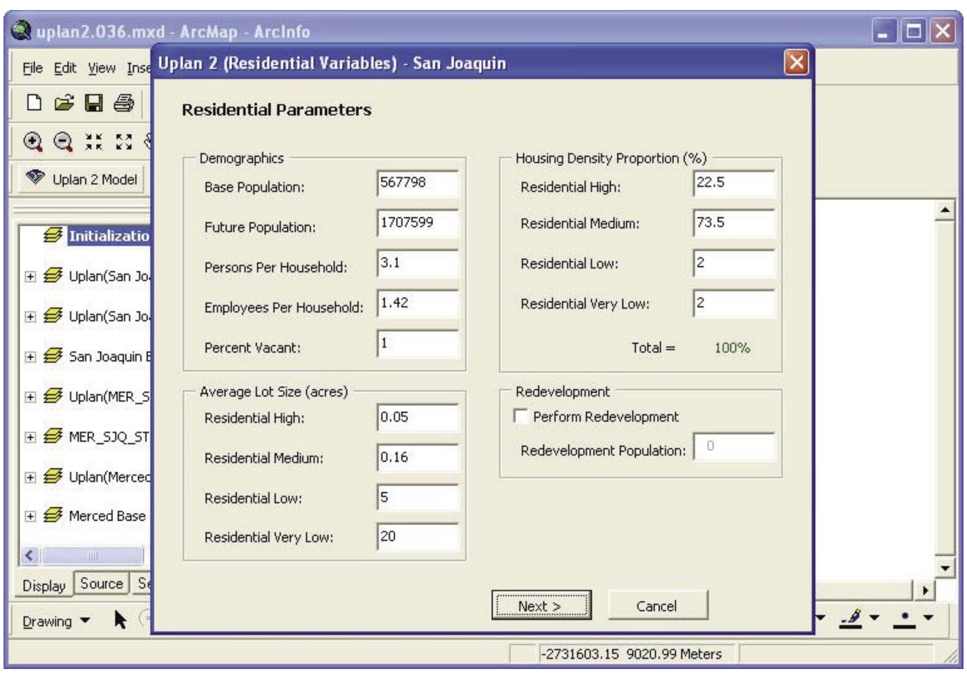

Figure 3. Screen Capture of UPlan 2 (Residential Variables).

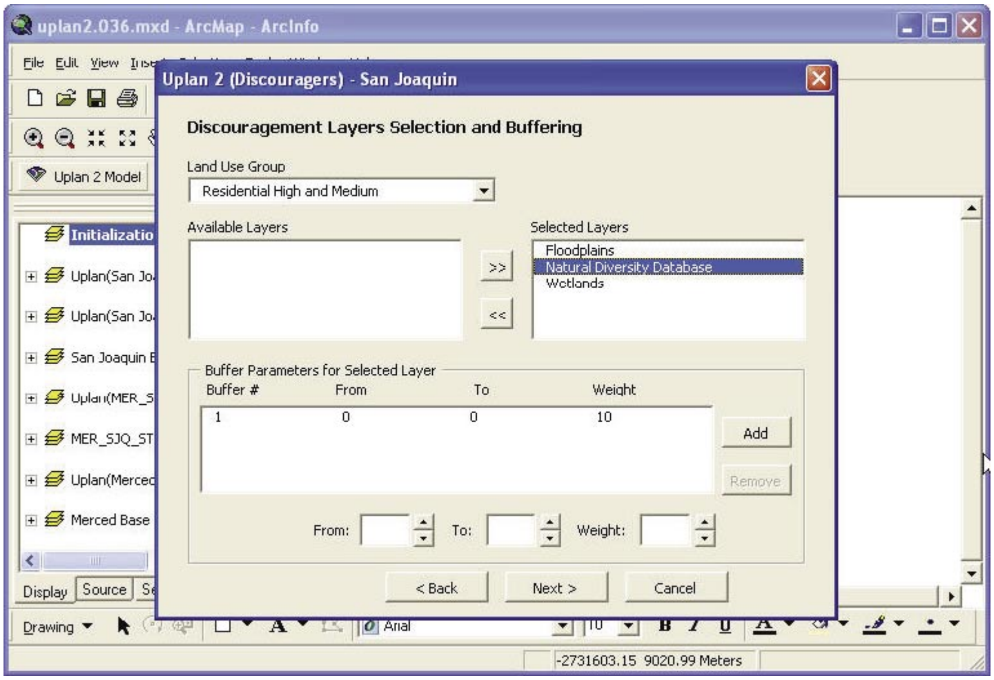

Figure 4. UPlan was used extensively at partnership meetings and public-participation meetings to help parties understand the implications of policy choices and value selections and, most of all, to help them communicate their interests to one another in the collaboration process.

Results

Based on what was heard at over 70 public meetings, five initial scenarios were developed: No Build, Current Policy, Some Changes, Alternative Modes, and Ultimate System. We did another round of 32 public meetings, plus allowed Internet users to provide input on the scenarios. An interesting phenomenon occurred. While many workshop attendees placed one checkmark to vote for the entire scenario, rather than vote for each component separately, most went out of their way to vote for the land-use description attached to the Alternate Modes scenario. (The overall favored scenario was Some Changes.) That description read, "Land is used differently. Higher densities, more mix of uses, walkable communities, and transit-oriented development receive priority." MCAG has no land-use authority, and so this information was passed to the appropriate organizations.

In discussions on the original set of scenarios, residents expressed high interest in components of certain scenarios, particularly Some Changes and Alternate Modes, but not necessarily every component of one scenario. Thus, five "hybrid" scenarios were developed for the final public workshops (Current Policy, Some Change, More Changes, Alternate Modes, and Alternate Modes + Roads). The "More Changes" scenario was overwhelmingly selected for its ability to reduce future traffic congestion while doing the best job of preserving pavement. It also increases transit service and provides increased options for alternative transportation.

As part of the RTP, a countywide EIR was developed. The extensive outreach and thorough process of PIP created a higher comfort level for the report from agencies and groups likely to comment, resulting in a smooth and unremarkable comment period. MCAG hopes that acceptance of the EIR will result in more streamlining as project EIRs are released. Certainly, MCAG's own process was streamlined as the agency was able to eliminate duplicate efforts in establishing a cumulative impacts analysis on a project-by-project basis by using the one developed for the countywide EIR.

The Partnership in Planning resulted in a well-developed and forward-looking Regional Transportation Plan–the first one in Merced County that was built on a common vision–that has significant backing from the public and the regulatory and non-regulatory members of the partnership. Perhaps just as important, the partnership has paved the way for future collaboration by creating relationships among the partners and the public which did not exist, or existed only weakly, prior to the partnership project.

The Partnership in Planning helped to develop a policy. Policy networks are informal relationships between various regional actors which can be established through communication, working on joint projects, or any kind of other shared activity (Hall 2004). Policy networks help establish the information and resource-sharing basis necessary to improve joint outcomes for affected agencies, local governments, and other relevant stakeholders. Policy networks provide communication channels by which local political entrepreneurs can organize other actors for collective action (Schneider and Teske 1992). The policy network resulting from the PIP process will be a key component of collaborative capacity in this region for the foreseeable future.

However, issues still remain. First, policy networks are strengthened by the commitment of all stakeholders. When one or two major stakeholders are not at the table, program results may be questioned. Second, policy networks are built on relationships. Not only does it take a long time to develop personal relationships, but even longer for that connection to seep upward and outward so that the relationship becomes one between agencies rather than individuals. When an individual leaves, the relationship often begins again from the ground floor. Third, for real change to happen, it must occur at the policy level in state and federal governments, where both relationship incentives and tone must be demonstrated.

The Partnership for Integrated Planning was a first step for most of the players. It was well-received and had many positive results. Components of the plan have been adopted by other Councils of Government and are being adapted by MCAG for other work elements.

Biographical Sketches: Mike McCoy is the co-founder of the Information Center for the Environment at the University of California, Davis. He leads research teams focusing on the use of modeling urban growth in resource-rich regions and the use of social-network analysis for the study of collaborative planning processes.

Candice Steelman has worked in public relations for over 15 years and is currently employed by the Merced County Association of Governments (MCAG) as the Public Affairs Manager, with responsibilities in media relations and legislative programs. Also, for the past six years, she has taught courses in Teamwork and Conflict Resolution, Marketing, and Public Relations for the University of Phoenix. For the pilot program, Partnership for Integrated Planning, funded by the U.S. Environmental Protection Agency, Federal Highway Administration, and California Department of Transportation, she designed the public-outreach program and worked with numerous state and federal environmental agencies to build environmental layers for a comprehensive GIS database. Her degrees include a B.A. in Journalism and a M.S. in Mass Communications, both from San Jose State University, California.

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Maine's Beginning With Habitat Program and Transportation Partnership

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Abstract: Transportation facilities and adjacent development are the greatest contributors to habitat loss and fragmentation in Maine. Transportation facilities present a linear structure that is either a physical barrier or zone of adverse habitat that has separated former habitat or, in the case of new facilities, a dividing or fragmenting influence on existing habitat. Maine's Beginning with Habitat (BWH) program and the Maine Department of Transportation have partnered to begin addressing transportation issues related to habitat and wildlife.

Beginning with Habitat is a collaborative, public-private partnership whose mission is to compile, integrate, interpret, and deliver the best available information, tools, and incentives to facilitate effective land-use planning and natural-habitat conservation at local, regional, and state-wide scales. In 2004, BWH won an Environmental Merit Award from EPA and the program is now serving as a model for other states that wish to integrate habitat protection with land-use planning. As Maine's landscape changes over time, the goal of the program is to sustain habitat that supports healthy populations of Maine's wildlife and native plants for current and future generations.

BWH was developed by a group of stakeholders concerned about the future of Maine's habitat and wildlife in the face of the increased rate of sprawling development. BWH provides all Maine towns with a collection of GIS maps and accompanying information depicting and describing various habitats of statewide and national significance found in the town. These maps provide communities with information that can help guide conservation of valuable habitats. During the last few years, BWH has met with over 140 towns and land trusts to give individualized presentations on the locations and conservation of high-value plant and animal habitat in their communities.

Current areas of synergy include:

- Developing Northeast regional relations with New England, the Canadian Maritimes, and Québec
- Creating a Maine Habitat and Transportation Working Group that has developed a six-point plan to integrate and act on habitat and transportation goals for the mutual benefit of Maine's transportatio networks and habitat
- Using BWH data for transportation scoping early in projects
- Using BWH Focus Areas of statewide ecological significance for transportation-project compensatory-mitigation planning
- Linking transportation and open space components of municipal land-use plans

In addition, an effort is underway to secure funding to develop a habitat-connectivity analysis for enhancement of BWH data and transportation planning. This analysis will use BWH data as well as other data to identify habitat connectivity areas in order to direct strategies to maintain and restore connections.

The partners of this cooperative program include:

- Maine Audubon
- Maine Coast Heritage Trust
- Maine Cooperative Fish and Wildlife Research Unit
- Maine Department Environmental Protection
- Maine Department of Inland Fisheries and Wildlife
- Maine Department of Transportation
- Maine Forest Service
- Maine Natural Areas Program
- Maine State Planning Office
- Maine's 13 regional planning commissions
- Nature Conservancy
- U.S. Fish and Wildlife Service

Introduction

Beginning with Habitat (www.beginningwithhabitat.org) was developed by Maine's natural resource agencies and organizations to address the biggest threat to wildlife in Maine: sprawl. An unexpected partnership has recently developed and continues to develop with Maine's Department of Transportation.

The Road and Planning Landscape in Maine

Most new road construction in Maine consists of local subdivision roads. These roads fragment habitat, decreasing its value for wide-ranging and area-sensitive wildlife species. Responsibility for land-use planning to oversee this incremental road development lies at the local level in Maine. Unlike most states that have strong county governments responsible for land-use planning, Maine has no official regional land-use planning. Instead, 492 individual towns in Maine make all their own land-use planning decisions, with only sporadic, voluntary coordination. Local decision makers are mostly planning-board volunteers with little or no training in planning, ecology, or transportation issues. For transportation issues, four Municipal Planning Organizations (Portland Area Comprehensive Transportation System (PACTS) in the Portland area, KACTS in the Kittery area, BACTS in the Bangor area, and the Androscoggin Transportation Resource Center (ATRC) in the greater Lewiston Auburn area) are relied on to come up with the overall transportation scheme for the areas they cover. These regional plans are currently oriented to traffic and level of service. They do not have strong habitat planning incorporated at this time. Unfortunately, neither the forces behind sprawl nor wildlife see political boundaries.

Beginning with Habitat Program Background

The Beginning with Habitat program (BWH) was designed as a mechanism to assist these local planners with their land-use decisions. BWH is a cooperative, non-regulatory landscape approach to conserving native species on a developing landscape. Its strength and uniqueness lie in the collaboration of nonprofit organizations and state and federal agencies. This partnership started with several years of planning that produced a pilot phase of the program in 2001.

BWH has the potential to be a key vehicle in Maine for getting road-related habitat issues into local planning to reduce the impacts of roads on wildlife.

Through the BWH program, participants (mostly towns and land trusts) are provided ecological education, data, tools, and resources. The most up-to-date wildlife and plant-habitat information available for conservation and land-use planning is provided to municipal officials, land trusts, conservation organizations, and state and federal agencies through presentations, GIS maps and interpretation, digital data, and follow-up assistance. GIS allows BWH partners to produce map products showing many data layers in a format that citizen boards and municipal staff can easily utilize.

BWH promotes a landscape model designed to ensure that all of Maine's wildlife species, both common and rare, will continue to be viable for future generations. The model, which was developed by the University of Maine's Cooperative Fish and Wildlife Research Unit (CFWRU), has three main components, each of which is shown on an individual map. Together, these maps can be used to build a conservation landscape.

The first map or component is Riparian Habitat. The Riparian layer is considered as the skeleton of the landscape. Riparian areas provide habitat for the majority of Maine's vertebrate species and connectivity among other habitat areas. According to the CFWRU, strong conservation of these areas would ensure that about 50 to 75 percent of Maine's vertebrate species would continue on the landscape into the future.

The second component in the model and map consists of identified high-value plant and animal habitats. The model predicts that conservation of these areas, along with the Riparian Habitats, would support up to 80 to 85 percent of vertebrate species in Maine over the long term. This map includes locations of rare, threatened, and endangered plants and animals; Essential and Significant Wildlife habitats (designated under Maine's Endangered Species and Natural Resources Protection Acts); rare and exemplary natural communities; and important habitat for US Fish and Wildlife Service (USFWS) trust species (identified through the USFWS Gulf of Maine Program).

Finally, to ensure the long-term viability of the remaining 20 percent of vertebrate species in Maine, BWH identifies and encourages communities to conserve large, undeveloped habitat blocks. These are unroaded areas that provide habitat for large area-dependent species, ensure habitat for more common species, enhance the viability of habitats of management concern, and provide open space for other social and community values.

As of May 2005, 137 towns and over 40 land trusts and regional groups have received BWH presentations and maps.

Beginning with Habitat Program and Maine Department of Transportation Partnership

Habitat planning and transportation planning face some similar challenges in Maine. Both habitat and transportation systems function at a scale that is not easily addressed by local land-use planning. The Maine Department of Transportation (MDOT) and BWH have come together to explore the ways in which planning for transportation and wildlife can be mutually beneficial. From the BWH point of view, roads and associated development are the greatest cause of habitat loss and fragmentation. Improved habitat connectivity is possible through changes in road, bridge, and culvert designs. Additionally, some habitat-conservation opportunities can benefit both transportation and wildlife goals.

From the MDOT point of view, this partnership provides an opportunity for MDOT to fulfill its commitment to natural-resource stewardship, as well as another means to address human-safety issues related to vehicle and wildlife collisions. In addition, efficient and sustainable transportation systems are impacted by land-use decisions. For example, increased curb cuts decrease a road's long-term effectiveness and ability to move traffic. Curb cuts also impact large habitat blocks. causing habitat fragmentation and loss. Cost savings for transportation projects can be reduced via upfront planning for wildlife. BWH provides some of the tools needed to do this efficiently. Furthermore, required mitigation can be streamlined through information provided by BWH.

What's Been Done to Date

Introductory meetings between MDOT and BWH were held in 2003. As a result, the first Maine Conference on Roads and Wildlife for Planning, Transportation, and Wildlife Professionals was held in January 2004, sponsored by Maine Audubon, Maine Department of Transportation and Maine Department of Inland Fisheries and Wildlife (MDIFW). As an outcome, the Maine Habitat and Transportation Working Group was established. This group's mission is to integrate and act on habitat and transportation goals for the mutual benefit of Maine's transportation networks and habitat. Group members attended and presented at the first Northeast Wildlife and Transportation Conference in September 2004.

At this meeting, the work of the Habitat and Transportation Working Group was synthesized into the following six-point plan:

1. Integrate MDOT with Maine's Comprehensive Wildlife Conservation Strategy and find ways to integrate natural resource and habitat planning with transportation planning, including MDOT's 20-year, six-year, and work-plan scoping efforts.
2. Develop a statewide habitat-connectivity map.
3. Promote the use of the ecosystem-based approach to decision making.
4. Integrate wildlife and transportation efforts with regional planning activities.
5. Develop a "tool box" guidebook (what to do, how to do it, resources to make it happen) for transportation and wildlife targeting towns.
6. Education and outreach–get the wildlife and transportation message out.

Compensatory Mitigation and MDOT Research Grant

A very tangible outcome of the BWH and MDOT discussions and partnership is the use of BWH Focus Areas by MDOT. Focus Areas are areas of statewide ecological significance identified by BWH. These areas, which are based on available information from MDIFW, the Maine Natural Areas Program (MNAP), and USFWS, synthesize and simplify existing habitat data to help focus conservation effort on the most important targets. They are nonregulatory and are not "no development" areas.

Through discussions with BWH, the MDOT Natural Resource Mitigation Specialist learned about Focus Areas and took the initiative to use the information for a project impacting 1.6 acres of wetland along a state road. There were no on-site opportunities along the project roadway for wetland restoration that would have any real ecological value. But nearby was a Focus Area (Saco Heath) with significant conservation land, including wetlands of statewide ecological significance. An adjacent 45-acre parcel had been identified by the Nature Conservancy (TNC) and was available from a willing seller. MDOT was able to purchase the land and transfer it to TNC, thereby meeting the mitigation requirements and adding significantly to state habitat-conservation goals.

MDOT recognized the BWH Focus Areas as potential tools that would help streamline environmental review, improve the mitigation process, and serve as a starting point for a watershed-based mitigation approach. Specifically, the BWH Focus Areas can serve as a screening tool for early identification of resources of statewide or regional importance and deciding which projects to scope. The usefulness of BWH Focus Areas to MDOT made it clear that an accelerated process was needed to identify Focus Areas statewide. Currently, they are only identified for part of the state. In March 2005, MDOT awarded a research grant to finish BWH Focus Area identification statewide.

The Future

The partnership has identified several additional areas of synergy, including: developing northeast regional relations within New England, the Canadian Maritimes, and Quebec, particularly with respect to:

- Moose-vehicle collision issues
- Using BWH data for transportation scoping early in projects
- Linking transportation and open-space components of municipal land-use plans

Ongoing and future initiatives include:

- Continuing the Habitat and Transportation Working Group's efforts
- A statewide study to identify key elements of habitat connectivity
- Developing educational materials on roads and wildlife for the general public
- Identifying Focus Areas for the rest of the state

The potential benefits of a partnership between habitat and transportation planners and professionals are enormous. Through continued coordination and communication, we hope to realize a range of outcomes to benefit Maine's citizens and wildlife. The future we envision as a result of this partnership will include:

- Transportation projects that are less expensive due to early identification of habitat needs
- Roads that are safer for people
- Roads that are more permeable for wildlife due to well-designed and placed bridges, culverts, and roads
- Reduced fragmentation of large, undeveloped habitat blocks by new roads
- Mitigation that provides the highest possible benefit for wildlife and habitat

Biographical Sketches: Barbara Charry has a B.A. in English from Grinnell College in Grinnell, Iowa and a M.S. in environmental science from Antioch New England in Keene, New Hampshire. She has worked for Maine Audubon as a biologist and GIS manager since 1992. Areas of work have included endangered-species management, grassroots organizing, natural-history information, northern forest issues, and sprawling development's impacts on wildlife.

Richard Bostwick has a B.Sc. in biology from Mt. Allison University in New Brunswick, Canada. He has worked for the Maine Department of Transportation in the fields of transportation and biology since 1984. His background includes resource identification and assessment, environmental work on NEPA and other planning studies, and animal-vehicle crash study for the Maine DOT.

Quick Fixes: Working Together to Address Herptile Road Mortality in New York State

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Abstract: Traditionally, state transportation agencies have designed and built environmental enhancements in response to regulatory requirements to mitigate project impacts. More recently, state transportation agencies have embraced an environmental ethic that goes beyond compliance and encourages agencies routinely to incorporate environmental enhancements into projects and activities. Generally, in-house staff or resource/regulatory agencies identify opportunities to address concerns regarding high-profile species (e.g., large mammals, endangered species).

Taking stewardship one step further, the New York State Department of Transportation (NYSDOT) has demonstrated innovative responses to problems brought forth by concerned citizens regarding a lesser-studied group of wildlife–amphibians and reptiles (collectively termed “herptiles”). These responses have resulted in valuable partnerships with private citizens, colleges, and resource agencies, thus increasing the agency’s credibility in its commitment to an environmental ethic and its reputation for getting things done.

This paper will establish how NYSDOT demonstrated its environmental stewardship on a working level with a quick response to expressed public concerns by highlighting two projects. In each instance, a private citizen alerted NYSDOT about their concern for high mortality rates of salamanders, frogs, and turtles in “hot spots” along the state highways. Common factors in these projects include: NYSDOT paid credence and a speedy response to a private citizen’s concern; maintenance forces applied their practical skills to develop an in-the-field solution to the problem; NYSDOT formed fruitful partnerships with colleges, private citizens, and resource agency experts; and costs were minimized by using surplus material, on-hand equipment, and simple designs.

By highlighting two specific examples, we will demonstrate that some problems can be solved quickly by bringing the right group of people together with a variety of skills and knowledge and a determination to get the job done. Methodology, results, and lessons learned will be presented and discussed.

The Canandaigua Lake Herptile Crossing was built in 2002 in response to expressed citizen concerns regarding the high rate of turtle mortality. This project included constructing suitable nesting habitat for turtles on private property and constructing a physical barrier to funnel turtles to existing culverts. NYSDOT formed partnerships with Finger Lakes Community College, the New York State Department of Environmental Conservation, and a private landowner. The Labrador Hollow Herptile Crossing was installed in 2003 in response to a 2002 posting on an internet listerv soliciting help in the “simply phenomenal” herp movement. A 12-inch culvert was installed to serve as a “critter crossing” and surplus w-beam guide rail was imbedded into the ground to guide salamanders and frogs to the culvert.

NYSDOT formed partnerships with the State University of New York’s College of Environment Science and Forestry (SUNY-ESF) and private citizens. These projects demonstrate how collaboration, flexibility, and responsiveness result in simple, creative designs with tangible benefits, fostering good will and a sense of stewardship.

This paper will also discuss research initiated by NYSDOT to identify and address the impacts of transportation on herptiles populations to guide future decision to address herptile-mortality concerns.

New York State DOT’s Road to Stewardship

The New York State Department of Transportation (NYSDOT) is the state’s largest public works agency. As such, the Department recognizes its obligation and responsibility to the people of New York State to protect, improve, and enhance the environment in the course of its business of planning, building, and maintaining a transportation system. Environmental stewardship builds on the values of the Department’s employees to protect the natural and cultural resources of the state. Caring for the environment while providing a transportation network allows NYSDOT employees to feel good about being “good neighbors” that a community or an individual will welcome rather than shun. Environmental stewardship builds credibility, trust, and goodwill, as well as building staff enthusiasm and morale.

NYSDOT’s environmental ethic has evolved over the last decade. In 1996, NYSDOT revised its mission statement to include “environmentally sound” alongside safe, efficient, and balanced transportation system. In 1998, the Department Environmental Initiative was launched (see http://www.dot.state.ny.us/eab/envinit.html). Since that time, NYSDOT has undertaken deliberate actions and adopted a more proactive approach to addressing environmental matters, including issuing Department-wide Environmental Initiative Guidelines and Procedures (http://www.dot.state.ny.us/eab/eieab3.pdf) and an Environmental Policy (http://www.dot.state.ny.us/eab/files/policyen.pdf).

In 2001, NYSDOT adjusted its organizational structure to establish environmental expertise on the ground to sustain its efforts of proactive environmental stewardship. Environmental support within NYSDOT has traditionally been provided by the Regional Landscape/Environmental Units housed in the Design Bureaus.

As environmental requirements and expectations increased, the need for maintenance and construction-phase assistance in the environmental field increased. To meet environmental-stewardship demands, the Department hired 22 seasoned environmental managers to work within the regional construction and maintenance units.

These managers' primary role is to identify and seize environmental stewardship opportunities, address various regulatory agency concerns, and make critical on-site decisions. This field presence of environmental staff maintains credibility with resource agencies and operation staff and provides ready access to machines, material, and manpower.

Presently, NYSDOT is undergoing a Transformation effort which continues to recognize the importance of environmental stewardship. This is evident in that "improving environmental conditions" has been identified as a priority result area, along with improving mobility and reliability, increasing safety, promoting economic sustainability, and enhancing security.

Herptiles and Roads in New York
New York State is host to 67 species of amphibians and reptiles. The state's diverse and widespread herptofauna includes most species present in New England and several additional species from adjacent northern, southern, and western regions. Each year, virtually all species of frogs, toads, and salamanders migrate from forest and fields to wetlands to breed. Turtles, in contrast, travel in the spring from waters to uplands in search of suitable nesting sites. This seasonal migration, along with their small size and slow rate of movement, make herptiles particularly susceptible to road mortality along NYSDOT's 16,500 miles of highway.

Efforts to Reduce Turtle Mortality–Canandaigua Lake Area Project
In New York State, turtles nest from late May to early July, depositing eggs in sandy or gravelly soil, lawns, mowed fields, roadsides, sphagnum moss, or sedge tussocks. During the nesting period, female turtles migrate from ponds and wetlands in search of suitable nesting areas, becoming vulnerable to mortality along roadways.

In western New York in the spring of 2000, NYSDOT was informed of an area of highway with high turtle mortality. A local citizen expressed concern about the high vehicular mortality of primarily painted turtles (*Chrysemys picta*) and common snapping turtles (*Chelydra s. serpentine*), both common species in New York, along a stretch of NYS Route 21 in Woodville at the south end of Canandaigua Lake. Initially, the citizen requested permission to erect "Caution Turtle Crossing" signs in the area. When that option was ruled out, other solutions were sought.

A partnership was formed among two NYSDOT Regions, the New York State Department of Environmental Conservation (NYSDEC), and Finger Lakes Community College. Collectively, these partners determined that to best reduce turtle mortality, a two-component strategy was warranted. This included (1) construction of suitable turtle-nesting habitat on the eastern side of Route 21 from where the turtles were crossing and (2) construction of a physical barrier approximately 1,400 feet in length to funnel turtles, frogs, and salamanders to four existing culverts to cross under the road.

This innovative solution resulted from utilizing the specialties of each of the collaborators. NYSDEC provided expertise on turtle biology and site selection, NYSDOT Region 4 assisted with planning and provided maintenance forces and equipment for project construction, NYSDOT Region 6 was also involved in project planning and provided funds for materials, Finger Lakes Community College performed a pre-construction assessment, and a private landowner permitted the turtle-nesting habitat construction on private property.

To create suitable turtle-nesting habitat, NYSDOT maintenance forces cleared a portion of an overgrown vineyard. Loose, gravelly fill from a nearby, recently cleaned ditch was placed in a crescent-shaped area approximately 30 meters by 10 meters (approximately 100 feet by 33 feet). A wooden barrier was placed between the newly created nesting area and Route 21 to discourage travel across the road.

In addition to the constructed turtle nesting habitat, NYSDOT installed a 1,400 foot (approximately 427 meter) wooden barrier along the Canandaigua Lake/wetland side of Route 21 to funnel herptiles to four existing culverts. This physical barrier is up to 16 inches high (41 cm) constructed of 2 inch x 8 inch (5 cm x 20 cm) lumber staked with metal sign posts.

This project was undertaken specifically to address the turtle mortality concern; it was not added on to a capital project or due to regulatory requirements. This field-designed solution took less than a week to construct and cost approximately $15,000 in materials. NYSDOT maintenance personnel and equipment were used during construction. Ongoing maintenance of the constructed turtle-nesting area consists of one late-season mowing each year to prevent overgrowth.

Facilitating Herptile Movement – Labrador Hollow Project
New York State is home to 18 species of salamanders and 14 species of frogs and toads. Of these, ten species of salamanders are affiliated with woodlands and temporary vernal pools. Each spring, these woodland salamanders migrate, oftentimes in large numbers, from upland forests to these salamanders' breeding ponds. Similarly, on warm spring and summer nights, frogs and toads emerge in great numbers to congregate in ponds. During migration, these herptiles become vulnerable to becoming roadkill as their journey takes them across roadways.

The Labrador Hollow project is another example of NYSDOT's efforts to address herptile roadkill in response to a citizen's concern. On April 1, 2002, a local birder posted a note on a birding listserv, indicating that he needed "to contact the right people to get a drift net and tunnel built for this area because the Herp Movement is phenomenal." The referenced area was along Route 91 in the Labrador Hollow area. The most prevalent species noted were spotted salamander (*Ambystoma maculatum*) (430), wood frog (*Rana sylvatica*) (350+), and northern spring peeper (*Pseudacris c. crucifer*) (2000+).

An Environmental Specialist from NYSDOT's Environmental Analysis Bureau, an avid birder, noticed this note on the listserv the next day and contacted the person, a graduate student at the State University of New York, College of Environmental Sciences and Forestry (SUNY-ESF). Follow-up contacts were made with Dr. James Gibbs, a herpetologist at SUNY-ESF, and to the regional environmental/landscape staff in the Syracuse office. After all the right people were connected, the collaboration began.

Within eight days of the original posting, a NYSDOT landscape architect from the regional landscape/environmental unit met with the birder/herp enthusiast for site reconnaissance. The area of concern was a 3.5-mile (5.6-km) section of State Route 91 within the state Labrador Hollow Unique Area. Considering that the NYS Department of Environmental Conservation owned land on both sides of the highway, the NYSDOT landscape architect, via e-mail correspondence, recognized that "the opportunity for a partnership with both agencies as well as the College are (sic) excellent." NYSDOT contacted NYSDEC and facilitated a fruitful partnership between the resource agency, the transportation agency, and the research college.

The following spring, SUNY-ESF, in partnership with NYSDOT, established a study area and conducted field surveys to determine concentrated areas of mortality. Concurrently, the NYSDOT maintenance environmental coordinator was pursuing an option with the maintenance Resident Engineer to install a herp culvert/crossing using maintenance forces in the summer prior to a paving project.

The enthusiasm for the project was great. Regional environmental staff, sometimes accompanied by their spouses and children, conducted night surveys of herptile movement. E-mails included excerpts such as "great flow of ideas and interests!" and "Oh what fun we are having!" The camaraderie and enthusiasm was infectious.

During the summer of 2003, NYSDOT placed a 12-inch (30.5-cm) culvert across the road to serve as a "critter crossing" for amphibians and reptiles. The culvert consisted of two twenty-foot (6-meter) sections of 12-inch diameter corrugated metal pipe that were surplused in the maintenance yard. The culvert was placed prior to a planned paving job in the summer, thus signs of the installation were covered shortly after construction.

In the autumn of 2003, SUNY-ESF students, in cooperation with NYSDOT, installed drift fence in the woods to guide salamanders traveling down the forested slope to the crossing location. The drift fence consists of old, metal W-beam guide rail that was available for reuse in the scrap pile at one of the maintenance residencies. The drift fence was staked with cut rebar.

SUNY-ESF students conducted post-construction monitoring in the spring of 2004 to determine the number of mortalities along the road in the vicinity of the crossing. The study design was altered from the pre-construction study due to time constraints and limited volunteers. The findings of the spring 2004 study were inconclusive. Future monitoring studies are anticipated.

Similar to the Canandaigua Lake Project, the objective of this project was to address road mortality of herptiles specifically in response to a citizen concern rather than a capital project or regulatory need. This project, too, was conducted with maintenance forces and equipment, as well as volunteers. The resourcefulness of the maintenance staff to use scrap and surplus material is noteworthy. It took two days to install the pipe and another two-week period (not a fulltime effort) to install the drift fence. The collaborative efforts of NYSDOT, SUNY-ESF, and NYSDEC resulted in an inexpensive, field-designed, and quick solution.

Lessons Learned

There are several lessons learned from these projects. Firstly, the Department should establish a post-construction monitoring program prior to construction. NYSDOT has found that it is not feasible for agency forces to monitor the project after construction. Departments considering similar projects should explore partnering opportunities with other organizations (such as a local college or interested environmental group) to monitor the effectiveness of the project. Secondly, departments should anticipate the need for repairs and finishing touches, then plan accordingly. Though scheduled maintenance is working well, NYSDOT has found that each of the referenced projects needs repair or finishing on some sections.

Research

Though the quick, solution-oriented response to an identified herptile roadkill problem is commendable, NYSDOT recognizes the importance of research to guide and ensure well-informed decisions. To that end, NYSDOT developed and submitted a request for proposals in the fall of 2004 to initiate a research project exploring viable mitigation measures in the project process that address herptile crossings.

In the spring of 2005, SUNY-ESF was awarded a contract entitled "Effects of New York State Roadways on Amphibians and Reptiles: Research and Adaptive Mitigation Program." This research project is funded through the Federal Highway

Administration (FHWA) Statewide Planning and Research (SPR) program. The study duration is scheduled for four years; NYSDOT's share of the project cost is $189,000.

There are unresolved questions to which answers would facilitate better decision making. Dr. James Gibbs, SUNY-ESF, has articulated several of these questions for NYSDOT, such as:

- Is herptile roadkill really a problem for local populations?
- What mitigation structures will these animals actually use?
- What habitat factors are associated with road-crossing sites?
- Can these road-crossing sites be accurately predicted through habitat modeling?
- Can such models be built into geographic information system (GIS)-based transportation planning systems?

SUNY-ESF proposes an integrated research and adaptive mitigation program that addresses three primary objectives:

1. Document the impacts of transportation infrastructure on herptile populations.
2. Determine the landscape, local habitat, and architectural attributes of effective herptile crossing structures.
3. Employ habitat analyses to identify "connectivity zones" where crossing structures would be most appropriately deployed along New York State roadways.

In support of these objectives, the research team will conduct five integrated studies defined in these tasks:

i. Conduct literature review
ii. Evaluate effects of roadways on amphibian and reptile populations
iii. Assess the use and effectiveness of various crossing structures
iv. Determine the optimal field placement of functional crossing structures for amphibians and reptiles
v. Develop a GIS-based predictive model/expert system and planning toolbox

In the summer of 2005, SUNY-ESF graduate students initiated field studies. For Task ii, the investigators will perform field surveys of herptile populations at various distances from roadways to determine whether a "road effect" on populations occurs and, if it does, to estimate the width and breadth of the effect zone. To assess the use and effectiveness of the various crossing structures (Task iii), the investigators will create a behavioral choice "arena" that exposes many herptile test subjects to variations in crossing-structure type. The purpose is to identify those architectural attributes of crossing structures most associated with herptile usage and to develop a cost/benefit ratio (financial costs versus biological benefits) of various structure designs. Additionally, the investigators have commenced a literature review of road/herptile research.

Conclusion

NYSDOT prides itself as an agency committed to environmental stewardship and customer focus. The Department's actions outlined in this paper demonstrate these commitments. The Department's established environmental ethic and commitment to responding to public concerns are keys to success. Environmental staff working in the maintenance division provides on-the-ground forces to address environmental issues.

Additionally, maintenance forces that are willing to commit material, machines, and staff enable the Department to keep solutions cost-effect and simple. Forming partnerships with colleges, resource agencies, and environmental groups is essential to tapping into the necessary expertise and materials. Further research is needed to grasp the herptiles/road effect and develop solutions. Findings from the ongoing research undertaken by SUNY-ESF and funded by NYSDOT will facilitate the Department in making better-informed decisions to address concerns related to herptile road mortality.

Biographical Sketches: Debra Nelson joined the New York State Department of Transportation in 1992 and is the manager of the water/ecology section of the NYSDOT Environmental Analysis Bureau in Albany. Debra is a Certified Ecologist, a Professional Wetland Scientist, and a member of the Transportation Research Board's Task Force on Ecology and Transportation.

Mary Ellen Papin holds an M.S. degree in environmental science and a B.S. degree in biology. After working in the environmental-services field, Mary Ellen joined NYSDOT in 1994 as an environmental specialist. Since 2001, she has been the maintenance environmental coordinator for the Region 4 Transportation Maintenance Division.

Tim Baker has a B.S. in environmental science from Norwich University. Tim joined NYSDOT in 1998 after working for environmental services consultants. He is presently the maintenance environmental coordinator in NYSDOT's Region 3 office in Syracuse.

Science-Based Approach to Adaptive Management of the TCH Corridor: Canadian Rocky Mountain Parks

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Abstract: In November 1996, we began a long-term research project in Banff National Park (BNP), Alberta, Canada. Our primary study area is situated in the Bow River Valley along the Trans-Canada Highway (TCH) corridor in BNP, located approximately 100 km west of Calgary. The first 45 km of the TCH from the eastern park boundary (phase 1, 2, and 3A) is currently four lanes and is bordered on both sides by a 2.4-m-high wildlife-exclusion fence. The remaining 30 km to the western park boundary (phase 3B) is two lanes and unfenced. Between 2005 and 2007, approximately 12 km of phase 3B will be widened to four lanes with additional fencing and wildlife crossings. Twenty-two wildlife underpasses and two wildlife overpasses were constructed on the first 45 km between 1980 and 1998 to permit wildlife movement across the four-lane section of TCH.

The research carried out to date has provided science-based information for mountain park transportation planners and resource managers. The results have been uniquely used in development of Golder Associates' environmental-screening report (environmental-impact assessment) for Parks Canada's TCH phase 3B twinning project. Research of wildlife-crossing performance demonstrated that a longtime series of data is required to assess the function and performance of these critical cross-highway corridors accurately.

Recommendations from the Golder Associates' report for phase 3B strongly underscored the importance of continued, long-term monitoring of TCH mitigation measures in the Bow Valley. After 8 years of study, there still remain noteworthy areas of uncertainty regarding the effects or performance of the current mitigation on regional-landscape connectivity (demographic and genetic). The long-term cumulative effects (beyond 2020) of the phase 3B project and earlier twinning projects will hinge on the degree to which connectivity can be restored across the TCH.

Healthy functioning ecosystems require viable wildlife populations. Thus, it is critical to know the performance of crossing structures at the population level. Although intuitively these measures should enhance population viability, to date there have been no specific studies that actually address their population-level effects. Obtaining data on individuals in a population can be problematic because wide-ranging, fragmentation-sensitive species like bears typically occur in relatively low densities and have low reproductive rates. However, modern molecular techniques now make it possible to identify individual animals, their sex, and genetic relatedness with only a few hairs. These innovations could provide a powerful, relatively inexpensive, and noninvasive way to acquire critical information regarding genetic interchange facilitated by crossings without ever having to capture or see the animal.

This paper highlights:

1. Key research findings from the 8-year study
2. Mitigation myths that have been dispelled
3. Important lessons learned
4. Future research needs in the short and long term
5. Newly formed international, public-private partnership to meet many of the critical research questions needed for future management decisions

Upcoming Banff research will begin empirically assessing the conservation value of wildlife crossings in restoring landscape connectivity using population-level approaches and nonintrusive DNA-based methodologies.

Introduction

There are few places in North America where the intersection of transportation and wildlife corridors is as ecologically significant and received as much attention as Banff National Park's (BNP) Bow Valley. Banff and neighboring Yoho National Park in British Columbia are the only national parks in North America bisected by a major transportation corridor. More than 5 million visitors per year visit BNP, more than any national park in North America. The Trans-Canada Highway (TCH), the Canadian Pacific Railway mainline, built areas, and nodes of human activity have been recognized by Parks Canada as important landscape stressors to ecological integrity (Banff-Bow Valley Study 1996). Parks Canada's mandate is to maintain or enhance ecological integrity; therefore mitigating the TCH makes good ecological sense.

Transportation corridors present some of the most severe human-caused impacts in the Canadian mountain park ecosystem and in the entire Yellowstone-to-Yukon region. The amount of traffic a road carries can be a crude measure of its ecological impact (Forman et al. 2003). The summer average daily traffic volume of the TCH is 25,000 vehicles per day, with peaks of up to 35,000 (Parks Canada, unpublished data). The anticipated growth in population and projected highway improvement plans in the Rocky Mountain cordillera, coupled with the resounding concern for maintaining large-scale landscape connectivity will continue to generate interest in conservation tools and applications for addressing the diverse issues linking transport, ecology, and local communities.

Objectives

From 1996-2002, we conducted a long-term investigation in BNP. Our study focused primarily on the TCH, its permeability for wildlife, and effects in terms of wildlife mortality, movements, and habitat connectivity in the Bow River Valley. Means of mitigating road effects on wildlife were evaluated and recommendations made for future transportation-planning schemes in the mountain parks. In 2005, with the formation of an international public and private partnership, we initiated a second phase of mitigation research in BNP's Bow Valley transportation corridor. The purpose of this article is threefold:

1. To show how science can be used in an adaptive-management process to guide transportation planning in Banff NP
2. To demonstrate how new scientific approaches may be used to further our knowledge of the design, monitoring, and evaluation of highway mitigation measures for wildlife populations in a regional landscape context
3. To describe an international public-private partnership for advancing road ecology in the Canadian Rocky Mountains

Study Area

Situated in southwest Alberta, BNP is approximately 120 km west of Calgary. Since the 1980s, fencing and wildlife crossings (overpasses and underpasses) have been installed along 45 of the 70 km of TCH in Banff (Woods 1990; McGuire & Morrall 2000). The mitigated sections of highway are referred to as phase 1, 2, and 3A. In 2005, expansion to four lanes with construction of fencing and nine wildlife crossings began on a 12-km section west of phase 3A near Lake Louise (phase 3B).

BNP highway mitigation is the only large-scale complex of wildlife-mitigation passage structures in the world. There is no other location with as many and as diverse types of wildlife-crossing structures or accompanying data on wildlife distribution, movement, and ecology. Besides having exceptionally diverse forms of wildlife-crossing structures (five designs) set in the landscape over two distinct time periods (recent structures built in 1997 and older structures built in the mid-1980s), Banff mitigation research can boast of having the world's longest year-round monitoring program and the most information on passage use by wildlife (9 years in November 2005). This alone has allowed the mitigation research in Banff to be on the leading edge of investigations regarding the effectiveness of highway-mitigation passages in maintaining landscape connectivity.

Banff National Park: Highway Mitigation Research, 1996-2002

Our mitigation research between 1996 and 2002 had three objectives:

1. To characterize road mortality of wildlife in the mountain parks (see Gunson et al, this volume)
2. To evaluate performance of the TCH mitigation measures
3. To use the empirical data from our study for planning phase 3B mitigation (see Clevenger et al. 2002)

Research Results, 1996-2002

The results from our research have been disseminated in a variety of venues. Some results have been published in previous ICOET (and ICOWET) proceedings between 1998 and 2003. A total of 13 articles have been published in peer-reviewed scientific journals (e.g. Biological Conservation, Journal of Applied Ecology, Conservation Biology). A comprehensive account of our research, methods, results, and management recommendations can be found in Clevenger et al. (2002).

The long-term monitoring has demonstrated its multipurpose utility in meeting transportation and resource-management needs. Monitoring data from the 24 wildlife crossings has aided BNP management in fulfilling a key objective of the BNP management plan–restoration of corridors and predator-prey relationships. The weekly monitoring has served as a bellwether and indicator of wildlife population status and trends, emulating one long, multi-species population-monitoring transect.

How have the research results been used in an adaptive-management process? In many ways, from removing one-way gates because animals could get through them to implementing our research-based recommendations on phase 3B (Clevenger et al. 2002).

The most novel and comprehensive use of our data was the environmental assessment of phase 3B by Golder Associates (see Jalkotzy, this volume). The Golder report predicted impacts and mitigation performance for phase 3B, using empirical data from our research on previous TCH mitigation phases and using valued ecosystem components (VECs, or indicator species) to evaluate road-mortality reduction and connectivity potential, i.e. performance of proposed wildlife crossings.

Although the Banff research data Golder used spanned 6 years, it is not complete and there are knowledge gaps. The research results are unable to tell us everything we need to know about mitigation performance with high precision and detail. Therefore, Golder concluded "the long-term cumulative effects of TCH mitigation will depend largely on the degree which connectivity can be restored across the TCH."

Pilot Study: Population-Level Study of Wildlife Crossings

There are many superlatives to describe Banff's Bow Valley, which also represents one of the world's best mitigation testing sites. There is a need for consistent evidence of performance and effects of wildlife crossings to support their continued and growing implementation by transportation and resource agencies.

Some important and unanswered research questions worth asking that would help management are:

1. For a given suite of wildlife crossings, what is the general level of connectivity occurring?
2. For a regional landscape with mitigation crossings, how much connectivity is necessary to maintain viable populations?
3. In other words, what are the population-level benefits of having wildlife crossings in place? To get at this population-level question, we began a pilot study in 2004 (Clevenger 2004, 2005a). Traditional means of study using mark-recapture and radio telemetry are extremely costly (even for single-species). Capturing an adequate sample of individuals is difficult logistically and is intrusive.

Today, advances in molecular technology and tools provide for DNA-based techniques that are low-cost, non-intrusive, and allow for greater sampling of individuals within populations of multiple species. Furthermore, compared to mark-recapture/telemetry methods for a single-species study, sampling DNA non-invasively allows for much greater sampling success within the population. Obviously, using one technique over the other depends on your research question, but for measuring genetic and demographic connectivity at crossings, the DNA-based technique shows great promise.

If animals could write their names, tell who are their relatives were, and how far they were from home, our problems would be solved. Since they are unable to do so, we began mitigation testing a technique where animals leave a bit of DNA (hair) when passing through an underpass. The Woodcock Foundation funded this testing.

The first year (2004) of the pilot study consisted of "research and development," where we tested different configurations and evaluated how animals responded to these configurations (Clevenger 2004, 2005a). We had varying degrees of success and response for each species; obviously some species can avoid hair-snagging devices quite easily. For several reasons, we decided our system should be targeted at bears (Clevenger 2004, 2005a). At the end of summer 2004 we felt confident that we had developed the best system for capturing hair from bears using underpasses.

Our pilot study took place at two of the Banff open-span underpasses (Healy, Duthil). The system consisted of two strands of barbed wire intertwined with a high-adhesive string and strung at a height of 35 and 75 cm above the ground (Fig. 1(a)). The barbed wire/sticky strings were securely fastened to a metal post staked to the ground. We placed the barbed wire/sticky string under one of the underpass structures (Fig. 1(b)). At a distance of 20-25 m from the barbed wire, we placed infrared sensors that activated video cameras when animals entered the underpass and broke the infrared beam. During nighttime hours, the system was configured to turn on infrared lights to illuminate the underpass.

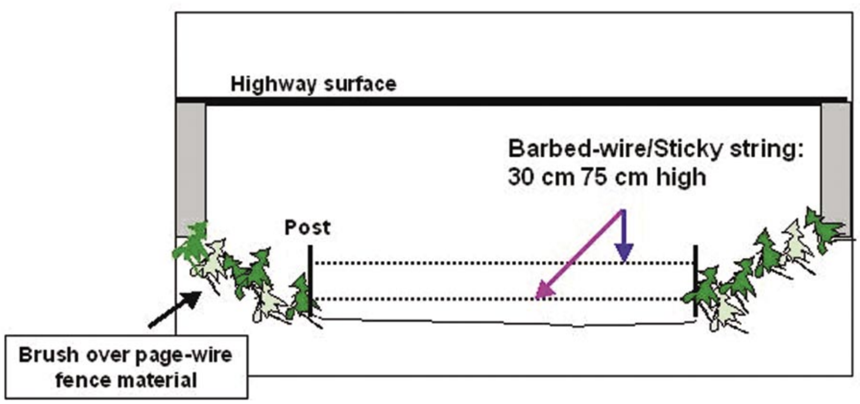

Figure 1(a). Ground-level view of DNA/hair sampling system at Banff underpasses.

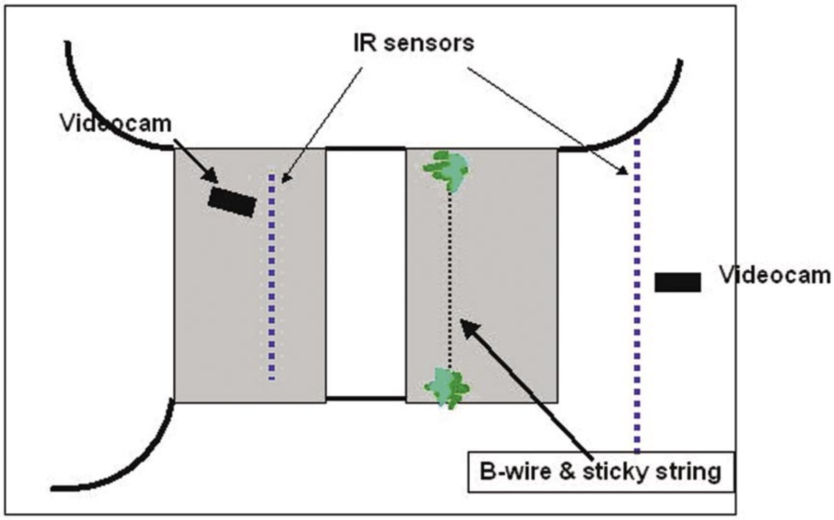

Figure 1(b). Aerial view of DNA/hair-sampling system at Banff underpasses and videocamera monitoring components. IR = infrared; B-wire = barbed wire.

The aim of our 2004-05 pilot study was to test the efficacy of the DNA/hair-sampling system to obtain hairs of passing large carnivores, primarily bears, when using the underpasses. We did this by quantifying the number of approaches, the behavior of animals entering the underpass (avoidance/turnaround or pass-through), and if they passed through, how successful were we at obtaining hair. When hair captures failed the results of video monitoring provided reasons why animals did not leave hair behind. Our 2005 field season ran from May to mid-August (3.5 months of monitoring). We checked the two underpasses daily and collected information on animal use of the underpass and DNA/hair-sampling success from racked trackpads, video cameras, and the hair-sampling system.

Results

There were a total of 56 approaches to the two underpasses by large carnivores; 43 approaches were by bear species (24 black bears, 19 grizzly bears; Table 1). Bears turned around or avoided the underpasses less than 10 percent of the time (two of 24 black bears and one of 19 grizzly bears turned around or avoided the underpasses). The hair-capture success rate was high for both bear species; more than 90 percent of the time, bears passing through the underpasses left hair. For grizzly bears, we were able to capture hair 94 percent of the time that they used the underpasses. Cougars can easily jump over the DNA/hair-sampling system, but in 2005 cougars used the underpasses five times. In three out of the five times (60 percent) that cougars used the underpasses, we obtained hair samples. Single wolves avoided the underpasses the first four times approaching; but each time one lone wolf successively came closer to the DNA/hair-sampling system. On the fifth and subsequent approaches, the wolf passed through the hair-sampling system. We obtained hair samples from the wolf during 3 of 5 (60 percent) times they used the underpasses.

Table 1. Summary data from 2005 pilot DNA/hair-sampling study in Banff National Park. Field study ran from May to mid-August 2005.

	N-approaches	**N-Avoids (%)**		**Pass/No hair (%)**	**Pass/Hair (%)**
Black bear	24	2 (8)		4 (18)*	18 (82)**
Grizzly bear	19	1 (5)		1 (5)	17 (94)
Subtotal	**43**	**3 (7)**		**5 (12)**	**35 (88)**
Wolf	9	4 (44)		2 (40)	3 (60)
Cougar	5	0 (0)		2 (40)	3 (60)
TOTAL	**56**	**7 (12)**		**9 (18)**	**41 (83)**

* Percent not including cubs.
** 91 percent not including cubs.

Application of DNA-Based Approach for a Population-Level Study

How might this particular DNA-based technique be used at wildlife crossings to help answer the important and unanswered research questions earlier?

The DNA/hair-sampling technique provides genetic and demographic data from individuals using the wildlife crossings, i.e., the individuals that are contributing to gene flow and demographic interchange between two populations that are hypothetically separated by a road or highway (in our case, the Trans-Canada Highway).

This is excellent information on ecological connectivity by itself. Even alone, some indices of connectivity could be determined to aid in assessing the conservation value of wildlife crossings. Yet a more realistic and comprehensive assessment of conservation value and population-level benefits of wildlife crossings could be obtained by contrasting DNA/hair-sampling data from crossings with background DNA data from the entire population. This could be done by using a common DNA/hair-sampling technique that consists of barbed wire around baited sites (Boulanger and McLellan 2001). These two sources of information (obtained from the crossings and the population) would allow for the determination of the type of connectivity (Clevenger 2005b) that is contributing to viable populations and healthy, functioning ecosystems.

An alternative to conducting a field-based study of wildlife-crossing performance at the population level is to model our desired performance criteria (viable populations). This can be done using models that account for variable (not static) landscape conditions, including accurate demographic parameters and real data on animal crossing frequencies and their response to different crossing types (e.g. see Clevenger and Waltho 2000, 2005). Modeling of this type, using readily available software such as RAMAS/GIS (Akcakaya 1998), can provide scenarios of varying highway/wildlife-crossing permeability, aid in assessing their conservation value, and provide a range of connectivity or permeability values that are needed to maintain viable populations.

An International Public-Private Partnership

How can we make studies of this type happen? Carrying out this work will require funding and support from not only Parks Canada, but also other external institutes and organizations.

A partnership was formed in February 2005 between public and private interests (agencies, institutes, and foundations) with the goal of promoting the integration of ecology into sustainable transportation systems and furthering road-ecology research in the Canadian Rocky Mountain parks.

A three-year program has been developed that consists of three main components: research, technology transfer, and education. The first component (research) will consist of field-based studies, analyzing existing and new data, and modeling. Research is the ‘foundation’ of the program we envision. The second component (technology transfer) addresses the ‘current needs’ of local transportation planners and land managers in the mountain parks, as well as beyond the park boundaries. This will be carried out by effectively disseminating science-based information through scientific publications, international conferences, workshops, and developing guidelines for management. The last component (education) is equally important as those above, and has the aim of educating future generations of transportation engineers and road ecologists. This will be achieved through university-based collaborations (graduate and postgraduate level research), professional development courses, and public education. The latter is critically important in influencing political change.

Conclusions

Sound scientific research needs to be the basis for management decisions in transportation and natural-resources management. Having proper funding mechanisms in place and adequate budgets to carry out research in road ecology is critically important, but probably never more urgent than today.

Transportation programs and projects are advancing forward at a rate much faster than the rate of collection of science-based data needed to properly inform and guide. More political and agency support for ecological research in transportation will make everyone’s job easier, streamline processes, and (most importantly) begin building more-sustainable transportation systems.

Biographical Sketch: Tony Clevenger is a senior wildlife biologist at the Western Transportation Institute at Montana State University. In 1996, he was contracted by Parks Canada to carry out longterm research assessing the performance of mitigation measures designed to reduce habitat fragmentation on the Trans-Canada Highway in Banff National Park, Alberta, Canada.

Tony is currently a member of the U.S. National Academy of Sciences Committee on Effects of Highways on Natural Communities and Ecosystems. Since 1986, he has published over 40 articles in peer-reviewed scientific journals and has co-authored three books including, Road Ecology: Science and Solutions (Island Press, 2003). Tony has worked as a research wildlife biologist for the World Wide Fund for Nature–International (Gland, Switzerland), Ministry of Environment–France (Toulouse), U.S. Forest Service, and U.S. National Park Service.

Tony is a graduate of the University of California, Berkeley, has a master’s degree in Wildlife Ecology from the University of Tennessee, Knoxville and a doctoral degree in Zoology from the University of León, Spain. He is currently an adjunct assistant professor at the Department of Ecology, Montana State University. He lives year-round outside Banff National Park.

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Chapter 5

Integrating Transportation and Resource Conservation Planning

Conservation Banking

Integrating Transportation Conservation With Regional Conservation Planning

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Abstract: Conservation planning in San Diego County has been ongoing since the early 1990's and has resulted in the establishment of the Multiple Species Conservation Program (MSCP) in southwest San Diego County and the Multiple Habitat Conservation Program (MHCP) in northwest San Diego County. Currently, the County of San Diego is developing regional plans for the unincorporated lands remaining in north and east San Diego County. These regional plans are (or will be) permitted under the Federal Endangered Species Act (Section 10: Habitat Conservation Plan) and the State of California Natural Community Conservation Planning Act.

This paper focuses on the integration of transportation conservation with the MSCP. "The MSCP is a comprehensive, long-term habitat conservation plan which addresses the needs of multiple species and the preservation of natural vegetation communities in San Diego County" (MSCP 1998). The MSCP covers 85 species, of which 20 species are federally listed and 14 are State listed, including 46 plant species and 39 animal species. The MSCP defines a design preserve within the plan boundaries that include large interconnected areas for the protection of the MSCP-covered species. The MSCP does not cover regional transportation projects, such as projects funded by the Federal Highway Administration.

District 11 of the California Department of Transportation and the Federal Highway Administration collaborated with Federal and State resource agencies to develop transportation projects that are consistent with the MSCP. The planning and development of improvements to Interstate 15, State Route (SR) 125 South, and the SR 905 Extension included the protection of large blocks of habitat in conservation banks. Numerous parcels were purchased as mitigation, including the Walsh property, Bonita Meadows Open Space Preserve, Johnson Canyon Open Space Preserve, San Ysidro Mountain, Lake Jennings, and Dennery Canyon. These parcels are key to the buildout of the preserve identified by MSCP. In addition, the design of SR 125 South and the SR 905 Extension included modifying the alignment to avoid and minimize impacts to sensitive natural resources within the MSCP.

Collaboration between the transportation agencies and natural-resource agencies has resulted in the preservation of large blocks of habitat to further the buildout of the MSCP preserve. The voter-approved extension of a $0.005 sales tax will provide a funding mechanism for the up-front purchases of land to continue this collaboration in recognition that it results in the most cost-effective mitigation and better conservation.

Introduction

Conservation planning in San Diego County (Figure 1) has been ongoing since the early 1990's and has resulted in the establishment of the Multiple Species Conservation Program (MSCP) in southwest San Diego County and the Multiple Habitat Conservation Program (MHCP) in northwest San Diego County. Currently, the County of San Diego is developing regional plans for the unincorporated lands remaining in north and east San Diego County. These regional plans are, or will be, permitted under the Federal Endangered Species Act (Section 10: Habitat Conservation Plan) and the State of California Natural Community Conservation Planning Act.

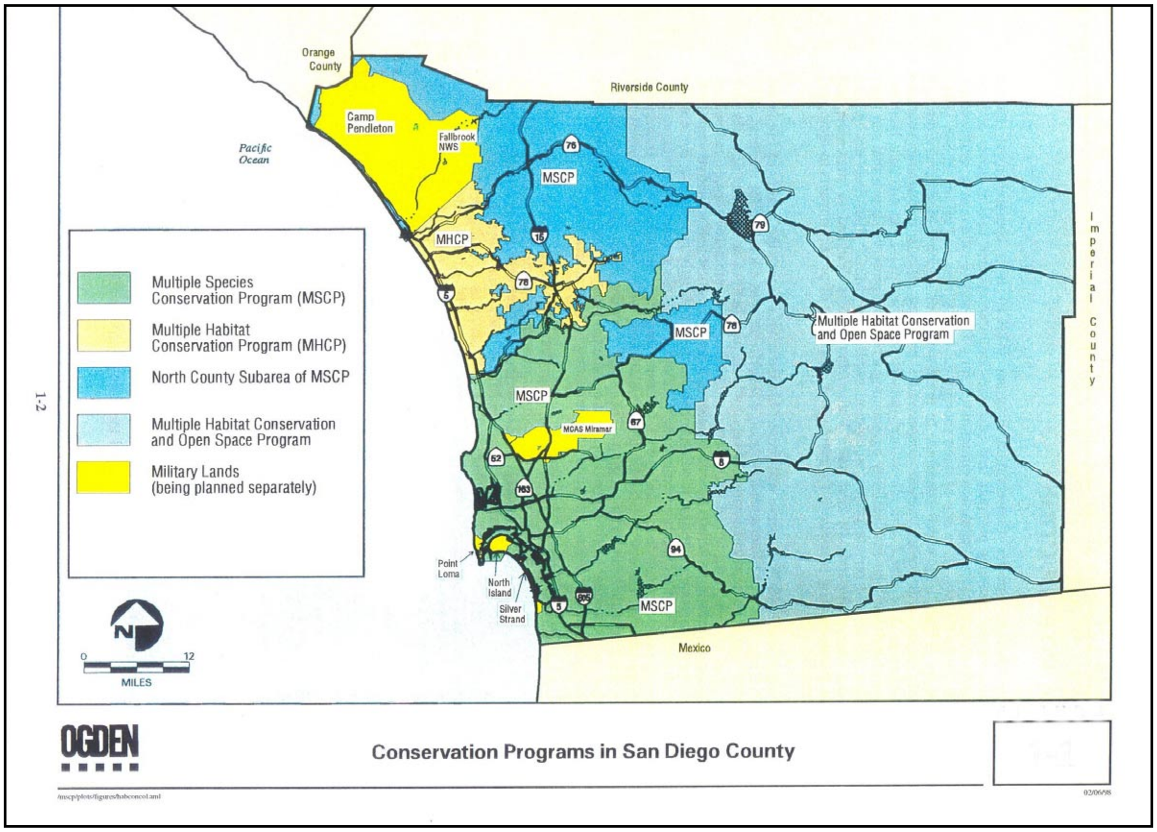

Figure 1. Regional conservation plans in San Diego County (MSCP 1998).

District 11 of the California Department of Transportation (Caltrans) has been working with Federal, State, and local governments to ensure that their conservation efforts compliment regional conservation-planning efforts. The MSCP (Figure 2) has identified a preserve system for 85 rare, threatened, and endangered species. The MSCP was developed to conserve both the diversity and function of southwestern San Diego County ecosystems through the preservation and adaptive management of large blocks of interconnected habitats and smaller areas that support rare vegetation (e.g. vernal pools, Otay tarplant). The MSCP defines a preserve within the 12 participating jurisdictions to protect large interconnected areas for the protection of the MSCP-covered species. When completed, the preserve will include approximately 171,920 acres. Currently 112,244 acres of land have been purchased and preserved through Federal, State, and local funding.

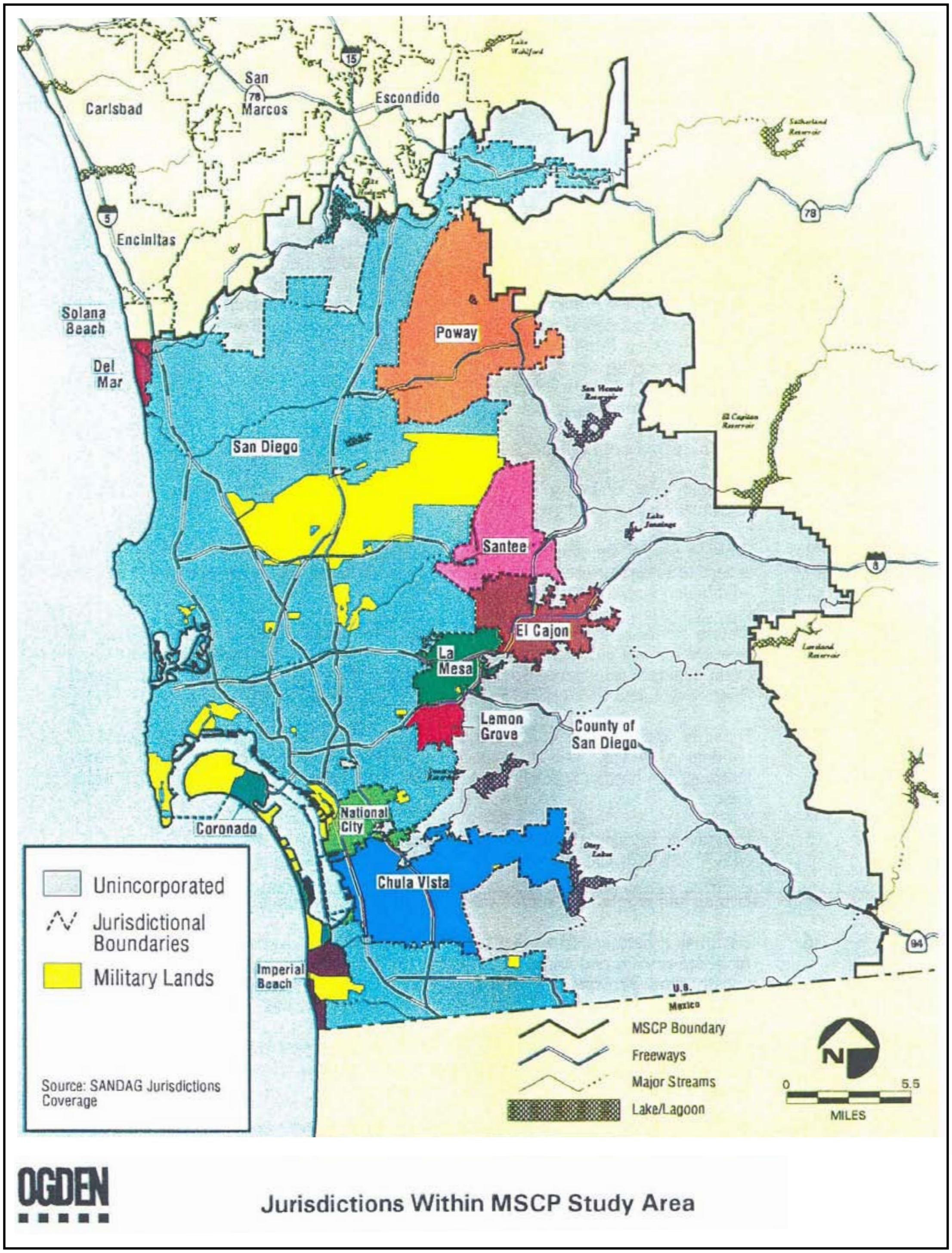

Figure 2. Multiple Species Conservation Program in San Diego County (1998).

The California Department of Transportation (Caltrans) has worked with the wildlife agencies to conserve large blocks of habitat through the establishment of mitigation banks within the identified preserve, instead of lots of small disjunct pieces. Some of these banks were established up front and can be used to mitigate for several projects rather than just one project. The advantages to purchasing pre-project mitigation lands include purchasing lands at lower prices, establishing larger preserves that support multiple species, and streamlining the National Environmental Policy Act/ California Environmental Quality Act process. Because highways can cause significant impacts to natural resources, they can also provide significant mitigation and contribute to the preservation of key pieces of the preserve.

As an example, Caltrans purchased the Bonita Meadows Open Space Preserve (Bonita Meadows Preserve), part of the Rancho San Diego Conservation Bank, the Wall-Hudson property at Dennery Canyon (Dennery Canyon Preserve), and the Walsh property at Lake Hodges in the early planning phases of multiple capital-improvement projects. In addition, Caltrans has purchased large blocks of land that support a variety of sensitive species as mitigation during the project-development process.

Caltrans and the Federal Highway Administration (FHWA) are not signatory agencies to the MSCP. Therefore, the regional highway projects were not covered. The wildlife agencies worked closely with Caltrans and FHWA to minimize impacts to the preserve during the development of the Least Environmentally Damaging Practicable Alternative (LEDPA). In instances where the roadway alignment impacted the preserve, mitigation was developed that expanded the preserve in other areas that were to be developed to ensure that an equivalent level of conservation was provided consistent with the original MSCP. “Equivalency” is defined as having the same or higher biological value of the preserve.

Combining upfront mitigation purchases with mitigation from project development has resulted in the continued build-out of the preserve. It has also enhanced the preserve by buying up development rights on these lands and expanding the preserve which helps offset the impacts to the preserve from construction of the projects. Mitigation to offset impacts to approximately 380 acres of habitat from capital improvements to Interstate 15, and the new construction of State Routes 125 South and the 905 Extension, has resulted in the preservation of over 1450 acres of habitat for a variety of MSCP-covered species. In addition, 34 pairs of coastal California gnatcatcher (*Polioptila californica californica*), 12 pairs of least Bell’s vireo (*Vireo bellii pusillus*), and 12 pairs of coastal cactus wren (*Campylorhynchus brunneicapillus couesi*) were protected within the preserved habitat. As Caltrans continues building capital-improvement projects in San Diego County, conservation strategies will be developed to protect and enhance existing resources and to restore and preserve habitat contiguous with regional design preserves. In the remaining areas of the County, where regional planning is in the planning phase, we are coordinating closely with Caltrans to plan for the regional-transportation projects and incorporate them into the plans.

The following is a description of the parcels purchased, the natural resources on the parcels, and the regional significance of these purchases for conservation biology.

Walsh Property

The Walsh property was originally purchased as three contiguous parcels totaling 105.4 acres immediately north of Lake Hodges and the northern boundary of the MSCP. The property includes 86 acres of coastal sage scrub supporting nine gnatcatcher pairs and three individuals, 6.2 acres of southern mixed chaparral supporting the MSCP-covered wart-stemmed ceanothus (*Ceanothus verrucosus*), and an area within the coastal sage scrub dominated by cholla (*Opuntia ssp.*) that supports a population of the MSCP-covered coastal cactus wren. In addition, the site is home to the MSCP-covered orange-throated whiptail (*Cnemidophorus hyperythrus beldingi*), San Diego horned lizard (*Phrynosoma coronatum blainvillei*), and California Rufous-crowned sparrow (*Aimophila ruficeps canescens*).

The purchase of the Walsh property contributes to securing a key interface between MSCP and MHCP north of the existing limits of the City of San Diego between San Diego and Escondido (Figure 3). The sloping hills surrounding Lake Hodges in the northeastern area of the City of San Diego support a variety of plant communities that support a variety of sensitive flora and fauna such as the golden eagle (*Aquila chrysaetos*). The area surrounding the preserve has been developed as residential communities with houses, malls, and recreation facilities. In addition, the Lake Hodges open-space area also provides local residents and visitors an opportunity to hike, bicycle, or ride horses through a myriad of trails.

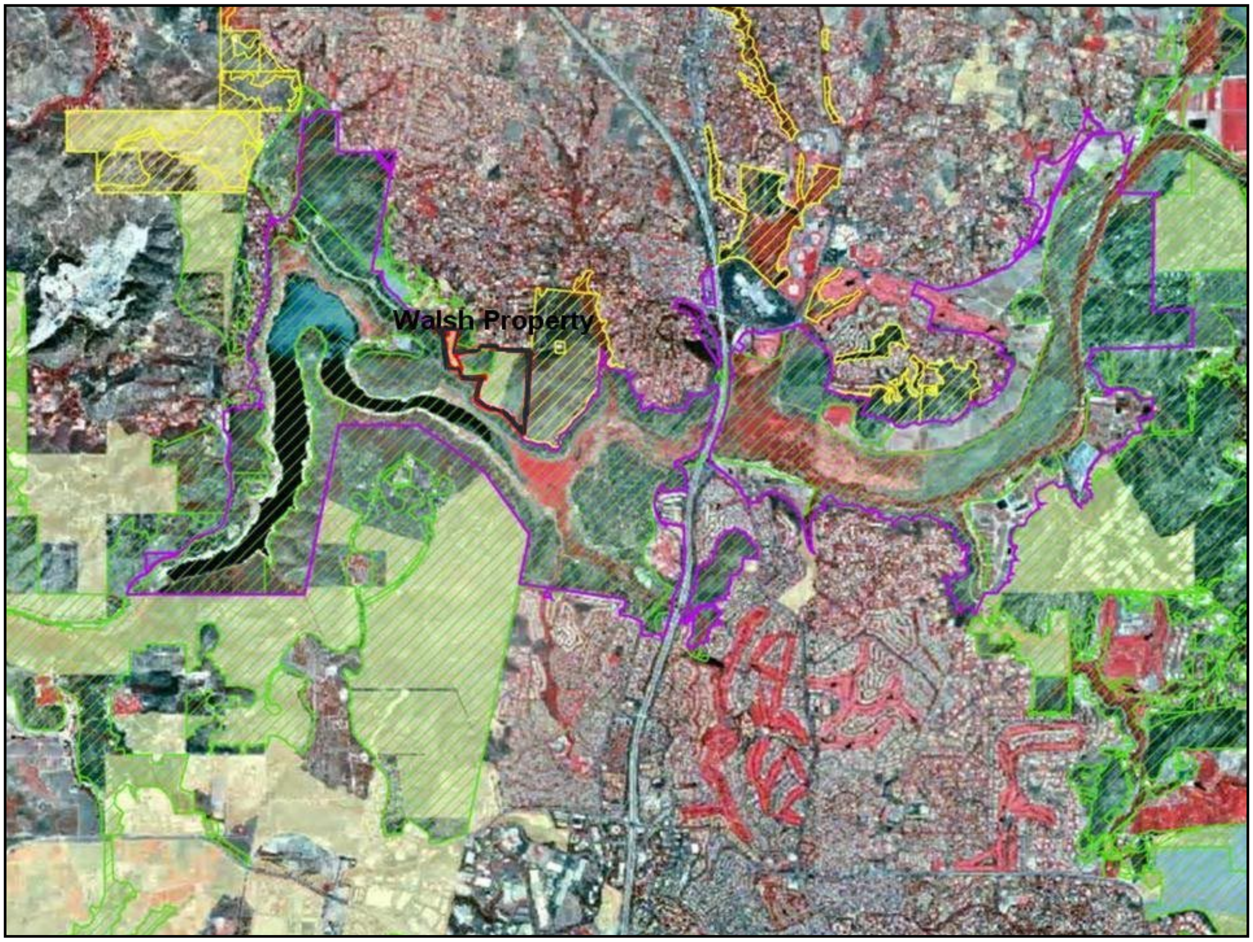

Figure 3. The Walsh Property along the northern border of Lake Hodges within the MSCP preserve system (hash marks).

Bonita Meadows

The 200-acre Bonita Meadows was originally purchased as three parcels that would be contiguous, except for the San Diego County Water Authority easement running north to south through the L-shaped open-space preserve (Figure 4). Bonita Meadows is a relatively flat valley bottom sloping up to mesas to the west and south with numerous tributaries draining the mesas to a main stream channel, which is dominated by native and non-native wetland-plant species. The slopes are primarily dominated by native grasslands on clay lenses and non-native grasslands on loamy soils with coastal sage scrub and maritime succulent scrub communities in patches throughout the site. The preserve includes 31 acres of habitat occupied by the federally threatened Otay tarplant (*Deinandra conjugens*), areas supporting the federally threatened San Diego thornmint (*Acanthomintha ilicifolia*), a small population of coastal cactus wren, six pairs and one individual coastal California gnatcatcher, California Rufous-crowned sparrow, San Diego horned lizard, orange-throated whiptail, variegated dudleya, and a variety of other MSCP-covered species.

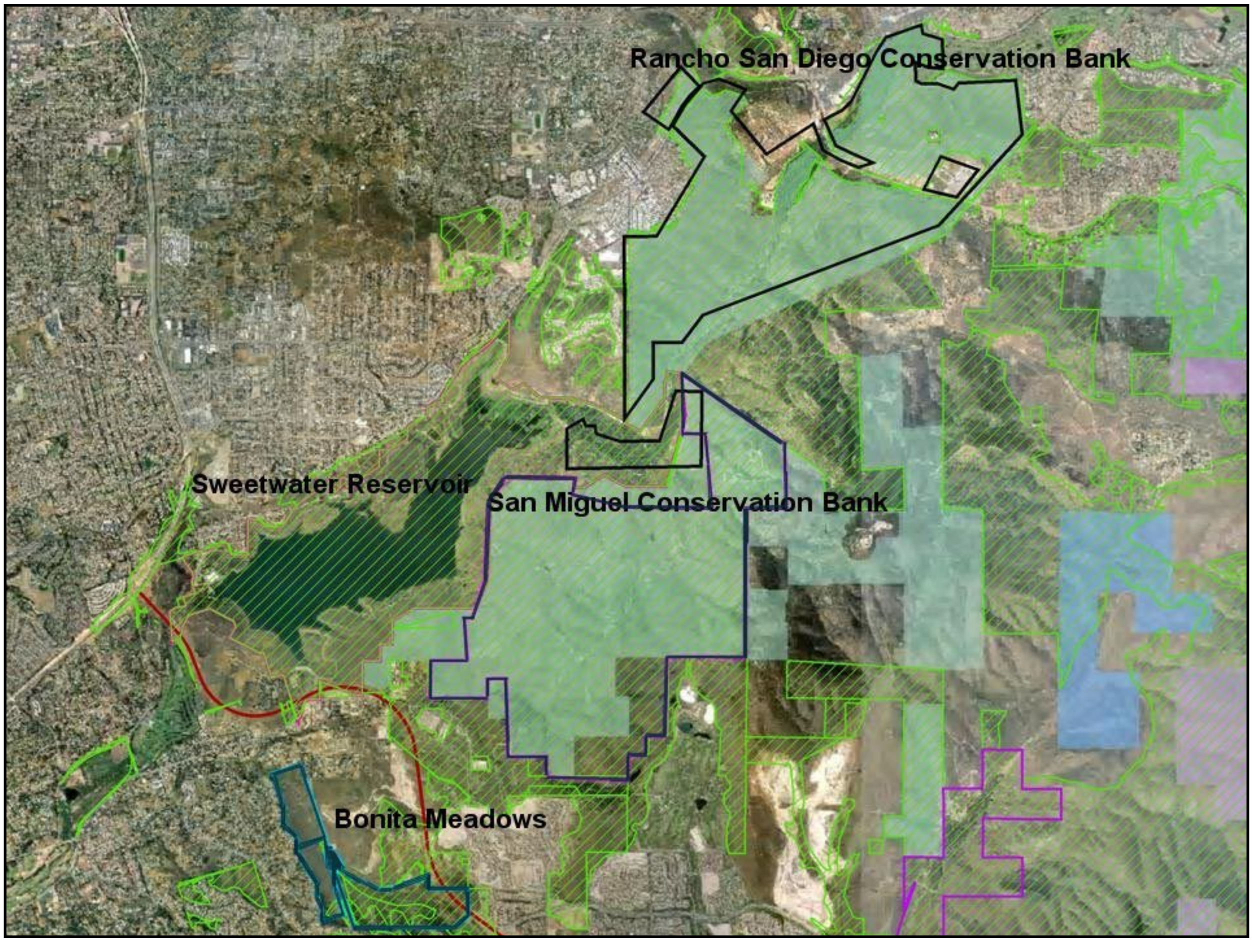

Figure 4. Large contiguous preserves in unincorporated San Diego County.

Bonita Meadows was slated to be developed and now adds to the preserve in southern San Diego County as an open-space preserve with trails for continued access by equestrian and pedestrian visitors. Bonita Meadows is contiguous with other preserved lands including the Tri-Mark property across the future SR 125, the Sweetwater Reservoir (owned and managed by Sweetwater Water Authority), and San Diego National Wildlife Refuge to the north. The main stream channel through Bonita Meadows is actively being restored with riparian and wetland habitats for the future colonization of riparian nesting birds such as the federally endangered least Bell's vireo (*Vireo bellii pusillus*).

Rancho San Diego Conservation Bank

The Rancho San Diego Conservation Bank (Rancho San Diego) was established by the County of San Diego, the San Diego Association of Governments (SANDAG), and Caltrans totaling 1,705.1 acres supporting 34 pairs of coastal California gnatcatcher and 28 pairs of least Bell's vireo. Rancho San Diego consists of 1,289 acres of coastal sage scrub, 67 acres of southern mixed chaparral, 155 acres of riparian woodland, 5.1 acres of marsh riparian floodplain, 11 acres of oak woodland, seven acres of native grassland, and 171 acres of non-native grassland. This large parcel supports a variety of MSCP-covered species, including the San Diego horned lizard, orange-throated whiptail, Otay manzanita (*Arctostaphylos otayensis*), and felt-leaved monardella (*Monardella hypoleuca* ssp. *lanata*).

Rancho San Diego is an important purchase due to its size, location, and diversity of communities. This parcel was slated for development, but instead was conserved and became the first piece of the San Diego National Wildlife Refuge. Rancho San Diego is contiguous with the Sweetwater Reservoir, the 1853 acre San Miguel Conservation Bank, and numerous private mitigation banks in the area (Figure 4).

Johnson Canyon

The Johnson Canyon Preserve was recently purchased in four parcels totaling 105.4 acres within the MSCP preserve on northeastern Otay Mesa (Figure 5). Two of the parcels are contiguous, spanning the canyon and part of the mesa to the northeast. A 52-acre parcel lies wholly on Otay Mesa and is currently undergoing restoration for vernal pool, Quino checkerspot butterfly, and coastal cactus wren habitats. The fourth parcel is four acres that are separated from the other three parcels by SR 125 and have a clay lens that supports a healthy population of Otay tarplant. Johnson Canyon currently supports populations of Quino checkerspot butterflies, coastal California gnatcatchers, coastal cactus wrens, the federally endangered San Diego button-celery (*Eryngium aristulatum* var. *parishii*) and San Diego mesa mint (*Pogogyne nuduiscula*), and a large population of variegated dudleya (*Dudleya variegatta*).

The area undergoing active restoration has been recontoured as a vernal pool/mima mound complex and the pools have been inoculated with federally threatened and endangered flora and fauna including San Diego fairy shrimp (*Branchinecta sandiegonensis*), Riverside fairy shrimp (*Streptocephalus woottoni*), spreading navarretia (*Navarretia fossalis*), San Diego button-celery, and Otay mesa mint. In addition and because of its proximity to the SR 125 alignment, many cactus and shrubs were salvaged from the alignment and transplanted to the restoration site, thus jumpstarting the restoration efforts.

Johnson Canyon was not included in the MSCP preserve because it was anticipated that the SR 125 alignment would run through it. During the environmental review process, it was determined that the Least Environmentally Damaging Practicable Alternative was to shift the alignment to the west. Thus the preserve was expanded in this area, partly to offset impacts to the preserve from the alignment. Johnson Canyon is an important part of the preserve because it locks up an area that borders the City of Chula Vista's open-space preserve and the county of San Diego's design-preserve system. The restoration and long term management of these four parcels will allow for the continued survival of numerous listed and covered species while providing for the dispersal and migration of species through the Johnson Canyon and downstream Otay River corridors.

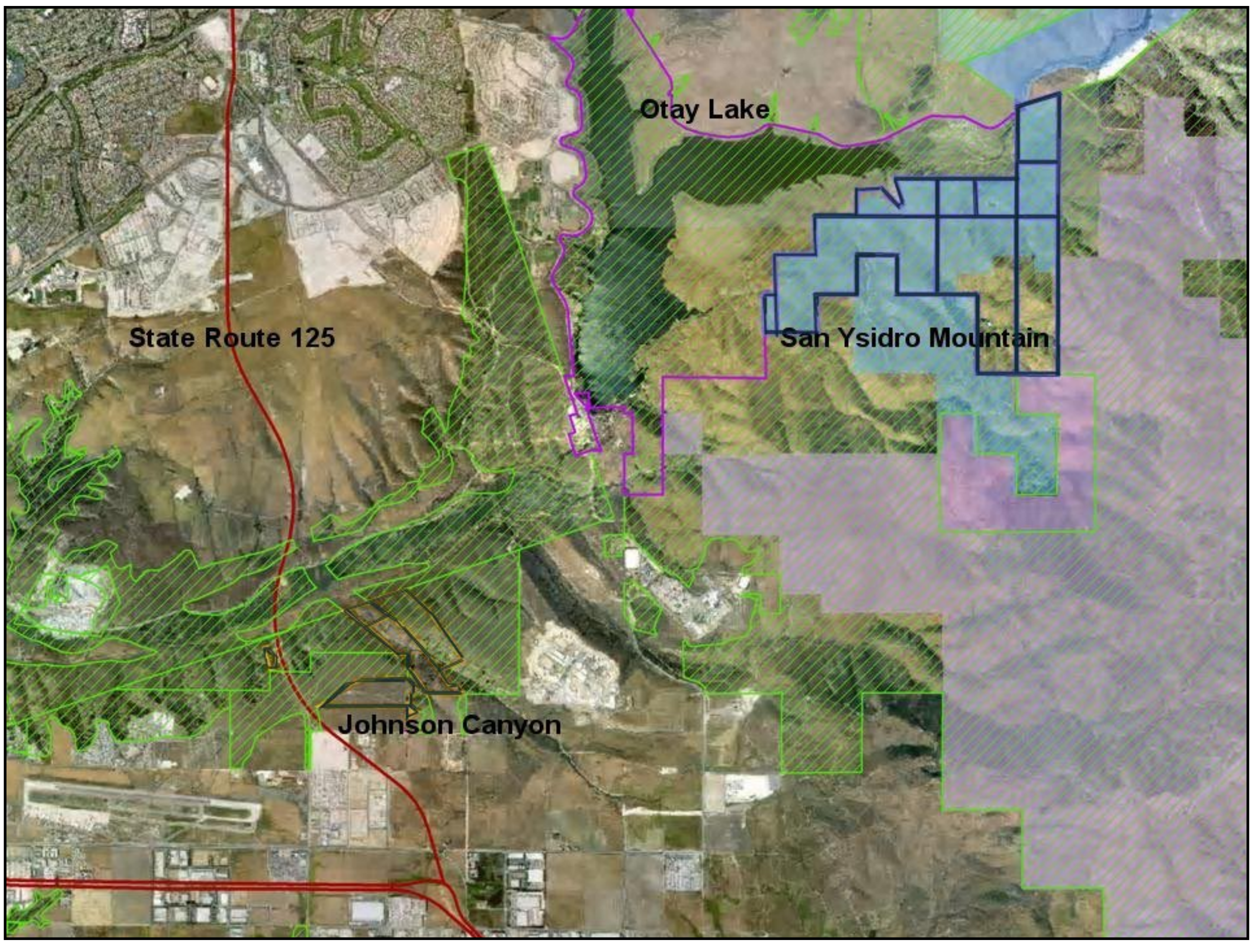

Figure 5. Johnson Canyon and the corridors to the San Ysidro Mountains.

San Ysidro Mountain

A combination of Federal and State grants purchased a few large contiguous blocks of land on the lower slopes of the San Ysidro Mountains above Otay Lake (Figure 5). Caltrans and California Transportation Ventures (the private entity constructing the toll-road portion of SR 125: CTV) provided funding to assist with the purchase of 566 acres of land (part of the larger overall purchase), short term restoration/enhancement actions, and the long-term management of the 566-acre parcel. When purchased, the parcel supported a population of Quino checkerspot butterflies, coastal California gnatcatchers, and variegated dudleya.

The San Ysidro Mountain site is an important purchase because it removed several development bubbles from the MSCP preserve. MSCP had identified this area as important for conservation, but was unable to reach agreement with the land owners. By working cooperatively with the State and Federal agencies, the entire area south of Otay Lake remaining in private ownership was purchased. This parcel borders Bureau of Land Management Wilderness, City of San Diego preserve lands, and U.S. Fish and Wildlife Refuge lands. Together, the open-space preserve in the area supports a variety of federally listed and MSCP-covered species, including Mexican flannelbush (*Fremontadendron mexicanum*), willowy monardella (*Monardella linoides* ssp. *viminea*), Dunn's mariposa lily (*Calochortus dunnii*), and Tecate cypress (*Cupressus forbesii*), which is home to Thorne's hairstreak butterfly (*Mitoura thornei*). The purchase of the contiguous blocks by Federal and State grants and Caltrans/CTV funds incorporated the last pieces needed to create a large block of conserved lands between Otay Lake and the Mexican border.

Lake Jennings

Lake Jennings (Figure 6) is another Caltrans/CTV purchase totaling 37.2 acres that supports seven cactus wren territories and the MSCP-covered barrel cactus (*Ferocactus viridescens*). The hilly site includes 27.5 acres of coastal sage scrub and 7.1 acres of non-native grasslands with drainages and a flat area on top of the hill. Lake Jennings was an important purchase within the MSCP because it helps build out the lakeside linkage of the "stepping stones" identified within the County's MSCP, the only linkage north and south for the coastal California gnatcatcher and coastal cactus wren. The site supports coastal cactus wren, is immediately adjacent to areas occupied by coastal cactus wren within the MSCP preserve, and is contiguous with the Helix Water District land surrounding Lake Jennings.

Dennery Canyon

Dennery Canyon was recently purchased as a single 86.3-acre parcel consisting of 8.95 acres of mesa fingers above slopes and drainages in the upper southern reaches of the canyon. The site supports 40.5 acres of maritime succulent scrub, 17.1 acres of coastal sage scrub, 18 acres of native grassland, and 4.4 acres of non-native grassland. The fingers have remnant-disturbed vernal pools that will be restored/enhanced and inoculated with spreading navarretia, San Diego button celery, and Otay mesa mint. Maritime succulent scrub is a rare coastal-plant community that supports the coastal California gnatcatcher, San Diego horned lizard, and a host of rare plant species. The site also supports the host plant for and is occupied by the Quino checkerspot butterfly.

The purchase at Dennery Canyon preserved one of the few remaining pieces of land surrounding the Canyon that was not previously protected for conservation (Figure 6). To the south is a small parcel that is undergoing vernal-pool restoration. Across the canyon to the east is a large area where extensive vernal pool/mima mound restoration has successfully created a mosaic of plant communities that support a variety of sensitive and rare flora and fauna. Dennery Canyon is the westernmost canyon remaining on the north rim of Otay Mesa. Preserving the entire canyon will fill out the preserve in the area. Under the City of San Diego's plan, portions of the mesa could have been developed. Instead, the site will be restored and complement the conservation occurring in and adjacent to the canyon.

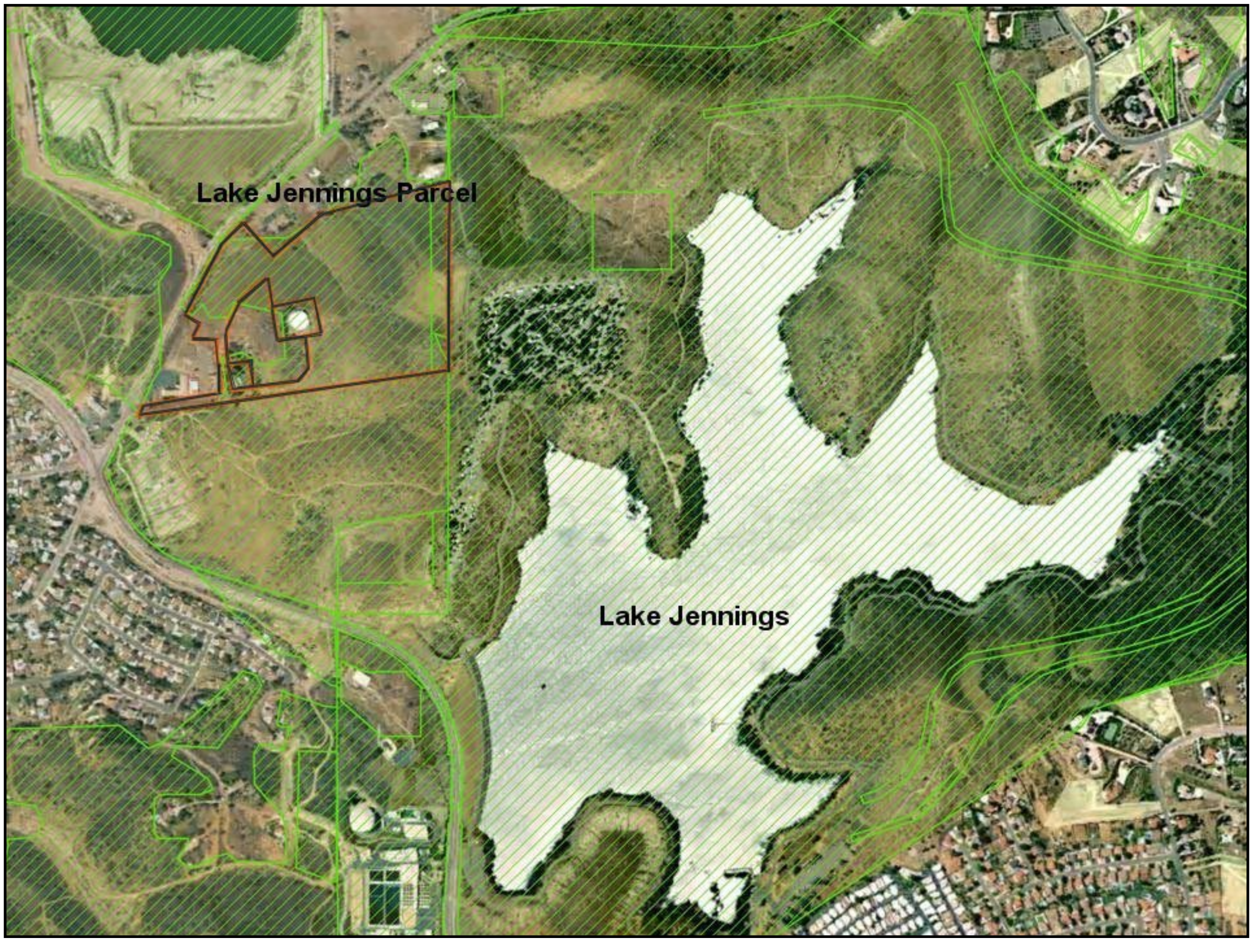

Figure 6. Lake Jennings within the MSCP preserve.

Transnet

Past collaboration between Caltrans and Federal and State resource agencies has successfully preserved large blocks of land contiguous with and/or within the MSCP preserve. The collaborative process, and in particular the establishment of contiguous banks, has resulted in more cost-effective mitigation and better conservation. In recognition of these benefits, a countywide initiative (Transnet) was developed. The voters of San Diego County approved the extension of the $0.005 sales tax to fund transportation projects.

Principle four of the Transnet Environmental Mitigation Program states that the "allocation for the estimated economic benefits of incorporating specified regional and local transportation projects into applicable habitat-conservation plans, thereby allowing mitigation requirements for covered species to be fixed and allowing mitigation requirements to be met through purchase of land in advance of need in larger blocks at a lower cost. The benefits of this approach are estimated at approximately $220 million. This amount will be allocated to a Regional Habitat Conservation Fund "which will be made available for regional habitat acquisition, management and monitoring activities necessary to implement the MSCP and MHCP..." (Transnet 2004). Transnet will not only provide upfront funding for the purchase of lands for pre-mitigation purposes, but will also contribute to the long-term management and monitoring of the preserve.

Figure 7. Dennery Canyon on the northwest end of Otay Mesa.

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Susan Wynn, Fish and Wildlife Biologist, U.S. Fish and Wildlife Service, Carlsbad Fish and Wildlife Office, California. (Author.)

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ODOT's Habitat Value Approach to Compensatory Mitigation Debit/Credit Calculations

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Abstract

In 2004, the Oregon Department of Transportation (ODOT), Parametrix, and several partnering agencies developed a statewide Banking Program to improve fundamentally ODOT's approach for addressing habitat mitigation and conservation and species recovery. As part of the Banking Program, a debit/credit accounting system was developed to ensure that compensatory mitigation and conservation actions adequately address impacts to species, habitat, and functions. The resulting Habitat Value metric represents a comprehensive view of ecosystem function and is the currency of the Banking Program. It constitutes a new approach to resource evaluation, and can be characterized as a new language that enables project-permitting discussions to move beyond a narrow focus on regulatory requirements.

Most mitigation and conservation bank programs measure debits and credits in acres or linear feet. Ratios are often applied as a surrogate means of addressing habitat quality and function. The Habitat Value approach moves away from using dimensions and ratios in favor of focusing on changes in the ecological function of the site. This type of analysis provides an opportunity to evaluate where systems may be most vulnerable to impacts and where management activities should be focused to protect or enhance overall ecosystem integrity.

Habitat Value is determined by using database correlations to predict which species will occur at a site based on field inventories of habitat characteristics. These correlations are the basis for determining which key ecological functions are likely to be performed. Because many project sites are adversely influenced by the presence of invasive plant species, it is necessary to incorporate an adjustment factor that reflects the fact that such sites are not functioning at their ecological potential. These habitat-species-function relationships are integrated to determine Habitat Value. There are two methods for determining Habitat Value, both of which utilize GIS and automated databases: a rapid assessment for use at low quality/low severity impact sites and a more detailed approach for high-quality/high-severity impact sites.

The Habitat Value approach can accommodate different types of impacts and mitigation/conservation activities, and is useful for alternatives analysis and impact assessments. The accounting system assesses debits and credits by predicting how species will respond to habitat modifications (i.e., changes in the extent or character of available habitat). Based on anticipated post-project conditions, a post-project Habitat Value is calculated and subtracted from the baseline Habitat Value in order to determine the debit or credit amount. Techniques have been developed to quantify the debit value of temporary direct, permanent indirect, and permanent direct impacts, as well as the credit value resulting from habitat restoration, creation, enhancement, and preservation.

As an interim measure to ensure that regulatory requirements are satisfied, accounting modules address the extent and abiotic function of wetlands and the extent and quality of habitat for certain ESA-listed species. These backstops make use of the Habitat Value accounting framework, but incorporate additional information relating to wetland function or species-specific habitat suitability. Additional modules can be added as needed to address water quality or other resources of specific regulatory interest (e.g., additional ESA-listed species, migratory birds).

Through the Habitat Value approach, the value of all habitat types (not just jurisdictional wetlands) can be quantified. When coupled with Ecoprovince Priorities that reflect regional restoration/conservation objectives, the Habitat Value approach accommodates out-of-kind mitigation. This new system provides the flexibility needed to focus on regional priorities while implementing the Clean Water Act, the ESA, the Fish and Wildlife Coordination Act, and the ODFW Habitat Mitigation Policy. This approach has been developed in close coordination with the U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, National Marine Fisheries Service, U.S. Environmental Protection Agency, Federal Highway Administration, the Oregon Department of Fish and Wildlife, Oregon Environmental Quality, and the Oregon Department of State Lands, in addition to ODOT.

As with the Banking Program in general, the debit/credit accounting system will incorporate new ideas and techniques to build on successes and address shortcomings. Further research will include the development of additional species-specific accounting modules for ESA-listed salmon species, vernal pool communities, Fender's Blue Butterfly, and threatened and endangered plants. Additionally, analysis may be modified to address abiotic functions and to incorporate landscape connectivity metrics. Finally, it may be possible to integrate the Habitat Value metric with other models, such as hydrogeomorphic models and the NMFS Five-Step Wetland Mitigation Ratio Calculator.

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On the Road to Conservation: State Conservation Strategies and Applications for Transportation Planning

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Abstract: Since 2001, the Department of Interior has been supporting state-based wildlife conservation via the State and Tribal Wildlife Grants Program (SWG). Funds are appropriated annually for state fish and wildlife agencies to address the broad range of their state's wildlife and associated habitats in a comprehensive fashion.

As part of the SWG, state fish and wildlife agencies are developing statewide comprehensive wildlife conservation strategies in partnership with a broad array of partners including other government agencies, conservation organizations, landowners, and the public. Each strategy will establish a vision and plan of action for limited state wildlife conservation funding. The finished product will be a strategic vision for conserving the state's wildlife–not just a plan for the fish and wildlife agency.

The strategies are due for completion in October 2005 and will be reviewed at least every 10 years to ensure conservation success over the long term. For the first time, we can look to a nationwide vision for wildlife conservation.

By design, Congress directed that the strategies focus on the "species in greatest need of conservation," yet address the full array of wildlife and wildlife-related issues. In that context, each strategy is required to include information on the distribution and abundance of species of wildlife and locations and relative condition of key habitats and community types. Most states will utilize GIS technology and many will produce maps of prioritized habitat throughout the state. For the first time, transportation agencies will have access to this information at the planning stage, rather than waiting until environmental review.

Over the last decade, transportation agencies have struggled to find ways to reduce costs and unnecessary delays to accelerate project delivery. Several legislative, policy, and procedural fixes have been attempted with mixed success. The statewide comprehensive wildlife-conservation strategies have great potential in aiding state transportation departments in streamlining project delivery. By utilizing natural-resource data in early stages of planning, they can avoid, minimize, and mitigate many impacts early and steer clear of costly delays later in the life of their projects. As an added bonus, the transportation agency adopts a proactive approach to conservation and becomes a full partner in implementing the conservation strategy for the entire state.

Introduction

The most significant threat to America's biodiversity is habitat loss and the greatest consumer of habitat is poorly planned, sprawling development. Low density, automobile-dependent development that spreads beyond the edges of existing communities and alongside highways devours and degrades the habitat that wildlife relies upon for its existence. The Natural Resources Inventory estimates that 2.2 million acres are lost to development each year (NRCS 2000). In a recent study of listings under the Endangered Species Act, researchers found that urbanization endangers more listed species than any other cause (Czech 2000).

Roads and highways enable the mobility necessary for development; hence the transportation-planning decisions that are made today will determine the location, direction, and shape of the urbanization that happens tomorrow.

Unfortunately, conservation, and growth efforts often happen in isolation and can then confound one another. For example, transportation projects are often planned without detailed information on core conservation areas, sensitive resources, or important habitat that might lie within the selected corridor. These conflicts do not come to light until the environmental review process, which then becomes more expensive and time consuming as transportation and resource officials attempt to reconcile infrastructure and conservation activities. If conservation efforts are taken into account at the earliest stages of transportation planning, both priorities can be realized and at less expense of time and money.

Two new and perhaps serendipitous developments from Capitol Hill may help states achieve this lofty goal. By Congressional mandate, state fish and game agencies are completing statewide conservation strategies in 2005. The new transportation bill signed in August 2005 requires transportation planners to incorporate conservation information into early, long-range transportation planning. Through smart and effective coordination, transportation agencies can both improve project delivery and better protect vital natural resources in their state.

By understanding the history of both transportation and conservation planning, we gain a better understanding of how it works (and doesn't work) in the present day. State and federal agencies spend considerable time and capital both protecting natural areas and building transportation infrastructure. While these sometimes conflict, they need not be antagonistic. Transportation planning that integrates existing conservation efforts will save money, protect resources, and expedite project delivery.

The Early Days "Let's Build It Before We're Too Old to Enjoy It"

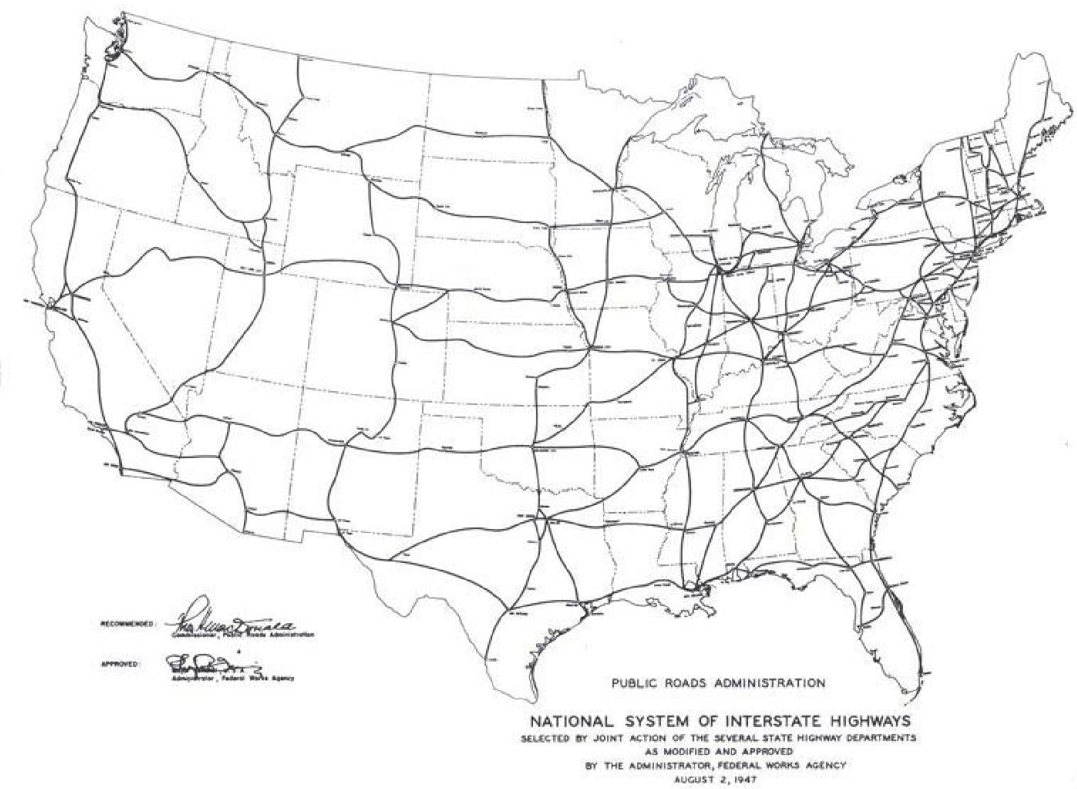
Prior to the twentieth century, most of our roads were built and maintained by local governments. Some eastern states built turnpikes during the 1800s, connecting their major cities and ports. The federal government planned and sporadically built pieces of a "National Road" which was later abandoned and turned over to counties. By and large, Americans relied upon railroads for long distance travel and used roads only as necessary for local trips (Gutfreund 2004).

The first national survey of road conditions in 1904 revealed that only 7 percent of the country's roads were surfaced. Even those were surfaced with gravel or low-quality macadam, suitable for horse and carriage, but unsuitable for the faster, heavier automobiles. A burgeoning automobile industry recognized that poor road conditions would discourage auto travel, and consequently auto sales. Soon thereafter, they began clamoring for high quality, publicly financed, long distance highways (Holtz Kay, 1997).

THE INTERSTATE SYSTEM: "Broader Ribbons across the Land"

When Dwight D. Eisenhower took office in 1953, he brought a vision of an integrated national highway system that would "protect the vital interest of every citizen." Having volunteered for the U.S. Army's transcontinental convoy in 1919, a young Eisenhower embarked on a 62-day trek from Washington, D.C. to San Francisco. From tedious to treacherous, the convoy met with mud, dust, ice, and rickety bridges. Years later, while serving in Germany during World War II, General Eisenhower coveted their autobahn network and a system of "broader ribbons across the land."

Congress passed the Federal-Aid Highway Act of 1954, providing $175 million to correct the nation's inadequate and obsolete highway network. Two years later, $25 billion was authorized for the next decade of highway building to be built with uniform interstate design standards and controlled access. The Interstate System was to be a grand plan for a system of highways developed through a cooperative alliance amongst state and federal transportation officials (Weingroff 2005).



The Three Cs

As the new Interstate highways began snaking through and around communities, the need for collaborative transportation planning could no longer be denied. The Federal-Aid Highway Act of 1962 first created the federal requirement for urban transportation planning in the U.S. In order to receive federal funding, urbanized areas (50,000+ population) were required to plan all transportation projects cooperatively with state and local governments. The resulting planning process would be guided by the three Cs: continuing, comprehensive, and cooperative.

Despite the lack of qualified planning agencies in many urban areas, all 224 existing urbanized areas had nascent planning processes underway within three years. The Bureau of Public Roads (predecessor to the FHWA) quickly thereafter required the creation of agencies to carry out the planning process, what we now know as Metropolitan Planning Organizations or MPOs.

The technical foundation of the 3-C planning process was realized over the next two decades, along with a focus on increasing capacity within MPO staff. Plans are based on projected demand for transportation, based on a four-step mathematical model:

1. Trip generation: Estimate the number of trips generated in each zone destined for locations in other zones. Trip estimates are based on assumed relationships among socioeconomic factors, land use patterns, and the existing number of trips.
2. Trip distribution: Develop a trip table showing the number of trips originated in each zone and destinations in each zone.
3. Mode split: For the number of predicted trips between each origin zone and destination zone, estimate the number of trips made via each mode available for that trip. Modes include driving alone, carpooling, using transit, etc.
4. Network assignment: Estimate the number of trips per mode for each possible path throughout the road and transit network. Assign all trips to a network. Compare the capacity of each road or transit segment to the projected demand to forecast the level of congestion to be expected at that location.

In theory, by projecting the future performance of roads transportation planners can accurately determine how and where to expand the network. In fact, much of the methodology we use for transportation planning was developed to meet the needs of urbanized areas such as Chicago, Detroit, and New York in the 1960s.

ISTEA and TEA-21

Over the next 30 years, Congress repeatedly strengthened the planning process by further engaging local elected officials and expanding the original focus beyond travel demand to incorporate a wide range of social, economic, and environmental concerns. In 1991, Congress proclaimed a new era in transportation legislation with the Intermodal Surface Transportation Equity Act (ISTEA). ISTEA set forth groundbreaking reforms such as flexible funding, preservation of the existing system, multi-modal alternatives, and delegation of decision making within transportation planning to the metropolitan level.

The Transportation Equity Act for the 21st Century (TEA-21) reaffirmed these objectives in 1998 and consolidated ISTEA's lists of planning factors. Both metropolitan and statewide transportation planners are expected to consider projects and strategies that will:

- Support the economic vitality of the United States, the States, and metropolitan areas, especially by enabling global competitiveness, productivity, and efficiency.
- Increase the safety and security of the transportation system for motorized and non-motorized users.
- Increase the accessibility and mobility options available to people and for freight.
- **Protect and enhance the environment**, promote energy conservation, and improve quality of life.
- Enhance the integration and connectivity of the transportation system across and between modes throughout the State for people and freight.
- Promote efficient system management and operation.
- Emphasize the preservation of the existing transportation system.

The planning factors call for plans that will "Protect and enhance the environment, promote energy conservation, and improve quality of life." However, the factors are merely guidance and not regulatory in nature. Failure to consider this or any factor is not reviewable in court and could be disregarded by any MPO or DOT planning office. Also, terms like "environment" and "quality of life" are exceptionally (and intentionally) vague. As a result, MPOs and DOTs are free to interpret these terms and their obligations to address planning factors in their own way or ignore them altogether.

Air Quality

In fact, the only environmental consideration that is required during the transportation planning process is air quality. The Clean Air Act established air-quality standards and regulations to meet those standards. Locations that fail to meet air quality standards are called non-attainment areas and are tasked with developing a State Implementation Plan (SIP). SIPs contain emission budgets and establish measures to reduce emissions from stationary, area, and mobile sources in order to attain or maintain air quality standards.

Our car-loving culture is a great contributor to air pollution, pumping four of the six most reviled pollutants into the air: ozone, carbon monoxide, particulate matter, and nitrogen dioxide. Together, the Clean Air Act and ISTEA require that federally funded or approved transportation plans, programs, and projects conform to the regional air-quality objectives as outlined in the SIP. Transportation plans must demonstrate that projected motor-vehicle emissions from the planned transportation projects will not exceed the budget established in the SIP. If the air quality in a particular location does not meet goals set out in the air-quality plan (SIP), the state DOT will not receive federal transportation funding except for essential safety projects and those projects with prior commitments. In fact, these sanctions may be imposed even if the lapse of conformity is not transportation related (FHWA).

Governance

Transportation planning occurs simultaneously at several different levels of government. According to the FHWA's *Citizens' Guide to Transportation Decisionmaking*, the major actors in transportation planning are:

- State Departments of Transportation (DOTs) are the largest units of government that develop transportation plans and projects. They are responsible for setting the transportation goals for the state. To do so, they work with all of the state's transportation organizations and local governments. They are responsible for planning safe and efficient transportation between cities and towns in the state.
- Metropolitan Planning Organizations (MPOs) represent areas with a population of 50,000 people or more. An MPO may have "council of governments" or "regional planning commission" in its official name. Each MPO is different because individual metropolitan areas are so different. A policy board, which is comprised of local elected officials, sets an MPO's policy. However, other groups, such as non-profit organizations, community organizations, or environmental organizations, can influence the direction an MPO follows. The MPOs' mission is to provide short and long-term solutions to transportation and transportation-related concerns.
- Local governments carry out many transportation planning functions such as scheduling improvements and maintenance for local streets and roads.
- Transit agencies are public and private organizations that provide transportation for the public. Public transportation includes buses, subways, light rail, commuter rail, monorail, passenger ferryboats, trolleys, inclined railways, and people movers.
- The Federal Government (U.S. DOT) oversees the transportation planning and project activities of the MPOs and state DOTs. The Federal Government also provides advice and training on transportation topics ranging from pavement technology to design to efficient operations of highway and transit systems. The Federal Government also supplies critical funding needed for transportation planning and projects. At least every two years, the Federal Government approves a program of projects submitted by State DOTs that includes projects proposed for Federal Funds.

Planning Products

At the metropolitan level, MPOs are required to develop the following:

- Long-Range Transportation Plan (LRTP): A long-term vision for the area, covering a planning horizon of at least 20 years
- Transportation Improvement Program (TIP): A short-term program (approximately five years) based on the long-range transportation plan and designed to serve the area's goals, using spending, regulating, operating, management, and financial tools
- Congestion Management System (CMS): Areas with populations over 200,000 are called transportation management areas (TMA) and are required to develop strategies to reduce congestion and increase mobility. In non-attainment areas, projects that increase capacity for single occupancy vehicles (by adding new roads or widening existing ones) must conform to the area's CMS.

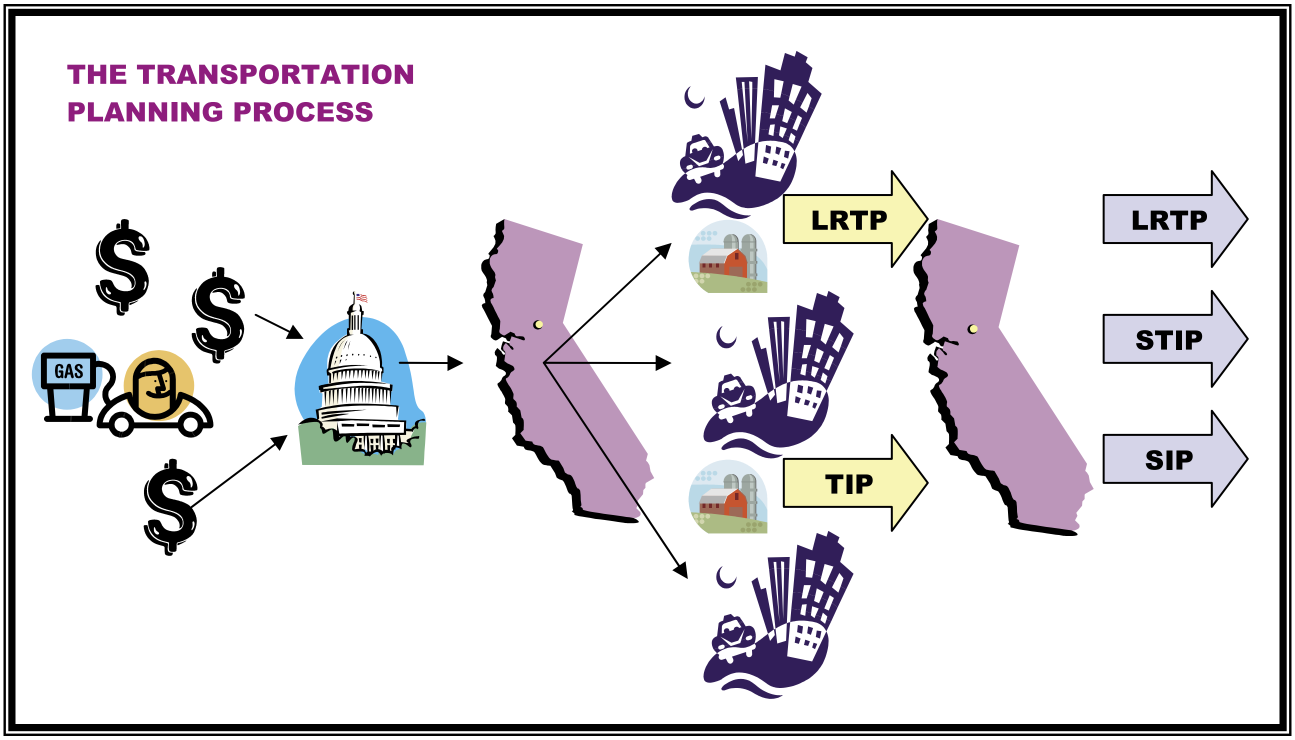
At the state level, DOT planning offices produce the following:

- Long-Range Transportation Plan (LRTP): A long-term vision for the state, covering a planning horizon of at least 20 years*
- Statewide Transportation Improvement Program (STIP): A short-term program for the state which incorporates and integrates the MPO plans. Developed on at least a two-year cycle, STIPs contain individual transportation improvements and projects. To be implemented, all federally funded projects must be part of an improvement program.
- State Implementation Plan (SIP): As required by the Clean Air Act, the SIP outlines measures the state will take to meet the National Ambient Air Quality Standards (NAAQS).

* Unlike metropolitan transportation improvement programs and long-range plans, statewide long-range transportation plans do not have a requirement to be financially constrained; that is, to demonstrate the likelihood that funds will be available to cover all proposed projects.

Funding

State departments of transportation receive funding from the U.S. Department of Transportation through the authorization of federal transportation law (ISTEA, TEA-21, SAFETEA-LU) and annual appropriations. Revenue is generated from gas tax collected by federal government and redistributed to states based on a formula of population and land area. Planning funds are given to DOTs to distribute among their MPOs, again based on a formula. Funds for metropolitan planning are called Planning Funds (PL) and amount to 1.25 percent of highway and transit program funding. Funds for state planning are called State Planning and Research Funds (SPR) and amount to 2 percent of highway and transit program funding.



Prelude to Conservation Planning: The Legislative Framework

Much like the transportation sector, conservation practice predated conservation planning. Early conservation efforts were focused on controlling the excessive harvesting of game species and migratory birds. In the late nineteenth century, great strides were made in preservation of public lands. Ecology and conservation biology emerged in the twentieth century, teaching us that protecting species and land was not enough; conservation can only be successful when we understand and protect the ecosystem. It would take decades before concepts such as island biogeography and population viability would begin to influence conservation practice and policy, highlighting the growing need for conservation planning.

The Environmental Revolution

The 1960s and 1970s are perhaps best known for rock and roll music, civil unrest, and the sexual revolution, but there was another revolution afoot that would also influence American culture for decades to come.

Congress passed several environmental protection laws during this time, largely credited with the environmental quality we enjoy to this day and providing the foundation for a burgeoning environmental movement:

- **Clean Air Act of 1963**. To reduce air pollution and ensure that all Americans have air that is safe to breathe, the Clean Air Act set emissions standards for stationary sources such as power plants and steel mills. The original version did not take into account mobile sources of air pollution such as automobiles, which had become the largest source of many dangerous pollutants. Several amendments to the Clean Air Act were passed over the next 30 years, authorizing standards for auto emissions, local air pollution control programs, air quality control regions (AQCR), air-quality standards and compliance deadlines for stationary-source emissions.
- **Land & Water Conservation Fund of 1964**. The Land and Water Conservation Fund declared a Congressional policy that "present and future generations be assured adequate outdoor-recreation resources" and that "all levels of government and private interests . . . take prompt and coordinated action . . . to conserve, develop, and utilize such [their] resources for the benefit and enjoyment of the American people." The Secretary of the Interior was directed to inventory, evaluate, and classify outdoor-recreation facilities and formulate and maintain a comprehensive nationwide outdoor-recreation plan.
- **National Environmental Policy Act of 1969**. The National Environmental Policy Act (NEPA) was one of the first laws written that established the broad national framework for protecting our environment. NEPA's basic policy is to assure that all branches of government give proper consideration to the environment prior to undertaking any major federal action that significantly affects the environment. NEPA requirements are invoked when airports, buildings, military complexes, highways, parkland purchases, and other federal activities are proposed.

- **Clean Water Act of 1972**. Enacted in 1972, the Clean Water Act's primary objective is to restore and maintain the integrity of the nation's waters. This objective translates into two fundamental national goals: eliminate the discharge of pollutants into the nation's waters and achieve water quality levels that are fishable and swimmable. The Clean Water Act was the first comprehensive national clean-water legislation, drafted in response to growing public concern for serious and widespread water pollution. It is the primary federal law that protects the nation's waters, including lakes, rivers, aquifers, and coastal areas.
- **Coastal Zone Management Act of 1972**. The Coastal Zone Management Act established a voluntary, national cost-share program to encourage coastal states to develop and implement coastal zone management plans. In order to be eligible for Federal approval, each state's plan was required to define boundaries of the coastal zone, to identify uses of the area to be regulated by the State, the mechanism (criteria, standards or regulations) for controlling such uses, and broad guidelines for priorities of uses within the coastal zone.
- **National Forest Management Act of 1976**. The National Forest Management Act reorganized, expanded, and otherwise amended the Forest and Rangeland Renewable Resources Planning Act of 1974, which called for the management of renewable resources on national forest lands. The National Forest Management Act requires the Secretary of Agriculture to assess forest lands, develop a management program based on multiple-use, sustained-yield principles, and implement a resource management plan for each unit of the National Forest System. It is the primary statute governing the administration of national forests.
- **Federal Land Policy and Management Act of 1976**. As the principal law governing how the Bureau of Land Management (BLM) manages public lands, FLPMA guides the BLM in management, protection, development, and enhancement of the public lands. FLPMA specifically requires the agency to manage for the multiple use and sustained yield of public land resources for both present and future generations.

ESA and HCPs

Among the class of environmental protection laws passed during this revolution, the Endangered Species Act of 1973 made perhaps the boldest step towards conservation planning, if only just for endangered species and their habitat. The ESA is intended not only to prevent the extinction of species listed as threatened or endangered, but provide for the conservation of the habitat on which they depend.

Once a species is listed, a recovery plan is developed and critical habitat is designated, including enough area for the species to expand its range and recover to healthy population levels. The Act authorizes land acquisition for the conservation of listed species, using funds from the Land and Water Conservation Fund. Efforts that reduce the amount or quality of habitat available to at-risk species are conditionally prohibited. In theory, this should constitute a conservation plan for the remaining habitat of each listed species. In practice, roughly 80 percent of listed species have recovery plans while only 30 percent have designated critical habitat (M. Senatore, pers. comm. 9/6/05).

Since the enactment of the ESA in 1973, the extinction of the bald eagle and the whooping crane were successfully averted. Thousands of acres of designated critical habitat have been preserved (USFWS 2002). However, we have also witnessed the extinction of the dusky seaside sparrow and hundreds more species have been added to the endangered list. In the past decade, at least 34 species of unique populations of plants and vertebrates have become extinct in the United States while awaiting federal protection (World Resources Institute). Most important, we have learned that a species-by-species approach to conservation is costly, time-consuming, and rarely successful. While maintaining a strong ESA is essential as a fail-safe mechanism, there are sensible ways to empower the states to play a greater leadership role in biodiversity conservation that, over time, could lessen the need for federal regulation. Moreover, the traditional role of states with regard to wildlife and other public resources and their role in land-use issues means the states are essential players in habitat-conservation efforts.

Responding to claims that the ESA was too restrictive for private landowners, the act was amended in 1982 to authorize the issuance of "incidental take" permits for private-sector land-development activities following the preparation and approval of a habitat-conservation plan (HCP). The permit can be issued only for otherwise lawful activities that will not appreciably reduce the likelihood of survival and recovery of the species if impacts are minimized and the plan is adequately funded. An HCP can cover a single development project or several projects within a multi-jurisdictional area. At a minimum, each HCP must specify:

1. The impact that will result from the taking
2. Steps that will be taken to minimize and mitigate the taking
3. Funding to implement the plan
4. An analysis of possible alternative actions including why they were not chosen
5. Other elements if found necessary or appropriate

Most HCPs set aside a certain amount of land in habitat preserves with long-term management, habitat restoration, and land-use controls. To date, more than 430 HCPs have been approved with many more in the planning stage. Early HCPs generally covered 1,000 acres or less. Today, 10 HCPs exceed 500,000 acres, with several larger than 1,000,000 acres (USFWS). HCPs continue to evolve and many serve more than endangered species. However, they are still set in motion by endangered-species regulation and are inherently reactive. As such, they fall short of true conservation planning.

What is Conservation Planning?

Conservation planning is proactive conservation of areas large enough to include whole communities of plants and animals in properly functioning ecosystems while taking into account natural disturbances, such as floods and fires. Plans generally use computerized mapping technology known as geographic information systems (GIS) to assess the status of species, habitats, and other conservation targets and to identify conservation priorities. A good plan includes a vision for the specified region and a conservation strategy to achieve defined goals and objectives. Regions may include areas defined by political boundaries, such as counties and regional governments or areas based on ecological attributes, such as watersheds or basins. Each region has unique technical, political, social, cultural, and ecological circumstances and challenges, and therefore, approaches vary considerably in primary emphasis, purpose, goals, technical sophistication, and level of participation. Successful conservation plans must involve partnerships among multiple, diverse stakeholders including local, county, state, and federal agencies, conservation organizations, academic institutions, and private landowners.

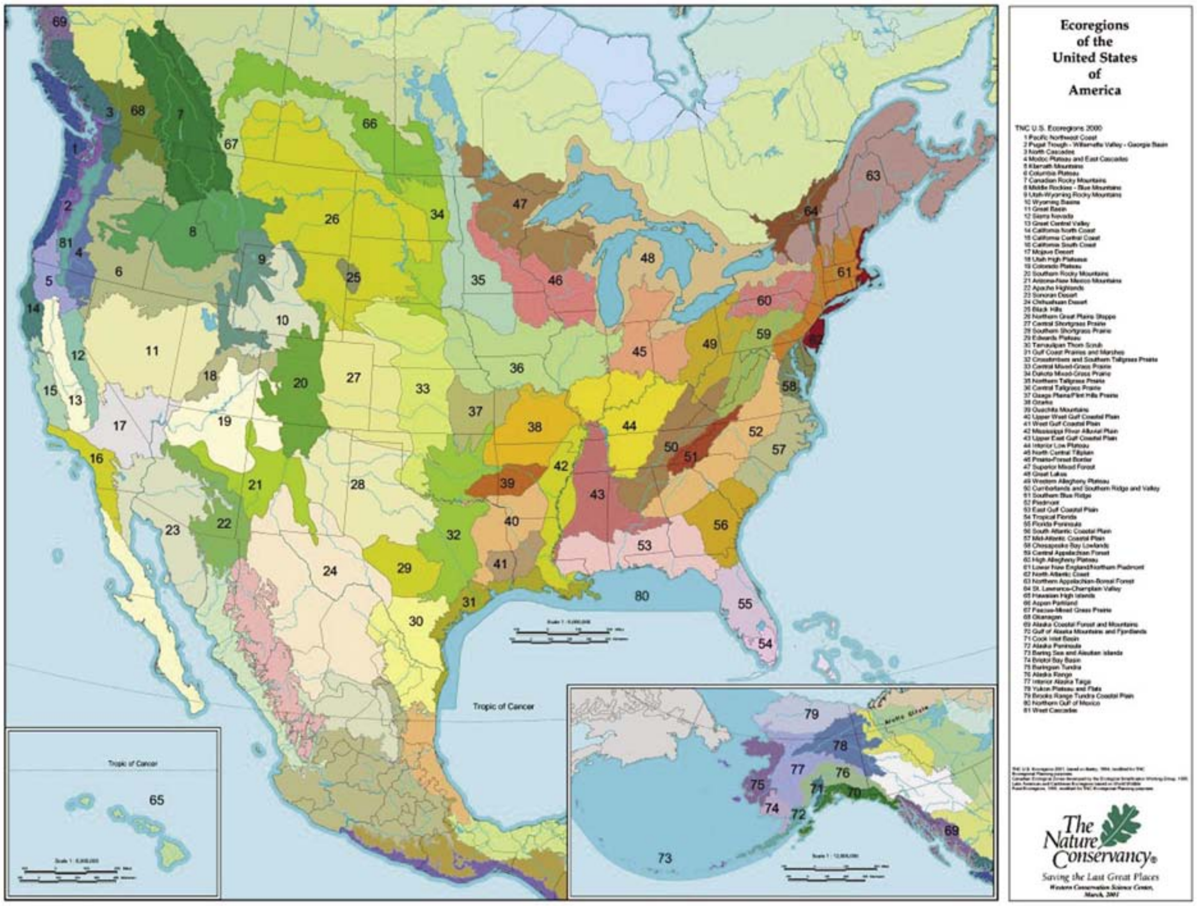
Ideally, regional strategies are nested within larger ones such as statewide or multi-state regional plans and connected to smaller plans that may fit within municipal or watershed boundaries. Although this integration may seem complicated, it is necessary to address resources at different scales. For example, the needs of some migratory birds can only be met with a global strategy, while the needs of small animals and plants that occur within a limited geographic range can best be addressed at small scales (The Biodiversity Partnership).

TNC Ecoregional Planning

Recognizing the need for a systematic, science-based approach to conservation, The Nature Conservancy (TNC) began developing ecoregional plans in the 1990s. Ecoregions are scientifically selected geographic locations representing Earth's 30+ major habitat types, often encompassing millions of acres. Plans are based upon careful review of the ecoregion's ecological significance, its concentration of different species of plants and animals, the overall quality of the natural communities, and the threats to the health of the area. Each ecoregional plan is a blueprint for conservation efforts to identify priorities and guide investment in the highest-quality conservation sites.

Ecoregional planning is defined by the following five steps:

1. **Identifying Conservation Targets:** Ecoregional planning teams identify the species, natural communities, and ecosystems in a given ecoregion.
2. **Gathering Information:** The teams gather data about the conservation targets such as location and health from a variety of sources, including the Natural Heritage programs, satellite images, and rapid ecological assessments.
3. **Setting Goals:** Ecoregional planning teams set goals for each of the conservation targets. Setting conservation goals involves determining how much of a particular target—a population or ecosystem, for instance—is needed to ensure its long-term survival. A conservation goal also includes how the target needs to be distributed across the landscape.
4. **Assessing Viability:** The team also assesses the health of each occurrence of each conservation target to ensure survival over the long term by choosing the best and most healthy examples of each target.
5. **Assembling Portfolios:** All this information is analyzed by the teams and expert partners and often through computer modeling to design an efficient network of conservation areas (or portfolio) that if protected in its entirety will ensure the preservation of biodiversity in the ecoregion (The Nature Conservancy, 2004).



This map was developed as a coordinated effort by TNC U.S. ecoregional planning teams. This set of ecoregions has been established in order to place each of TNC's conservation projects within an ecological context and to serve as a planning unit for Ecoregional Planning. Each ecoregional team reviewed the initial set of ecoregions established by the US Forest Service and recommended updates based on a variety of factors influencing conservation efforts. These updates have been compiled into a contiguous coverage.
See: http://gis.tnc.org/data/MapbookWebsite/map_page.php?map_id=27.

Early Conservation Planning: Filling the Gaps

Within the past few decades, there have been some notable efforts to address conservation needs for certain habitat types such as wetlands and old growth forests, but generally only in response to federal mandates such as the Clean Water Act and Endangered Species Act.

To capitalize on these efforts and new technology, the U.S. Fish and Wildlife Service launched the Gap Analysis program in the late 1980s. Congress funded the cooperative fish and wildlife research units and other university scientists to map the vegetation, land cover, species distributions, land ownership, and land management of each state in order to identify "gaps" in the conservation network. The U.S. Geological Survey now manages the program and most states have completed at least one coarse-scale biodiversity assessment. The development and refinement of geographic information systems and gap methodology stimulated interest in statewide wildlife-conservation planning.

A handful of states took advantage of the Gap Analysis information and other relevant data to develop statewide conservation strategies:

- In 1994, Florida completed "Closing the Gaps," a statewide conservation analysis.
- The Oregon Biodiversity Project engaged public agencies and private organizations in the development of a statewide biodiversity assessment and strategy.
- California created the Legacy Program to provide biodiversity information to resource agencies and support broad-scale conservation planning.
- Pennsylvania, New York, New Jersey, Georgia, New Hampshire, Washington, and Maryland, each taking a slightly different approach, convened groups of resource professionals and stakeholders to discuss statewide conservation planning (The Biodiversity Partnership).

State Wildlife Grants Program (SWG)

Primary responsibility for wildlife management has always rested with the states. Traditionally, state fish and wildlife agencies have focused on game management and responding to their constituents within sport hunting, fishing, and recreation communities. The federal resource and land-management agencies manage wildlife occurring on public lands and endangered species. Essentially, our conservation framework disregards all non-game, non-listed species and nearly all private landowners. Without protection, these species are vulnerable to overexploitation, habitat loss, and eventual listing. Without incentives, private landowners may develop rather than conserve vital habitat.

Acknowledging that conservation is much more cost effective than endangered species recovery, Congress established a program to assist state fish and wildlife agencies in conserving the non-game and non-listed wildlife species through wildlife diversity programs. The 2002 Department of Interior Appropriations bill included language creating the State and Tribal Wildlife Grants Program (SWG) providing new, dedicated funding for cost-effective, proactive conservation efforts intended to prevent wildlife from declining to the point of becoming endangered. State fish and wildlife agencies receive federal appropriations according to a formula based upon the state's size and population. A non-federal match of 50 percent is required for SWG projects.

SWG projects include the restoration of degraded habitat, removal of invasive vegetation, reintroduction of native species, partnerships with private landowners, research, and monitoring (IAFWA, 2004).

Comprehensive Wildlife Conservation Strategies (CWCS)

Much like the earliest transportation planning, conservation planning began as a condition of receiving continued federal funding under the State Wildlife Grant Program. Congress charged state fish and wildlife agencies with completing a Comprehensive Wildlife Conservation Strategy (CWCS) by October 1, 2005. The strategies will not only address "species of greatest conservation need" but also the "full array of wildlife and wildlife issues" and establish a plan of action for conservation priorities with limited funding. To "keep common species common," all strategies are based on targeting resources to prevent wildlife from declining to the point of endangerment. Ideally, each strategy will create a strategic vision for conserving the state's wildlife, not just a plan for the fish and wildlife agency.

Fish and wildlife agencies have engaged and embraced diverse partners (public and private landowners, local, state and federal agencies, non-government conservation interests, and citizens) to develop strategies that reflect the conservation issues, threats, opportunities, and priorities unique to their individual state. While the strategies will be as diverse as the states themselves, Congress identified eight essential elements the strategies must contain in order to ensure nationwide consistency:

1. Information on the distribution and abundance of species of wildlife, including low and declining populations as the state fish and wildlife agency deems appropriate, that are indicative of the diversity and health of the State's wildlife
2. Descriptions of locations and relative condition of key habitats and community types essential to conservation of species identified in (1)
3. Descriptions of problems which may adversely affect species identified in (1) or their habitats, and priority research and survey efforts needed to identify factors which may assist in restoration and improved conservation of these species and habitats
4. Descriptions of conservation actions determined to be necessary to conserve the identified species and habitats and priorities for implementing such actions
5. Proposed plans for monitoring species identified in (1) and their habitats, for monitoring the effectiveness of the conservation actions proposed in (4) and for adapting these conservation actions to respond appropriately to new information or changing conditions
6. Descriptions of procedures to review the Strategy at intervals not to exceed 10 years
7. Plans for coordinating (to the extent feasible) the development, implementation, review, and revision of the Strategy with Federal, State, and local agencies and Indian tribes that manage significant land and water areas within the State or administer programs that significantly affect the conservation of identified species and habitats
8. Broad public participation is an essential element.

The U.S. Fish and Wildlife Service will review and approve each strategy as they are completed and state fish and wildlife agencies are required to revisit and update strategies at least every 10 years to ensure conservation success over the long term.

The practical effect of this new planning requirement was to take advantage of the many disparate, ad hoc, and unrelated conservation-planning initiatives, combining them under one all-inclusive, sanctioned, and funded program. The scale is ambitious, yet manageable and fits easily into an existing administrative framework. Strategies are intended to remain dynamic, serving as the home base for prioritizing conservation efforts in each state and coordinating the roles and contributions of all agencies and conservation partners. Implementation of strategy goals and objectives is ensured through continued federal funding, matched by additional sources. In theory, the strategies represent the future of wildlife conservation in the U.S. Collectively, they will create–for the first time–a nationwide approach to wildlife conservation (Teaming with Wildlife, 2004).

Integrated Planning

If each strategy is indeed a strategic vision for conserving the state's wildlife, implementation will require more than the state fish and wildlife agency. For the conservation strategies to be successful, all sectors must embrace the goals, engage in the process, and accept responsibility for their own roles and contributions–including transportation agencies.

Utilization of the habitat-mapping data included in the strategies can serve as an effective early warning system to identify transportation projects that will have a major impact on wildlife. Planners can overlay conservation maps with existing roads and long-range transportation needs to discover potential conflicts before considerable resources are invested. Efforts to avoid sensitive areas are easier and less expensive during the planning phase than during review, permitting, and construction.

This is also a good opportunity to explore needs for mitigation and identify the best remaining sites for acquisition and restoration. Often, by the time a road project develops through the planning, review, and design process, many of the opportunities for high quality and affordable mitigation have been lost.

Figures 1–3 represent a simplified scenario of incorporating conservation data into the transportation-planning process.

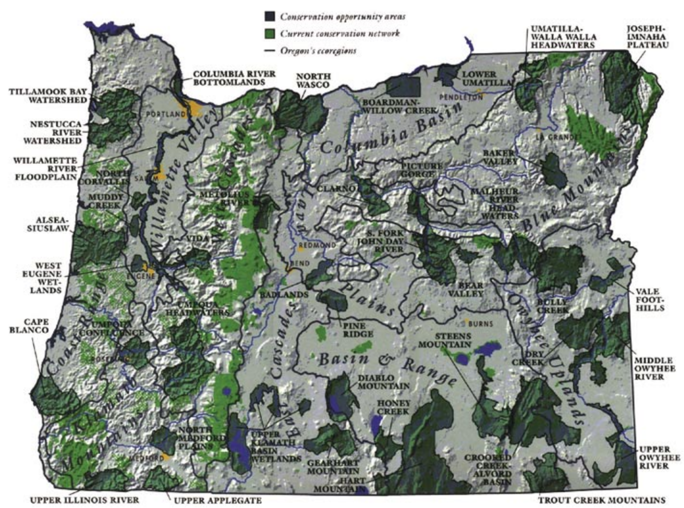


Figure 1. Oregon's Biodiversity Project. Light green patches indicate the existing conservation network. Dark green patches indicate "conservation opportunity areas," or those lands that have been identified as having conservation value and in need of special consideration.

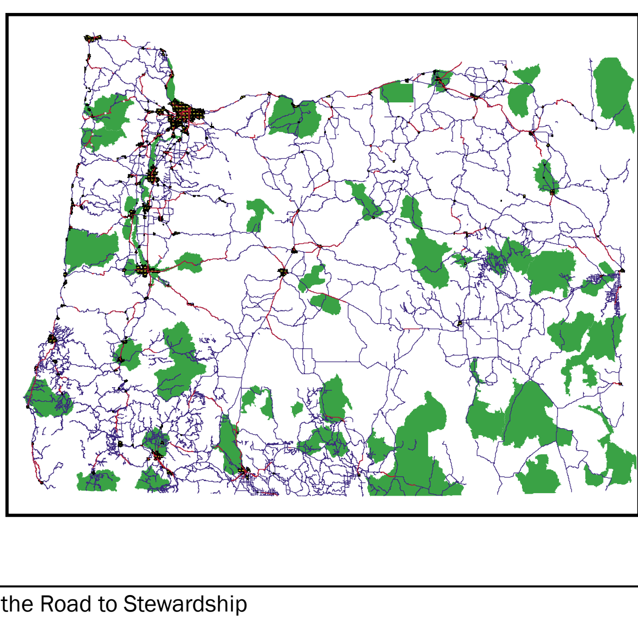


Figure 2. This map shows Oregon's conservation opportunity areas in green, overlaid with the existing road network in blue. In red, the map also indicates the projects in Oregon DOT's state transportation improvement program (STIP). At a glance, we can see precisely where transportation projects will intersect with and potentially impact valuable conservation areas.

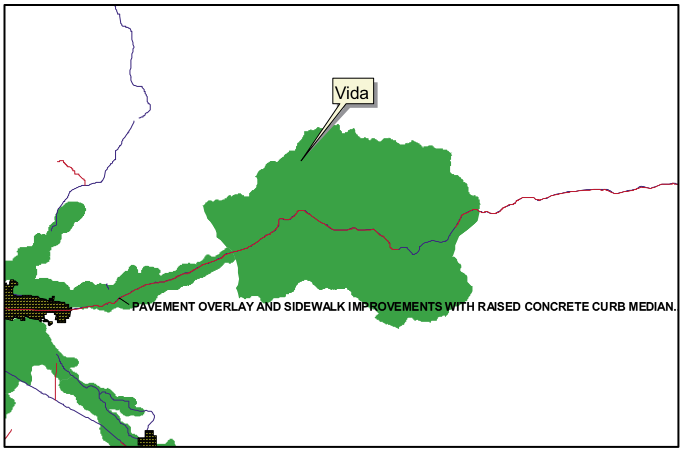
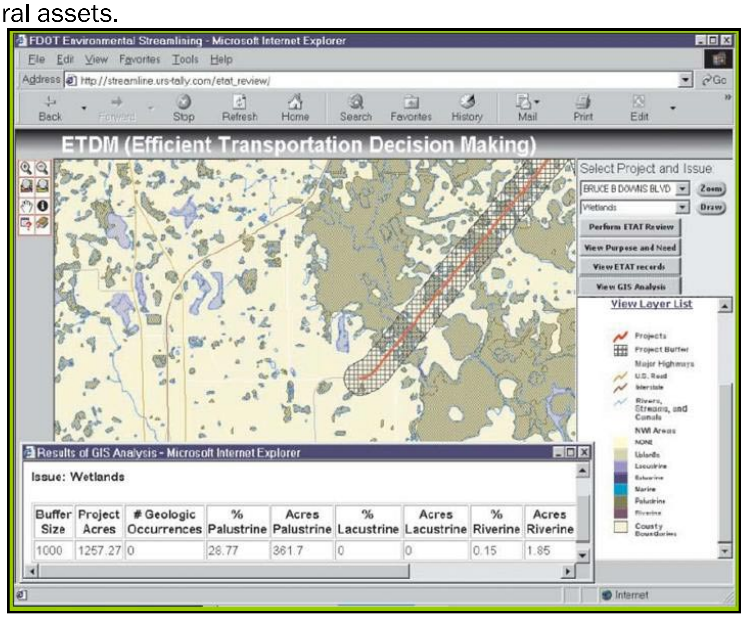


Figure 3. Zooming in on individual projects within conservation-opportunity areas to explore possible measures to avoid or minimize impacts. For those impacts that cannot be avoided, the map also provides invaluable information on high-quality, available areas to meet mitigation requirements.

Florida DOT's ETDM Process

Over a decade ago, the state of Florida compiled a statewide plan which identified lands that must be conserved in order to sustain declining wildlife species and natural communities. The report, *Closing the Gaps in Florida's Wildlife Habitat Conservation System*, assessed the status of species and habitat that encompass Florida's biodiversity. The project mapped two categories of strategic land: areas that were already under some form of conservation protection (20 percent of the state's area) and areas that needed additional protection (an additional 13 percent). *Closing the Gaps* was the first statewide conservation program of its kind, built upon a sophisticated process with a strong scientific approach. Notably, it included the assembly and analysis of numerous data sets and assessments of focal species and population viability. The project has played a key role in guiding land-acquisition decisions. Since publication in 1994, the state has acquired 20 percent of the previously unprotected strategic-habitat areas.

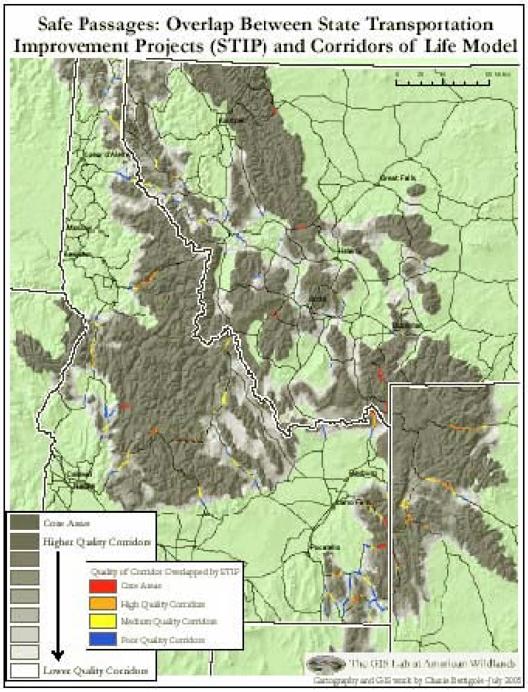
Following the 1998 adoption of TEA-21, the Florida Department of Transportation (FDOT) began efforts to expedite projects without sacrificing environmental concerns. Building upon directives in TEA-21, FDOT teamed up with the Federal Highway Administration (FHWA) and other government agencies to develop a refined and improved methodology for making transportation decisions while complying with all federal and state environmental regulations. The result–FDOT's Efficient Transportation Decision Making Process (ETDM)–redefines how the state plans and builds transportation projects while protecting Florida's natural assets.



Buffer Size	Project Acres	# Geologic Occurrences	% Palustrine	Acres Palustrine	% Lacustrine	Acres Lacustrine	% Riverine	Acres Riverine
1000	1257.27	0	28.77	361.7	0	0	0.15	1.85

Each of the seven FDOT regions has an Environmental Technical Advisory Team (ETAT) composed of representatives from the relevant planning, consultation, and regulatory agencies. Proposed road projects are screened by the ETAT, based upon a checklist of criteria, including social and environmental impacts. GIS data are used to perform evaluations and are accessible to all agencies, as well as to the public through the Florida Geographic Data Library (FGDL).

One point of analysis is the compatibility of the proposed project with the state habitat plan. By overlaying maps of strategic habitats with FDOT's short- and long-range transportation plans, the ETAT can easily identify potential environmental concerns at the earliest stage of planning. At that time, options for avoiding or minimizing environmental impacts are greatest and the costs of addressing conflicts are nominal.



NGO Contributions

American Wildlands' (AWL) GIS lab has developed two models to locate the highest priority areas for mitigating highways with crossing structures, fencing or other wildlife measures in local landscapes. To prioritize work, habitat cores and corridors from AWL's regional Corridors of Life model are overlaid with State Transportation Improvement Projects (STIP). State transportation departments rely on AWL's scientific methodology to justify expenditures of federal appropriations for wildlife mitigation.

AWL has created working groups to advocate for wildlife protection and habitat connectivity for six highway projects in critical wildlife cores or corridors, resulting in the development of wildlife underpasses, safety fencing, informational signs to warn drivers of wildlife hot spots, and other protective actions. To date, they have improved five different highway projects in Idaho, Wyoming, and Montana that have resulted in the commitment to construct seven wildlife underpasses and two bridges for fish passage in the region. So far, this includes over $2.7 million for wildlife mitigation and $2.2 million in private land conservation adjacent to highway mitigation.

Linking Colorado's Landscapes is a science-based approach to restoring landscape connectivity, led by the Southern Rockies Ecosystem Project (SREP) with the objective of identifying critical movement corridors for wildlife. Phase I produced a statewide assessment of these linkages. Through a series of expert workshops and computer modeling of wildlife-habitat connectivity, nearly 200 linkages were identified across the state. The linkages were then prioritized for further analysis based on their ecological significance. Phase II provides an in-depth assessment of the highest-priority linkages, focusing on the areas where these linkages intersect with major transportation routes. A highway-permeability analysis was conducted along these segments, providing the foundation for recommendations for improving the permeability of these roadways for wildlife. These recommendations are being supplied to the Colorado Department of Transportation for integration into highway projects and transportation planning.

SAFETEA-LU: Section 6001

After three years, two election cycles, and twelve extensions, on August 10, 2005, the President signed the federal transportation bill, funding highways and transit through FY 2009 to the tune of $286.5 billion. The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) included provisions that integrate consideration of wildlife conservation into the transportation-planning process.

Under the new law, each metropolitan planning organization (MPO) and state department of transportation (DOT) will consult with federal, state, tribal, and local land-use management, natural-resources, wildlife, environmental-protection, conservation, and historic-protection agencies in developing their long range transportation plans. Each consultation will include a comparison of the transportation plan with conservation maps or inventories of natural and historic resources. Each plan will also include a discussion of potential environmental-mitigation activities and potential areas to carry out these activities, including activities that may have the greatest potential to restore and maintain the environmental functions affected by the plan.

In light of this new requirement, the statewide conservation strategies will begin to demonstrate their full value and utility. Transportation planners can use the spatial data in the strategies to meet the requirement and more importantly, to make more informed early decisions about road building.

Sec. 6001. Transportation Planning.
The long-range transportation plan shall be developed, as appropriate, in consultation with State, tribal, and local agencies responsible for land use management, natural resources, environmental protection, conservation, and historic preservation.
Comparison and Consideration
Consultation under clause (i) shall involve comparison of transportation plans to State and tribal conservation plans or maps, if available, and comparison of transportation plans to inventories of natural or historic resources, if available.
Mitigation Activities
A long-range transportation plan shall include a discussion of potential environmental mitigation activities and potential areas to carry out these activities, including activities that may have the greatest potential to restore and maintain the environmental functions affected by the plan.
Consultations
The discussion shall be developed in consultation with Federal, State, and tribal wildlife, land management, and regulatory agencies.

Conclusion

Our nation is approaching a crossroads–unimpeded urbanization may soon collide with the limits of our country's natural resources. The rate of urbanization surpasses population growth and threatens to overwhelm previous victories in environmental protection. Our natural heritage is in peril–threatened by habitat loss, and the greatest consumer of habitat is poorly planned, sprawling development.

Over the next few decades, America can avert this collision between growth and biodiversity. Because transportation infrastructure necessarily precedes development, decisions about where and how we build roads will determine the location, direction, and shape of future urban growth. State transportation agencies and planners can steer investment toward greater mobility for better communities and away from impacting our remaining natural areas.

Biographical Sketch: Trisha White is the Director of Defenders of Wildlife's Habitat & Highways Campaign at their national headquarters in Washington, D.C. The Habitat & Highways Campaign seeks to reduce the impact of surface transportation infrastructure on wildlife and encourage state and local authorities to incorporate wildlife conservation into transportation and community planning. In partnership with the Surface Transportation Policy Project (STPP), Trisha authored a best practices report, *Second Nature: Improving Transportation Without Putting Nature Second*, which has since been awarded the 2004 Natural Resource Council of America Award of Achievement for best publication.

White is also:

- International Conference on Ecology and Transportation (ICOET) sponsor and member of steering and program committees
- Member, Federal Highway Administration's Europe Scan tour on wildlife mortality
- Member, Transportation Research Board Task Force on Ecology and Transportation
- Board Member, Southern Rockies Ecosystem Project

Prior to Defenders, Trisha spent three years with World Resources Institute's Biological Resources program and one year as environment policy consultant to the U.S. Agency for International Development's Global Environment Center. In 2000, she received her Masters degree in Environment & Resource Policy from the George Washington University.

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Additional Resources

The American Association of State Highway and Transportation Officials (AASHTO) is a nonprofit, nonpartisan association representing highway and transportation departments in the 50 states, the District of Columbia, and Puerto Rico. It represents all five transportation modes: air, highways, public transportation, rail, and water. Its primary goal is to foster the development, operation and maintenance of an integrated national transportation system.
http://www.transportation.org

American Wildlands (AWL) is a science-based, regional, conservation organization that has worked for on-the-ground change and has successfully led numerous Wilderness and Wild & Scenic River initiatives throughout the American west:
http://www.wildlands.org

The Association of Metropolitan Planning Organizations (AMPO) is the transportation advocate for metropolitan regions and is committed to enhancing MPOs' abilities to improve metropolitan-transportation systems:
http://www.ampo.org

The Defenders of Wildlife's Habitat & Highways Campaign seeks to reduce the impact of our road network on wildlife and to incorporate consideration for conservation into transportation planning:
http://www.habitatandhighways.org

The Florida Closing the Gaps Project: Florida Fish and Wildlife Commission identified the minimum amount of land in Florida that, if protected, will ensure the long-term persistence of most elements of Florida's biodiversity. The project included a biodiversity assessment, a map of Strategic Habitat Conservation Areas and a strategy to conserve Florida's biodiversity:
http://www.floridaconservation.org/oes/habitat_sec/Closing_Gaps.pdf

The International Association of Fish and Wildlife Agencies (IAFWA), founded in 1902, represents the government agencies responsible for North America's fish and wildlife resources. IAFWA applies expertise in coalition building, science, policy, and economics to serve its members as a national and international voice on a broad array of wildlife and conservation issues:
http://www.iafwa.org/

The Nature Conservancy (TNC) is a leading international, nonprofit organization with the mission of preserving the plants, animals, and natural communities that represent the diversity of life on Earth by protecting the lands and waters they need to survive:
http://www.nature.org/aboutus/howwework/cbd/

NatureServe is a non-profit conservation organization that provides the scientific information and tools needed to help guide effective conservation action. NatureServe and its network of natural-heritage programs are the leading source for information about rare and endangered species and threatened ecosystems:
http://www.natureserve.org

The Southern Rockies Ecosystem Project (SREP) is a non-profit conservation-biology organization working to protect and restore large, continuous networks of land in the Southern Rockies ecoregion of Colorado, Wyoming, and New Mexico. SREP realizes this vision for a healthy ecoregion by connecting networks of people in order to connect networks of land:
http://www.restoretherockies.org

The Surface Transportation Policy Project (STPP) is a diverse, nationwide coalition working to ensure safer communities and smarter transportation choices that enhance the economy, improve public health, promote social equity, and protect the environment:
http://www.transact.org

Teaming With Wildlife: Recognizing the need to take action to prevent wildlife decline, more than 3000 groups came together as the Teaming With Wildlife coalition. This coalition includes wildlife managers, conservationists, hunters and anglers, businesses, and many others who support the goal of restoring and conserving our nation's wildlife:
http://www.teaming.com

TRANSNET'S ENVIRONMENTAL MITIGATION PROGRAM

Janet Fairbanks (Phone: 619-699-6970, Email: jfa@sandag.org), Senior Regional Planner, San Diego Association of Governments (SANDAG), 401 B Street Suite 800, San Diego, CA 92101, Fax: 619-699-1905

Abstract

In 1987, voters approved the TransNet program, which is a half-cent sales tax to fund a variety of important transportation projects throughout the San Diego region. This 20-year, $3.3-billion transportation-improvement program expires in 2008. In November 2004, 67 percent of the region's voters supported the extension of TransNet to 2048?thereby generating an additional $14 billion distributed among highway, transit, and local road projects in approximately equal thirds. Two percent of the available funds will be earmarked annually for bicycle paths and facilities, pedestrian improvements, and neighborhood safety projects. The San Diego Association of Governments (SANDAG) sets the priorities and allocates TransNet funds.

A unique component of the 2004 ballot measure was the creation of an environmental-mitigation program (EMP) which includes an allocation for the estimated direct mitigation costs for mitigation of upland and wetland habitat impacts for regional and local transportation projects. The focus of the program is to mitigate environmental impacts of regional and local transportation projects while implementing the Multiple Species Conservation Program (MSCP), the Multiple Habitat Conservation Program (MHCP), and future amendments to these programs.

The ballot measure identified $850 million to be used for the EMP. The EMP principles state that two funds shall be established. The first fund (the Transportation Project Mitigation Fund) covers direct mitigation costs for regional and local transportation projects estimated to be $650 million ($450 million for regional projects, $200 million for local projects).

These funds will be used for the mitigation needs of the 47 major transportation infrastructure improvement projects and programs identified in the TransNet extension. Although the extension does not begin until April 2008, an early action program was approved to address priority projects. In order to maximize land-acquisition opportunities, satisfying the mitigation requirements for these priority projects will be addressed comprehensively rather than on a project-by-project basis.

The priority TransNet projects include the widening of SR 76 between Melrose Drive and I-15, the extension of SR 52 from SR 125 to SR 67, the Mid-Coast light-rail extension from Old Town to University City, the I-15 Managed Lanes Corridor from SR 78 to SR 163, the I-15 managed lanes, the SR 52 managed Lane/HOV project from I-15 to SR 125, the I-5 north coast corridor environmental effort, and the I-805 corridor environmental effort.

The second fund (the Regional Habitat Conservation Fund) will be approximately $200 million ($150 million for regional projects and $50 million for local projects). These funds will be made available for regional habitat acquisition, management, and monitoring activities necessary to implement the MSCP and the MHCP. Funds are estimated based on economic benefits derived from purchasing land with the Transportation Project Mitigation Fund. Land will be purchased in advance of need in larger blocks at a lower cost and with mitigation ratios predetermined and held constant over time for each of the habitat-conservation plans. Funds will be made available when: 1) the economic benefit of each approved transportation project derived from coverage under the applicable habitat-conservation plan is determined and 2) funding is available from TransNet revenues.

What do we mean by "economic benefit?"
With today's rising land prices, we know if we buy land today, it will cost less than if we wait and buy it later. Smart investors know this, which is why land in Southern California is at a premium.

Transportation projects will be built over the next 30 years depending on need and funding availability. If a project impacts habitat, mitigation lands must be acquired prior to the issuance of permits. If land is purchased in advance of need, with mitigation ratios held constant over time, an economic benefit is derived because the mitigation obligation is known and the land is purchased at today's prices. The savings derived by purchasing land today, rather than at some time in the future, constitutes the economic benefit.

The Environmental Mitigation Program will be a collaborative effort among SANDAG, the region's jurisdictions, the Wildlife Agencies (California Department of Fish and Game and the U.S. Fish and Wildlife Service), and other regulatory agencies (Coastal Commission, Army Corps of Engineers, EPA, and the Regional Water Quality Control Board), as well as from the environmental community and the science/technical community.

Biographical Sketch: Janet's work with SANDAG includes habitat conservation, environmental and open-space planning, and the Regional Comprehensive Plan. She has been a planner in the San Diego region for the past 24 years working for SANDAG, the City of San Diego, and the County of San Diego. She is a member of the American Planning Association, the American Institute of Certified Planners, and the California Planning Roundtable. She earned a Master's degree from San Diego State University and a Bachelor of Arts degree from the University of Oregon.

Chapter 5

Conservation Planning

Incorporating Results From the Prioritized "Ecological Hotspots" Model into the Efficient Transportation Decision-Making (ETDM) Process in Florida

Daniel J. Smith (Phone: 352-213-3833, Email djs3@ufl.edu), Research Associate, Department of Biology, University of Central Florida, Orlando, Florida 32801

Abstract: In 2000, an expert-based decision-support model to identify and prioritize sites for ecopassages was developed for the Florida Department of Transportation (DOT). The model used a weighting algorithm and several ecological factors (chronic road-kill sites, landscape gradients, focal species hot spots, greenway linkages, presence of listed species, strategic habitat-conservation areas, riparian corridors, rare habitat types, existing conservation lands, and proposed road projects) to prioritize existing road segments for retrofits designed to reduce road-kills and restore important habitat linkages.

In 2003, the Florida DOT began implementing the Efficient Transportation Decision Making (ETDM) process. This process was designed to examine and address potential environmental impacts prior to the planning, design, and construction of new transportation projects. Proposed projects are analyzed using an environmental-screening tool and reviewed by local and state officials and the public.

In 2004-2005, we were engaged by the Florida DOT to update the prioritization-model results for use as a data layer in the environmental-screening process of ETDM. For this purpose the original calculating algorithm was used, with final priorities ranked on a scale of 0 to 1. Many updated coverages were available and cell resolution was improved to increase model precision and accuracy. Updated coverages included roads (including speed limit and annual average daily traffic factors), land cover, road-kills, road projects, and managed conservation lands.

In addition, a new development-threat index based on road density, population density, 2003 existing land use, future land use and municipal boundaries was created. Datasets were combined into six categories for ranking: biological features, landscape features, infrastructure, managed conservation lands, conservation planning, and road-kill. For those road segments prioritized statewide, 72 percent were located in existing protected areas and 27 percent were found in proposed public-conservation lands. Relative weighting and aggregation of data were key determinants to locations of high priority road segments. One hundred seventy-six proposed road projects coincide with prioritized road segments and present significant opportunities for conservation planning.

Introduction

In 2000, an expert-based decision-support model to identify and prioritize sites for ecopassages was developed for the Florida Department of Transportation (DOT). The model used a weighting algorithm and several ecological factors (chronic road-kill sites, landscape gradients, focal species hot spots, greenway linkages, presence of listed species, strategic habitat-conservation areas, riparian corridors, rare habitat types, existing conservation lands, and proposed road projects) to prioritize existing road segments for retrofits designed to reduce road-kills and restore important habitat linkages (Smith 1999).

In 2003, the Florida DOT began implementing the Efficient Transportation Decision Making (ETDM) process. Proposed projects are analyzed using an environmental-screening tool and reviewed by local and state officials and the public. Objectives of the ETDM include:

- Introducing potential environmental and socio-cultural effects much earlier in the planning/project development process
- Studying projects more efficiently
  - Build on agency/citizen input at each stage of review
  - Reduce time and money invested in the project if fatally flawed
  - Discontinue review if environmental impacts are a non-issue
- Expediting permits and project approval

In 2004-2005, we were engaged by the Florida DOT to update the prioritization-model results for use as a data layer in the environmental-screening process of ETDM.

Overview of ETDM

The ETDM process was designed to examine and address potential environmental impacts prior to the development, design, and construction phases of new transportation projects. This process is illustrated in figure 1.

The planning screen involves:

1. Environmental Technical Advisory Team (ETAT) project coordination, review, assessment, and recommendations
2. Community outreach through public meetings and citizen involvement

In the programming screen, ETAT members update the direct-impact assessment and document the "degree of effect," provide scope for technical studies, participate in dispute resolution on significant issues, and establish the FHWA/FDOT class of action (e.g., EA, EIS). Community outreach is also facilitated by continuing work-program public hearings and making programming summary reports available online.

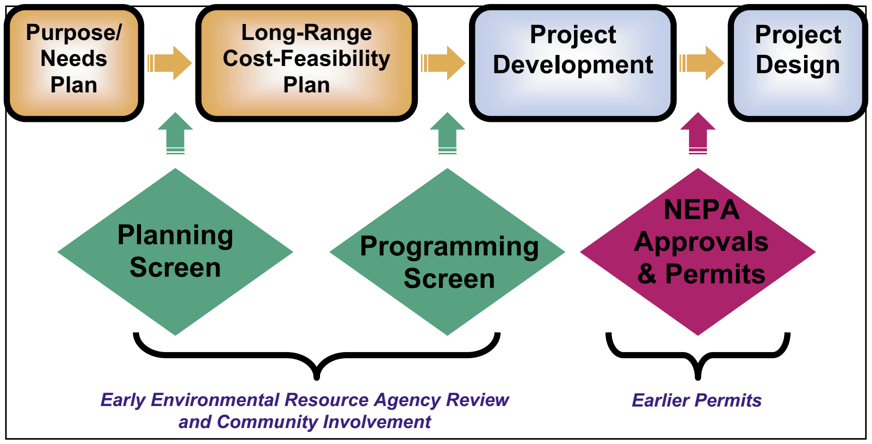


Figure 1. Flow chart of the ETDM process showing environmental-review elements.

Based on data layers associated with each issue, Florida DOT staff performs the GIS analysis (figure 2) on the project. Twenty-one different elements from three issue types (e.g., environmental, social, economic) are evaluated. Approximately 50 different environmental data layers are included in the analysis. Projects can be buffered by five optional distances (100 ft, 200 ft, 500 ft, 1/4 mile, and 1/2 mile) to address potential impacts to adjacent areas.

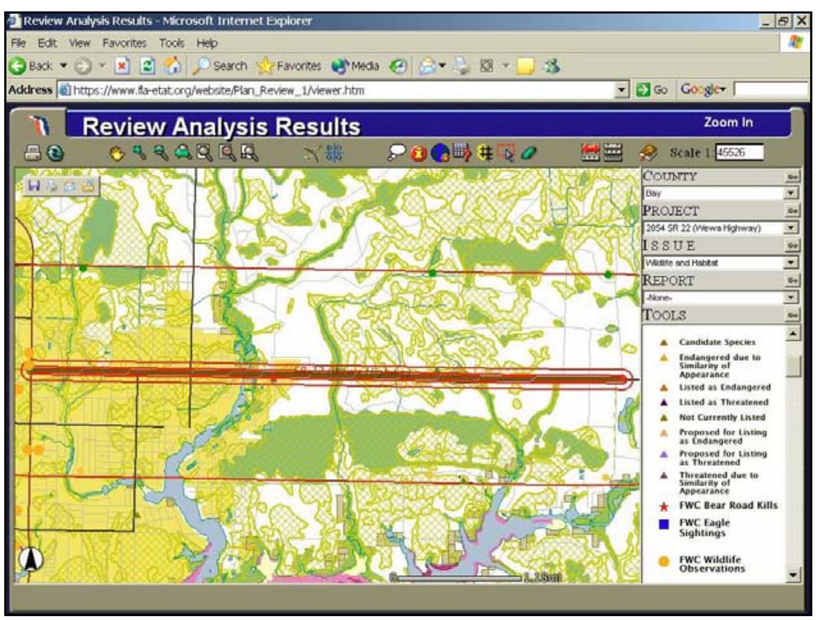
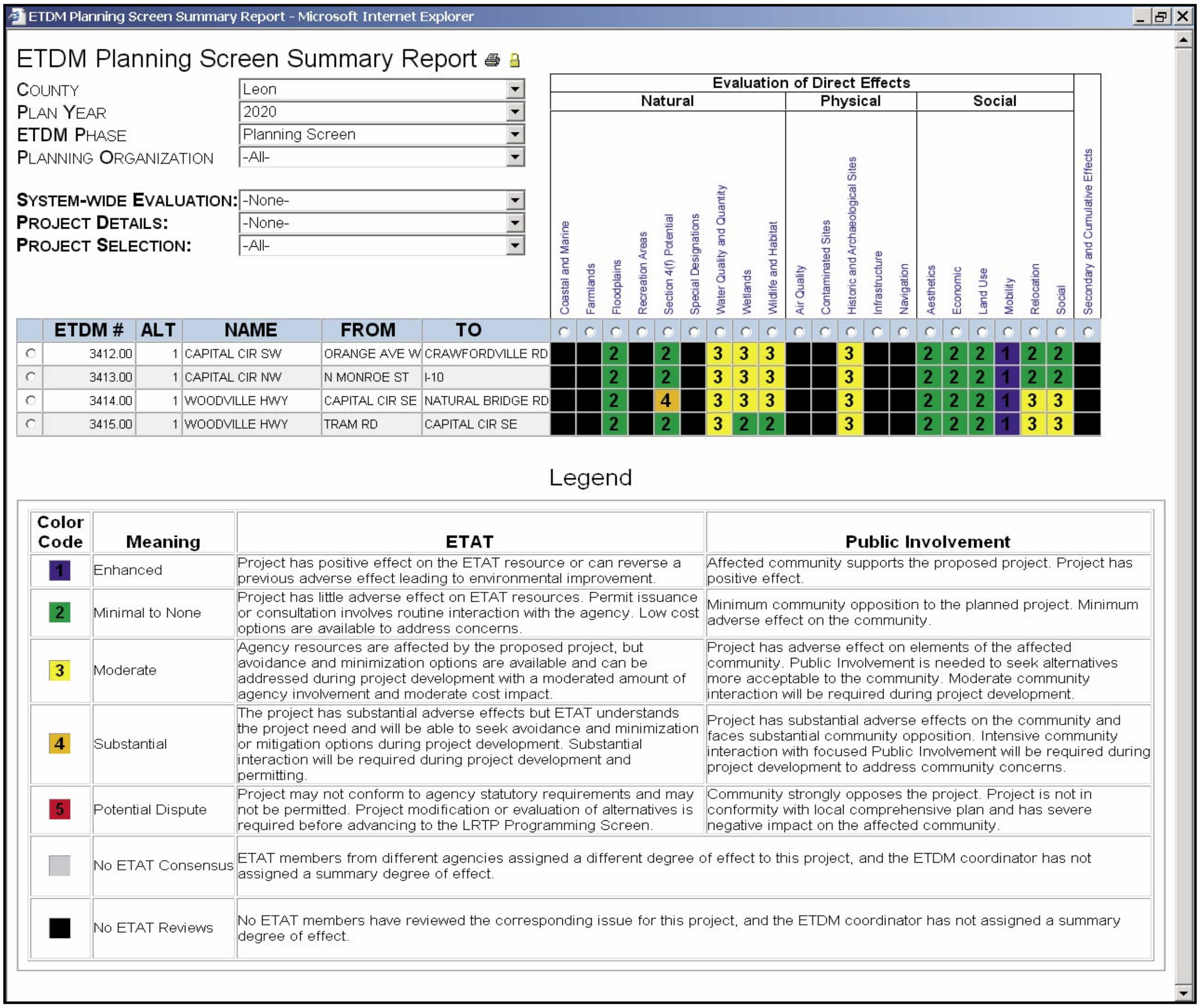


Figure 2. An example of GIS analysis results from the ETDM online environmental-screening tool.

The results of the GIS analysis are made available on the internet to project reviewers. An online Environmental-Screening Tool is used by ETAT members to review the project and evaluate potential impacts (figure 3). This information forms the basis for recommendations to avoid, minimize and/or mitigate potential adverse impacts associated with the project. Recommendations may include additional studies to address identified impacts.



ETDM Planning Screen Summary Report - Microsoft Internet Explorer

ETDM Planning Screen Summary Report

COUNTY	Leon
PLAN YEAR	2020
ETDM PHASE	Planning Screen
PLANNING ORGANIZATION	-All-
SYSTEM-WIDE EVALUATION:	-None-
PROJECT DETAILS:	-None-
PROJECT SELECTION:	-All-

					Evaluation of Direct Effects																				
					Natural									Physical					Social						
ETDM #	ALT	NAME	FROM	TO	Coastal and Marine	Farmlands	Floodplains	Recreation Areas	Section 4(f) Potential	Special Designations	Water Quality and Quantity	Wetlands	Wildlife and Habitat	Air Quality	Contaminated Sites	Historic and Archaeological Sites	Infrastructure	Navigation	Aesthetics	Economic	Land Use	Mobility	Relocation	Social	Secondary and Cumulative Effects
3412.00	1	CAPITAL CIR SW	ORANGE AVE W	CRAWFORDVILLE RD			2		2		3	3	3			3			2	2	2	1	2	2	
3413.00	1	CAPITAL CIR NW	N MONROE ST	I-10			2		2		3	3	3			3			2	2	2	1	2	2	
3414.00	1	WOODVILLE HWY	CAPITAL CIR SE	NATURAL BRIDGE RD			2		4		3	3	3			3			2	2	2	1	3	3	
3415.00	1	WOODVILLE HWY	TRAM RD	CAPITAL CIR SE			2		2		3	2	2			3			2	2	2	1	3	3	

Legend

Color Code	Meaning	ETAT	Public Involvement
1	Enhanced	Project has positive effect on the ETAT resource or can reverse a previous adverse effect leading to environmental improvement.	Affected community supports the proposed project. Project has positive effect.
2	Minimal to None	Project has little adverse effect on ETAT resources. Permit issuance or consultation involves routine interaction with the agency. Low cost options are available to address concerns.	Minimum community opposition to the planned project. Minimum adverse effect on the community.
3	Moderate	Agency resources are affected by the proposed project, but avoidance and minimization options are available and can be addressed during project development with a moderated amount of agency involvement and moderate cost impact.	Project has adverse effect on elements of the affected community. Public Involvement is needed to seek alternatives more acceptable to the community. Moderate community interaction will be required during project development.
4	Substantial	The project has substantial adverse effects but ETAT understands the project need and will be able to seek avoidance and minimization or mitigation options during project development. Substantial interaction will be required during project development and permitting.	Project has substantial adverse effects on the community and faces substantial community opposition. Intensive community interaction with focused Public Involvement will be required during project development to address community concerns.
5	Potential Dispute	Project may not conform to agency statutory requirements and may not be permitted. Project modification or evaluation of alternatives is required before advancing to the LRTP Programming Screen.	Community strongly opposes the project. Project is not in conformity with local comprehensive plan and has severe negative impact on the affected community.
	No ETAT Consensus	ETAT members from different agencies assigned a different degree of effect to this project, and the ETDM coordinator has not assigned a summary degree of effect.	
	No ETAT Reviews	No ETAT members have reviewed the corresponding issue for this project, and the ETDM coordinator has not assigned a summary degree of effect.	

Figure 3. An example of the planning-screen summary from the ETDM online envirThe public has access to several types of online information:

1. Agency reviews of project effects
2. Agency reviews of project purpose and need
3. Environmental-review summary reports
4. GIS analysis results
5. Transportation-plan overview
6. Use of the ETDM Mapper (figure 4)

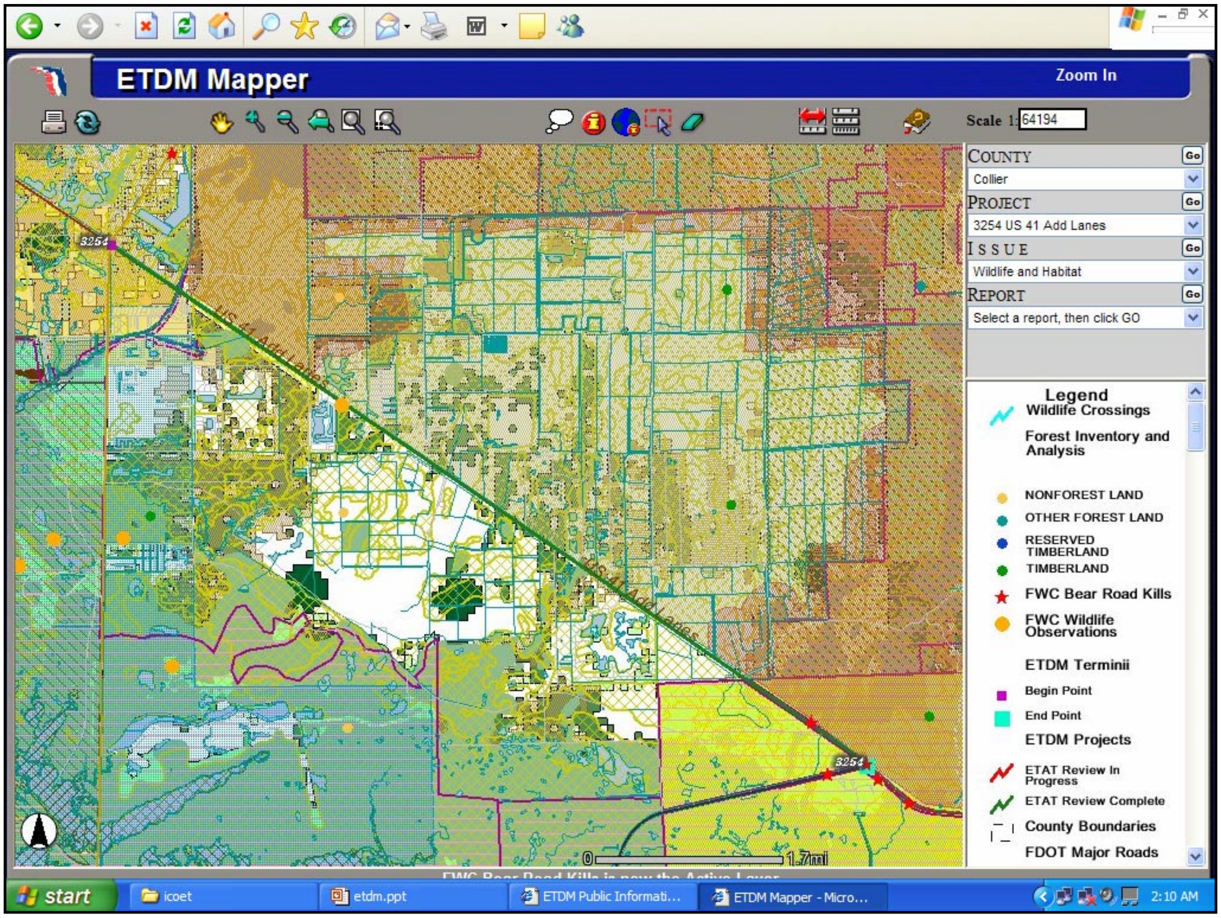


Figure 4. The ETDM mapper. It can be used by the public to see resources potentially impacted by proposed transportation projects.

The "Ecological Hotspots" Prioritization Model

First created in 2000, the model was designed for use by transportation/conservation planners. It integrates state conservation initiatives such as the Florida Greenways (Hoctor et al. 2000) and Florida Forever (the state conservation land-acquisition program) initiatives with transportation planning programs. A McHargian overlay process was employed (McHarg 1971). It combines multiple sets of resources into one data layer to highlight cumulative effects (locations with multiple impacts or "hotspots").

Criteria and rankings were based on responses to a survey conducted at the 1996 International Conference on Wildlife Ecology and Transportation in Orlando, Florida (Smith et al. 1996). Eleven criteria were identified and ranked as follows:

1. Chronic road-kill sites
2. Known migration/movement routes
3. Focal species hot spots
4. Landscape linkages (designated greenways)
5. Presence of listed species
6. Strategic habitat-conservation areas
7. Riparian corridors (with potential for retrofitting existing structures)
8. Core conservation areas
9. Presence of ephemeral breeding sites
10. Public ownership (or in public land-acquisition program)
11. Proposed road-improvement project

Spatial data layers corresponding to these criteria were normalized on a scale of 1 to 16 and grouped into six categories to balance weightings and to account for redundancy of information:

Category	Layers/Elements	Weight
Landscape Features	8	6
Biological Features	2	7
Chronic Road-kill Sites	1	9
Conservation Planning	5	5
Public Ownership	1	3
Infrastructure	1	1

The original calculation algorithm (Smith 2003) was used (figure 5). Final priorities were presented on a scale of 0 to 1 (zero the lowest priority and one the highest priority).

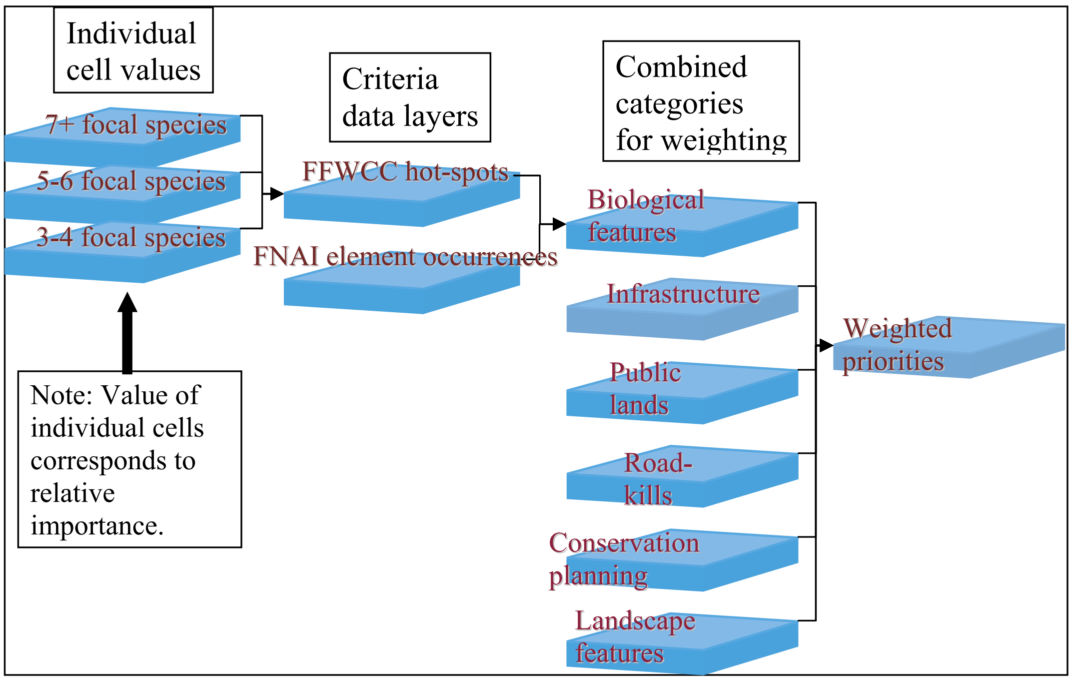


Figure 5. An example showing the function of the analysis algorithm. Each combined category is multiplied by its assigned weighting and then added together to generate a final priorities layer.

Many updated and new coverages were available and cell resolution was improved (from 100 m to 30 m) to improve model precision and accuracy. Updated or new coverages included:

Category	Data Layer
Infrastructure	Road projects (2004-2009) Speed limit
Chronic Road-Kill Sites	Florida black bear (2004) Florida panther (2004)
Public Ownership	Managed conservation lands (2005)
Conservation Planning	Strategic habitat-conservation areas (FWC 2000) Proposed conservation lands (Florida Forever 2005) FNAI priority habitat areas (2003) Greenway final rankings (2004) Integrated wildlife habitat-ranking system (FWC 2001)
Biological Features	FWC focal species hotspots (2000) FNAI element occurrences (2000)
Landscape Features	FWC land cover (2003) FNAI priority wetlands (2003) Intermittent wetlands in natural context Physiographic features Severe slopes

Note Abbreviations: Florida Natural Areas Inventory (FNAI), Fish and Wildlife Conservation Commission (FWC).
References: Cox and Kautz 2000, Endries and Gilbert 2001.

Results of the prioritization process can be applied to different scales (e.g., statewide, state/federal roads template, public roads template). The scale most applicable for use in ETDM is a statewide data layer. Priorities for the entire state are shown in figure 6. The darkest areas shown in figure 6 are the highest priorities and generally correspond to existing conservation lands. Category weighting and aggregation (natural breaks) of data were key elements in the prioritization process. Model priorities indicate significant focus toward nationally and regionally significant conservation areas and riparian corridors. Listed species road-kills (e.g., Florida panther and black bear), element occurrences, and focal species hotspots strongly influenced results due to the high weighting assigned to these criteria.

For state/federal road segments ranked 0.514-1 (figure 7), 72 percent were located in existing protected areas and 27 percent were found in proposed public-conservation lands. One hundred seventy-six road projects from the Florida DOT 5-year work plan coincide with prioritized road segments and present significant opportunities for conservation planning.

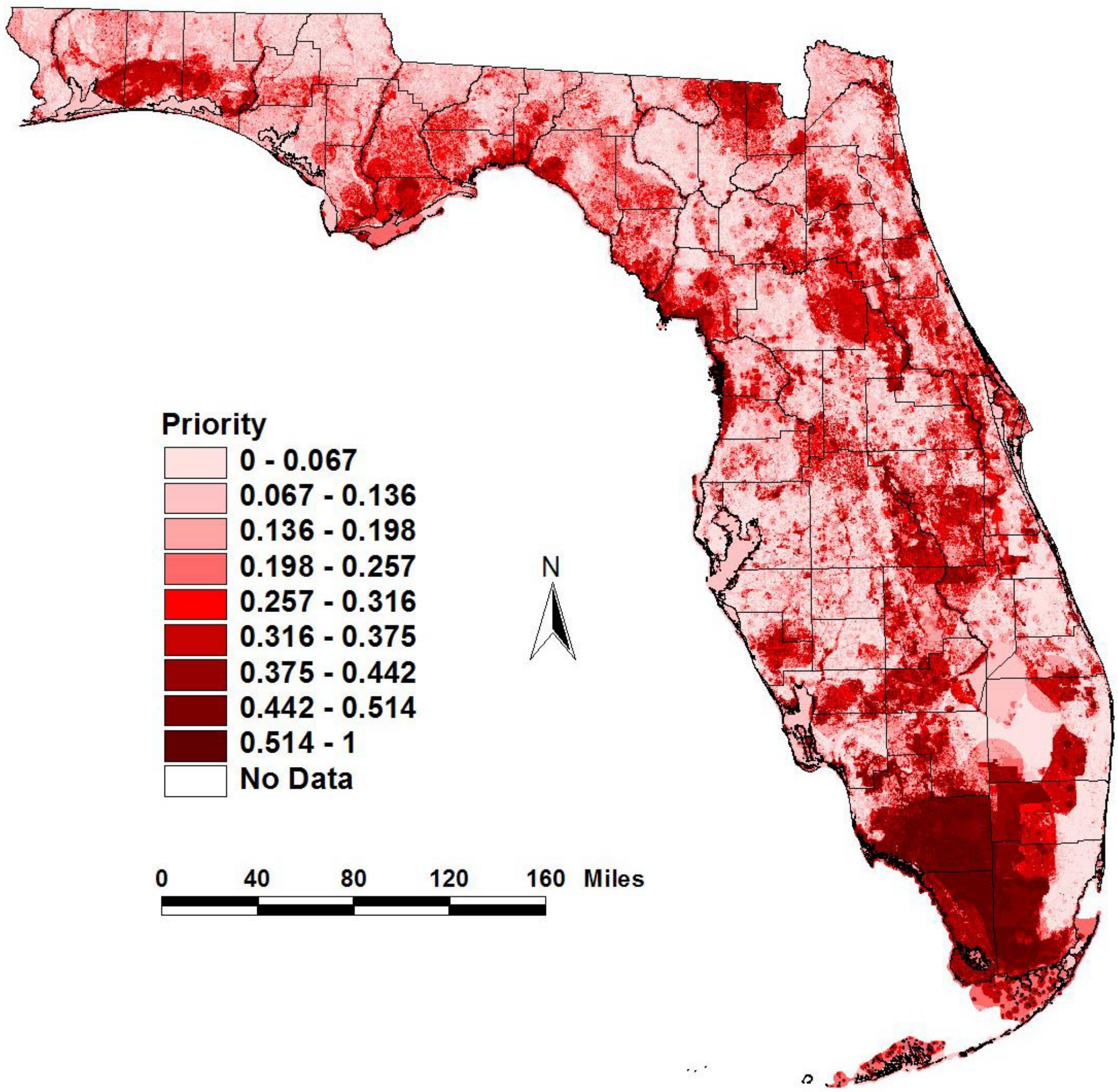


Figure 6. Ecological hotspots–statewide priorities.

In addition to the updated ecological hotspots priorities, a new development-threat index (scale of potential/existing development) based on annual average daily traffic level, road density (km/km2), population density (U.S. Census block groups), 2003 existing land use, MPO urban planning areas, and city/town boundaries was created (figure 8). Water bodies and large wetlands were considered to have no data in this analysis. Noteworthy from figure 8, the areas of greatest threat from development (darkest shades) are located on the fringe of major cities and along major transportation corridors (e.g., interstates, toll roads, and other major federal highways).

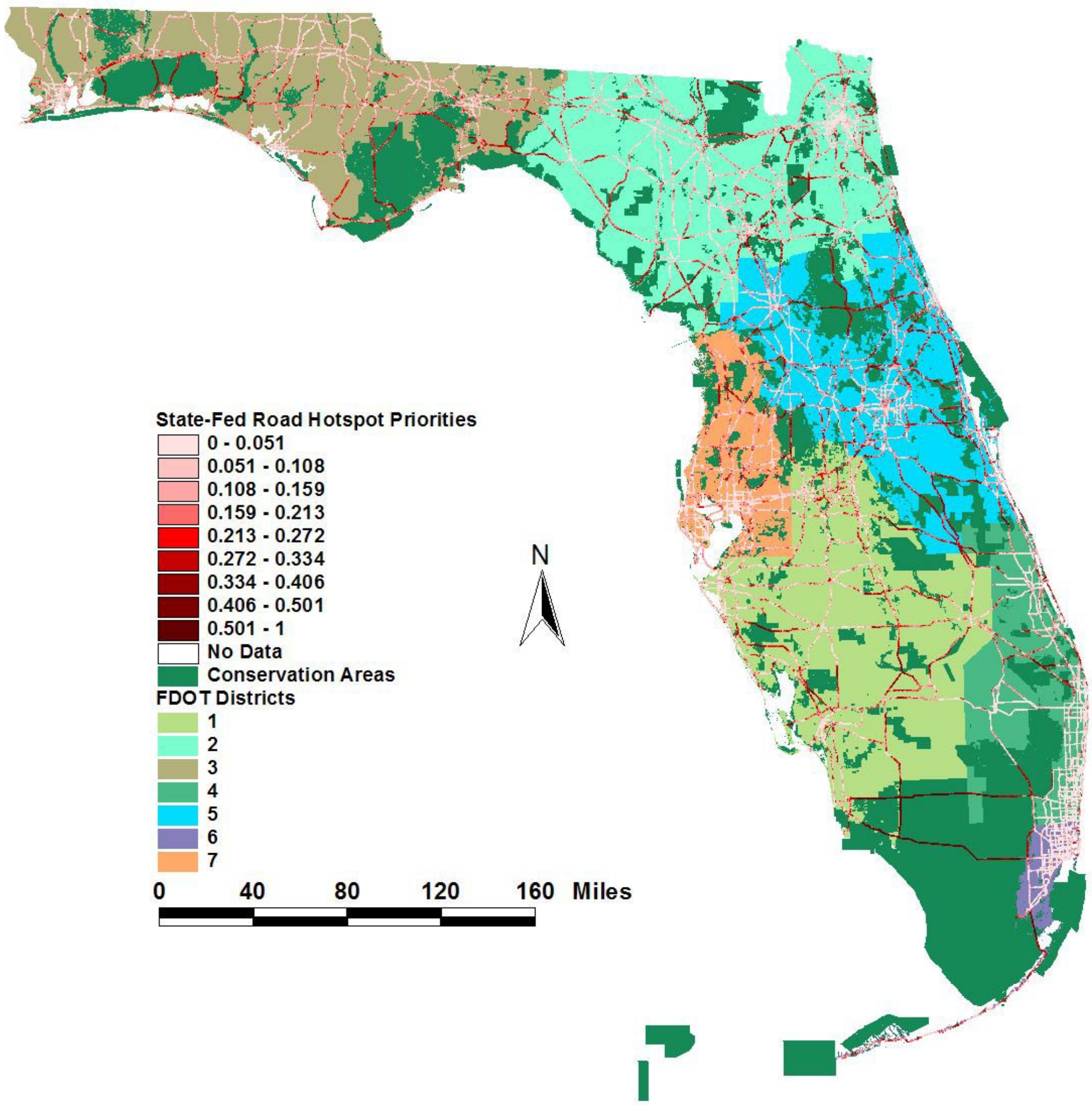


Figure 7. Ecological hotspots–state and federal roads.

Conclusion

ETDM currently provides many environmental data elements that can be examined independently by ETAT members to evaluate potential impacts of individual projects. The prioritized "ecological hotspots" data layer provides ETAT members an alternative method for displaying potential cumulative impacts (in a prioritized format) for any given location. It represents a systematic approach to data synthesis–identifying specific locations (at a 30-m scale) with the greatest potential adverse impacts.

The development-threat index may be most appropriate for use in determining urgency in land-acquisition projects. The prioritized "ecological hotspots" data layer can be used alongside other environmental and cultural resource comparison criteria in ETDM to generate summary reports that official reviewers use to detail the potential project's "degree of effect" and to provide options for adverse impact avoidance and minimization.

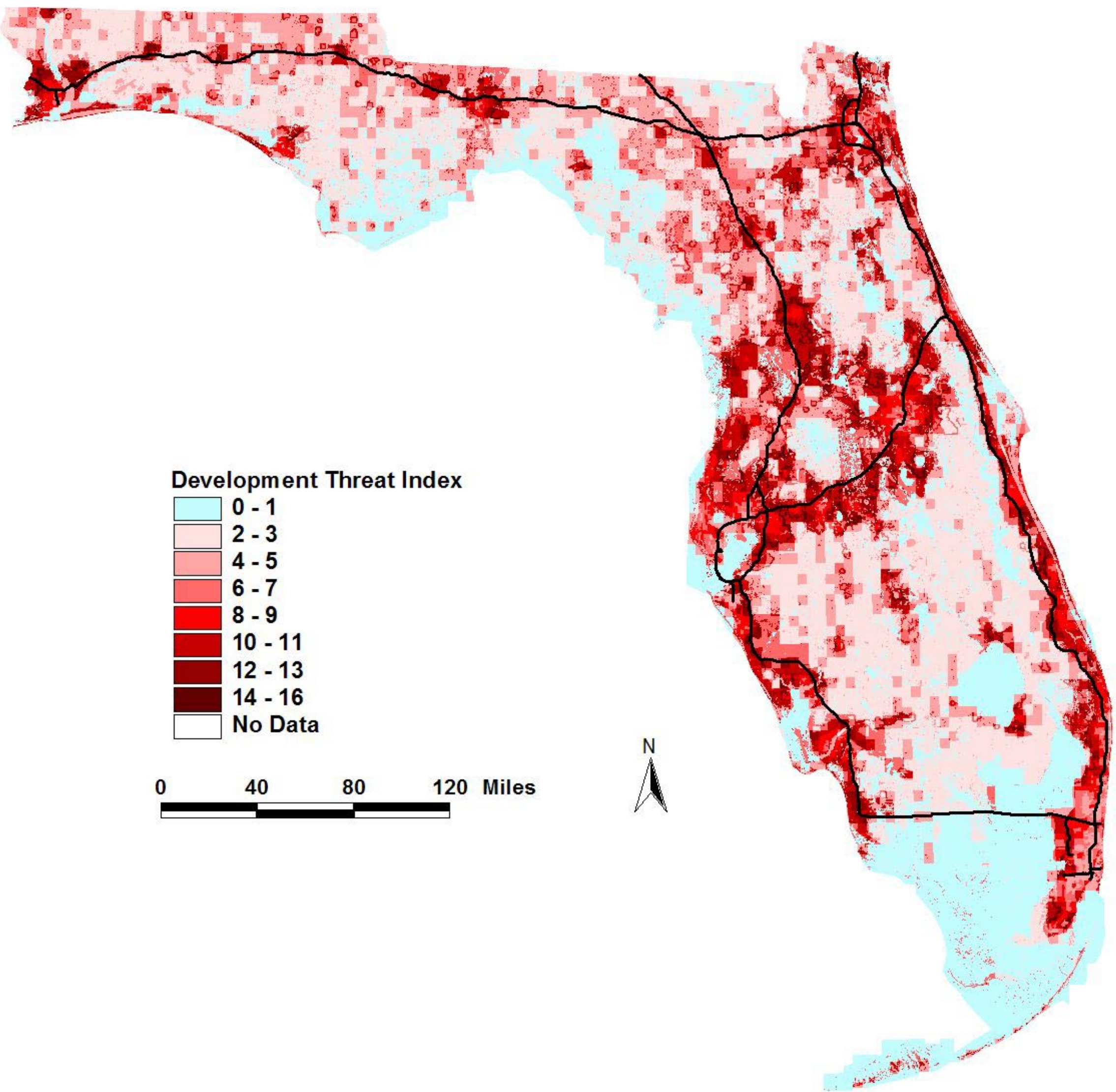


Figure 8. Scale of existing/potential development. It is composed of AADT levels, road density, population density, and existing land use, city/town limits, and MPO planning areas, and 1- and 2-km urban-area buffers.

Biographical Sketch: Daniel J. Smith has a Ph.D. in wildlife ecology and conservation from the University of Florida (2003). He has conducted research on the ecological effects of roads for the past 10 years. Specific research interests include the effects of habitat fragmentation and land management practices on native biodiversity and the change in landscape form and function. He is currently a research associate in the program for conservation biology in the Department of Biology at the University of Central Florida.

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Appendix. Model Criteria and Grid Values.

Category	Criteria	Base Value
Landscape	**Gradients**	
Features	Topography	
	> 75 m	16
	60-74 m	13
	40-59 m	10
	20-39 m	6
	< 20 m	3
	Slope	
	15.4-19.2 degrees	16
	11.5-15.3 degrees	13
	7.7-11.4 degrees	10
	3.9-7.6 degrees	6
	0-3.8 degrees	3
	Physiography (isolated upland features)	
	Ridges	16
	Hills	13
	Inclines	10
	Slopes	6
	Bar	3
	Ecotone (natural lands)	16
	Riparian	
	Streams/lakes/springs in rare habitats	16
	Streams/lakes/springs in native communities	14
	Canals in rare/native communities	12
	Streams/lakes/springs in disturbed natural areas	9
	Canals in disturbed natural areas	7
	All in substantially converted lands	5
	All in urban areas	2
	Intermittent Wetlands (context)	
	Rare habitats	16
	Native communities	13
	Disturbed natural areas	10
	Substantially converted lands	6
	Urban areas	3
	Priority Wetlands (context)	
	Rare habitats	16
	Native communities	13
	Disturbed natural areas	10
	Substantially converted lands	6
	Urban areas	3

Appendix. (Continued).

Category	Criteria	Base Value
Landscape	**GFC Habitat/Land Cover**	
Features	Rare/Important Habitats	16
(cont.)	Native Communities	13
	Disturbed Natural Areas	10
	Substantially converted Lands	6
	Human-dominated Areas	3
Biological	**GFC Focal Species Hotspots**	
Features	10-12 species in wetlands	16
	7-9 species in uplands	12
	4-6 species in uplands/wetlands	8
	1-3 species in uplands/wetlands	4
	FNAI Element Occurrence (listed species locations)	
	Endangered	16
	Threatened	12
	Species of Special Concern/Bird Rookery	8
	Other Rare Species	4
Road-kill	**Road-kill**	
	Endangered Species (panther, key deer)	16
	Threatened Species (black bear)	13
	Parks (t & e), Other Focal Species (river otter, beaver)	10
	Parks—high traffic	7
	Parks—low traffic	4
Planning	**Strategic Habitat-Conservation Areas (FWC)**	
	Seven	16
	Six	14
	Five	12
	Four	9
	Three	7
	Two	5
	One	2
	Proposed Conservation Lands (Florida Forever)	
	Three	16
	Two	11
	One	5

Appendix. (Continued).

Category	Criteria	Base Value
Planning	**FNAI Priority Habitat Areas**	
(cont.)	Six	16
	Five	13
	Four	10
	Three	7
	Two	4
	One	2
	Greenway Final Rankings (linkages)	
	One	16
	Two	14
	Three	12
	Four	10
	Five	8
	Six	6
	Seven	4
	Eight	2
	Integrated Wildlife Habitat-Ranking System	
	Nine	16
	Eight	14
	Seven	12
	Six	10
	Five	8
	Four	6
	Three	4
	Two	2
	One	1
Public	**Public Lands (FLMNA 2005)**	
	Public or private trust preserves/national parks	16
	Restricted access public-conservation lands	11
	Multi-use conservation areas	5
Infrastructure	**Road Projects**	
	Proposed, Bridge Replacements	16
	Existing	8
	Speed Limit (non-urban)	
	70 mph	16
	55-65 mph	12
	35-50 mph	8
	15-30 mph	4

Linking Colorado's Landscapes

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Abstract: In partnership with the Colorado Department of Transportation, the Federal Highway Administration, the Nature Conservancy, and Colorado State University, the Southern Rockies Ecosystem Project (SREP) launched Linking Colorado's Landscapes in fall 2003. Linking Colorado's Landscapes is a multifaceted collaboration to promote wildlife linkages in the context of long-range planning. Phase I consisted of a statewide analysis of wildlife linkages, the objective of which was to identify broad linkage zones that facilitate movement for Colorado's diverse array of wildlife species and to prioritize amongst them. Building upon linkage assessment methodologies used elsewhere, we developed a science-based approach integrating local and regional expertise (via a series of workshops) and computer modeling. Recognizing that connectivity is a function of individual species' perceptions of suitable habitat and barriers in the landscape, a focal species approach was employed as the basis for linkage identification in both the workshops and the modeling. By integrating both qualitative and quantitative processes, we were able to produce a comprehensive biological assessment of the most critical wildlife linkages in the state.

In total, 176 linkages were identified via expert workshops, with additional linkages modeled for Canada lynx, gray wolf, and pronghorn. In prioritizing linkages for further analysis in Phase II, we also considered: the presence of local partners; stretches of roadway with frequent animal-vehicle collisions; planned transportation projects projected by CDOT through 2030; and the distribution of linkages across the state and their complementary contributions to landscape connectivity. Twenty-three linkages were selected and were grouped into 12 high-priority linkage complexes based on similarities in species usage patterns and geography.

Phase II of Linking Colorado's Landscapes provides an in-depth assessment of each high-priority linkage. Based on this compilation of site-specific information, we will next provide recommendations for possible crossing structures, management alternatives, and other measures to improve permeability in these linkage areas. Phase II analyses include: an assessment of additional species that utilize the linkage; identification of specific crossings; an assessment of land ownership and management within the linkage; and an evaluation of existing natural or man-made features that facilitate or impair movement. The resulting linkage assessment packages and recommendations will be distributed in spring 2006 and will serve as a guide for the Colorado Department of Transportation (CDOT) and other local and regional transportation planners, community leaders, and conservationists working to develop more wildlife-friendly landscapes and transportation networks.

Introduction

Habitat fragmentation is now recognized as one of the greatest threats to biodiversity and the decline of species worldwide (Ehrlich 1986; Wilcove et al. 1998), a trend expected only to increase across the Southern Rockies (SREP 2004). Transportation infrastructure in particular is a significant cause of habitat fragmentation, with negative impacts on wildlife (e.g., Harris and Gallagher 1989; Maehr 1984; Reed et al.1996).

Animals are frequently killed on roads as they move from one part of their range to another (Forman et al. 2003) or they may avoid roads altogether (Gibeau and Heuer 1996; Jalkotzy et al. 1997), limiting their habitat area and ability to fulfill certain needs. The impacts are pervasive—Forman (2000) estimates that 20 percent of the land in the U.S. is directly influenced by public roadways. In Colorado alone there are over 85,000 miles of roads administered by the state Department of Transportation, including 953 miles of designated interstate highways (CDOT 2004). In addition, there are countless miles of county, private, and Forest Service roads that further serve to fragment the landscape.

Mitigation to protect and restore habitat connectivity is both complex and costly. A broad, comprehensive landscape analysis provides the most efficient means for focusing conservation efforts in the most critical linkages. Linking Colorado's Landscapes was designed to focus conservation efforts on areas of the landscape that provide important connectivity functions for native wildlife. The purpose of this work was to identify and prioritize wildlife linkages across the state of Colorado to promote safe passage for wildlife.

Linking Colorado's Landscapes is a two-phase project led by the Southern Rockies Ecosystem Project (SREP) in collaboration with the Federal Highway Administration (FHWA), the Colorado Department of Transportation (CDOT), Colorado State University (CSU), and the Colorado Chapter of the Nature Conservancy (TNC), the Colorado Division of Wildlife (CDOW), the U.S. Fish and Wildlife Service, and the U.S. Forest Service.

Phase I

The primary objective of Phase I of Linking Colorado's Landscapes was to identify broad linkage zones that facilitate movement for Colorado's diverse array of wildlife species and to prioritize amongst them for further study. Building upon the methodology developed by the South Coast Missing Linkages Project (SCML) in California (Penrod et al 2001), we developed a science-based approach integrating local and regional expertise (via a series of workshops) and spatial analysis. Similar to SCML, Linking Colorado's Landscapes evolved under the direction of a lead group (SREP) supported by an Executive Committee composed of representatives from CDOT, FHWA, CSU, and TNC. This seven-member team provided vision, guidance, and expertise throughout the project, as well as a foundation for additional collaborations in subsequent phases of the project.

The Executive Committee proposed a two-track methodology as a comprehensive approach to identifying and prioritizing critical wildlife linkages. This approach was designed to compile information from a variety of sources including existing research on wildlife movement, local knowledge from agencies and other informed individuals, and spatial modeling of predicted movement paths for several different wildlife species. By integrating both qualitative and quantitative processes, we intended to produce a more accurate and complete picture of the most critical wildlife linkages in the state, highlighting clear priorities for further in-depth analysis in Phase II.

Recognizing that connectivity is a function of individual species' perceptions of barriers in the landscape, we employed focal species as the basis for linkage identification. We reviewed dispersal, home range, and habitat requirements of numerous native species to select a comprehensive set of 28 focal species that captured the range of connectivity needs. Maintaining our focus on a suite of focal species allowed us to concentrate our efforts while ensuring that the linkages are appropriate for the species for which they are intended. These focal species guided linkage identification in both the workshop and modeling tracks.

The goal of the workshop track in the two-pronged approach was to compile existing information and knowledge about habitat and linkages for the selected focal species via a series of regional workshops. This track is analogous to the first three steps outlined by Beier et al. (2005) for the SCML project (building a coalition; selecting core habitat patches and prioritizing linkages; and selecting focal species), although we pursued a somewhat modified approach.

Rather than one statewide expert workshop, we elected to hold five daylong workshops at locations across the state (Alamosa, Fort Collins, Meeker, Montrose and Pueblo). The intent was to encourage greater local participation and allow more people the opportunity to contribute to the process. In addition, we used these occasions to host additional information sessions to which local officials, planners and interested community members were invited. Each of the workshops followed the same format, focusing on the primary goal of identifying linkage areas for the focal species based on the expertise of the workshop participants, and compiling information about the functionality of each linkage and its role in the landscape to prioritize the linkages. The information from these workshops was compiled and scored, based on a prioritization scheme that evaluated conservation significance, opportunity and threat.

The second track (or 'modeling track') was incorporated as a parallel process designed to complement the expert workshop track outlined in the scope of work. These analyses integrated layers of spatial data about the physical characteristics of the landscape (e.g., topography, vegetation, roads, development etc.) with information about wildlife-habitat preferences and movement patterns to model areas of the landscape that are key to wildlife movement. Through this modeling, habitat patches and the multiple linkages between them were identified for gray wolf, Canada lynx, and pronghorn.

Finally, we overlaid the highest-priority linkages identified by each track for large carnivores and ungulates. This comparison provided the foundation for determining the location of the most critical wildlife linkages that are the focus of the Phase II linkage assessments. In selecting high-priority linkages, the Executive Committee considered the priority ranks from the two biological prioritization processes as well as several other factors: the presence of local partners that are prepared to engage in these efforts and other feasibility considerations; stretches of roadway with frequent animal-vehicle collisions; the location of planned transportation projects projected by CDOT through 2030; the complementary contributions that each linkage offers to network connectivity across the greater landscape; and the distribution of linkages across the state. All of these factors guided the selection of the final suite of 12 high-priority linkages.

Phase II

The primary objective of Phase II is to provide in-depth analyses of each high-priority linkage, analogous to steps 4-7 as described by Beier et al (2001), i.e. developing linkage design, providing management recommendations, and creating implementation and monitoring plans. Linkage assessments identify additional species that utilize the linkage; identify specific crossing locations; assess land ownership and management within the linkage; and evaluate existing features that facilitate or impair movement. Based on this compilation of site-specific information, we can develop recommendations for possible crossing structures, management alternatives, and other measures to improve permeability in these linkage areas. The resulting linkage-assessment packages and recommendations will serve as a guide for CDOT and other local and regional transportation planners, community leaders, and conservationists working to develop more wildlife-friendly landscapes and transportation networks.

Within each site, we characterize the roadway on its permeability (or lack thereof) relative to the suite of focal wildlife species identified for each linkage in Phase I. These linkage assessments are not designed to provide long-term analyses of wildlife movements through the linkage area. Instead, they are detailed snapshots that can act to define future mitigation and monitoring priorities.

Site visits were conducted between June and August 2005. These roadway assessments were conducted along nearly 200 miles of highway in the identified high-priority linkage areas. Highway interference zones were identified where each linkage intersected with a highway or interstate. For each linkage, the highway interference zone was defined by easily-identifiable physical locations such that landscape-level wildlife movements across the roadways were captured. We then characterized potential roadway barriers through the following variables: number of lanes, shoulder barriers, median barriers, and other features. We also identified unique situations that could potentially serve as a wildlife crossing locale. These situations were categorized into three types: 1) structures, 2) fill slopes, and 3) at-grade crossing areas. Finally, we took note of all road-stream crossings and recorded the condition of the inlet and outlet, the substrate type, and vegetation cover.

Detailed information was collected for each situation type that was encountered. Structures were defined as any bridge or culvert that could provide a safe passage for wildlife species underneath the roadway. We also recorded locations of structures along each roadway designed to allow animals to escape the highway right-of-way such as one-way deer gates and ramps. Fill slopes were defined as any location were the roadway was elevated above the surrounding land. These locations typically occurred where the roadway bisected drainages, but were also common along topographic depressions lacking a hydrological component. While it was not uncommon to have some sort of drainage structure under the roadway to allow for water flow, these structures (typically corrugated pipes) are almost always under 1 m in diameter, thus forcing wildlife up the fill slope to attempt a surface crossing of the roadway. All other potential wildlife-crossing locations were designated as at-grade crossings. Unlike structure and fill slope locations, at-grade locations are not specific points along the roadway. Rather, they incorporate longer stretches of the roadway (typically 0.5-2 miles in length). These locations typically include stretches of roads that run parallel to drainages, places where a particular vegetation type comes up to the shoulder of the roadway, or choke points. These areas are also typically stretches of the road where there have been a high level of animal-vehicle collisions. For each situation, we measured a suite of variables unique to the situation type. We also recorded any incidental sign of species activity at each situation location. This included species use of structures, tracks and scat, game trails, and roadkill.

The information collected during these site visits provides the basis for understanding the current level of permeability through these linkages. Additional information about the landscape context is also essential to developing a comprehensive understanding of the linkage situation and opportunities for mitigation at specific crossing points within the linkage. For each linkage, the following information was compiled in the linkage assessment reports: vegetation, topography and landscape context; habitat and dispersal needs for each of the focal species; animal-vehicle collisions per half-mile (from Colorado State Patrol records); land ownership and management, zoning and lot sizes adjacent to the roadway; current and projected traffic volumes; speed limits; and general demographics of the nearby communities.

Following the site evaluation and information compilation, we developed preliminary recommendations to maintain and/or enhance wildlife movement across the roadway. Recommendations were based on the functionality and feasibility of implementation and were grouped into zones, highlighting stretches of highway within that larger linkage that provide clear opportunities and offer the greatest benefit to improved permeability. Recommendations were categorized into several categories: structural, fill slope, vegetation, barriers, aquatic, traffic awareness, and monitoring.

The next step in this process involves review of the linkage assessments by agency biologists and the development of specific recommendations for the key highway segments highlighted within each linkage. To facilitate these discussions, we will host a one-day workshop with a select group of CDOW biologists and engineers for the state and federal transportation agencies. The workshop has two goals: 1) review the key findings of the linkage assessments to further define the focal highway segments, and 2) for commonly found situations, facilitate collaboration between the biologists and engineers to discuss potential solutions that are both feasible from a design standpoint and ecological functional so as to adequately provide for species-movement needs.

The workshop will then be followed up with a series of site visits with regional engineers and biologists from CDOT, FHWA, and CDOW to evaluate the site-specific considerations at each crossing location. These recommendations will complete the final linkage reports (Spring 2006).

Implementation

Linking Colorado's Landscapes does not end with the completion of Phase II. This is an on-going project, in which our focus narrows at every step until permeability is restored at the most critical crossing points. The Phase II linkage assessments provide important guidelines for achieving this goal. Based on the preliminary recommendations and other information compiled in the linkage assessments thus far, it is clear that there are numerous mitigation opportunities at existing structure locations. Such situations range from minor restoration and management to large-scale reconstruction of structure and include actions such as, the removal of sediment in a culvert; revegetation at the entrances to a structure; fence maintenance; excavation to enlarge clearance area through a structure; or enlarging existing structures to facilitate movement for a greater variety of wildlife species.

However, some situations will require the construction of new structures to overcome the fragmentation presented by highways. One such project is the proposed vegetated wildlife overpass at west Vail Pass in Eagle County, Colorado (Fig. 1). This pilot project would provide a safe passage for wildlife and help to reconnect populations for a variety of native wildlife including elk, moose, deer, mountain lion, black bear, and the recently reintroduced Canada lynx. In addition, the overpass would connect via eight-foot high fencing to existing span bridges, creating multiple crossing opportunities at more frequent intervals. This pilot wildlife overpass will have tremendous visibility on this heavily traveled route, giving the public an opportunity to experience its safety, visual appeal, and utility.

Figure 1: Photosimulation of proposed wildlife overpass on the west side of Vail Pass.
Courtesy of Digital Animation Services.

An overpass is proposed as the structure of choice in this area because of the type of animals that will be using the structure, as well as the cost effectiveness in engineering an overpass. Constructing an underpass or span bridge would be prohibitively expensive at this location and would cause unacceptable traffic delays. The proposed overpass, on the other hand, would complement the already existing wildlife underpasses in this area, ensuring that wildlife have multiple options for crossing I-70.

Four independent studies have identified this location as a high priority for restoring connectivity through the spine of the Rockies. Additional site-specific monitoring will determine the exact location of the structure.

Education and Outreach

Animal vehicle collisions present a major safety hazard for both people and wildlife. Improving driver awareness is an essential component of any comprehensive efforts to reduce these types of collisions and improve landscape permeability. Because crossing structures are not feasible in many locations and wildlife will continue to be at risk of being hit by a vehicle, driver education and awareness is a major tool in preventing collisions with animals on all types of roads and in all locations.

To address these safety issues, SREP spearheaded Colorado Wildlife on the Move, an on-going driver education and outreach campaign which urges drivers to watch for wildlife on Colorado highways, particularly during migration seasons. A broad array of partners (including state and federal transportation agencies, as well as rental car companies, insurance companies and a non-profit insurance information organization) have come together in support of this campaign, highlighting the diverse community that is struck by the issue of animal-vehicle collisions. By capitalizing on the widespread concern about these issues, we can catalyze support for other restoration and protection measures that will help not only to create safer roadways, but also to improve the permeability of the landscape for our native wildlife.

In an effort to educate motorists about how to avoid dangerous and costly collisions, the campaign prepared a safety-awareness poster and driver-safety tip sheet that includes suggestions for how to avoid hitting animals. These posters and tip sheets have been distributed to rental-car offices, tourist-information centers, highway rest stops, motor-vehicle offices, Forest Service visitor centers and State Patrol offices.

Biographical Sketch: Julia Kintsch is the Program Director for the Southern Rockies Ecosystem Project and has been leading the Linking Colorado's Landscapes project for two years. Julia holds bachelor's degrees in environmental science and German from the University of Colorado at Boulder and a master's degree in landscape ecology from Duke University. Prior to joining SREP, Julia worked as a conservation planner for the Michigan Chapter of The Nature Conservancy and was a Peace Corps volunteer in Senegal, West Africa. The Southern Rockies Ecosystem Project is a nonprofit conservation-science organization working to protect, restore, and connect ecosystems in the Southern Rockies of Colorado, Wyoming, and New Mexico.

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The Missing Linkages Project: Restoring Wildland Connectivity to Southern California

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Abstract

In Fall 2001, the ground-breaking Missing Linkages report identified 232 wildlife linkages in California. South Coast Wildlands immediately spearheaded an effort to prioritize, protect, and restore linkages in the South Coast Ecoregion.

We first forged a partnership with 15 federal and state agencies, conservation NGOs, universities, county planners, and transportation agencies. By partnering from the start (rather than developing a plan on our own and asking others to "unite under us"), we garnered spectacular support and are making rapid progress. With our partners, we:

1. Selected 15 priority linkages (out of 69 linkages in the ecoregion) on the basis of biological importance (size and quality of core areas served) and vulnerability
2. Held workshops to identify 12 to 20 focal species per linkage
3. Researched the needs of focal species, obtained high-resolution spatial data, and collected field data to develop a linkage design based on GIS analysis of movement of focal species
4. Made detailed recommendations for protecting key habitat parcels, creating highway-crossing structures in specific locations and land-use guidelines in and adjacent to the proposed linkages
5. Presented the design to partners who are now procuring easements and land, changing zoning, restoring habitat, and mitigating transportation projects

Arizona began a similar effort in 2004. One key difference is that the southern California effort is led by a small conservation NGO, while the Arizona effort is led by state and federal agencies, including the transportation agencies. The ultimate key to success is to streamline the Linkage Designs into transportation projects, land-use plans, and conservation plans (such as the state Comprehensive Wildlife Strategy). This collaborative, science-based, core-to-core approach promises not merely to slow the rate at which things get worse, but to actually improve connectivity over today's conditions.

Biographical Sketch: Dr. Spencer is a wildlife ecologist with the nonprofit Conservation Biology Institute, which provides scientific expertise for efforts to conserve biological diversity. He specializes in the pragmatic application of science to improve ecosystem health, design and manage nature reserves, and recover endangered species. Dr. Spencer has helped create several multi-species conservation plans in California and serves as a science advisor to various governmental agencies and conservation organizations involved in conservation planning. He's also performed or directed research on a variety of rare mammal species, including the critically endangered Pacific pocket mouse and Stephens' kangaroo rat. Dr. Spencer has been a science advisor to the South Coast Missing Linkages project since its inception and serves as President of the Board of South Coast Wildlands.

The Swiss Defragmentation Program—Reconnecting Wildlife Corridors Between the Alps and Jura: An Overview

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Abstract: Switzerland has one of the densest infrastructure networks of Europe (3-4 km/km2 on the Central Plateau). Fragmentation of natural habitats has become a major conservation concern as vulnerable species become rarer and the red list of endangered species becomes longer. The mortality of animals on roads remains high, with more than 8,000 roe deer killed yearly by traffic. Many amphibian spawn sites along lakeshore have been cut off from their wintering grounds by roads, with populations then disappearing. Highways have proven to be an impassable barrier for the lynx, impeding colonization of eastern Switzerland.

Switzerland participated actively in the COST 341 European research program "Habitat fragmentation due to transportation infrastructure." A census of bottlenecks where infrastructure intercepts important wildlife corridors was carried out during this program. Fifty-one points needing restoration measures were identified. Many of these are along first-generation highways built along an east-west axis and cutting off any possible exchange between wildlife populations in the Alps and the Jura.

A ministerial guideline sealed a partnership between the Swiss Agency for Environment, Forests, and Landscape (SAEFL) and the Swiss Federal Roads Authority. The defragmentation program has been included in the highway-maintenance program and is to take place over the next 20 years. Five conflict points have been recently retrofitted in the context of highway-widening schemes.

A program methodology is being developed. Conflict points will be addressed as the involved highway section comes up for maintenance. In order to facilitate long-term planning, different instruments have been developed. Standards have been defined by the Swiss Association of Road and Transportation Experts (VSS 2004) to guide engineers and biologists in the analysis of existing structures and potential permeability for fauna. Criteria were developed to facilitate the choice of the optimal type of passage for each given situation.

Further research and standards are being launched to homogenize monitoring programs and develop best practice for retrofitting culverts, as well as to anticipate and eliminate wildlife traps created by certain structures.

Habitat Fragmentation in Switzerland

With 71,000 km of main roads and a total road length of more than 111,000 km, Switzerland has one of the densest infrastructure networks of Europe (3-4 km/km2 on the Central Plateau) (Oggier et al. 2001). Figure 1 shows the high density of roads in the Swiss lowlands.

Figure 1. Road map of Switzerland showing main roads and county roads. (Reprinted with permission from: Bundesamt für Landestopographie BA4827)

Traffic Casualties Influence Wildlife Populations

More than 20,000 large mammal road casualties are counted every year (BUWAL, 2003). This affects a number of wildlife populations. For example, road casualties are responsible for 23 percent of the European lynx mortality in Switzerland (Oggier et al. 2001). The species was reintroduced in the 1970's and has yet to recover on a national basis. Highways have proven to be an impassable barrier for the lynx, impeding colonization of eastern Switzerland. To address overpopulation in the west, Lynx had to be captured and transferred to the east at high cost (Breitenmoser 1995).

As the red lists of endangered species in Switzerland lengthen, fragmentation has become a major conservation concern. Due to pressure on habitat, certain vulnerable species (such as the Capercaillie) have dwindled to small isolated populations. Infrastructure barriers complicate restoration efforts. Forests roads attract leisure activities, creating disturbances in once-tranquil habitats.

Along lakeshores, many amphibian spawn sites have been cut off from their wintering grounds by roads, with populations then disappearing (Ryser 1988). More than 1000 conflicts points where roads cross migration paths are known (Oggier et al. 2001).

Birds of prey also cause a high toll to traffic mortality. Almost 30 percent of known mortality of the Barn owl is along roads (Marti 1998).

Inventory of Environmental Bottlenecks

Switzerland participated actively in the COST 341 European research program "Habitat fragmentation due to transportation infrastructure" (Trocmé 2003). The goal of this European program was to describe in each participating country the extent of fragmentation, give an overview of measures used to address the problem and elaborate (on the basis of shared experience) a manual of best practices (Iuell 2004).

A survey of bottlenecks where infrastructure intercepts important wildlife corridors was carried out (Holzgang et al. 2001) during the COST program in Switzerland. The basis of this survey was a study of the main wildlife corridors. Hunting statistics and questionnaires to gamekeepers and huntsmen were used to map dispersal patterns of game, such as roe deer, red deer, wild boar, chamois, and ibex. A simple landscape-permeability model using a geographical-information system (GIS) was also used to define movement axes based on topography and habitat continuums. Figure 2 shows the extensive connectedness within Switzerland for terrestrial forest-dwelling wildlife.

The axes of movement are shown as broad green strips. The corridors are sections of the axes where wildlife movement is bounded permanently by natural or anthropogenic structures or intensive agriculture areas.

An overall assessment reveals that 47 (16 percent) of a total of a 303 supraregional wildlife corridors are now largely disrupted and impassable to wildlife. The functionality of more than a half is moderately to severely impaired (171 corridors; 56 percent). Approximately a third (85; 28 percent) can be classified as intact. A total of 78 supraregional corridors have been identified that need restoration in order to guarantee sufficient permeability between the Central Plateau, the Jura, and the Alps and provide an exchange between populations.

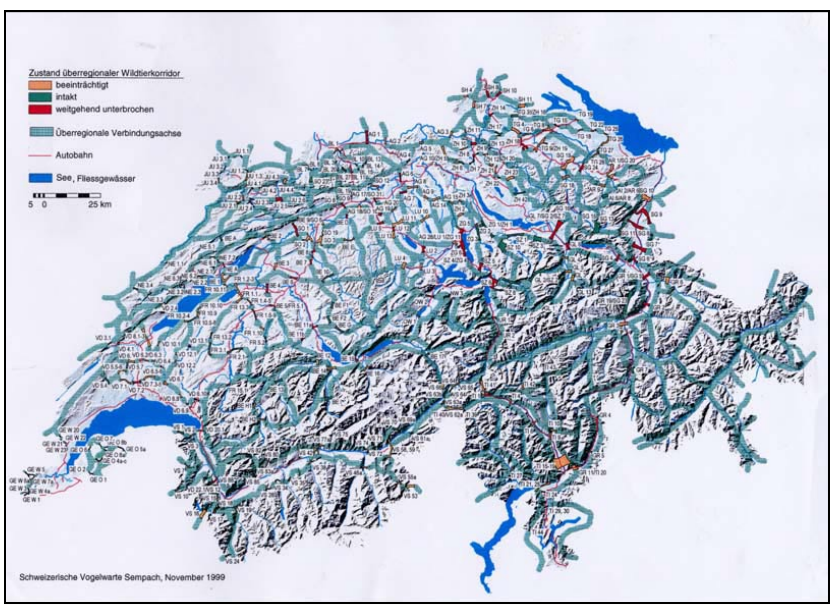

Figure 2. Overview of the wildlife corridors and axes of movement of supraregional importance showing Switzerland's extensive network for terrestrial wildlife. Green is intact, orange is impacted, and red is interrupted corridors (source: Schweizerische Vogelwarte Sempach 1999).

Defragmentation Program

The wildlife corridor study has been embedded in a much larger strategy, namely a national ecological network (REN). The REN (Berthoud 2004) is based on available data of potential habitat (including existing nature reserves) and combined with the data from the wildlife corridors. The purpose of the REN is to optimize habitat connectivity by focusing habitat-upgrading efforts and ecological compensation in agricultural areas in the sites with most potential.

Inventory

The survey of the wildlife corridors showed 51 spots interrupted by infrastructure needing constructive measures to restore permeability. Many spots are along first-generation highways built along an east-west axis and cutting off any possible exchange for wildlife populations between the Alps and the Jura. The measures advocated go from simply planting natural structures leading up to existing mixed use passages to the full retrofitting of highway sections with fauna overpasses for large ungulates. The measures taken along transport infrastructure are to be coordinated with further incentives from the REN.

Figure 3 shows an extract of the Ecogis website (Ecogis 2003) where the inventory can be consulted by the public. The red striped area is a corridor interrupted by a highway. A viaduct allows animals through, but urbanization is encroaching on the passage.

Figure 3. Wildlife corridors near Marin by Neuchâtel in the three-lake district. Extract of the Ecogis website showing in beige is an impaired corridor and in red is an almost fully disrupted corridor (http://www.ecogis.admin.ch.) (Courtesy of BUWAL 2003.)

Application of the inventory: sealing a partnership between nature conservation and road building

The inventory was published (Holzgang et al. 2001) and sent to all the regional authorities. A working group was set up on the federal level between the SAEFL and the Swiss Federal Roads Authority in order to achieve a consensus on what restoration measures were needed and how to initiate them. A ministerial guideline (UVEK 2001) followed. That guideline defined the width of fauna overpasses and the locations where retrofitting would be necessary. A standard width of 40 to 50 m was assigned for overpasses along corridors of supraregional importance with a possibility of narrowing the width to 20-30 m under special circumstances (topography, choice of species). These standards are based on a comparative study of 12 overpasses of different width and their efficiency for wildlife (Pfister et al. 1999). The study showed that between 20 and 50 m width, the frequency of use increases and then flattens off. Small passages were not as readily used.

It was decided to integrate retrofitting in the normal highway upkeep planning, with the result that the defragmentation program will be spread over a time period of 20 years.

A new transport master plan is being developed on the federal level. The inventory of the wildlife corridors is part of the baseline information which will be taken into account by future projects.

On the regional level, the corridor inventory is to be incorporated in the spatial-planning schemes in an effort to keep these corridors free from urbanization. To date, the inventory has been incorporated in 17 of the 26 cantonal spatial-planning schemes. Legally it is weighted only as a recommendation. Because the inventory remains non-binding for local communities, conflicts continue to arise.

However, a federal court injunction stopping a project interrupting a corridor has given new force to the inventory (BGE 2001).

First results of the defragmentation program
To date, five locations have been retrofitted: Grauholz (BE), Neu-Ischalg (BE), Birchiwald (BE), Baregg (AG), and Hirschsprung (SG).

Like the passage shown in figure 4, most of these locations have benefited from transport infrastructure-widening schemes. In such cases the new over- or underpass is part of the environmental-impact study and financed through the infrastructure-building project.

Figure 4. Neu-Ischlag in Canton Bern. The 50-m-wide overpass spans both the existing highway and a new high-speed train line. Photo courtesy of Tiefbauamt canton Bern.

Figure 5 shows the mitigation measures chosen for the T10 road-widening project in the three-lake district (see figure 3). The alignment was modified so as to permit the crossing of a watercourse with a high bridge. The old road was ground level and let the stream through a narrow culvert. The road stretch had been often fatal for European beaver, a species reintroduced in Switzerland and still vulnerable.

Figure 5. The T10 between Morat and Neuchâtel cuts through important wildlife corridors. Appropriate mitigation measures such as this bridge replacing a culvert were taken. Photo courtesy of Marguerite Trocmé.

The highway shown in figure 3 by Cressier will soon undergo major maintenance work. The so called UPlaNS (maintenance plan) underwent an impact assessment (Aquarius 2004). Figure 6 shows the networking measures planned so as to guide wildlife to the viaduct through agricultural land. The project has not yet passed authorization because opposition from farmers has to be addressed.

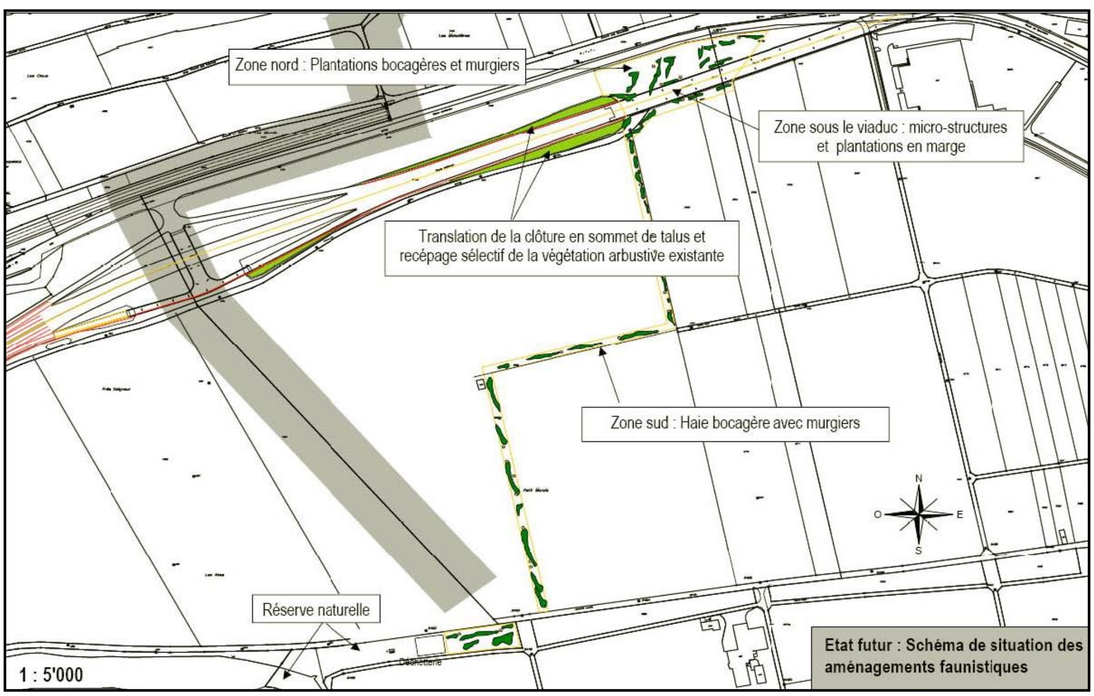

Figure 6. Maintenance program of the A5 includes mitigation measures for wildlife.
Improving the efficiency of a viaduct by planting guiding structures.
Reprinted with permission of Aquarius/BZA/30.6.2004 Document No AQ 80 308 80 8114.

Standards

To facilitate long-term planning, different instruments have been developed. Standards have been defined by the Swiss Association of Road and Transportation Experts (VSS 2004) to guide engineers and biologists in the analysis of existing structures and potential permeability for fauna. The standards were written by a mixed group of engineers and biologists and are based on the results of the COST 341 action.

A base standard SN 640 690a explains ecological networks and the impact of fragmentation by transport infrastructure in simple terms. For each project phase, standard SN 640 691a develops a standardized procedure that explains in which phase which studies need to be made so that specialists are integrated early enough in the project team.

Standard SN 640 692 focuses on permeability models, giving recommendations for the choice of priorities. The idea is to use (as much as possible) topography and related structures. Wildlife-mitigation measures need to be embedded as a clear concept in future ecological networks.

The last standard (SN 640 694) lists the possible mitigation measures with quality requirements. A selection grid should facilitate the choice of the optimal type of passage for each given situation.

Research

A standard procedure for wildlife-passage-monitoring programs is being developed by the SAEFL. Standard questionnaires will be asked for and results are to be stored in a central data base.

A three-phase approach will be tested. Phase A, just after construction, answers simply the qualitative questions of which species are using the passage. Phase B, two years later, looks at the frequency of use, if animals are actually crossing the structure and the influence on wildlife road casualties. Phase C, five to 10 years later, looks at the impact of the passage on wildlife populations. For each phase, best methods will be suggested (Fornat, Righetti, personal communication).

Further research and standards are being launched to develop least-cost practice for retrofitting culverts as well as to anticipate and eliminate wildlife traps created by certain annex structures of roads and rail.

Biographical Sketch: Born in Paris in 1961, Marguerite Trocmé grew up in Ottawa before moving to the U.S. and received her bachelor of science degree in biology from Brown University in Providence, Rhode Island in 1983. In 1985, a master's degree in environmental engineering from the Ecole Polytechnique Fédérale (EPFL) of Lausanne, Switzerland followed. She then worked both for the Swiss World Wildlife Fund and the Swiss Ornithological Institute before joining the Swiss Agency for the Environment, Forests, and Landscape in 1989. She is responsible for the impact appraisal of federal infrastructure projects on nature and landscape. She was vice-chairman of the European COST 341 Project. She has led and edited studies and publications in the areas of the impact of high tension lines, roads, and aviation on natural ecosystems.

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Chapter 5

Landscapes and Road Networks

Does the Configuration of Road Networks Influence the Degree to Which Roads Affect Wildlife Populations?

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Abstract: Roads act as barriers to animal movement, thereby reducing the accessibility of resources on the other side of the road. Roads also increase wildlife mortality due to collisions with vehicles, and reduce the amount and quality of habitat. The purpose of this study was (1) to determine whether or not the configuration of road networks has an influence on the degree to which roads detrimentally affect wildlife populations and (2) to identify characteristics of road network configurations that make road networks less detrimental to the persistence of animal populations. To explore these questions, we used a spatially explicit individual-based stochastic-simulation model of population dynamics.

A measure assumed to reduce the effects of the road network is the bundling of roads and traffic in order to keep as large areas as possible free from disturbances due to traffic. However, the suitability of this measure may be questionable because a group of several roads bundled together, or an upgraded road with more traffic on it, creates a stronger overall barrier effect that may be more detrimental to population persistence than the even distribution of roads across the landscape. Our modelling results clearly supported the bundling concept. Population persistence was generally better (and never lower) when all traffic was put on one road than when it was distributed on several roads across the landscape. If traffic cannot be combined on one road, the model results suggested it is better to bundle the roads close together than to distribute them evenly across the landscape.

We also were interested in the question of whether the effect of a road network was determined by the number and size of the pieces ("patches") that it fragments a landscape into or by the total length of roads in the landscape. We expected that the effect of a road network would be the more detrimental the more patches it creates. The results were surprising: The expectation that fragmenting the landscape into more patches would be more harmful to population persistence (while total road length is kept constant) was contradicted by the model results in the case where the degree of road avoidance by the animals was low. This implies that for animals that do not very strongly avoid roads, it is more important to preserve core habitats at a sufficient distance from roads than to keep the number of patches low.

Our results are an important step towards a network theory for road ecology and towards the design of less-detrimental road networks. Empirical studies comparing landscapes with differing road network configurations should be conducted in the future to validate the predictions and to provide a basis for developing more practical models for use in planning and designing of highway networks.

Keywords: barrier effect, bundling of roads, core habitat, landscape connectivity, landscape fragmentation, population viability analysis (PVA), road avoidance, road configuration, roads, spatially explicit population model (SEPM), traffic mortality.

Introduction

Road construction is a major driving force of landscape change almost everywhere in the world today. However, the increase of landscape fragmentation due to transportation infrastructure has a number of undesirable effects on wildlife (Forman et al. 2003). Noss (1993) alleges that roads may be the single most destructive element in the process of habitat fragmentation and pose a major threat to many species. The ecological effects of roads have been considered the "sleeping giant of conservation ecology" (Forman and Alexander 1998). Therefore, there is growing concern about these effects among traffic planners, landscape planners, wildlife biologists, and others involved in the decision-making process about the construction of new roads (Jaeger 2001, 2002; Forman et al. 2003).

The two main ways roads detrimentally affect wildlife populations are by increasing mortality due to collisions with vehicles and by acting as barriers to animal movement, thus effectively fragmenting habitat. They also reduce the amount of habitat and the quality of habitats adjacent to the roads (figure 1). The same amount of traffic can be accommodated by different road networks. Therefore, we asked whether the configuration of the roads, while total length of the roads is held constant, is likely to affect the degree to which roads detrimentally affect animal populations. As the amount of habitat lost due to road construction is relatively small, we focussed on the effects of traffic mortality and habitat subdivision on population persistence.

The effects of roads are expected to depend on animal behavior at the roads. Many studies have documented absolute numbers of animals killed by vehicles (e.g., Stoner 1925, Knutson 1987, Trombulak and Frissell 2000) and several have estimated the proportion of animals killed in relation to overall mortality (otters *Lutra lutra*, Hauer et al. 2002; European badger *Meles meles*, Clarke et al. 1998; hedgehogs *Erinaceus europaeus*, Huijser and Bergers 2000; gray wolves *Canis lupus*, Paquet et al. 1996, Callaghan 2002). Gibbs and Shriver (2002) showed that road mortality may contribute significantly to widespread population declines in turtles in the United States. Hebblewhite et al. (2003) concluded that the black bear population in Banff National Park (Canada) has been declining since 1994; 36 percent of all mortality was highway mortality. Van der Zee et al. (1992) demonstrated that the increasing number of roads was most closely related to the decline of the badger in the Netherlands.

The number of animals killed by traffic depends not only on how often animals encounter roads, but also on their behavior at the roads. How often roads are encountered depends on the configuration of the landscape and on the movement behavior of the species. We characterize the behavior of animals at roads by the degree to which an animal that encounters a road does not attempt to cross it (e.g., Oxley 1974; Wilkins 1982; Mader 1984; Clarke et al. 1998). We call this behavior "road avoidance" (figure 2). If the animals avoid the road entirely, there is no traffic mortality, but the population is entirely separated into smaller subpopulations, each of which will have a higher extinction risk. Recolonization of local extinctions will not be possible, ultimately leading to extinction of the whole population. In some situations, this effect of road avoidance may be even more harmful than the mortality due to vehicle collisions. Therefore, if the animals strongly avoid the roads, traffic mortality is expected to be low and the effect of habitat fragmentation is expected to be more important (Jaeger and Fahrig 2004a, Jaeger et al. 2005).

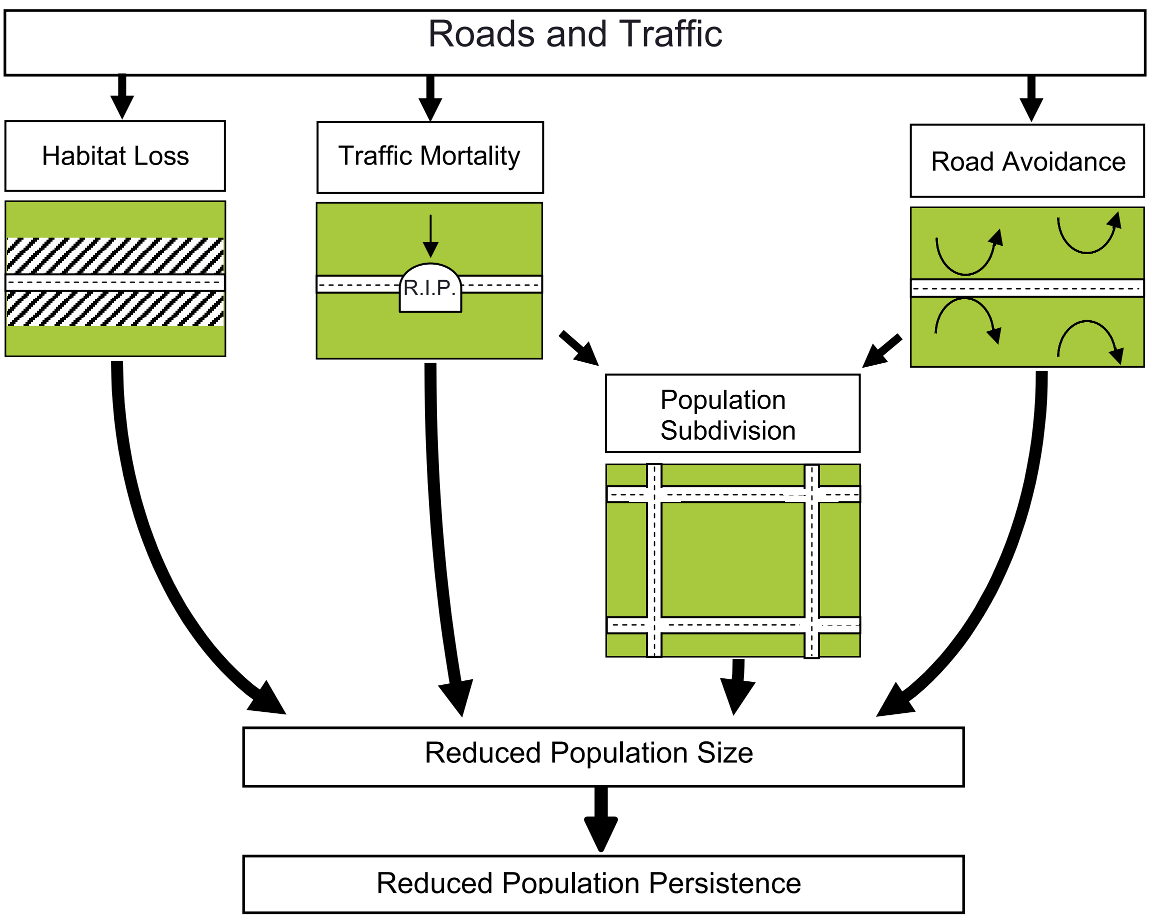

Figure 1. The four impacts of roads and traffic on the persistence of wildlife populations. Both traffic mortality and road avoidance contribute to population subdivision and isolation (modified after Jaeger et al. 2005).

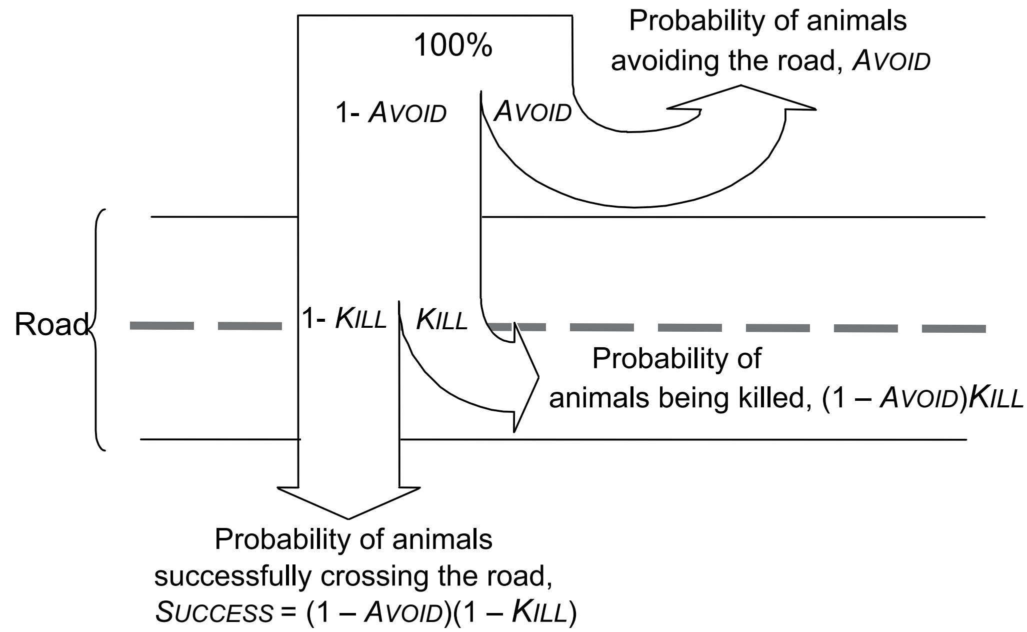

Figure 2. Illustration of road avoidance (*AVOID*) and the probability of animals killed on the road (*KILL*). The two variables are specified independently of each other; their ranges are from 0 to 1. Barrier strength, B, comprises both effects, B = 1 – *SUCCESS* = 1 – (1 – *AVOID*)(1 – *KILL*).

The purpose of this study was (1) to determine whether or not the configuration of road networks has an influence on the degree to which roads detrimentally affect wildlife populations and (2) to identify characteristics of road-network configurations that make road networks less detrimental to the persistence of animal populations. To investigate these questions, we used a spatially explicit individual-based simulation model of population dynamics.

One approach to reduce traffic impacts is to keep as large areas as possible free from disturbances due to traffic. The combination of traffic rather than spreading it out across the entire landscape can be done in two ways: (1) avoiding the construction of new roads by upgrading of existing roads (*"Ausbau vor Neubau"*) and (2) placing unavoidable new roads as close as possible to existing infrastructure, e.g., other roads, railways, canals (*"Verkehrsbündelung"*).

Accordingly, traffic planners and nature conservationists in Germany and Switzerland have proposed and used these two ideas as principles to guide road construction since the 1970s. However, the suitability of this approach may be questionable because a group of several roads bundled together or an upgraded road with more traffic on it creates a stronger overall barrier effect that may be even more harmful to population persistence than the even distribution of roads across the landscape. The effectiveness of the two principles for population persistence has never been tested and there is no direct empirical evidence so far that supports these principles or their criticism.

We also were interested in the question of whether the effect of a road network is determined rather by the number and size of the pieces ("patches") that it fragments a landscape into or by the total length of roads in the landscape. We expected that the effect of a road network generally is that the more patches it creates, the more detrimental the road network is (while total road length is kept constant).

We therefore compared two groups of networks: (1) roads that were evenly distributed across the landscape versus roads that were bundled together in one part of the landscape (close to each other or combining all traffic on one larger road) and (2) a parallel pattern of roads versus a gridded pattern (where the patches or "meshes" form a checkerboard). We recorded persistence probability, times to extinction, and critical road densities, i.e., the density of roads where the probability of population persistence is reduced to 0.5. We discuss our results in the context of road planning decisions and potential mitigation measures.

Methods

We used a stochastic, spatially explicit, individual-based model of population dynamics (Fahrig 1997), which we extended to include roads (Jaeger and Fahrig 2004a, 2004b). The model included three subroutines (for movement, reproduction, and mortality) applied in random order to each individual in each time step. Animals moved on a grid of habitat cells with a given probability: in a straight line to a distance between 0 and a maximum and with an angle between 0 and 360º, chosen randomly. The number of offspring was randomly selected from a Poisson distribution. Mortality was a simple probability. The model was density independent, with the exception that there was a maximum number of individuals permitted per cell. When this maximum was exceeded, the cell population size was reduced to the maximum by random killing of individuals. The model did not include environmental stochasticity or genetic effects.

We used two variables to describe road avoidance and traffic mortality: *AVOID* for the degree of road avoidance (i.e., the probability of an animal avoiding the road when encountering it) and *KILL* for the probability of an animal being killed on the road, given that it attempted to cross (figure 2). Both variables ranged from 0 to 1. Barrier strength (i.e., the combination of these effects), *BARRIER*, also ranged from 0 to 1: *BARRIER* = 1 – (1 – *AVOID*)(1 – *KILL*).

If, on encountering a road, an individual decided not to attempt to cross the road, it moved a second step away from the road for the remainder of its movement distance, with an angle corresponding to a reflection of its path at the road (figure 3). Animals that encountered the edge of the grid were reflected back onto it.

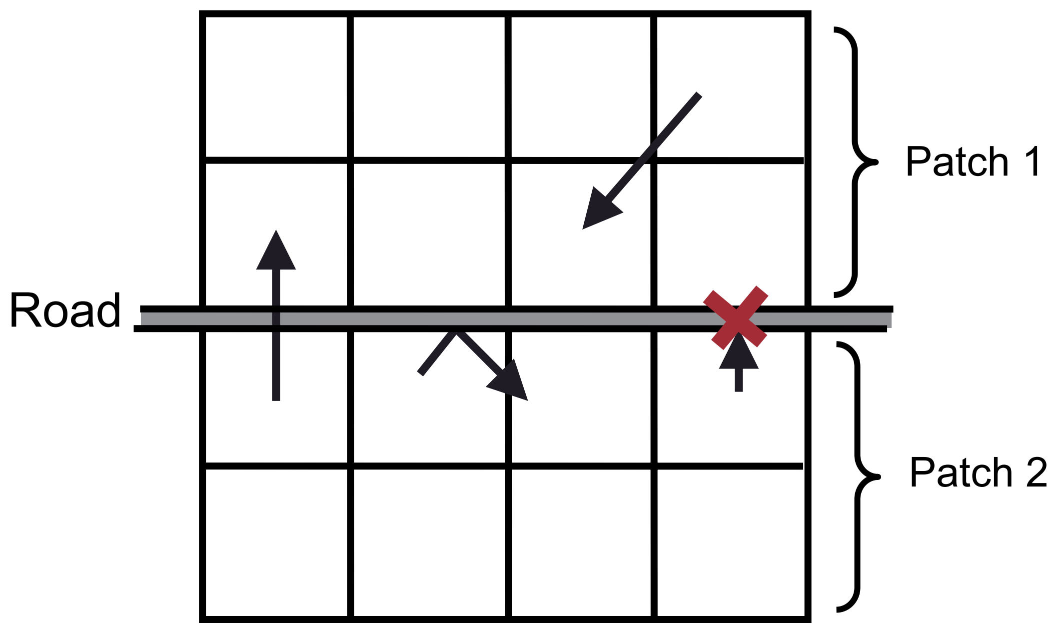

Figure 3. Illustration of the four types of movement of the individuals in the spatially explicit individual-based stochastic-simulation model (for a grid of 4 x 4 cells).

The values of the other parameters used in the simulations are given in Table 1. The demographic parameters were chosen to represent a species with no extinction risk when there was only one road present regardless of the values of *AVOID* and *KILL*, because we were interested in the full range of road effects.

Table 1. Parameter values used in the simulation experiments.

Parameter	Values
Grid size	(1) 48 x 48 (2304 cells; figure 4) and (2) 24 x 24 (576 cells; figure 5)
Starting number of individuals	80
Time steps in simulation	1 000
Mean number of offspring	0.5/individual/time step (Poisson distribution)
Mortality probability	0.33/individual/timestep
Movement probability	1.0/individual/timestep
Maximum cell occupancy	2 individuals
Movement distance distribution	Exponential
Median movement distance	1.7 cells
Maximum movement distance (cut-off)	10 cells

Parameter	Values
Movement direction distribution	Uniform
Road avoidance, *R*	(1) Varied from 0.0 to 1.0 (in steps of 0.1). (2) Varied as a function of traffic volume.
Traffic mortality, *K*	(1) Varied from 0.0 to 1.0 (in steps of 0.1). (2) Varied as a function of traffic volume.
Number of roads	(1) Varied from 4 to 12 for two series of road configurations: (a) equidistant and parallel to each other versus (b) forming a rectangular grid (figure 4). (2) Varied from 1 to 2 in a bundled versus evenly distributed configuration (figure 5.)

We conducted 500 runs for each parameter combination. After each model run, we recorded the number of individuals remaining and the time to extinction if the population went extinct. We calculated persistence probability as the proportion of the 500 populations that survived for 1,000 time steps.

In the first set of simulations, we increased the number of roads and the number of patches using two different series of road patterns (figure 4). In the first series, all roads were equidistant and parallel to each other (patch number increased proportional to the number of roads); in the second, the roads formed a grid pattern and patch number increased as *n* = (*L*/2 + 1)2 where *L* is the number of roads. The roads were assumed to be between the cells of the grid and did not lead to habitat loss, i.e., all cells were habitat cells for all road patterns. We varied both road avoidance, *AVOID*, and traffic mortality, *KILL*, independently between 0 and 1. We recorded the probability of population persistence for these series. We then compared persistence probability of patterns with the same road length but different numbers of patches, and also of patterns with the same number of patches but different road length.

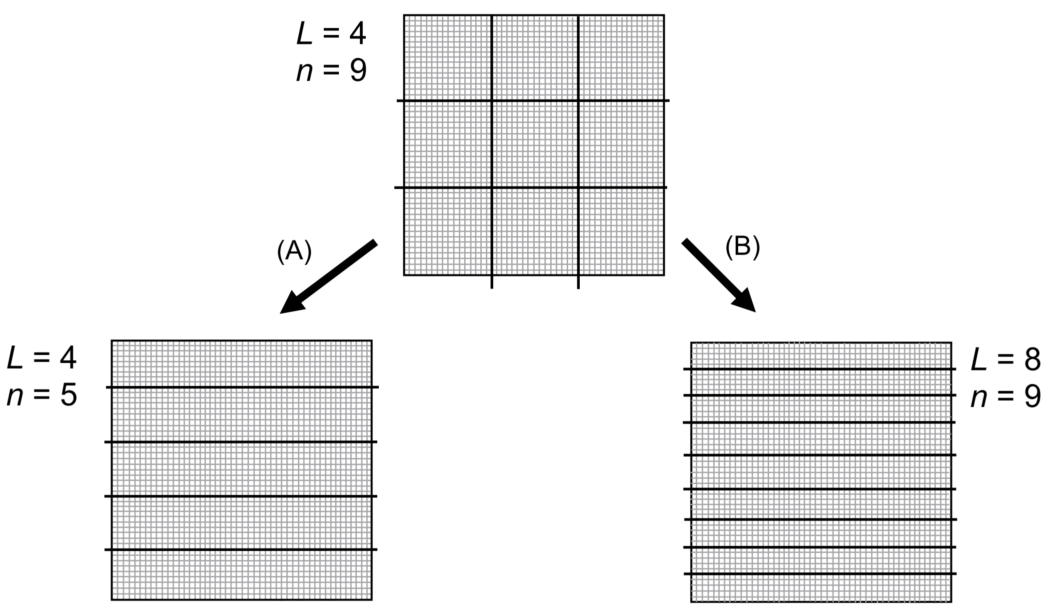

Figure 4. Comparison of two road network configurations (gridded pattern vs. parallel configuration of the roads). The roads (black lines) are between the cells of the model (cells are indicated by the grey lines). (A) Comparing configurations with the same number of roads (*L* = 4) and a smaller number of patches; (B) comparing configurations with the same number of patches (*n* = 9) and an increased number of roads.

In the second set of simulation runs, we used three different road configurations where total traffic volume was the same (figure 5): evenly distributed versus close together versus all traffic combined on one road. Consequently, the number and size of the habitat patches differed among the three configurations.

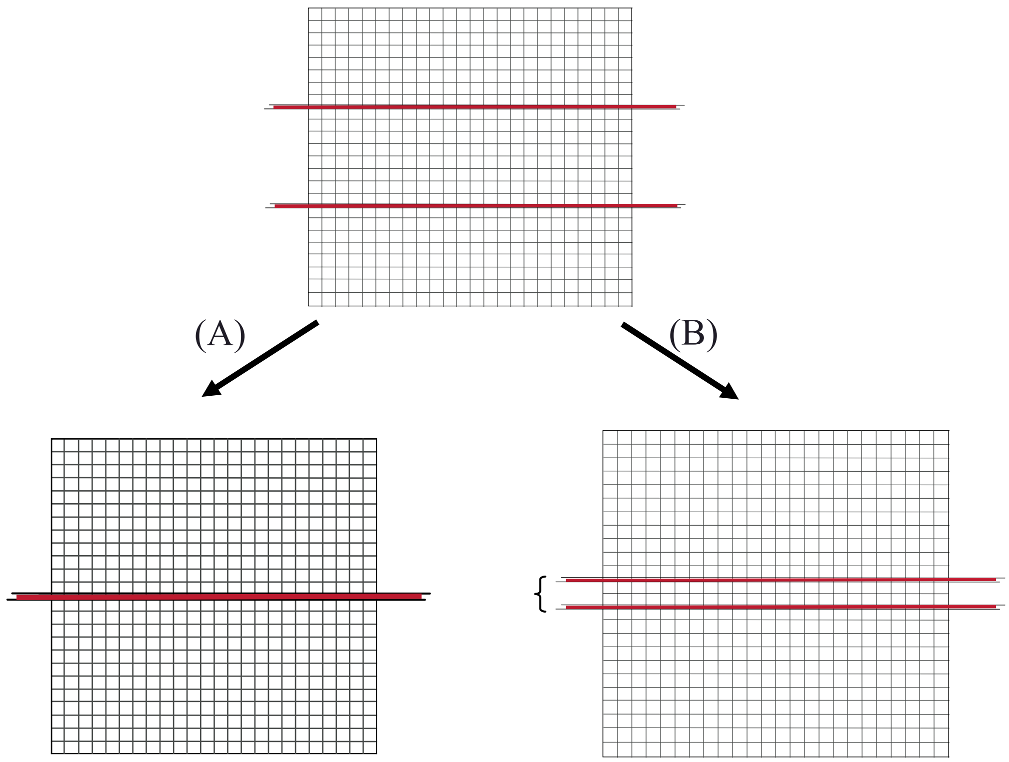

Figure 5: Comparison of three road network configurations (bundled versus evenly distributed). The roads (black lines) are between the cells of the model (cells are indicated by the grey lines). Total traffic amount is the same in all three situations shown. (A) Comparing configurations with two evenly distributed roads and all traffic on one large road and (B) comparing configurations with two evenly distributed roads and two roads located close to each other.

Results

Both extinctions and recolonizations of empty patches by individuals moving across a road occurred in the simulations when *AVOID* < 1. Road configuration clearly had an influence on population persistence.

Comparison of parallel pattern with gridded pattern

For constant degree of road avoidance, the probability of population persistence decreased as a function of increasing traffic mortality (figure 6). For constant traffic mortality, the probability of population persistence increased as a function of increasing road avoidance, *AVOID,* at least as long as road avoidance was below 0.9 (figure 7). For very high values of *AVOID* (i.e., > 0.9), population persistence decreased (figure 7).

In contradiction to our expectation that increasing the number of patches would always reduce population persistence, the effect of the crossed road patterns was in most cases less detrimental than the effect of the parallel road patterns (figures 6 and 7) when *AVOID* was less than 0.7, even though the number of patches in the crossed road pattern was higher than in the parallel road pattern. However, the two lines intersected at some degree of road avoidance which implied that, for higher values of *AVOID*, the impact of the crossed road pattern was more severe than the impact of the parallel road pattern (figure 7), which was in correspondence with out expectation.

A parallel road pattern with higher number of roads, while patch number was constant, always resulted in a more detrimental impact on population persistence than the gridded road pattern (figures 6 and 7).

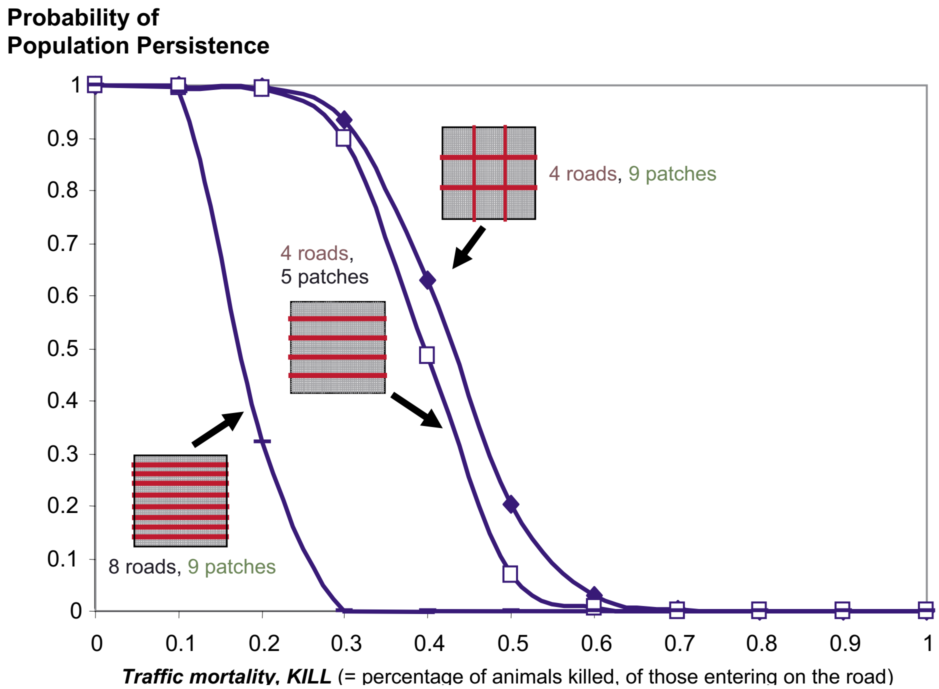

Figure 6: Results of the simulations for comparison of a gridded road configuration (with four roads and nine patches) with a parallel road configuration that has the same number of roads (but fewer patches) and with a parallel configuration that has the same number of patches (but more roads). All patches are of same size within each configuration. Road avoidance, *AVOID*, was kept constant in all simulation runs (= 0.5) while traffic mortality, *KILL*, was varied from 0 to 1.

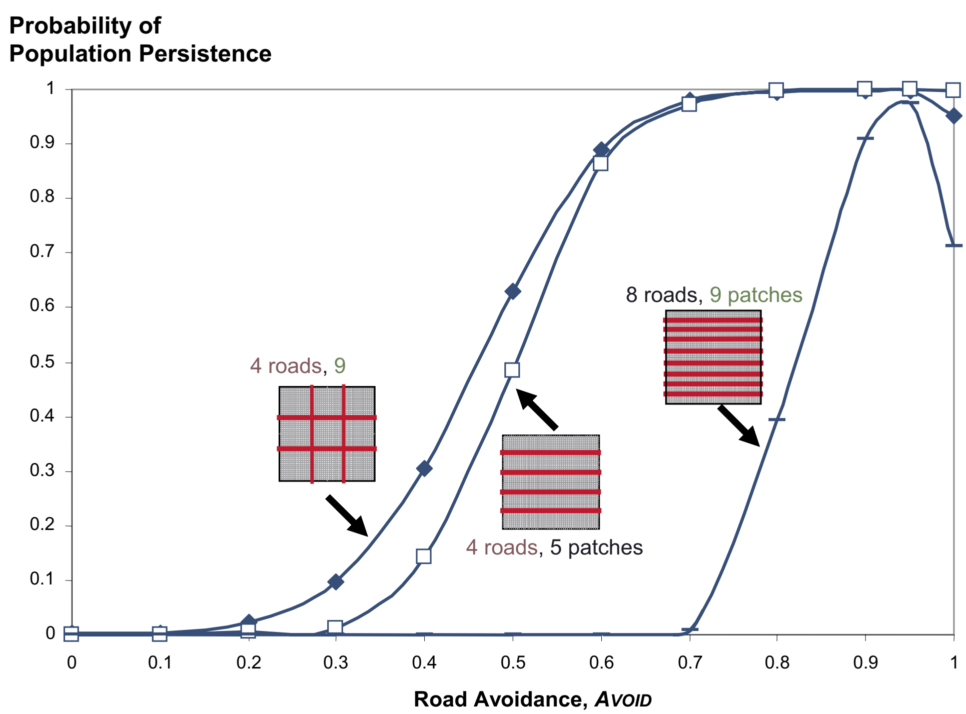

Figure 7: Results of the simulations for comparison of a gridded road configuration (with four roads and nine patches) with a parallel road configuration that had the same number of roads (but fewer patches) and with a parallel configuration that had the same number of patches (but more roads). All patches were of same size within each configuration. Traffic mortality, *KILL*, was kept constant in all simulation runs (= 0.4) while road avoidance, *AVOID*, was varied from 0 to 1.

The comparison of the critical road densities, where population persistence is reduced by 50 percent as a function of increasing road density while traffic mortality, *KILL*, and road avoidance, *AVOID*, are kept constant, also demonstrates that the degree to which roads affect wildlife populations depends on the configuration of the road network (figure 8). For low values of road avoidance, the parallel road pattern was more detrimental. For high values of road avoidance, the gridded road pattern was more detrimental. For intermediate values of road avoidance, both road patterns were equally detrimental to population persistence (figure 8). For more details, see Jaeger et al. (in prep.).

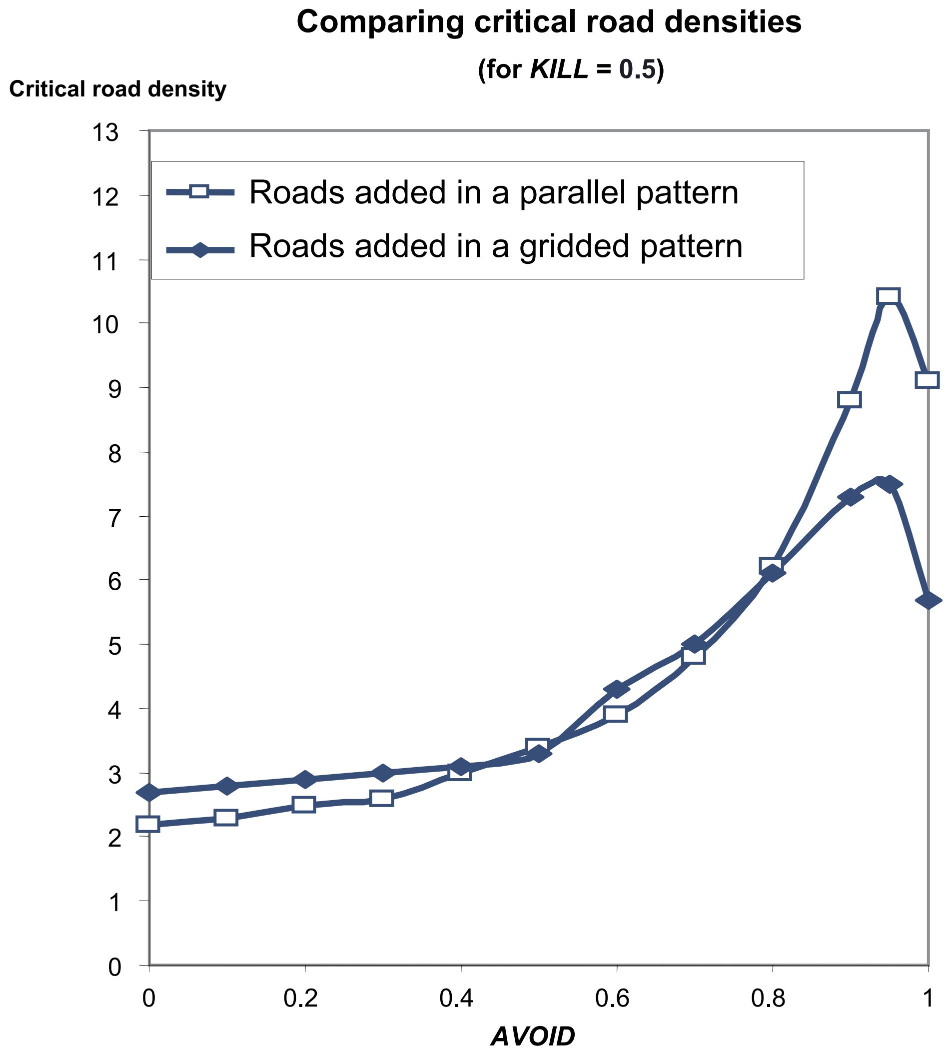

Figure 8. Results of the simulations for comparison of a gridded road configuration with a parallel road configuration. Traffic mortality, *KILL*, was kept constant in all simulation runs (= 0.5) while road avoidance, *AVOID*, was varied from 0 to 1. The critical road density is the density of roads where population persistence probability is reduced to 50 percent. For *AVOID* < 0.4, population persistence was reduced to 50% at lower road densities in the parallel road pattern than in the gridded road pattern, i.e., the parallel road pattern was more detrimental. For 0.4 < *AVOID* < 0.8, both patterns were equally detrimental. For *AVOID* > 0.8, the gridded road pattern was more detrimental, i.e., population persistence was reduced to 50 percent at lower road densities in the gridded road pattern than in the parallel road pattern.

Bundling of roads

We tried several functions for the dependency of *KILL* and *AVOID* on traffic volume (for details see Jaeger and Fahrig, in prep.), starting with data from Seiler (2003) for ungulates. In most cases, putting all traffic on one road was less detrimental (and never more detrimental) than the other two configurations. Two roads bundled in the center were almost always less detrimental (and never more detrimental) than the two roads distributed evenly (figure 9).

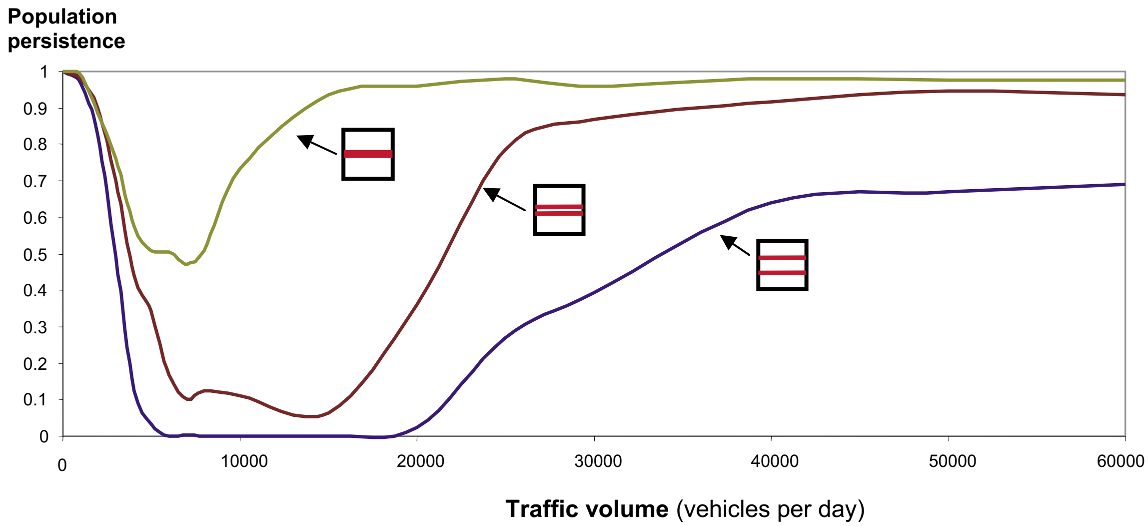

Figure 9: Results of the simulations for comparison of three road configurations (figure 5). The same traffic volume was distributed over two roads distributed evenly or bundled in the center or placed on one large road leaving larger areas undissected, using Seiler's (2003) data on *AVOID* and *KILL*. Natural mortality was 0.32 (per individual and time step). (These curves are based on only 200 model runs per data point.) For details, see Jaeger and Fahrig (in prep.).

Discussion

Our objective was to examine whether the degree to which road networks affect population persistence depends on the configuration of the road networks and on the interaction of the target species with the roads. This dependency has important implications for the management of landscapes. For example, our results suggest that even though a population may show no negative response to a certain number or density of roads, a different configuration of the road network (with the same total length of roads) may cause the extinction of the population.

One example of an animal population that crossed the extinction threshold is the European badger in the Netherlands (Van der Zee et al. 1992). Others that are suspected to be across or close to the threshold are turtles in the U.S. (Gibbs and Shriver 2002), otters in Eastern Germany (Hauer 2002), and badgers in Great Britain (Clarke et al. 1998).

The model results clearly supported the bundling concept. Population persistence was generally higher (and never lower) when all traffic was put on one road than when it was distributed on several roads across the landscape. If traffic cannot be combined on one road, the model results suggested it is better to bundle the roads close together than to distribute them evenly across the landscape.

The results for the gridded versus parallel road pattern were surprising: The expectation that fragmenting the landscape into more patches would always be more harmful to population persistence (while total road length is kept constant) was contradicted by the model results when the degree of road avoidance by the animals was low (figures 7 and 8).

One explanation is that the amount of core habitat is larger in the gridded road pattern (figure 10). Individuals located in the cells close to a road ('road effect zone,' Forman and Deblinger 2000) were more likely to encounter a road during their next movement and be killed if they exhibited low road avoidance (e.g., amphibians). Individuals located in the cells far away from any road (i.e., located in core habitat) would survive during their next movement because they cannot encounter a road. Therefore, there were more cells where individuals were not affected by traffic mortality in the gridded road pattern. However, when road avoidance was high, then the 'road effect zone' became less harmful and the isolation of the patches became relatively more important. In this case, the gridded pattern was more harmful because the number of patches was higher.

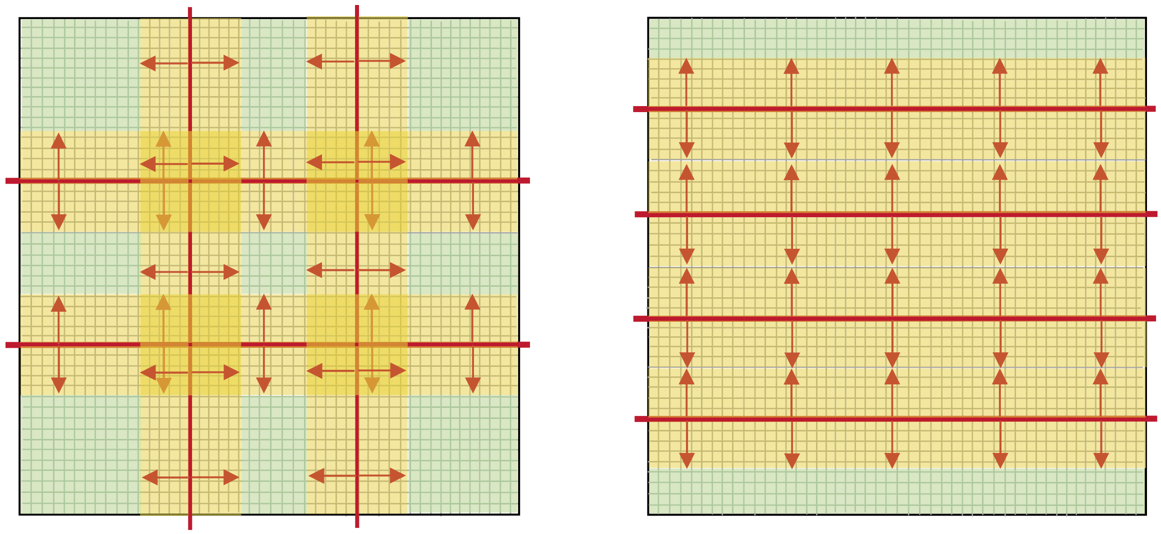

Figure 10: Explanation of why the parallel road pattern was observed to be more detrimental to population persistence than the gridded road pattern when road avoidance is low. Individuals located in the cells close to a road ('road effect zone' indicated by the arrows assumed as extending over five cells) are more likely to encounter a road during their next movement. Individuals located in the cells far away from any road (i.e., located in core habitat) will survive during their next movement because they cannot encounter a road. The gridded pattern (left) has more core habitat (784 cells) than the parallel road pattern (right, 384 cells). Therefore, there are more cells where individuals are not affected by traffic mortality. If road avoidance is high, then the 'road effect zone' is less dangerous for the individuals but the isolation of the patches becomes relatively more important.

Our results indicate that, for animals exhibiting low road avoidance, the effect of the roads is determined by the density of roads and the shape of the patches rather than by the number of patches. Increasing the number of patches (while road configuration changed from parallel to crossed) in many cases increased, or did not decrease, population persistence when road density was kept constant. This was counter to our expectation that increasing the number of patches would always reduce population persistence.

The reason was that the animals encountered the roads less often in the crossed road pattern series because, on average, the locations of the animals were farther away from the nearest road (figure 10). However, for animals strongly avoiding roads, the crossed road pattern often became more detrimental. For animals entirely avoiding roads, the effect of the road network on population persistence is determined by the number (and shape) of the patches rather than the density of roads.

This implies that for animals that do not strongly avoid roads, it is generally more important to preserve core habitats at a sufficient distance from roads than to keep the number of patches low (figure 10).

Our results are qualitative, not quantitative. Several factors will influence the degree to which the road network affects population persistence by affecting the relative susceptibility of the population to additional mortality and population fragmentation. The most important of these factors are habitat loss and reduction of habitat quality. If the animals need access to resources on both sides of the road (landscape complementation, e.g., breeding habitat is on one side, whereas foraging habitat is on the other), crossing the road is mandatory for survival. The effects of both traffic mortality and fragmentation will then be more detrimental.

Conclusion

Most current studies of population viability do not include the effects of roads; if they have been included then only incorporated into the overall mortality rate (e.g., Kramer-Schadt et al. 2004) which does not account for the effects of road avoidance and road configuration. However, the spatial configuration of the road network is potentially an important factor and should be included in viability analyses of animals that are affected by roads.

The degree to which a road network affects wildlife populations depends on the configuration of the road network. Which configurations are less detrimental than others? Our results indicate that this may depend on the behavior of the animals at roads. However, some general statements can be made:

1. It is always beneficial (or never harmful) to bundle the traffic.
2. If road avoidance is low, a gridded pattern is less harmful than a parallel pattern of same total road length because of the amount of core habitat is higher.
3. Core habitat should be maximized if animals are affected by road mortality: Large un-dissected areas should be protected from road construction.

4. If road avoidance is high, then the parallel road pattern is less harmful because the number of patches is lower (i.e., the patches are larger) and traffic mortality is not an issue: The number of patches should be low if road avoidance is high because the animals are strongly affected by isolation.

If animals avoid roads entirely, it is wise to minimize the number of patches (fragmentation) rather than the number of roads. If animals do not avoid roads but are often killed by traffic (e.g., amphibians), it is more useful to minimize the number of roads. When the target species exhibits both road avoidance and traffic mortality (or if their behavior at roads is unknown) then both the number of roads and the number of patches should be minimized.

Putting up fences along both sides of the roads corresponds to 100-percent road avoidance (*AVOID* = 1). Fences separate a population into smaller subpopulations, each of which will have a higher extinction risk. Recolonization of local extinctions will not be possible, ultimately leading to extinction of the whole population. In some situations, this effect of fences is even more harmful than some mortality due to vehicle collisions when there is no fence (Carr et al. 2002; Jaeger and Fahrig 2004a). When the number of roads increases (while *K* and *AVOID* are constant), fencing may become a more useful measure.

Road fencing combined with wildlife-crossing structures has decreased vehicle collisions with ungulates by at least 80 percent (Ward 1982; Lavsund and Sandegren 1991; Child 1998; Clevenger et al. 2001). Fenced roads in combination with crossing structures correspond to roads with *AVOID* < 1 and *KILL* = 0. However, it is unlikely that all roads in any large region will be fenced in combination with crossing structures because of the high costs. Therefore, other measures need to be considered, including the removal of roads. In the case that the animals need access to resources on both sides of the roads, fencing will never be beneficial, unless accompanied by wildlife-crossing structures.

It may also be possible to influence the interaction of the target species with the roads. For example, clearing roadside vegetation or adding reflectors or wildlife detection systems will alter animal and driver behavior, which may change *AVOID* and *KILL*. Finally, it is important to remember that traffic mortality and the degree of road avoidance are affected by traffic volume and speed (e.g., Allen and McCullough 1976; Bertwistle 1999; Hubbard et al. 2000; Seiler 2004, Seiler 2005).

The effects of other factors, such as movement range of the organism, density-dependence in movement rate or population growth rate, possible density-dependence in *AVOID* or *KILL*, environmental stochasticity, and reduced gene flow (possibly leading to loss of genetic variability) are not straightforward. Further research will be necessary to evaluate the direction and magnitude of the effects of these factors on our predictions.

Important topics for future research are:

- Road avoidance behavior (empirical data and modeling)
- Relative importance of total road length and road configuration
- Effect of different habitat types (landscape complementation)
- Effect of different matrix types
- Landscape connectivity, e.g., the effects of overpasses and underpasses and the question of where to place them

The results from this model are an important step towards a network theory for road ecology and towards the design of less-detrimental road networks. Future research should investigate the behavior of animals at roads in empirical studies and focus on how traffic mortality and road avoidance depend on traffic volume. Such data will greatly improve the model predictions.

In addition, empirical studies comparing landscapes with differing road network configurations (while total road length is constant) should be conducted to validate our model results and provide a basis for developing more practical models for use in planning and designing of highway networks.

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Lenore Fahrig is professor of biology at Carleton University, Ottawa, Canada. Dr. Fahrig studies the effects of landscape structure on wildlife populations. She uses spatial-simulation modeling to formulate predictions and tests those predictions using a wide range of organisms, including plants, insects, amphibians, mammals, and birds. Her current work on road-system ecology includes empirical studies of road impacts on small mammal and amphibian populations and movements, as well as generalized simulation modelling of population responses to road networks. Dr. Fahrig has published over 50 papers in landscape ecology. Many of her recent papers focus on ecological impacts of roads. She is currently a member of the U.S. National Academy of Sciences Committee on Ecological Impacts of Road Density.

Klaus C. Ewald has been full professor of nature and landscape protection in the Department of Forest and Wood Sciences since 1993 and since 1998 in the Department of Environmental Sciences of the ETH Zurich, Switzerland. Dr. Ewald studied geography and biology at the University of Basle and graduated in geography in 1969. Afterwards he spent five years as a scientific employee of the Swiss League of Nature Protection. During this period, he continued his education at the Institute of Landscape Management and Nature Conservation at the University of Hanover. A grant form the Swiss National Science Foundation enabled him to carry out one of the first examinations of historical and ongoing landscape changes in Switzerland. From 1977-1986 he established and directed the Section of Landscape Research at the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) in Birmensdorf. He completed his habilitation thesis in geography in 1980 at the University of Basle and lectured on nature and landscape protection. In 1986, Dr. Ewald received a professorship in the Faculty of Forestry Science at the Albert-Ludwigs University in Freiburg im Breisgau, Germany. From 1987 until 1993, he was professor of landscape management and director of the Institute.

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Good and Bad Places for Roads: Effects of Varying Road and Natural Pattern on Habitat Loss, Degradation, and Fragmentation

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Abstract: Improving ecological conditions around the road network is emerging as a significant objective of transportation, along with providing safe and efficient mobility. Reading landscape patterns is a key to success. The prime goal of this article is to identify ecologically appropriate and inappropriate locations for road construction, removal, and mitigation in the network. Other goals include understanding the effect of road location between two large natural patches, and progress in developing an ecologically optimum network form.

Simple spatial models are used with three independent variables: (1) road size or connection, (2) road location relative to natural patch or corridor, and (3) size/width of patch or corridor. Dependent variables are habitat loss, degradation, and fragmentation. Modeling results suggest that in a landscape of dispersed natural patches and corridors, by far the greatest road effect (ecological impact) results from a highway that bisects or highway network that subdivides a large natural patch.

Overall, effects are greatest where a road crosses or is alongside large patches and wide corridors. For both types, the least effect is where a small road is alongside the margin. Road effects are relatively low around narrow corridors and lowest around small patches. Model results indicate that the probability of species crossing between two large natural patches is lowest where a highway slices across near the midpoint.

A highway network has a greater effect on habitat conditions in a natural landscape than in an agricultural or suburban landscape. Habitat degradation appears to have a greater ecological effect than does habitat loss or fragmentation in the landscape. An ecologically optimum road network contains: a few large roadless areas; a few busy roads rather than many lightly used roads; and perforated roads (for species movement) between the large roadless areas.

In conclusion, a simple patch-corridor analysis of a landscape points to clear solutions for locating road construction, removal, and mitigation to maximize ecological benefits. The two overarching principles are minimizing roads in and around large natural patches and maximizing effective habitat connectivity between the large natural patches.

Introduction

Transportation aims to provide safe and efficient mobility. However, a consequence of society's road network is a huge detrimental effect on nature's patterns and processes across the landscape. Roads tend to be relatively straight lines, traditionally curved to avoid hazards and natural topographic features. However, the widespread abundance of natural patches and corridors in the landscape (fig. 1) now, with rigorously documented ecological characteristics, offers a promising new handle for evaluating and minimizing road impacts. With road construction, removal, or mitigation at strategic points, this cumulative impact can be dramatically and efficiently reduced. In this article, I identify spatial patterns, strategic points, and working principles for transportation and society.

Road ecology is the lens for solution. In the 1980s major thinking, initial publications, and government action began in Europe (Ellenberg et al. 1981, Langton 1989, Aanen et al. 1991). In the U.S.A., the conceptual framework for road ecology as a field was first developed in half a chapter of the book, *Toward a Sustainable Future* (National Research Council 1997). Beginning in about 1995, a remarkable energizing interaction sprang up among transportation specialists, ecologists, wildlife biologists, and other scientists in both Europe and North America (Evink et al. 1996, van Bohemen 1996, Forman and Hersperger 1996, Friedman 1997, National Research Council 1997). The widely dispersed lines of thought and evidence quickly coalesced, and were developed into a meaningful body of theories and principles, together with a richness of published studies and useable applications, in the book *Road Ecology* (Forman et al. 2003).

Today, major new highway systems are under construction in China, India, and Eastern Europe. Meanwhile, in the U.S.A., road construction is limited (<1% annual increase) and focused on local development areas near cities (Transportation Research Board 2002). Road ecologists now can often estimate the ecological effect of a small road or a multilane highway for a specific site or local habitat. Similarly, an effect can be estimated, albeit in more general terms, for the broader landscape (fig. 1). Both effects are important for planning and policy.

Habitat loss, degradation, and fragmentation are frequently related to roads and are particularly useful and convenient measures of road effects at both site and landscape scales. Indeed these habitat conditions are readily related to spatial arrangement (effectively distance between road and habitat), to road size (partially a function of width but mainly related to traffic volume), and to size and shape of natural habitat.

Figure 1. Landscape composed of large and small wooded patches, wide and narrow corridors, and an open background matrix. Note wide corridor (right center) providing connectivity for wildlife movement between large patches and small road (upper right) providing human access into large wooded area, with consequent habitat degradation effects. Road ecologists and transportation planners should be able to read these fundamental landscape patterns and pinpoint the ecologically best and worst locations for a busy highway or a small road. Southeastern Australia. R. Forman photo.

The approach for considering natural habitat is a key to this analysis and the consequent pinpointing of good and bad road locations. First, landscape-ecology analyses have highlighted the value of the patch-corridor-matrix model (Forman and Godron 1981, Forman 1995, Bennett 1999). In effect, all points in virtually any landscape are either in a patch, a corridor, or the background matrix, each with simple spatial attributes, such as large-to-small, wide-to-narrow, and perforated-to-continuous (fig. 1). Extensive literature and evidence relates a range of ecological characteristics to these spatial patterns (Forman 1995, Meffe et al. 1997, Bennett 1999, Liu and Taylor 2002, Gutzwiller 2002). Therefore, the arrangement of roads relative to these basic spatial patterns provides considerable insight into landscapes worldwide. Reading this landscape pattern is a key to identifying the best and worst locations for large and small roads.

Thus the broad objectives of this article are to understand the relationship between road network and natural habitat and to provide planning guidelines for the network to improve ecological patterns and processes in the landscape noticeably. The specific questions are:

1. Where in a landscape of natural patches and corridors is the ecologically best place for constructing, removing, or mitigating a road?
2. What is the ecological effect of location of a road slicing between two natural patches?
3. What is the relative importance of road-caused habitat loss, degradation, and fragmentation in different landscapes?
4. What is the ecologically optimum road network form and what are the determinant principles?

Methods and Assumptions

The basic approach is simple spatial modeling using two to four "representative" conditions for each of the variables considered. Independent variables are: (1) road size or connection; (2) road location relative to patch or corridor; and (3) size/width of patch or corridor. The varied patch/corridor forms are also weighted for their relative ecological importance. The dependent variables are habitat loss, degradation, and fragmentation, plus their sum. Independent variables and their combinations are compared to provide understanding of relative, rather than absolute, effects, such as from highest to lowest (ecologically worst to best).

In selecting the conditions or values of each variable, I chose to scale variables to one another relative to expected effects, rather than attempting to use numbers from specific studies which only indirectly relate to the questions here. This procedure helps provide broad applicability to diverse landscapes. However, the conditions chosen inevitably evolve out of my experience observing certain landscapes worldwide, as well as our studies of roads, traffic, birds, and other ecological characteristics in the northeastern USA (Forman and Deblinger 2000, Forman et al. 2002, 2003).

For the roads variable, the following are used for comparison: busy highway, small road, and highway network. I think of "busy highway" as referring to a two-lane or multilane road with more than about 15,000 vehicles per commuter day (Forman et al. 2002), although various factors could lower or raise that traffic level. A small road might have perhaps <8000 veh./day, or even <400 veh./day (AASHTO 2001). In one analysis here, low traffic refers to a small road, and high traffic to a busy highway. A network of small roads is not included in the analysis, though its important role in facilitating human access and disturbance in large natural patches and natural landscapes (fig. 1) is indirectly recognized in the habitat-degradation assay.

For the natural patterns variable, the following are used for comparison: large patch, small patch, wide corridor, and narrow corridor. Natural (ecological) pattern refers to one of these spatial elements in a landscape, which may have formed by natural processes alone or in combination with human activities. A large natural patch is considered to contain many uncommon or rare species in the patch interior, whereas a small patch contains few or none. A wide natural corridor provides for frequent movement along its length of some patch-interior species, whereas a narrow corridor provides for infrequent or rare movement along its length of patch-interior species. For weighting the relative overall importance of the natural patterns, the analysis presents ecological characteristics widely documented in the literature as correlating with the natural patterns are presented in the analysis.

Roads are placed through the middle of a natural pattern or alongside it. In one analysis, roads are placed at different locations across a wide natural corridor connecting two large patches.

In scaling road and natural patterns, the busy highway produces a degradation zone on each side that extends an arbitrary 25 percent of the width of the large natural patch and 75 percent of the wide corridor. A small road has a degradation zone on each side that extends to 10 percent of the width of a large patch, 50 percent of a small patch, and 100 percent of a narrow corridor.

Road effects are measured by habitat loss, degradation, and fragmentation (Forman et al. 2003, van Bohemen 2005). These are separately estimated in the analyses and then summed for an overall effect. Roadkill is not added as an assay since it is strongly related to the natural spatial patterns and the three major habitat variables included. Also, roadkill's main ecological effect seems limited to certain types of species (Mech et al. 1988, Langton 1989, Fahrig et al. 1995, Iuell et al. 2003) . Habitat loss refers to the area of natural habitat removed for a road and its roadsides. Habitat degradation refers to the zone alongside a road where natural habitat is significantly altered. Dozens of factors can degrade adjacent habitat (Forman et al. 2003). However, the two primary causes of a wide zone of habitat degradation here are considered to be traffic noise plus disturbance due to human access.

The third component, habitat fragmentation, at a landscape scale is mainly due to wide swaths of agricultural, residential, and other land, not roads. In this study, fragmentation refers to the functional separation or barrier to natural flows and movements between natural areas on opposite sides of a road. The clearest case is when a busy highway as a partial barrier bisects a large natural patch, corridor, or a natural landscape. However, where the busy highway bisects farmland or residential land that in turn separates two natural patches, the highway further reduces flows and movements between the patches. In this case, habitat fragmentation is increased due to degradation (e.g., by traffic noise) of the agricultural or residential land by the highway.

In one analysis, the overall effect of the road network is compared for agricultural and suburban landscapes versus natural landscapes. Agricultural and suburban landscapes with scattered natural patches and corridors illustrate the patterns of the preceding analyses. In contrast, the natural landscape (such as forest or desert) has a matrix of natural or semi-natural ecosystems where road effects may be quite different.

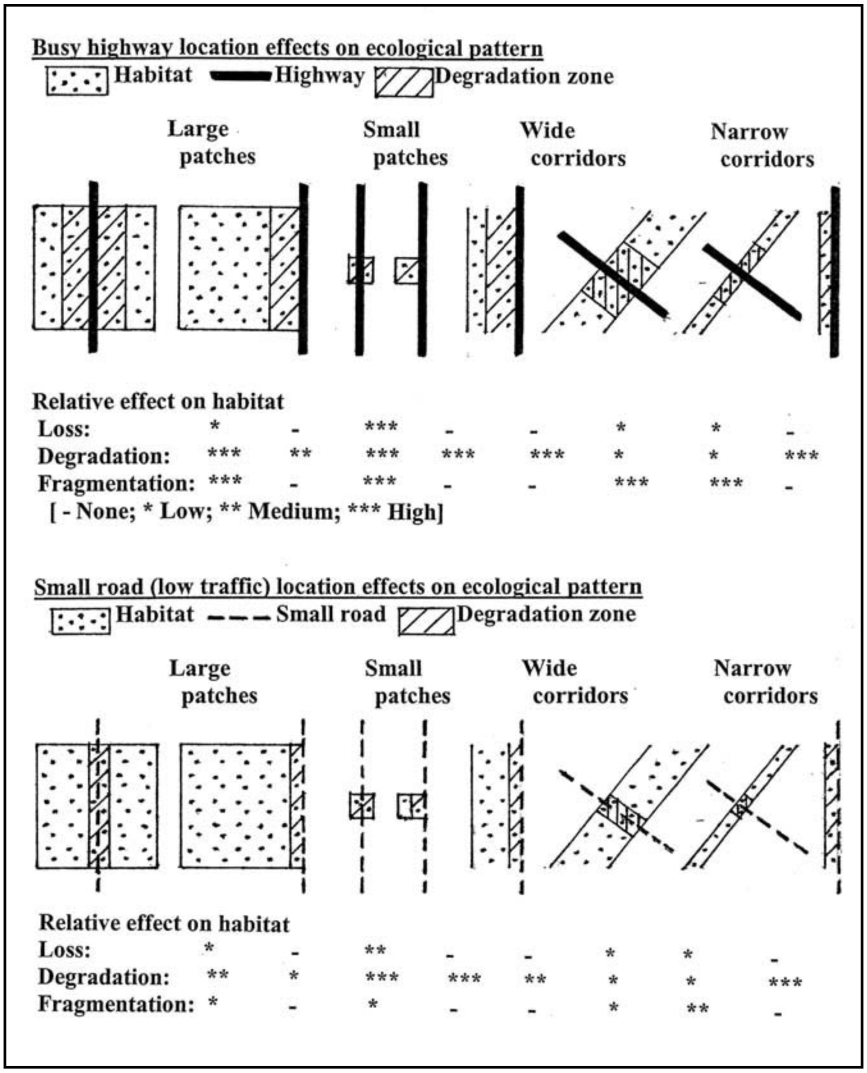

Figure 2. Location of busy highway and small road relative to natural patches and corridors in the landscape. The relative effect of a road on habitat loss, degradation, and fragmentation of a particular patch or corridor is indicated by the number of asterisks in eight columns (corresponding to the preceding eight diagrams) and is estimated based on the spatial arrangements portrayed.

The final question on network form highlights the importance of getting beyond the useful but preliminary concept of road density to understand the ecologically optimal form of a road network for a landscape or region. This is an evolving search, with one additional key principle and pattern added to the two principles previously identified for an optimum network (Forman 2004).

Results and Discussion

Roads relative to natural patches and corridors in the landscape

When a busy highway is placed across the center of a large natural patch, relatively little of the overall habitat is directly lost (fig. 2, top). However, the spatial model suggests that a considerable amount of habitat is degraded and that the large patch is noticeably fragmented. The relative effect of placing the highway alongside a large patch is much lower, since there is no habitat loss or fragmentation and the area of habitat degradation is less. Placing the busy highway across or alongside a small natural patch (fig. 2, top) has a major impact on that patch. Overall, a highway across or alongside a wide or narrow corridor produces an intermediate effect on habitat conditions (fig. 2, top). Alongside the corridor, the highway produces severe habitat degradation, whereas crossing the corridor the highway has a major habitat-fragmentation effect.

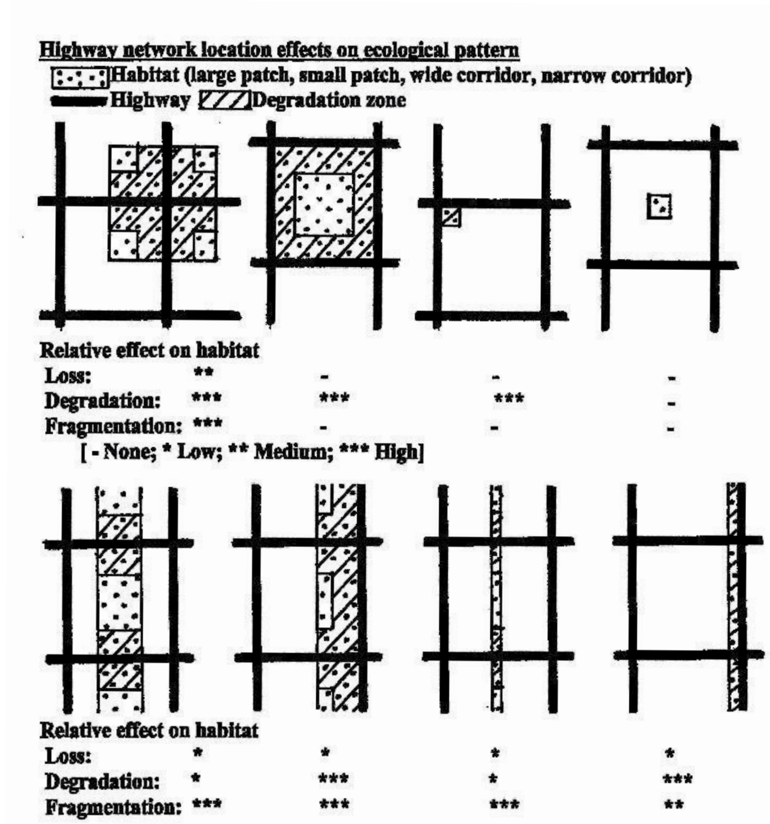

Figure 3. Location of highway network relative to natural patches and corridors in the landscape.

Spatial patterns of nature with associated ecological characteristics

***1. Large patches*: Clean aquifer/groundwater protection**
Connected headwater stream network
MVP of patch-interior species
Large-home-range species
Facilitate semi-natural disturbance regime
Microhabitat proximities for multihabitat species

***2. High corridor connectivity*: Continuous habitat**
Facilitates dispersal of species
Recolonization of large patches
Gene flow reduces inbreeding depression

***3. Small patches*: Stepping stones for dispersal & recolonization**
Protect isolated microhabitats & species
High species densities
Escape_cover

***4. High boundary length*: Enhances game species in edge**

***5. Low boundary length*: Reduces edge and often exotic species**

***6. Low corridor connectivity*: May reduce spread of exotics & pests**
Decreases gene flow

Figure 4. Major ecological characteristics associated with natural patches and corridors in the landscape. Ecological characteristics are synthesized from two decades of extensive literature.

A small road placed across or alongside natural patches and corridors produces a similar, though less-severe overall effect on habitat conditions (fig. 2, bottom). The number of “effect asterisks” provides a summary effect of habitat conditions for each of the 16 patch/corridor and road combinations (fig. 2, top and bottom). Thus, in this preliminary analysis, the most severe effect (nine asterisks) is where a highway crosses a small natural patch and the least effect (one asterisk) occurs where a small road passes alongside a large patch.

The relative effects of a highway network on the natural patches and corridors highlight additional patterns. The greatest effect illustrated (eight asterisks) is where the network crosses and subdivides a large patch into sections (fig. 3). The effect is also severe (seven asterisks) where the network passes both along and across a wide corridor. The least effect is in the case of a small patch in the center of a network enclosure. These preliminary summary effects refer to the specific ecological spatial patterns, such as a large patch or narrow corridor.

However, since the ecological spatial patterns are clearly of different overall ecological value, the results of figures 2 and 3 are now weighted for ecological value (fig. 4). Large natural patches are by far the most important (Forman 1995, Meffe et al. 1997, Gutzwiller 2002). Wide corridors are considered to provide better connectivity for species movement than narrow corridors (Forman 1995, Bennett 1999, Gutzwiller 2002). Small patches provide less benefit (Forman 1995, Meffe et al. 1997, Gutzwiller 2002). Boundary length conditions and low corridor connectivity are considered to be of still lower ecological priority in the landscape (Forman 1995) and are not included in the analysis.

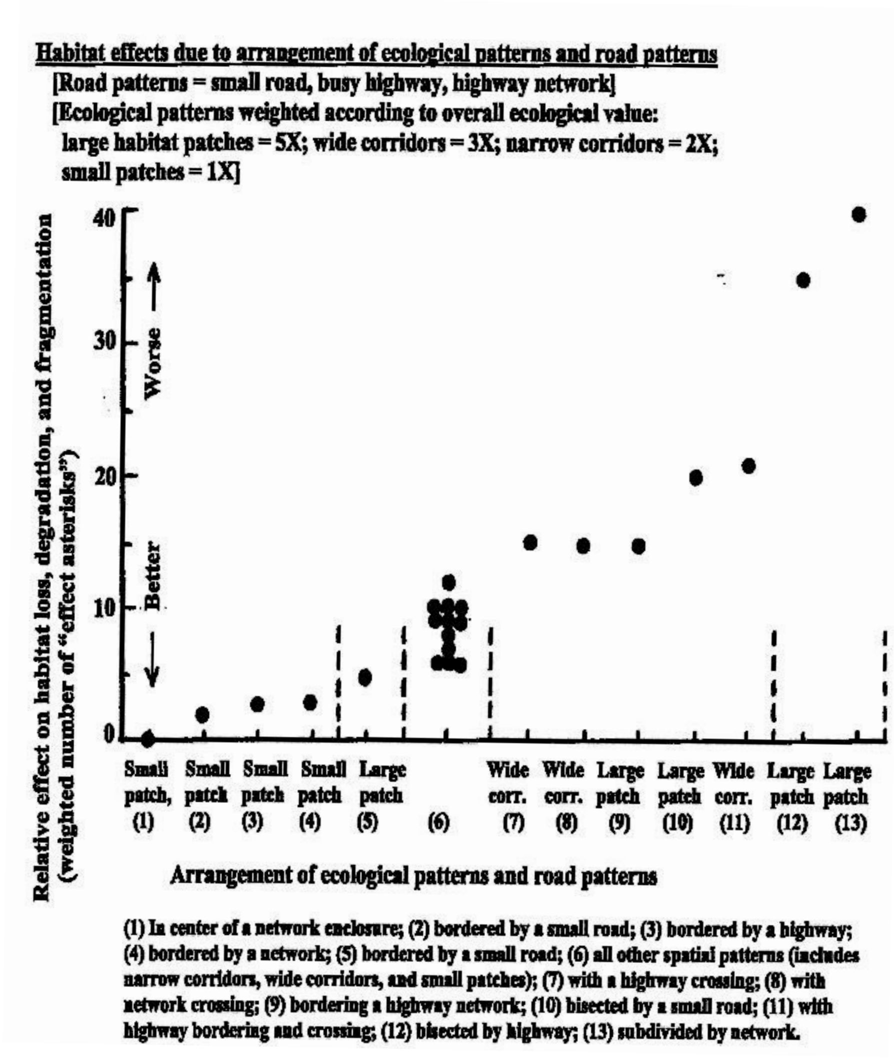

Figure 5. Summary of habitat effects according to arrangements of ecological and road patterns. The ecological effect of 24 arrangements of roads relative to patches/corridors in a landscape were separately estimated [– None; * Low; ** Medium; *** High] for habitat loss, degradation, and fragmentation (figs. 2 and 3). Natural patches/corridors were then weighted for overall ecological values (see top of figure). Weights were multiplied times the number of asterisks to give a weighted number of “effect asterisks” for each of the 24 spatial arrangements.

Thus the ecological spatial patterns are arbitrarily weighted for ecological value as follows: large natural patches = 5X; wide corridors = 3X; narrow corridors = 2X; and small patches = 1X (for large patches 10 to 20X is more realistic, but using the conservative 5X gives about the same comparative results). The weights are then multiplied times the summary number of habitat "effect asterisks" for each of the 24 patch/corridor and road/network conditions in figures 2 and 3. In this way, the relative effect of arranging road and ecological patterns on habitat loss, degradation, and fragmentation in the landscape can be estimated.

Based on the spatial model, by far the greatest effects are where the highway or network bisects or subdivides a large natural patch (fig. 5). Relatively large effects occur for most other road arrangements involving large patches, as well as wide corridors. The effect of roads crossing or along narrow corridors is relatively low. The least ecological effect is where roads are placed on or next to small natural patches (fig. 5). Although small patches may be severely affected, normally they are of relatively little ecological value.

A closer look at road arrangements relative to the important large natural patches and wide corridors is instructive. The highway or network that bisects or subdivides a large patch (fig. 6, top) effectively destroys many of the large-natural-patch values (fig. 4). Serious degradation of habitat conditions occurs in five of the large-patch and wide-corridor arrangements (fig. 6, top and bottom): a highway network surrounding a large patch; a small road bisecting a large patch; and three cases where a highway crosses a wide corridor. In another five ("try to avoid") arrangements, habitat effects are noticeable, though less severe. Unlike these important large-patch and wide-corridor cases, the overall effects of placing roads across or alongside small patches and narrow corridors are relatively minor (fig. 5).

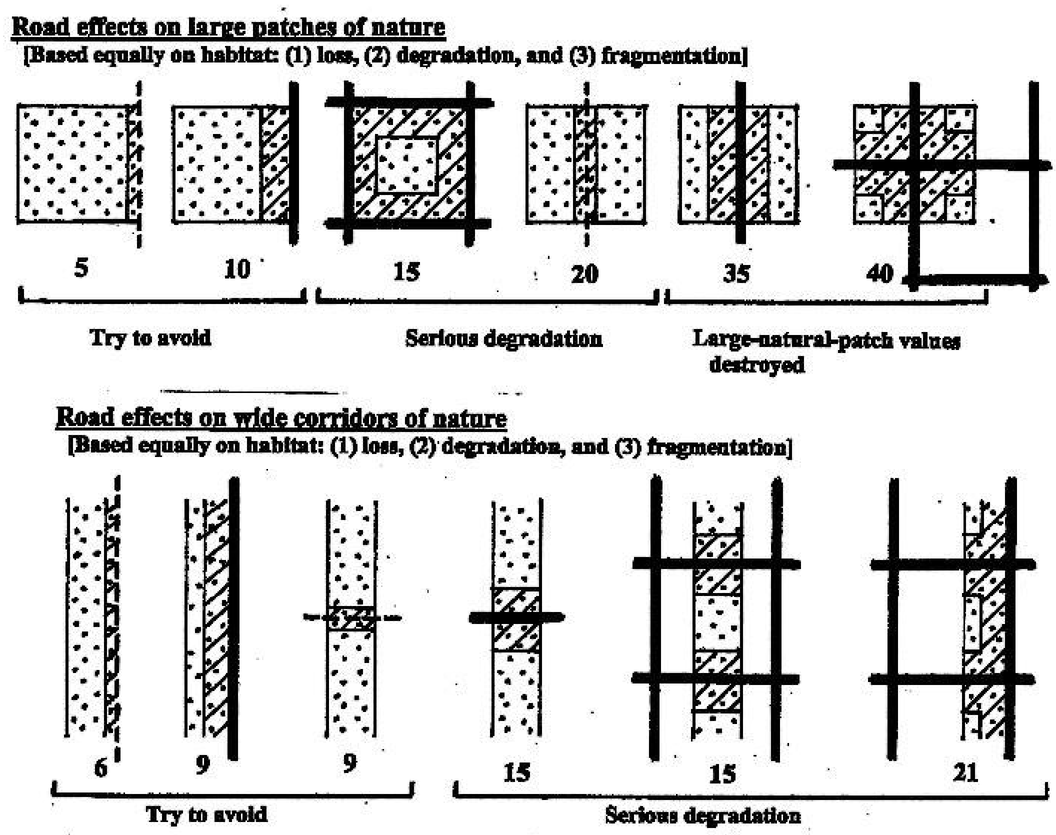

Figure 6. Busy highways and small roads relative to large patches and wide corridors, which are the most important natural patterns. Numbers refer to the weighted number of "effect asterisks" (fig. 5), and represent most of the arrangements of roads and patches/corridors with the greatest ecological effect.

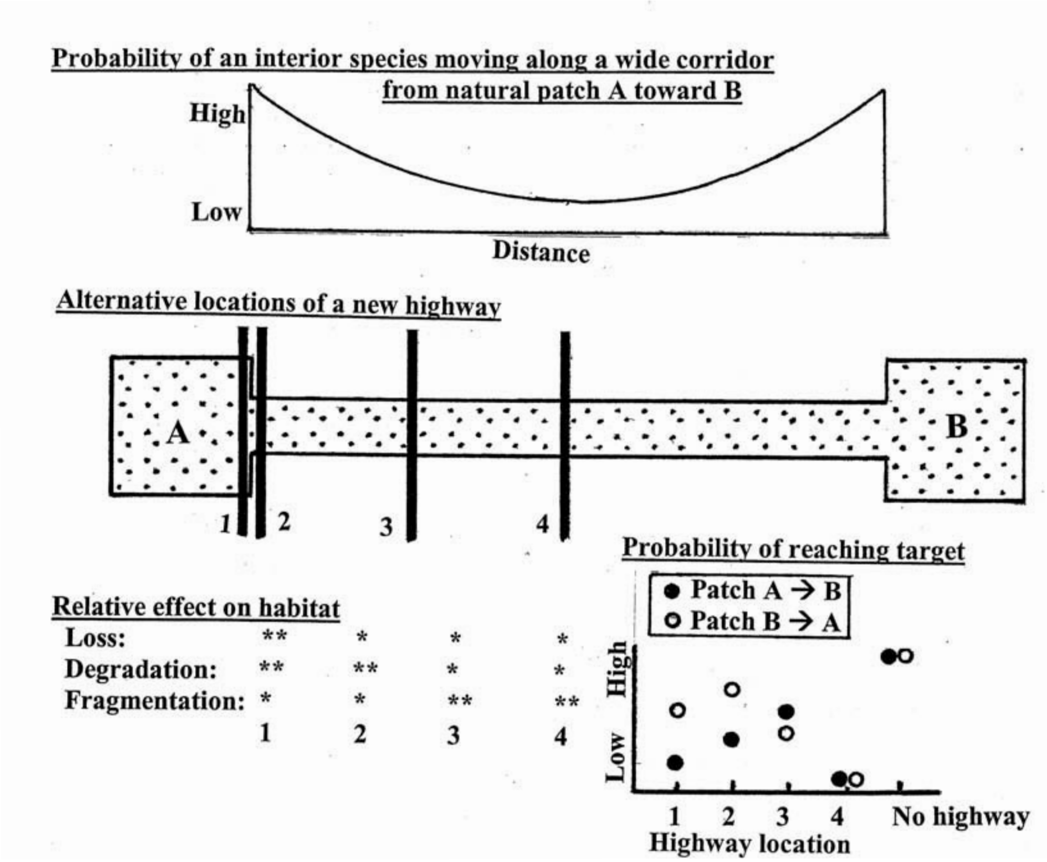

Figure 7. Location of a highway and the probability an interior species will successfully cross between large natural patches. Large habitat patches A and B are connected by a wide natural corridor. Curve at top is hypothesized based on scattered literature evidence. Numbers indicate alternative highway locations. Graph in lower right is estimated based on curve at top plus habitat effects in lower left.

Road location between two natural patches

Consider an interior species moving along a wide corridor from large natural patch A toward large patch B (fig. 7, top). Initially, there is a high probability of moving forward, but with distance the probability drops as animals progressively become further from their preferred habitat in A (Wegner and Merriam 1979, Forman and Baudry 1984, Bennett 1999). Perhaps after passing the midpoint, the animals see or realize that they are now closer to the target patch B, so the probability of onward movement increases.

Now consider the effect on species movement of adding a busy highway that slices between the large natural patches (fig. 7, middle). The highway could be in the edge of patch A, alongside the patch, cross at about 25 percent of the distance along the corridor, or at the midpoint between the patches. The loss, degradation, and fragmentation measures suggest that road locations would all have about the same summary effect on habitat conditions of the large patches and wide corridor (fig. 7, lower left).

However, combining this effect on habitat conditions with the forward-movement probability (fig. 7, top) provides insight into the probability of an interior species reaching a target patch (fig. 7, lower right). The spatial model indicates that a highway at the midpoint between patches results in the lowest chance of species reaching a target patch. For species movement from patch A to B, the greatest success rate is where a highway is a quarter of the length along the corridor. However, for an animal moving in the opposite direction from patch B to A, the highest probability of successful movement appears to be with a highway alongside patch A. Locating a highway at the 25 percent point between patches may be the best ecological solution.

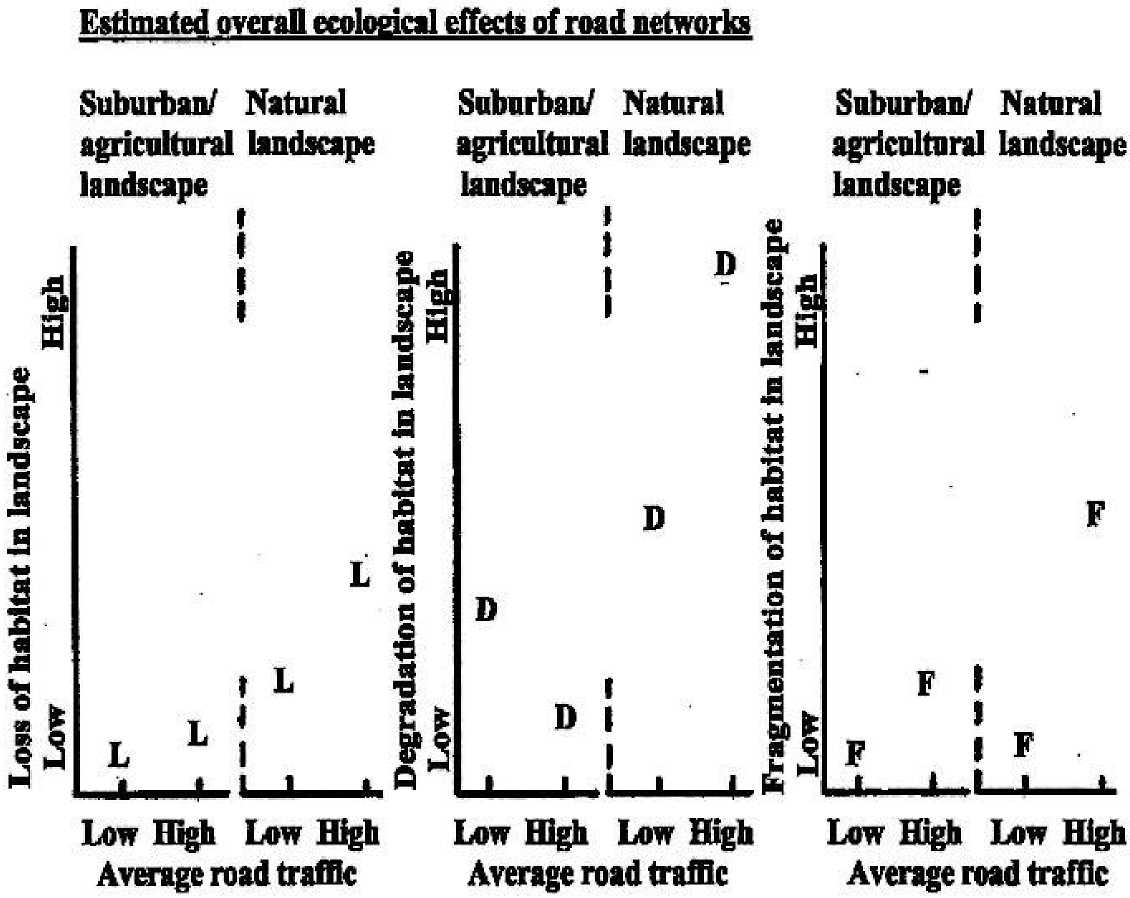

Figure 8. Estimated overall effects of road networks on habitat loss, degradation, and fragmentation in different landscapes. Suburban and agricultural landscapes typically have dispersed natural patches and corridors present, whereas natural landscapes are mainly covered with natural or semi-natural habitat.

Road-caused habitat change in different landscapes

The patches-and-corridors analysis (figs. 2 to 6) is particularly applicable in suburban and agricultural landscapes, where land-use change has resulted in natural patches and corridors in a matrix less suitable for patch-interior species of conservation interest. In contrast, a natural landscape contains a matrix of natural or semi-natural habitat in which a road network typically has been built. Thus the relative effect of habitat loss, degradation, and fragmentation due to the road network can be expected to differ in different landscape types. A network of low-traffic small roads probably also differs in effect compared to a network of high-traffic busy highways.

The three graphs in figure 8, which are based largely on qualitative estimates, suggest that the overall ecological effect of a road network is greater in a natural landscape than in a suburban or an agricultural landscape. The graphs also indicate that habitat degradation has the greatest effect in different landscapes and that (relatively) habitat loss is a minor effect. High-traffic roads have a greater effect than low-traffic ones.

One exception appears in the suburban or agricultural landscape, where low-traffic roads are the primary access for human-caused habitat degradation in the interior of large natural patches (fig. 8). The habitat fragmentation effect of high-traffic roads in suburban and agricultural landscapes is due in part to the degradation effects alongside highways passing through built land or farmland.

Ecologically optimum network form

Road density has often been used as an overall measure of the effect of a road network on wildlife populations (Mech et al. 1988, Mladenoff et al. 1995, Forman and Hersperger 1996, Clevenger et al. 1997). It has also been related to hydrologic conditions, stream density, fire ignition and control, human access effects, and indeed overall ecological conditions in a landscape (Jones 2000, Jaeger 2000, Forman et al. 2003). Yet, although easily measured and communicated, road density is a relatively crude or general measure.

Network form appears to be a much more sensitive measure of ecological conditions, but as yet is little studied (Reed et al. 1996, Tinker et al. 1998, Forman and Mellinger 1999, Jaeger 2002, Forman et al. 2003).

Two principles and consequent patterns have been identified in the search for an optimum ecological network form (Forman 2004): (1) maintain a few large roadless natural areas and (2) concentrate the bulk of the traffic onto a small number of large roads. Large natural areas sustain clean water-supply aquifers, interior species of conservation interest, and much more (fig. 4). One large highway creates less area impacted by noise, emissions, and habitat loss than do two small highways (Ellenberg et al. 1981, Forman et al. 2003).

A third principle is proposed here: perforate or mitigate roads that separate the large natural areas. The goal is to maintain effective species connections among the areas and thus sustain viable populations of key interior species.

The three principles are listed in order of overall significance. More are likely to be identified or developed. Many network forms can accomplish these three principles. One promising network form is presented with the principles illustrated (fig. 9).

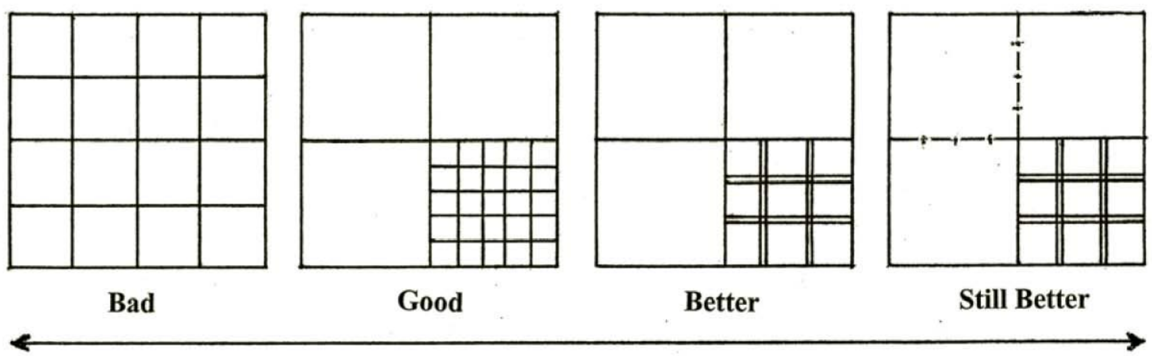

Figure 9. Road network form, illustrating three principles underlying an ecologically optimum network. The principles: (1) maintain a few large roadless natural areas; (2) concentrate the bulk of the traffic onto a small number of large roads; and (3) perforate or mitigate roads that separate the large natural areas. See Forman (2004); also Forman (1995), Forman et al. (2003).

Conclusion

The patch-corridor-matrix model of landscapes provides a convenient, effective, and readily understood handle for prioritizing locations for road construction, removal, and mitigation to provide ecological benefits. The results of the patch-corridor and road analyses presented point to two overarching principles for planning and policy: (A) minimize roads in and around large natural patches or areas and (B) maximize effective habitat connectivity between the large natural patches. Both are accomplished in strategic locations with new-road avoidance and/or road-segment removals (Kruse 1998, Iuell et al. 2003, Forman et al. 2003, Switalski et al. 2004). The second technique can also include road mitigation and compensation, including wildlife underpasses and overpasses, roadbed and road surface modifications, woody vegetation in roadsides, and other approaches (Friedman 1997, Iuell et al. 2003, Forman et al. 2003, Forman 2005, Clevenger and Waltho 2005, van Bohemen 2005). Several more-detailed guidelines are also pinpointed in this article.

I sense that these are sufficiently important and straight-forward (indeed compelling) to become guidelines in road construction, road removal, and road mitigation. Implementation will visibly accomplish a vision: a sustainable emerald network of large natural patches connected by major wildlife, water, and walker corridors across landscapes, effectively meshed with a road network providing safe and efficient mobility for people and goods.

Major societal objectives will be combined on the land. The conservation community should become strong supporters and collaborators with transportation.

Biographical Sketch: Richard T. T. Forman is the PAES Professor of Landscape Ecology at Harvard University, where he teaches ecological courses in the Graduate School of Design and in Harvard College. His research and writing include landscape ecology, road ecology, land-use planning and nature conservation, and urban-region ecology. He received a B.S. (Haverford College), Ph.D. (University of Pennsylvania), honorary Doctor of Humane Letters (Miami University), and honorary Doctor of Science (Florida International University). He has taught at Rutgers University and the University of Wisconsin, served as president or vice-president of three professional societies, and received awards and honors in Australia, China, Colombia, Czech Republic, England, France, Italy and the U.S.A. He has authored numerous articles and his books include *Landscape Ecology* (1986), the award-winning *Land Mosaics* (1995), *Landscape Ecology Principles in Landscape Architecture and Land-use Planning* (1996), *Road Ecology* (2003), and *Mosaico territorial para la region metropolitana de Barcelona* (*Land Mosaic for the Greater Barcelona Region: Planning a Future*) (2004).

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Regional Analysis for Transportation Corridor Planning

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Abstract: Developing regional assessments of environmental needs can help streamline the environmental-review process for transportation projects, thus leading to faster and less-costly reviews and more effective biological or ecological mitigation. This study is a demonstration of a rapid-assessment approach using a high-resolution vegetation map derived from agency data to model 12 endangered or threatened species' potential occurrence on 6638 polygons. Those units, occurring on 44 capacity-improvement sites along the 315-km of State Highway 99 in the study, were classed to measure their degree of similarity, thus permitting estimates of the potential for multi-project mitigation planning.

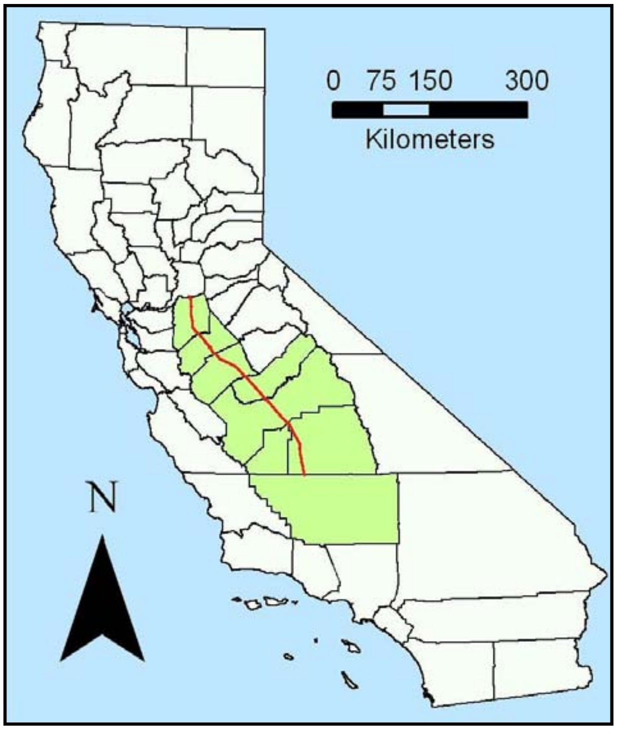
Introduction

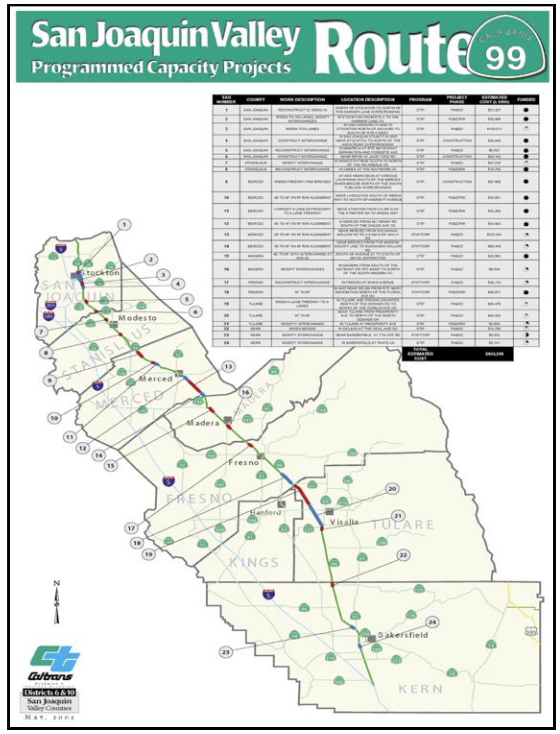
Land use and natural resources planning in the United States is often conducted project by project. Through this practice, we fail to assess cumulative impacts of sequential transportation projects or to plan comprehensively for natural resources, for land use, and for the transportation demand associated with land use on a regional basis. Similarly, environmental-mitigation planning for transportation projects is generally conducted piecemeal, although some efforts are underway to use regional contexts to inform the planning process. Interesting examples may be found in Florida (Florida Department of Transportation 2001); Oregon (Oregon Bridge Delivery Partners 2005); San Diego, California (San Diego Association of Governments 2005); and Merced County, California (McCoy and Steelman, ICOET Conference Proceedings 2005).

In California, 7,868 individual transportation projects with potentially adverse environmental impact were conducted in 1999. Of these, 436 were serious enough to require full Environmental Impact Reports (EIRs) and 2,700 relied on some exemption to regulation. In 2,000 projects, negative declarations were filed, claiming that each project would have no significant environmental impact (CEQANet Database 2005). The pressures of growth have not lessened in the intervening years: to date in 2005, 8,826 projects have been registered (CEQANet 2005), foreshadowing a yearly total of over 10,000.

Our interest was to explore how developing contextual biological information could potentially aid in streamlining of environmental review, decreasing costs associated with environmental review, and improving the quality of mitigation projects for a subset of the current projects. We examined a 315-km stretch of State Highway 99 in the San Joaquin Valley on which 150 projects are currently planned (figures 1 and 2). Of these, 18 are programmed and valued at about $1 billion. An additional 26 projects are planned and 44 projects are capacity enhancing (California Transportation Information System (CTIS) 2005). State Highway 99 is one of the oldest and most heavily used highways in California and was the location of the first highway divider (Dr. June Carroll painted a white line down the middle of the road) ever built (Wikipedia 2005). It carries the majority of the long-distance traffic in the western San Joaquin Valley of California, spanning seven counties. State Highway 99 represents one of the most productive agricultural regions in the world and serves a number of rapidly growing cities (Sacramento, Stockton, Modesto, Fresno, Turlock, Visalia, and Bakersfield) and the southern Sierra Nevada mountains (CalTrans 2005).

We used a high-resolution (from one-square-foot imagery) vegetation map (derived from California Department of Transportation (CalTrans) DHIPP inventory imagery) that spans 1 km to either side of the highway. We used the vegetation types in the map to model the potential distribution of 12 endangered or threatened species using a multiple-logistic regression approach. The number and composition of potential species at each of the 44 capacity-improvement highway sites was determined. Using a clustering algorithm, the degree to which the capacity sites contained similar modeled species was calculated. This permitted an early assessment of which sites might have similar mitigation requirements, potentially allowing contextual planning of mitigation activities that will have greater ecological value to the target species than mitigation projects conducted on a site-by-site basis.





Figures 1 and 2. Study Area. The study uses the section of the Highway 99 landcover map found in Fresno and Madera Counties, California. The maps show the southern extent of Highway 99, the seven counties in which the identified projects are happening, and the location of the modeling efforts presented in red. Fig. 2 courtesy of the California Department of Transportation.

Methods

We digitized polygons from 1-ft resolution ortho-rectified digital imagery using heads-up digitizing (figure 3; ESRI 2005). The polygons were then labeled with vegetation types according to the Manual of California Vegetation (Sawyer and Keeler-Wolf 1995, Thorne et al. 2004). In addition, USGS Anderson landcover classes were used for Urban and Agriculture (Anderson et al. 1976). The resulting landcover map had 38 landcover classes. These landcover classes were then used for modeling potential species ranges or habitats.

Twelve species were chosen in consultation with state and federal wildlife agencies for the initial assessment to represent both species of the greatest policy concern to conservationists and regulators and a diversity of ecological characteristics. The 12 species selected for modeling represented a variety of taxa, including:

- Two amphibians, the western spadefoot toad (*Spea hammondii*) and the California tiger salamander (*Ambystoma californiense*)
- Two reptiles, the giant garter snake (*Thamnophis gigas*) and the blunt-nosed leopard lizard (*Crotaphytus wislizeni silus*)
- Two birds, the burrowing owl (*Speotyto cunicularia*) and the Swainson's hawk (*Buteo swainsoni*)
- Two mammals, the San Joaquin kit fox (*Vulpes macrotis mutica*) and the Tipton kangaroo rat (*Dipodomys nitratoides nitratoides*)
- Two plant species, Colusa grass (*Neostapfia orcuttii*) and Heartscale (*Atriplex cordulata*)
- Two invertebrate species, the vernal pool fairy shrimp (*Branchinecta lynchii*) and the valley elderberry longhorn beetle (*Desmocerus californicus dimorphus*).

While this is not a complete list of species of concern in the region, the combined habitat needs of these species represents a broad set of habitats in the study area.

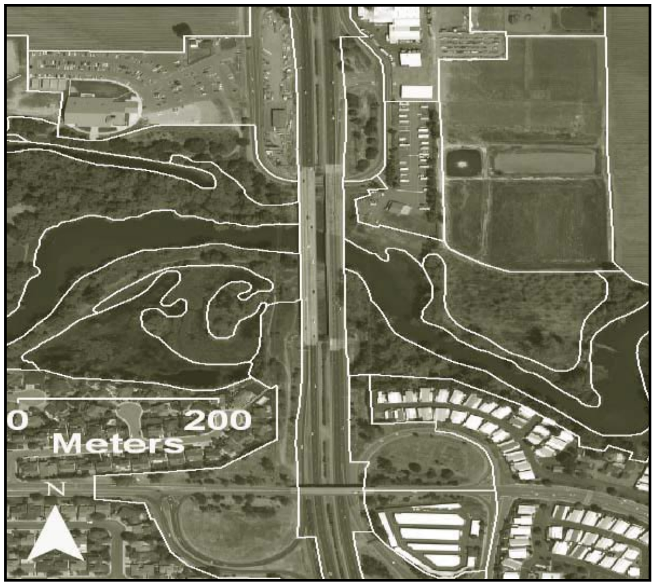


Figure 3. A section of imagery, with the polygon layer superimposed.

Species modeling was a two-step process. In the first phase, we developed a statewide range map for each species, using a logistic regression (Carrol et al. 1999; Guisan and Zimmermann 2000; Thorne et al. unpublished). In this process, we overlaid species-occurrence data (at least 20 occurrences per species) from the California Natural Diversity Database (California Department of Fish and Game, 2004) on a raster stack of 11 environmental-predictor variables. The environmental-predictor variables included five climate layers (annual precipitation, January minimum temperature, July maximum temperature, July precipitation, and summer relative humidity) derived from the PRISM climate data set (Climate Source 2000), five soils layers derived from the STATSGO (U.S. Department of Agriculture 1994) soils dataset for California (soils pH, soil organic matter content, and indices for loam, sand, and clay content), and a 100-meter digital-elevation model. This overlay gave a table of environmental variables associated with the species occurrences. Because the CNDDB database does not contain information on species absences, we simulated species-absence information by determining the values of the environmental variables at a set of random locations throughout California. We developed a logistic-regression model separating the known occurrence points from the random points and returning a probability value for species occurrence given the values of the environmental variables. By applying the logistic-regression model to the raster stack of environmental variables, we created a probabilistic statewide range map for each modeled species.

In the second phase, we assigned habitat-quality values ranging from 0 to 1 for each species to the vegetation polygons in the Highway 99 map. These habitat-quality values were based on the California Wildlife Habitat Relationships model (California Department of Fish and Game 2002) for the terrestrial vertebrates, and by review of the life-history literature for the invertebrates and plant species. For each polygon in the Highway 99 map, we then calculated for each species its potential of occurrence and the habitat-quality value by the probabilities from the statewide range map to give an index ranging from 0 to 1. To determine species presence from these indices, they needed to be normalized across taxa. We normalized these values by comparing the ranked values for each species across every polygon. We counted a species as present in a polygon if its index was in the top two-thirds of the ranked values after eliminating all the zero values.

We then developed a Jaccard similarity analysis (McCune and Grace, 2002) to measure similarity of species composition between the 44 CalTrans capacity improvement projects.

Results

The landcover, or vegetation map, comprised 6683 polygons across 630 km2. Nine of the 12 species modeled were predicted to occur in the study region (Table 1). The area each species potentially covers is the first set of information that could be used in planning, because it identifies the relative rarity of each species. We also show how many sites each species is found at and the number of polygons occupied by the species (Table 2). Figure 3 shows potential species richness along the highway corridor, derived by summing the probability of each species for every mapped polygon in our map. Since the probability of a rare species occurring in a sub- km2 polygon is typically much less than 100 percent, the maximum estimated richness (the most likely number of target species probably found within the polygon) is 4.075, representing some combination of the modeled species at that location. Areas with the highest species richness may become candidate areas for mitigation.

Each of the 44 sites identified from CalTrans plans was then examined and a list of those potential species found at each compiled (Table 3). The lists from all 44 sites were then compared using the Jaccard similarity coefficient (figure 4). Four sets of five or more sites were found to have exactly the same potential species. These sets of sites, mapped in figure 5, are candidates for regional planning of mitigation activities.

Table 1. The potential spatial extent of 12 modeled species by spatial extent along 315 km of State Highway 99, California

Species Name	Percent of study region area at 10% probability	Percent of study region area at 50% probability	Area at 10% probability (sq km)	Area at 50% probability (sq km)	Primary Landcover Class	Secondary Landcover Class
Blunt-nosed leopard lizard	10.7	0	12.4	0	California annual grasslands	Ruderal forbs and grasses
Tipton kangaroo rat	0	0	0	0	Cropland and pasture	California annual grasslands
Colusa grass	0	0	0	0	Temporarily flooded vernal pools	None
Heartscale	0.004	0.004	0.005	0.005	Shrub and brush rangeland	None
Valley elderberry longhorn beetle	0.22	0.22	0.26	0.26	Fremont cottonwood - mixed willow riparian forest	Valley oak forest and woodland
Western spadefoot toad	53.9	10.42	62.5	12.1	Cropland and pasture	Orchards, groves, vineyards, nurseries
Vernal pool fairy shrimp	0	0	0	0	Temporarily flooded vernal pools	None
California tiger salamander	11.37	7.23	13.2	8.4	California annual grasslands	Ruderal forbs and grasses
Burrowing owl	29.1	28.52	33.8	33.1	Cropland and pasture	California annual grasslands
Giant garter snake	0.2	0	0.2	0	California annual grasslands	Canals
San Joaquin kit fox	10.9	10.6	12.7	12.4	California annual grasslands	Ruderal forbs and grasses
Swainson's hawk	27.8	16.4	32.2	19	Cropland and pasture	California annual grasslands

Table 2. The potential presence of 12 modeled species by highway project along 315 km of State Highway 99, California

Species	Planned Projects	Programmed Projects	Polygons in Planned Project	Polygons in Programmed Project	Total Polygons Occupied by Species
Atriplex cordulata	0	0	0	0	1
Blunt-nosed Leopard Lizard	16	10	135	66	541
Burrowing Owl	22	10	184	111	1149
Colusa Grass	0	0	0	0	21
California Tiger Salamander	20	13	149	81	690
Giant Garter Snake	16	13	127	95	745
San Joaquin Kit Fox	21	13	141	77	598
Western Spadefoot Toad	22	14	148	82	730
Swainson's Hawk	20	14	187	93	1094
Tipton Kangaroo Rat	9	9	80	89	563
Valley Elderberry Longhorn Beetle	8	6	18	9	84
Vernal Pool Fairy Shrimp	0	0	0	0	14

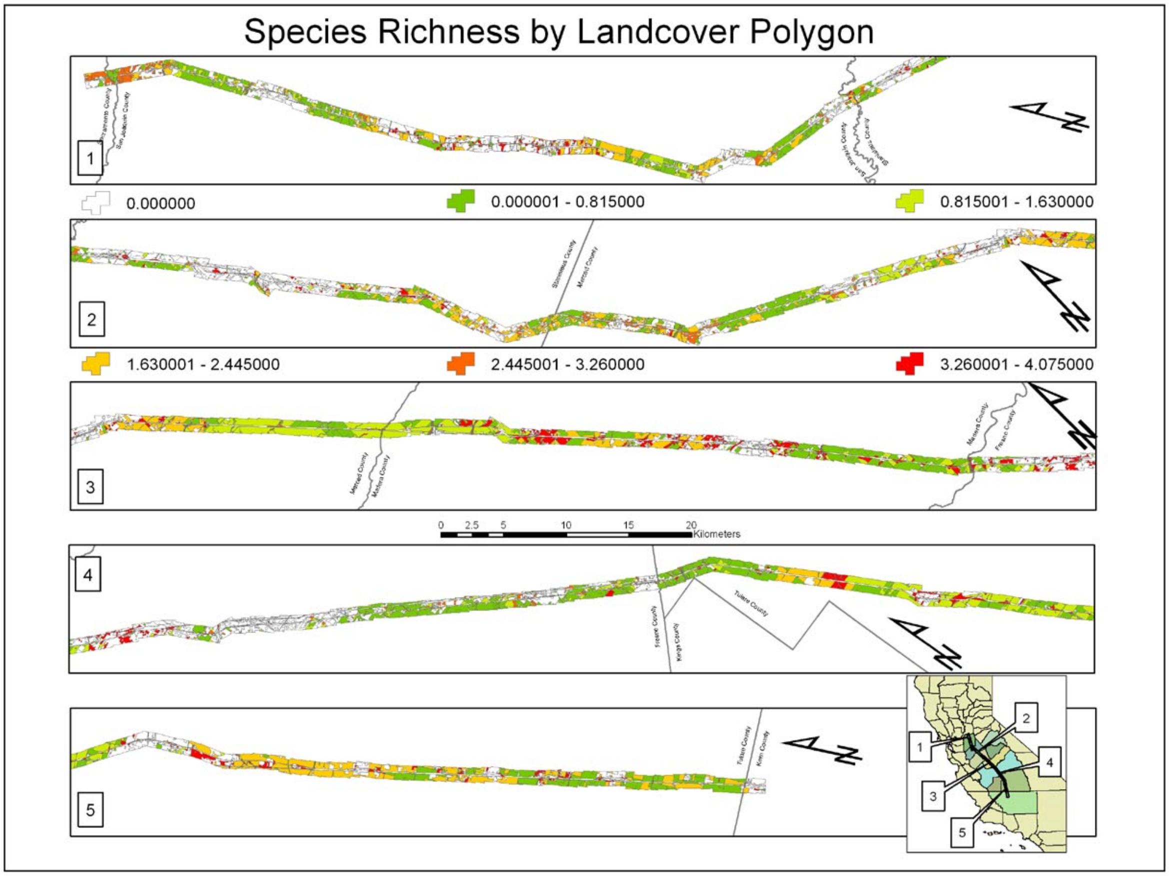


Figure 3. Potential species richness along the Highway 99 corridor. The sum of probabilities of presence for 12 modeled species was calculated for each of the 6683 map units in the landcover map. Red indicates the potentially highest species richness locations.

Table 3. Modeled species presence at each of 44 capacity improvement project sites on State Highway 99, California. This table shows which species were identified at which sites by the species modeling.

Transportation Project Title	Species Name	Atriplex cordulata	Blunt-nosed Leopard Lizard	Burrowing Owl	Colusa Grass	California Tiger Salamander	Giant Garter Snake	San Joaquin Kit Fox	Western Spadefoot Toad	Swainson's Hawk	Tipton Kangaroo Rat	Valley Elderberry Longhorn Beetle	Vernal Pool Fairy Shrimp
SR120/99 INTERCHANGE IMPROVEMENTS		0	0	0	0	0	0	0	0	0	0	0	0
43 EXPRESSWAY		0	1	0	0	1	0	1	1	0	0	0	0
JENSEN TO CENTRAL WIDENING		0	1	1	0	1	0	1	1	0	0	0	0
JENSEN WIDENING		0	1	1	0	1	0	1	1	1	0	0	0
ROEDING AUX LANES		0	1	1	0	1	0	1	1	0	0	0	0
RAMP UPGRADES		0	1	1	0	1	0	1	1	0	1	0	0
WIDENING AVE 7 TO AVE 12		0	1	1	0	1	1	1	1	1	1	1	0
AVE 16 TO AVE 21 1/2 WIDENING		0	1	1	0	1	1	1	1	1	0	1	0
SR 99/SR152 SB AUXILIARY LANE		0	1	1	0	1	0	1	1	1	0	0	0
NORTH MADERA WIDENING		0	1	1	0	1	1	1	1	1	0	1	0
ISLAND PARK 6-LANE		0	1	1	0	1	1	1	1	1	1	1	0
SR 49 16th Street/Oliver Ave. Widening		0	0	1	0	0	1	0	0	1	0	1	0
99/140 INTERCHANGE IMPROVEMENTS		0	0	0	0	0	0	0	0	0	0	0	0
SR-99 WIDENING - WESTSIDE BLVD. TO HUNTER RD.		0	1	1	0	0	1	0	1	1	1	0	0
SR 99 Hammatt IC to Merced River Bridge		0	0	1	0	1	1	1	1	1	1	0	0
SR99 AT MARIPOSA AND FARMINGTON		0	0	1	0	1	1	1	1	1	0	0	0
SR 99/WILSON/MARCH LANE INTERCHANGE		0	0	1	0	1	1	1	1	1	0	0	0
SR 99/MORADA LANE INTERCHANGE		0	0	1	0	1	1	1	1	1	0	0	0
SR 99/EIGHT MILE ROAD RECONSTRUCTION		0	0	0	0	0	0	0	0	1	0	0	0
SR 99 ARCH RD.-SR120 WIDENING		0	0	1	0	1	1	1	1	1	0	0	0
SR 99 WIDENING/CERES TO KIERNAN		0	1	1	0	1	1	1	1	1	0	1	0
SR132 EAST INTERCHANGE		0	1	1	0	1	1	1	1	1	0	1	0
SR 190 PASSING LANES		0	1	1	0	1	0	1	1	1	1	0	0
AIRPORT WIDENING		0	1	1	0	1	1	1	1	1	1	1	0
FARM SHOW INTERCHANGE		0	1	1	0	0	0	1	1	1	1	0	0
PROSPERITY WIDENING		0	1	1	0	1	1	1	1	1	1	0	0
Kingsburg to Selma 6-lane freeway		0	1	1	0	1	1	1	1	1	1	0	0
South Madera & Gateway Improvement Proj		0	1	1	0	1	1	1	1	1	1	0	0
Fairmead Interchange & 6-lane Freeway		0	1	1	0	1	0	1	1	1	0	0	0
Mission Ave Interchange/Freeway		0	1	1	0	1	1	1	1	1	1	0	0
Atwater Freeway		0	0	1	0	0	1	0	1	1	1	0	0
Livingston Stage II Freeway		0	0	1	0	1	1	1	1	1	1	0	0
Freeway Upgrade & Plainsburg Road I/C		0	1	1	0	1	1	1	1	1	1	1	0
Arboleda Road Freeway		0	1	1	0	1	1	1	1	1	1	1	0
Bradley Overhead widening (from 2 to 4-lane)		0	0	0	0	0	0	0	0	0	0	0	0
Route 59 Widening		0	0	1	0	0	1	0	0	1	0	1	0
Castle Highway		0	1	1	0	1	1	1	1	1	0	1	0
Central Galt Interchange		0	0	1	0	1	1	1	1	1	0	0	0
Route 99 Widening in South Stockton		0	0	1	0	1	1	1	1	1	0	0	0
Route 132 Expressway		0	0	0	0	0	0	0	0	0	0	0	0
Route 219 4-lane expressway		0	0	0	0	0	0	0	0	0	0	0	0
Pelandale Interchange Reconstruction		0	1	1	0	1	1	1	1	1	0	0	0
Goshen/Kingsburg 6-Lane		0	1	1	0	1	1	1	1	1	1	1	0
Tagus Ranch 6-lane freeway		0	1	1	0	1	0	1	1	0	1	1	0

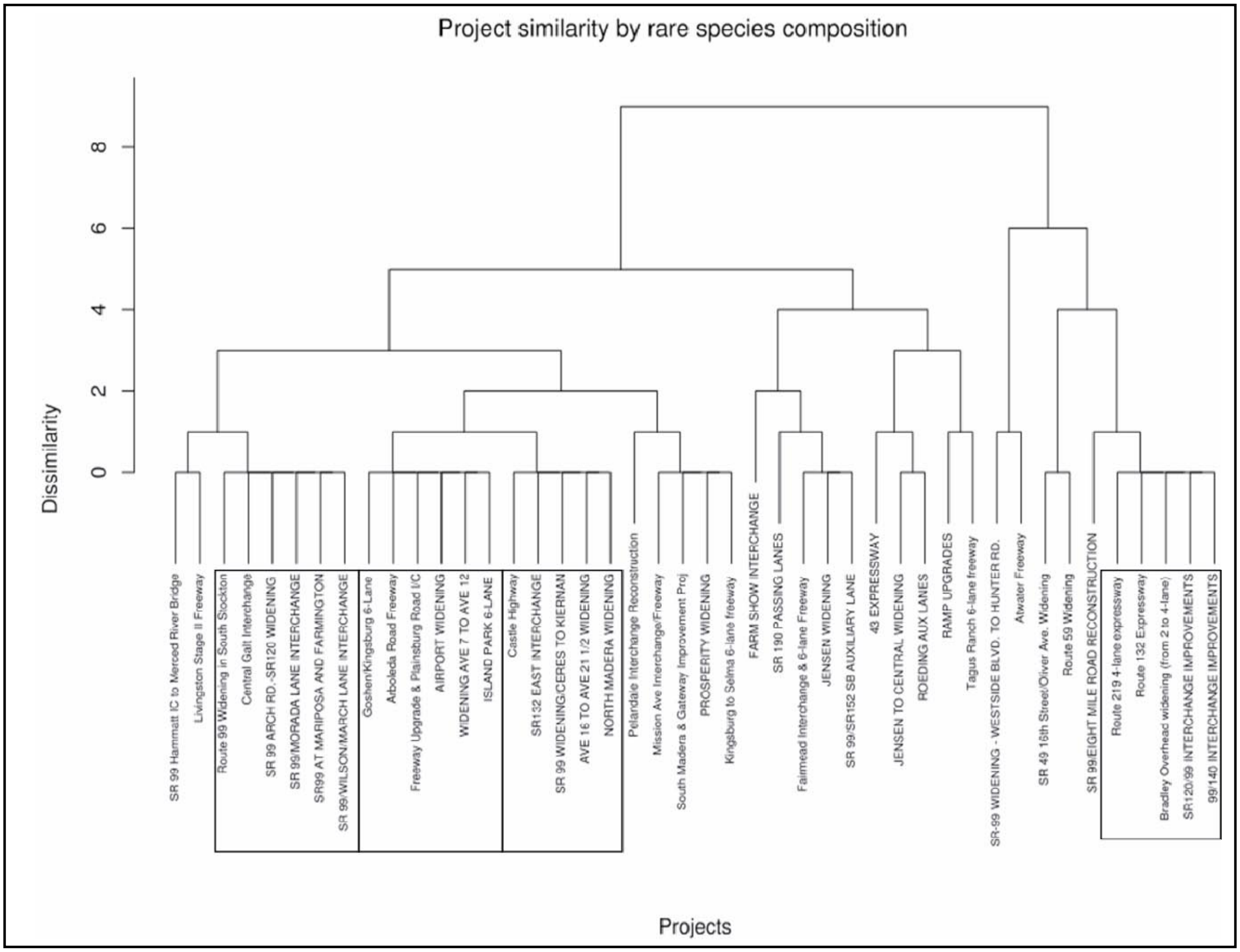


Figure 4. The degree of similarity between 44 capacity-enhancement projects on State Highway 99, California. Project similarity was measured using a Jaccard similarity coefficient, based on modeled species shared or not shared at each site. Four sets of at least five sites shared all modeled species identified and are represented in the boxes of the diagram.

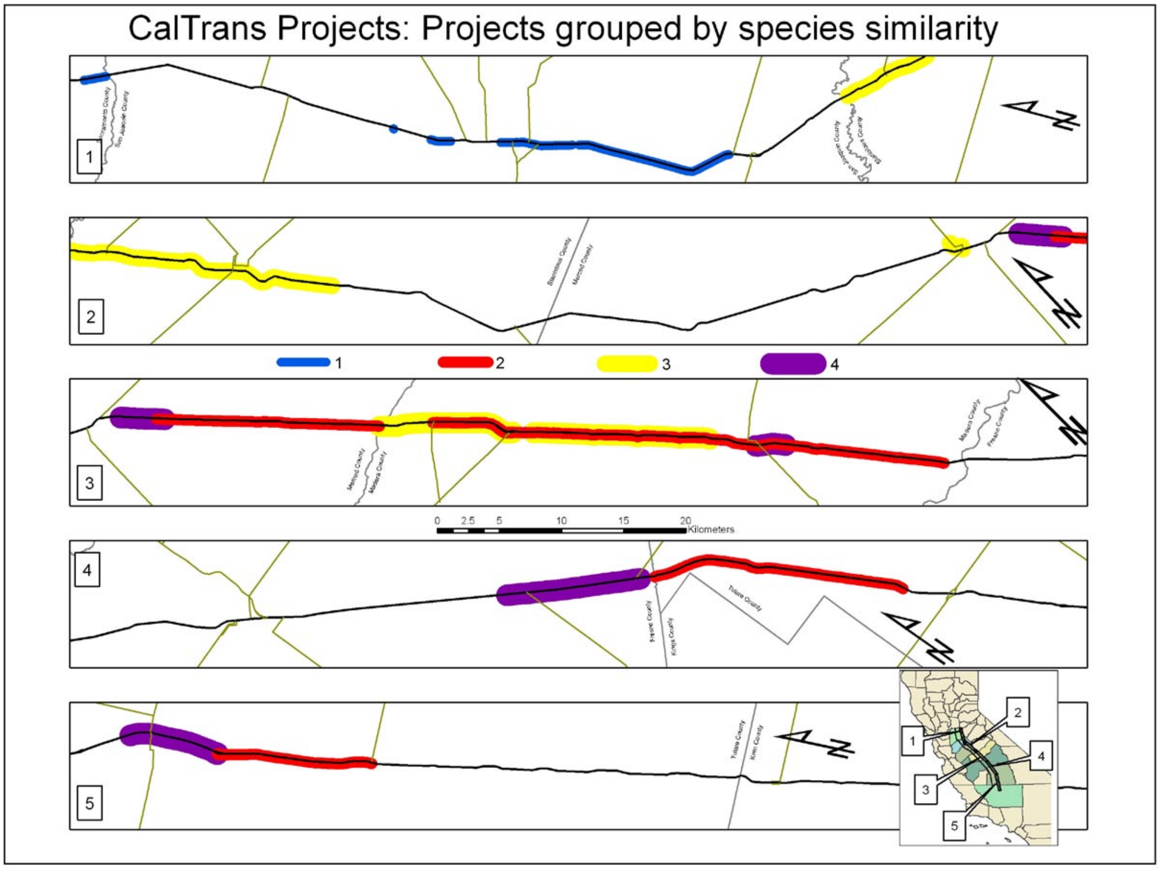


Figure 5. Physical location of four sets of capacity enhancement sites that share endangered species.

Discussion

This pilot project is a demonstration of how transportation agencies can assemble regional data that would help in environmental review and in effective mitigation planning. The value of multi-species, multi-project planning is threefold:

- It permits faster environmental review.
- It can reduce the costs of environmental review.
- It offers the possibility of more environmentally effective mitigation planning, such as combining partial costs from multiple projects to protect a resource at an off-site location which might not be effectively protected or restored using on-site techniques.

This example could be made more thorough by increasing the number of species modeled, by including ecosystem processes in the modeling, and by the development of policy regarding vegetation types or habitats in addition to individual species. Further expansion could involve the inclusion of other human activities on the landscape, such as urban buildout models (e.g. Johnston et al. 2003), and the use of a more regional, rather than linear base vegetation map.

For this approach to be effective, some initial outlays in cost are required. Specifically, the agencies need to assure adequate base data to support species modeling. The development of these data can be made more effective by identification of the size area being considered. Effective environmental planning uses a variety of types of information, including critical habitat level maps, which likely will have to be developed; species presence and absence data; and a wide range of transportation-development plans. The integration of this information can serve a wide range of needs once it is developed.

Another need for the adoption of this type of approach is agency support for flexible, proactive programmatic mitigation and the finance mechanisms to implement identified solutions. Biologists, planners, and GIS personnel need to work together to develop these scenarios and these activities that will require department support, since these collaborations are not always considered part of the work flow.

The next steps are to develop an understanding of regional environmental priorities; to secure adequate environmental data from all relevant spatial scales; and to support flexible policy and finance mechanisms.

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Biographical Sketch: Jim's professional interests include biogeography, conservation biology, and ecology. He has done several studies that focus on incorporation of biological data to county-level planning.

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The Ecologically Ideal Road Density for Small Islands: The Case of Kinmen, Taiwan

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Abstract

The ecological system and natural resources of small islands are limited. Especially, their ecological system is very vulnerable to the invasion by alien species. The planning of development in small islands must be very delicate and advanced comparing with large islands or continental areas because there is no tolerance for experiments or mistakes in developing small islands.

This research is aimed to obtain the acceptable road density for small islands from the ecological point of view and taking Kinmen Islands (Taiwan) as an example. Three derivations of finding the acceptable road density for small islands were developed in this analysis. One method is to adopt the allowable density of roads for sustaining viable populations of wolves in continental areas to small islands. Since wolves are the top predators of a healthy ecological system and with sustainable wolf population the ecological system is believed to be sound, this road density could be the ideal one for a small island. However, the allowable road density for wolves was obtained in continental areas and it is not clear that if it is valid in direct application on small islands.

The second method is modifying the road density from model islands to fit the ecological characteristics of objective islands. In this research I took Okinawa (Japan) as the model island and derived a suitable density of roads for Kinmen. In the third method, I selected the largest small island as the model island and applied the derivation procedure of the second method to find another ecologically ideal density of roads for Kinmen.

The result has shown that the smaller islands have higher density of species but should have lower ideal road density. It was also found that the current road density of Kinmen has exceeded the results obtained by the three models. Although this research is focused on Kinmen, it is believed by the author that the same approaches could be applied to other small islands when reviewing their road-developing policies. The applications of this analysis on habitat islands or ecologically isolated zones in continent areas have been demonstrated. It has been shown that the procedures and results of the application are similar to those for small islands.

Key words: road density, small islands, ecological impacts, Kinmen.
(The full text of this paper can be found in *Ecological Engineering*, 2006.)

Chapter 5

Science and Partnerships

A GIS-Based Identification of Potentially Significant Wildlife Habitats Associated With Roads in Vermont

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Abstract: Since 1998, issues regarding wildlife conservation and transportation planning and development in the State of Vermont have become part of a rigorous collaborative effort between the Vermont Fish and Wildlife Department (Department) and the Vermont Agency of Transportation (Vtrans). In recent years, these efforts have become increasingly sophisticated and more broadly applied throughout the state to understand better the inherent conflicts and strategies for improving wildlife movement, reducing wildlife mortality, and improving the safety of the traveling public. Given the growing investment of interest and resources by these state agencies, it is necessary to identify potentially significant wildlife-linkage habitat (WLH) throughout the state. Such information would allow for these agencies to make informed decisions regarding the conservation of important WLH and investments for mitigation of impacts associated with transportation such as underpasses, land conservation, and other measures.

Geographic Information System (GIS)-based models have been developed in other states and in Canada to identify potentially significant WLH. Many of these projects have relied on landscape-level GIS data such as development density, habitat conditions, topography, among others. This project was designed to develop a GIS-based analysis using landscape-scale data to identify or predict the location of potentially significant WLHs associated with state roads throughout Vermont. This project relied on available GIS data including: (a) land-use and land-cover data; (b) development-density data; and (c) contiguous-habitat data (unfragmented habitat). The GIS conserved lands data was also used as a way of analyzing the feasibility for conserving or ranking potentially significant WLHs identified as a result of this project. These data were classified according to their relative significance with respect to creating potential WLH. The elements that comprise the overall GIS data layers were ranked in accordance with their relative significance to creating potential WLH.

In addition, we developed a comprehensive, centralized database of all wildlife road mortality, wildlife road crossing, and related habitat data for all species for which data exists throughout the state of Vermont. This involved updating an existing database developed for a complimentary project designed to compile all existing data on black bear road mortality, road crossing, and significant habitats. It also included incorporating all data on moose collisions and deer collisions. In addition, new databases were created to record existing bobcat, amphibian, and reptile information. In order to expand and improve wildlife road-mortality data, this project developed a partnership with VTrans field staff enabling them to record a new array of wildlife road-mortality information in a consistent and reliable fashion.

The analysis, in conjunction with the newly updated wildlife road-mortality data, provides a scientifically based, planning tool that will assist both agencies in understanding and improving their abilities to conserve wildlife in Vermont with respect to transportation planning, permitting, and issues regarding secondary growth.

Introduction

During the past decade, the Department and Vtrans have learned a great deal about the effects of roads and related transportation on wildlife, habitats, and ecosystems (e.g., mortality, fragmentation, disruption of behavior, loss of habitat, and cumulative impacts associated with development) (Foreman and Alexander 1998, Trombulak and Frissell 2000, Jackson 2000). Scientific knowledge of issues related to the effects of transportation on wildlife and ecosystems has grown significantly in recent years as evidenced by the International Conference on Ecology and Transportation that occurs every two years (see ICOET Proceedings 1997, 1999, 2001, 2003). In Vermont, both the Department and Vtrans have coordinated to advance the study, evaluation and understanding of issues regarding transportation planning and wildlife conservation in Vermont. The Department and Vtrans have demonstrated a strong commitment to collaboratively addressing these common issues concerning wildlife conservation, safe roads, and a growing interest in developing more contemporary approaches for addressing the effects of transportation development on wildlife and ecological functions.

In states such as Florida, Oregon, Washington, and Idaho, scientists and transportation planners have analyzed road conditions, human development, habitat conditions, animal-movement data, and other information to identify important wildlife corridors. WLH possess certain features such as lack of human development, suitable vegetation, topography, water courses, and discreet habitat features. They are known or suspected to be used by animals that are representative of a wide array of species movement and habitat needs and interests. WLH serve critical functions by allowing wildlife to move, migrate, disperse, reproduce, and access important habitats within a large landscape context. Such habitat is critical for avoiding the effects of fragmentation and population isolation which, for some species such as wide-ranging carnivores (or even some species of salamanders) can lead to extirpation of populations.

GIS technology has proven to serve as an extremely useful tool for analyzing landscape-scale habitat data to identify important WLH (Connor et al. 1998; Stroms et al. 1992 for connecting large blocks of unfragmented habitat for a variety of wildlife species in many parts of the United States (Endries et al. 2003; Singleton et al. 2001). Accurate and detailed information pertaining to wildlife-habitat distribution and quality allows for efficient and effective identification of significant wildlife resource issues by transportation-planning and wildlife-conservation agencies (Ruediger et al. 2003). The ability to identify significant WLH associated with roads throughout the state of Vermont will also allow Vtrans and the Department to coordinate and make fiscally sound, scientifically defensible investments in wildlife-passage infrastructure, land and habitat conservation, and improved public-safety measures.

Given the growth in our mutual understanding and appreciation for environmental, engineering, and transportation issues and the prospects for future investments in mitigation to address concerns related to wildlife conservation and human health and safety, it behooves us to identify important wildlife-linkage habitats. This project identifies and to a certain extent, prioritizes those areas most important for a variety of wildlife conservation needs and thus enables the Department, Vtrans, and other conservation organizations to make better decisions regarding transportation planning, design, and (when necessary) mitigation. Equally important, this information allows for the identification of areas where opportunities exist to reduce or avoid animal/vehicle collisions and improve individual and population migration success, thus improving the safety of the traveling public. Finally, as discussed above, it will improve efficiency of permit reviews by providing a degree of predictability not currently available; we will be able to identify areas with high probabilities for wildlife and habitat concerns that may require special attention in permit processes.

Methods

Since the spatial data used in this project was preexisting and designed for other purposes, each of the data layers required some modification and reclassification. The spatial information was organized within the model to reflect the influence of each data layer on wildlife-habitat suitability. The data layers were normalized to values ranging from 1-10. Normalization is the process of reclassifying data layers to a common scale so that each layer has equal impact on the final analysis. The GIS layers themselves were weighted as a percentage of their importance for purposes of identifying WLH in Vermont. Land-cover/land-use (LCLU) data were weighted at 27.5% for the project, development-density data were weighted at 45%, and “core” habitat data were weighted at 27.5%. The grid-cell size used in this project was a 25-meter-by-25-meter grid cell, which was consistent with that of existing Core Habitat and Land-Cover/Land-Use data. This weighting influenced the final analysis of the model in terms of the breadth of areas identified as WLH. However, in general, it did not seem to make a great deal of difference in the results of the model if slight modifications were made to these ranking values.

Land cover/land use (LCLU)

The LULC data used in this project was developed from Landsat Thematic Mapper Imagery. This data is designed for landscape-level analysis and is useful for broad scale wildlife-habitat interpretation. The smallest unit of land use was 2 acres, corresponding to a grid-cell size of 25 meters by 25 meters. The grid-cell size was consistent with that of core habitat.

Similar to other models (Endries et al. 2003 and Singleton et al. 2001), the classifications (ranks) for the elements that comprise the LCLU data were adjusted to reflect more accurately their relative importance as wildlife habitat, particularly for the movement of large mammals near roads. Element classifications were based on professional judgment by experienced wildlife biologists with the Department (Table 1).

During the ranking process, the transportation LCLU type was reclassified as a near-mean value of 4 out of 10. This does not suggest that these areas provide suitable habitat, but rather is a function of the purpose of the project to identify important habitats in close proximity to roads. Using transportation as a value of 4 enables the model to view habitat variables near roadways without discrediting the roadways altogether. It also allows there to be development LCLU types with lower ranking. This value assumes that it is more likely for wildlife to cross roads in areas without other types of development.

Table 1. LCLU reclassification values

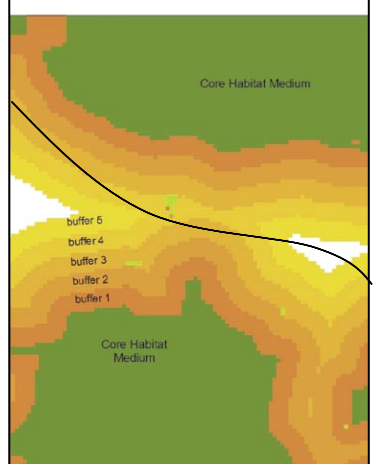
LCLU Type	Final Reclassification Value
Transitional	9
Water	5
Barren	5
Residential	1
Commercial	1
Industrial	1
Transportation	4
Other developed	3
Orchards	6
Other agricultural	5
Deciduous forest	10
Coniferous forest	10
Mixed forest	10
Forested wetland	10
Wetland	10
Row crop	6
Hay/pasture	5

Core habitat

The Core Habitat GIS layer was developed by the University of Vermont's spatial analysis laboratory. The layer describes patches of unfragmented habitat throughout the state. This was accomplished by dividing the state into 25-square-meter grid cells and determining the presence or absence of anthropogenic feature such as roads, structures, buildings, agricultural lands, and quarries. For the purposes of the core-habitat project, it was assumed that the fragmenting features could influence ecological functions of a habitat patch out to 100 meters.

For purposes of this project, the core-habitat data layer was converted from a binary-raster format into a polygon shapefile. This allowed for the calculation of the total acreage of each unfragmented area. Three classes of core-habitat patch size were created in order to differentiate the relative values of unfragmentated habitat patches. Habitat patch size classifications are intended to represent the habitat interests of various wildlife species ranging from small mammals and reptiles and amphibians to larger wide-ranging mammals such as black bear, moose, and otter. These categories are: (a) 0-1499 acres; (b) 1500-10,000 acres; and (c) greater than 10,000 acres. The second size classification was designed to include the home-range habitat size of Vermont's wide-ranging mammals such as moose. The third and largest core-area classification was a product of the data as 44 parcels were outliers with over 10,000 acres of unfragmented core habitat. It is assumed that the large habitat patches would provide suitable habitat for many species of wildlife. These size classifications were designed generally for comparative purposes and do not necessarily reflect the exact habitat-size requirements for specific species.

Fig. 1. Unfragmented Habitat and least-cost travel analysis.



As shown in figure 1, the acreage of each core polygon was used to calculate corresponding buffer areas. In order to keep the buffers relative to the size of the unfragmented blocks, the buffers were created as a function of the size of the habitat patch. The first buffer was a function of the square root of the area of the core-habitat patch. This distance was multiplied by 2 through 5 to create five buffers around each polygon. The buffers were dissolved between each polygon so that buffers from two separate polygons would not be additive. This procedure made it possible to receive a value for each cell corresponding to the highest value without giving higher values to those cells in between core-habitat areas. Once the five buffers were created they were converted into raster format and added together. This created a gradient from core areas to non-core areas. The values were normalized to values of 1 to 10 to fit into the analysis (see Table 2).

Table 2. Core-habitat description

Description	Count	Explanation	Assigned Value
Large core	44	10,000+ acres	8
Medium core	230	1,500-9,999 acres	7
Small core	13,825	0-1,499 acres	6
Buffer 1		sqrt(ACRES)	5
Buffer 2		sqrt(ACRES) * 2	4
Buffer 3		sqrt(ACRES) * 3	3
Buffer 4		sqrt(ACRES) * 4	2
Buffer 5		sqrt(ACRES) * 5	1

The buffer analysis allows the model to rank the value of habitat based on proximity to unfragmented habitat. Furthermore, the model can now reflect the potential for habitat patch size to influence wildlife-habitat suitability.

Housing density

Both the core habitat and the LCLU layers describe the presence of human development within an individual grid cell. In the LCLU data layer, all residential areas have an equal influence on the landscape and for ecological-modeling purposes. The core-habitat data layer discredits any grid cell with anthropogenic influences, but does capture the value of land near these core areas. The core-habitat data layer attempts to recognize the varying degrees of impacts associated with developed landscapes by providing a weighted value based on the distance from grid cells with developed lands to those without development. For purposes of this project, it is important to more carefully account for the varying degrees of development and human influences on wildlife movement and habitat use.

Therefore, a new data layer was designed using Emergency 911 information (e-sites) that locates all houses and buildings throughout the state. Using the ESRI Spatial Analyst extension, housing density was extracted from the existing point data layer. A 500-meter search radius was used to define houses per square mile for each 25-meter grid cell. These densities where normalized and arranged into ten classes, zero houses per square mile being the highest-ranking category and greater than or equal to 80 houses per square mile being the lowest-ranking category. Due to the broad array of wildlife species, this project considers and the varying degrees of tolerance of those species to human activity, it is difficult to select a single development density that would apply for this project. The data was organized to align the lowest value of housing (highest housing density) with the outer perimeter of town and villages (fig. 2a). The assigned values then gradually increase from the village to areas of zero housing density (fig. 2b).

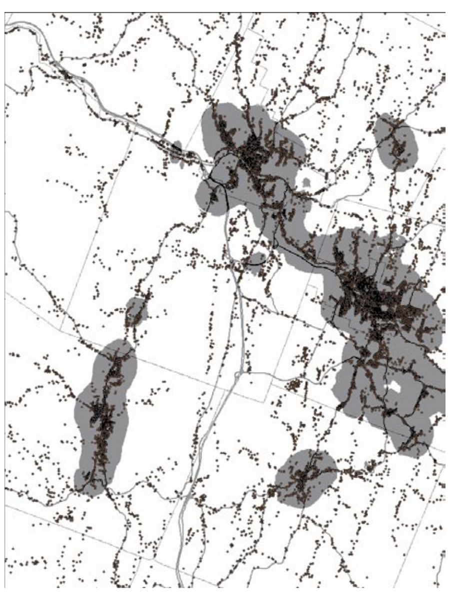


Fig. 2a. Lowest value category aligned with the perimeter of development centers.

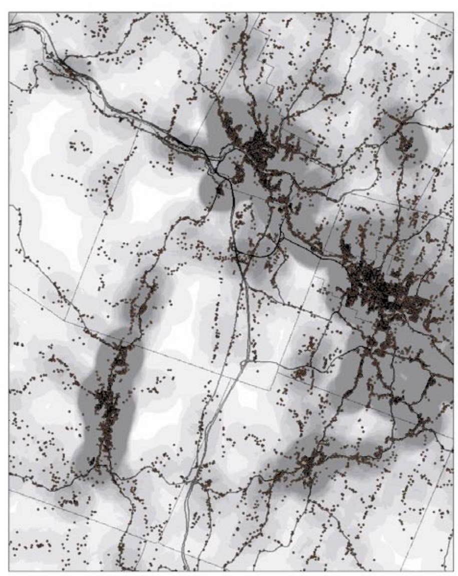


Fig. 2b. Values gradually increasing from village perimeter to areas of zero housing density (dark to light).

Similar to the other data layers, housing density is a measure of human development, but the use of a density gradient allows for consideration of the varying degrees of influence from human activities on wildlife movement and behavior. The analysis assumes that wildlife can tolerate different levels of human interaction, whereas in the other two layers, most development is devalued altogether.

Combining and analyzing the GIS data layers
The GIS data layers used for this analysis were weighted according to their influence on habitat suitability and wildlife movement. Each layer represents a percentage of an equation for calculating the suitability of habitat with respect to wildlife movement. The final analysis used the following equation to calculate a wildlife-habitat suitability value for each 25-meter by 25-meter grid cell:

Wildlife-Habitat Suitability = (LCLU)*27.5% + (Housing Density)*45% + (Core Habitat)*27.5%

The results of this analysis cover all the various biophysical regions of the state and incorporate multiple habitat types. Thus, they do not represent a true value of habitat quality in the field, but instead rely on known variables to generalize the probability of suitable habitat being found in each grid cell.

Based on the WHS results, a GIS data layer was developed that depicts the relative value of habitat along state roads for wildlife movement. A 100-meter buffer from transportation right-of-ways on state roads was applied to determine relative distance to WHS data. Road GIS data was clipped to these buffers to produce each of the nine .5 increments of the wildlife crossing value. The nine increments produce priority areas within a region or district and were designed so a region could easily select areas with the highest or lowest suitability for potentially significant WLH.

Revised process for analyzing WLH conditions in the Champlain Valley biophysical region
Vermont is comprised of eight different biophysical regions and the differences among these regions likely influences the movement of wildlife, species composition of an area, and the factors that create WLH. The model is likely suitable (from a general landscape scale) for most of the biophysical regions of Vermont, but without question is not well suited for identifying WLH within the Champlain Valley biophysical region. Therefore, we adjusted the analysis for the purpose of more accurately identifying WLH within the Champlain Valley. In this case, GIS data for surface water and wetlands were added to the analysis. All variables were weighted differently from the original analysis.

Using the Vermont Hydrology Dataset (VHD) describing streams derived at a scale of 1:5,000 a Euclidean distance analysis created a surface in which almost every cell was affected by the fine scale of the data. Though at larger scales this information would be important in identifying isolated crossing locations, at the landscape scale it is too specific. The amount of “noise” or “clutter” created by identifying every waterway masked the trends and patterns the analysis was trying to portray.

The final analysis used information from the National Hydrology Dataset (NHD) that was derived from a scale of 1: 100,000. A Euclidian distance analysis using this information, though generalized, provides a better representation of the major stream corridors. The distance from all surface waters (streams, rivers, lakes, ponds) as well as all identified wetlands was classified in 50-meter intervals from 0 meters to 500 meters. The components of the surface water group are not additive, meaning there is no preference given to areas near both a lake and a stream. Instead, the maximum value of any surface water is used.

Using a Euclidian distance analysis, wetlands were used in much the same way as the surface-water information. For each cell within 500 meters, a distance from the nearest wetland was calculated and classified in 50-meter intervals from 0 meters to 500 meters. The wetland information gives no priority to different sizes, types, or densities of wetland, but creates a gradual surface of distance to the nearest wetland.

Results

Results of this project include:

a. Wildlife-Habitat Suitability. 25-m by 25-m grid raster describes a value of habitat suitability. It uses housing density, LCLU, and core-habitat information to create a gradually changing statewide coverage. This layer describes the probability of finding suitable contiguous and linkage habitat conditions within each cell. It does not describe the actual quality of habitat in each cell.
b. Wildlife-Crossing Value. Polyline shapefile that describes the value of the Wildlife-Habitat Suitability within 100 meters of the road centerline. The Wildlife-Crossing Values are designed to identify areas in a region as relative priority areas. This provides a roadway-specific description of potential WLH and may be useful for purposes of transportation planning and identification of sites that may be priority areas for wildlife crossing structures.
c. Correlation of WCV and Wildlife Road-Mortality Data. In addition, current wildlife road-mortality data was applied to the WLH results to examine the extent to which areas of concentrated mortality occur within areas predicted as potentially significant WLH.

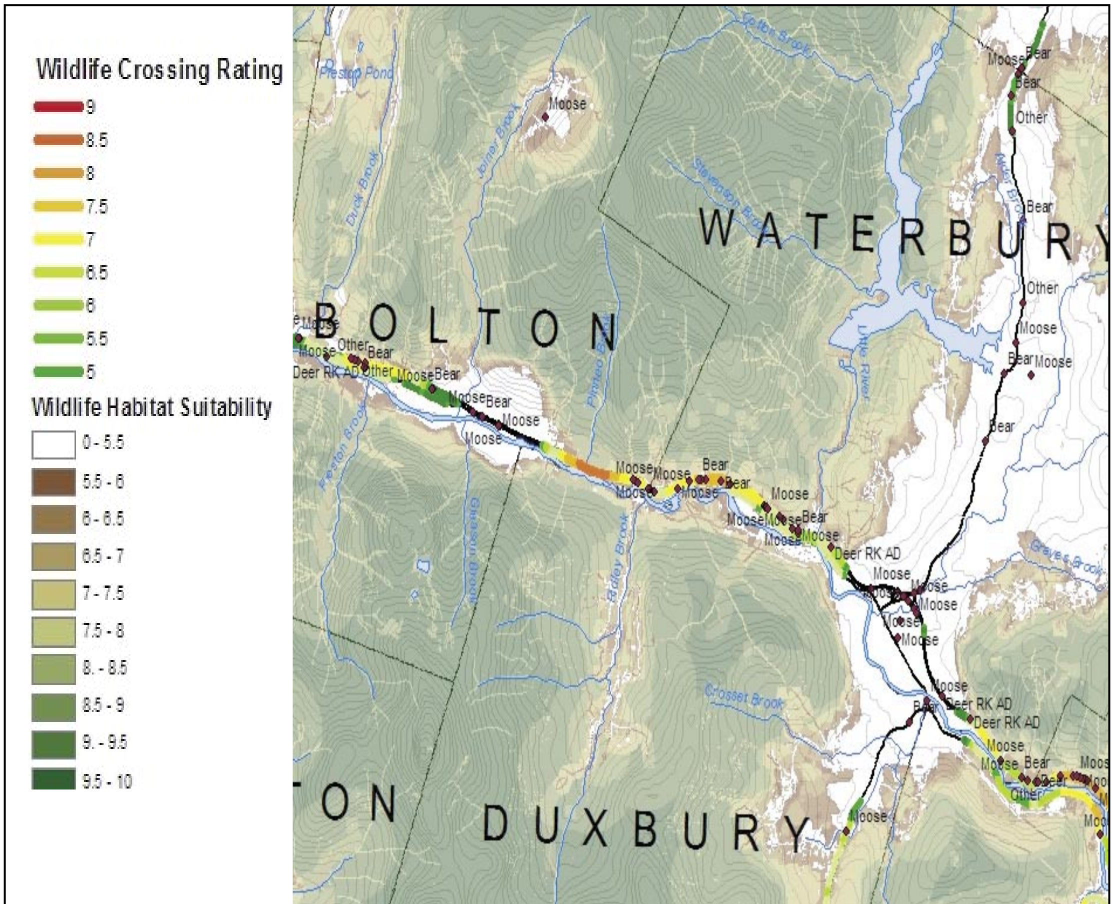


Fig. 6. Final analysis depicting habitat suitability, wildlife-linkage habitat values throughout a stretch of state highway, and road-mortality data as point locations.

Discussion

GIS and WLH identification

The WLH analysis was designed to objectively consider the suitability of habitats associated with state highways for wildlife movement. This analysis relied on several basic landscape-level databases, including: (1) land cover and land use; (2) development density; and (3) "core" or contiguous habitat, hereinafter referred to as "core" habitat for purposes of consistency with the GIS data layer from VCGI. Conserved-land GIS data were also included as a feasibility component to the analysis so that we could examine the extent to which potentially significant WLHs were associated with conserved lands and whether conserved lands were already providing a positive benefit for WLHs. This information may prove beneficial for future decision making regarding locations for wildlife-passage structures and their long-term success. The model identifies areas associated with the state road system that intersect critical or important wildlife corridors.

The landscape-level GIS data used to identify potential WLH is expected to account for the broad, general habitat requirements of many species of wildlife ranging from wide-ranging mammals such as black bear, otter, and moose, to smaller animals such as reptiles and amphibians. This analysis was also correlated to a statewide wildlife road-mortality database to examine the extent to which road-mortality data informs the identification of WLH. Though the model does not identify the best possible habitat for each individual species, it attempts to link large, undeveloped areas with relatively low human disturbance in association with conducive land use and land-cover types. In addition, it does not implicate areas with a high frequency of road crossings, but rather areas with the highest probability of wildlife crossing at that location.

Other states and countries have conducted GIS-based assessments to identify and prioritize important wildlife-linkage habitat. Montana (Craighead 2001, Ruediger et al. 2004), Florida (Endries et al. 2003), California (Penrod et al. 2001), Washington (Singleton et al. 2001), Iowa (Hubbard et al. 2000), and Utah (Carr et al. 2002) represent some of the states that have conducted similar investigations. The Canadian provinces of Alberta and British Columbia have also conducted similar investigations (Gibeau et al. 2001, Tremblay 2001). Some of these states and provinces have advanced beyond the planning and evaluation process and have modified their highway infrastructure based on their analysis of wildlife-movement and habitat-suitability data.

While GIS analytical techniques vary among WLH projects in other states, a common theme among these models is a process termed cost-weighted coverage or least-cost analysis (Singleton et al. 2001, Craighead 2001, Endries et al. 2003, Gibeau et al. 2001, Tremblay 2001, Carr et al. 2002). Cost-weighted coverage (CWC) is created through the reclassification of common landscape variables based on their relative impediment or benefit to wildlife movement. Setting these landscape variables to a common scale normalizes the data so that each variable is represented in the model or analysis based on its relative significance to wildlife movement. This process can be used as a model of least resistance to wildlife. The data layers used to perform such an analysis are generally similar among GIS modeling projects and include specific habitats, predefined wildlife-movement areas, expert-opinion models, species population-density data, development density, land-cover types, and conserved lands.

In some cases, a statewide analysis was designed for a single species of wildlife while others have designed an analysis for general groups or suites of wildlife (e.g., wide-ranging mammals/carnivores). There are also general GIS analyses that incorporate species-specific information and known biologically important areas, such as was done in Florida where information on 130 species was incorporated into a GIS-linkage habitat model (Endries et al. 2003). In Washington State, a linkage-habitat model relied on species-specific habitat and movement data, as well as general landscape-level data related to large carnivore habitat (Singleton et al. 2001). This analysis found that the model that relied on broad, general landscape-level GIS information provided an “adequate approximation of the broad landscape patterns common to the species-specific models” (Singleton et al. 2001). Similar modeling efforts have not been conducted in New England.

Since this project was designed to address both wildlife movement and transportation safety, an emphasis was placed on wide-ranging mammals, particularly black bear and moose. Spatial GIS landscape data was available for analyzing the potentially suitable linkage habitat for these types of wildlife species. Additionally, road-mortality and road-crossing data exists for these species, which allows for some consideration of correlation between the habitat variables and actual animal movement. However, given the general landscape variables used for this analysis, it is possible that the areas identified as potentially significant WLH may apply to a variety of wildlife that require connectivity across a broad area to access habitat, disperse, breed, reproduce, and find food.

Wildlife road-mortality data collection and correlation to the GIS WLH project

Historically, the Department and Vtrans have collected vehicle-collision data for white-tailed deer, moose, and black bear. This data has been collected for decades and the resulting database is extensive. For most applications, we decided not to use the deer road-mortality data since we did not believe that deer represent a species whose movements are representative of WLH. In 2001, the Department created a statewide black bear GIS database. This information was collected from written information from the five wildlife districts as well as from interviews with wildlife biologists, foresters, and Department enforcement officers. The resulting database contains records dating back to 1971. Moose-collision data originates from information recorded by Department enforcement officers and wildlife biologists that has been recorded in the state police CAD system. Due to the variation in how individuals recorded location information in this database, it was necessary to perform substantial quality-control of the data. Based on quality control efforts, these road-mortality locations within the databases are now accurate to within 0.5 mile, though for most points the accuracy is much better. Based on the new data-collection system developed as a result of this project, wildlife road-mortality records are submitted by tenth of a mile marker or with UTM coordinates.

An expanded wildlife road-mortality database was created to account for existing bobcat, reptile, and amphibian road mortality and crossing information. Historic bobcat den habitat, feeding habitat, and road-crossing information was organized in a Microsoft Excel database and digitized in Arcview. In 1995, this information was collected through surveys of licensed trappers in Vermont conducted by Department biologists. This is an incomplete database of bobcat habitat and road-crossing information and therefore does not represent the full distribution and abundance of important bobcat habitat. Additional information will be incorporated into the database as it becomes available. Given the wide-ranging nature of bobcats, they may represent an important indicator species for purposes of identifying or confirming important WLH.

Road-crossing and mortality information for amphibians and reptiles was collected by the Department through interviews with herpetological experts and professionals in Vermont. The source of this information ensured reliable data. Only those areas of large-scale species movement or where rare or unique species were known to cross roads were recorded. This information is also regional in nature and does not represent a complete understanding of the distribution and abundance of important habitats for amphibians and reptiles in Vermont.

Collecting reliable data on wildlife road mortality in a consistent fashion is a challenge, given that it requires a great deal of time and attention. For purposes of this project, the Department and Vtrans have developed a data-collection system that relies on Vtrans district road-maintenance staff. This system includes a data-collection protocol that is now being used by Vtrans district maintenace staff. The system records information on 10 species or groups of wildlife. This data-collection protocol was implemented in January 2004 and is ongoing. In addition, baseline institutional knowledge of well-known wildlife road crossing or mortality locations was summarized through interviews with Vtrans district area supervisors. This information is also included in the wildlife road-mortality database.

This new wildlife road-mortality data collection system has some inherent challenges with respect to long-term consistent collection of reliable data. The quantity and quality of data is contingent on the time and interests of Vtrans District field staff and their ability to collect and record this sort of information. Data collection appears to vary among districts. In order for this program to be effective in the long term, it will be essential for Department and Vtrans biologists to maintain positive and effective communication with Vermont Fish and Wildlife Department game wardens, wildlife biologists, and Vtrans district field staff. Our ability to analyze road-mortality data will improve as the database grows.

Table 3 illustrates the percentage of wildlife collision events that have occurred in the different Wildlife Crossing Ratings. We found that 58% of total wildlife road-mortality events occur within corridor ratings equal to or greater than 7 and that 75% of total road-mortality events occur within corridor ratings greater than or equal to 6. This is significant since the corridor rating value of 6 or greater is associated with slightly over a third of the state's roadways. At first glance, the percentages of wildlife being hit in high value areas, such as greater than 8.5, might seem surprisingly low, but relative to the length of roadways carrying these higher values it seems to make more sense. In theory, if we were able to eliminate 100% of wildlife collisions from roads with Wildlife Crossing Values greater than 8.5 (totaling only 31.8 miles) we would be reducing the yearly collisions by almost 20%. This might not be a very practical goal but it does illustrate the supposed accuracy of the model itself.

Table 1. Statewide matching of wildlife road-mortality information and wildlife linkage habitat values.

Wildlife-Linkage Habitat Rating	% of Bear Collisions	% of Moose Collisions	% of Total Road Mortality	% of Historical Wildlife Collisions AOT	Length (miles)
> 9.0	2.2	0.5	12.4	0.0	3.7
> 8.5	4.6	9.0	18.6	5.2	31.8
> 8.0	13.9	29.2	34.0	14.1	149.8
> 7.5	29.9	43.8	48.1	28.6	340.3
> 7.0	44.0	53.6	58.2	37.0	575.4
> 6.5	52.7	63.6	68.4	47.4	924.6
> 6.0	62.2	70.1	76.0	57.8	1295.0
> 5.5	68.2	74.7	81.8	66.1	1639.4
> 5.0	72.6	77.3	85.9	71.4	1887.3

Conserved lands GIS data layer

The final GIS project includes the Vermont conserved-lands data layer for purposes of conservation and transportation planning. Though some of the effects of conserved land (such as parcel size, location, and distribution) may influence wildlife movement, these data were not integrated into the analysis because they would have added a significant source of bias. The analysis was designed to be independent of political and human factors that may not relate directly to wildlife movement.

This data layer is very useful for performing feasibility assessments for WLH conservation and transportation planning. This project enables the user to examine the abundance, size, location, and distribution of conserved lands to WLH and plan for future land-conservation efforts in an informed fashion. This will be most useful for transportation planning and mitigation purposes by allowing Vtrans and the Department to target those lands necessary for ensuring the effectiveness of wildlife-crossing structures.

Regional disparity of road, development and habitat conditions

Scientists have classified eight different biophysical regions in Vermont. The ecological differences among the eight biophysical regions in Vermont are a function of many environmental variables including climate, geology, topography, soils, vegetation, and correspondingly, animals. These differences are important considerations with respect to this WLH analysis because the variables identified for the majority of the state may not be applicable to the Champlain Valley.

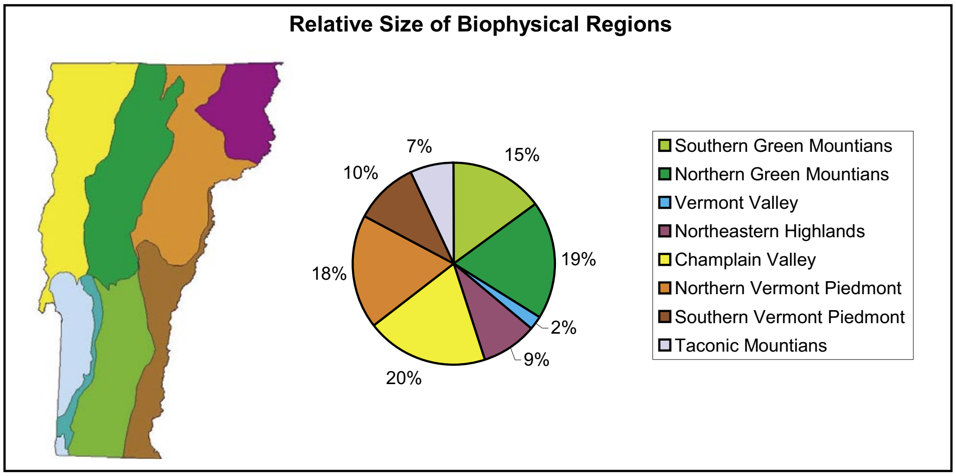


Chart 1. Relative size of biophysical regions.

The primary variables used for purposes of this analysis placed a high value on those areas with large patches of unfragmented habitat and/or with less-developed land. This likely represents the interests of wide-ranging mammals very well, and many species of wildlife that rely on similar habitat conditions. However, areas like the Champlain Valley support a great diversity of species, some of which are not found in many other parts of the state and that require smaller areas of linkage habitat to move throughout suitable range/habitat and meet their life requisites. Given the ecological and geological factors of the Champlain Valley, wetlands, streams, and rivers may serve a significant role in wildlife movement through the landscape. These habitat features are widespread within this biophysical region. Therefore, the analysis was adjusted using these variables to more accurately reflect the potential WLH conditions in that region.

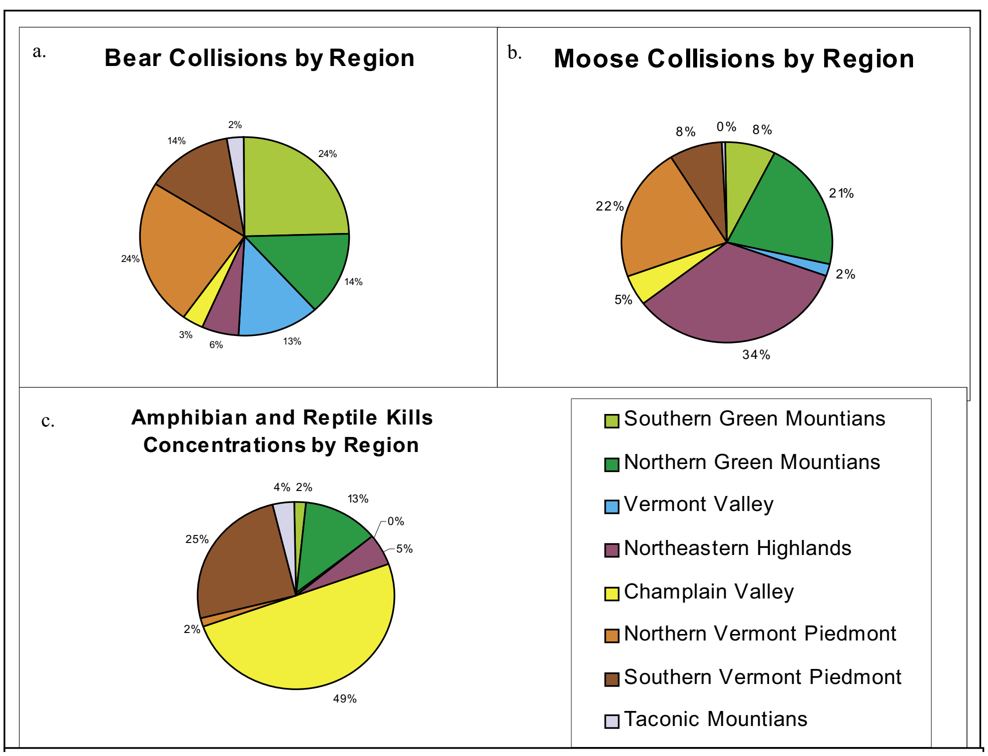


Chart 2. (a) Bear, (b) Moose, (c) Amphibian, and reptile collisions by biophysical regions.

Distribution of historical wildlife road-mortality data (Chart 2) associated with the biophysical regions indicates that black bear and moose may not represent a useful indicator species of important linkage habitat in areas like the Champlain Valley. Moose may not represent a useful indicator species in many areas of the state and further investigations are necessary to better understand their role in this WLH effort. However, existing amphibian and reptile road-mortality data suggest that perhaps amphibians and reptiles represent a useful group of indicator species for identifying linkage habitats in areas like the Champlain Valley. This is a very general illustration of this data and is limited to a large extent by the volume of road-mortality data available. Bear collisions are common in the mountainous regions of the state and there have been low numbers of bear kills in the Champlain Valley, Taconic Mountains, and the Northeastern Highlands. The relatively low number of reported bear road-mortality data for these regions may be due to habitat conditions, traffic volume, road conditions, reporter effort, or (most likely) a combination of all of the above. The Taconic Mountain region of Vermont is a relatively small region and is limited with respect to the movement of large, wide-ranging mammals (at least by routes 7 and 7A) and the associated high level of development that appears to represent a significant barrier to wildlife movement for that region.

Moose road-mortality data indicates the greatest concentrations of moose/vehicle collisions occur in the northeast highlands (10% of Vermont), northern Vermont Piedmont, and northern Green Mountains. This is not surprising as these observations have been made for over a decade and appropriate warning signs have been established at most high-density moose-crossing locations.

Table 4. Comparison of wildlife-crossing values and the associated road mortality both outside and within the Champlain Valley Biophysical Region sections

Outside Champlain Valley						
Crossing Rating	% road sample	% of Bear (356)	% of Moose (1384)	% of MATS Roadkill (not deer)(237)	Amphibians and Reptiles (28)	MATS Deer (209)
9.0	0.1	2.2	0.6	0.0	0.0	0.0
8.5	1.2	4.8	9.5	0.8	0.0	1.4
8.0	5.7	14.0	30.7	4.2	7.1	4.3
7.5	12.4	30.6	46.0	14.3	17.9	17.7
7.0	20.1	44.7	56.1	22.4	21.4	26.3
6.5	31.1	53.4	66.3	36.3	32.1	39.2
6.0	42.6	62.9	72.6	47.7	32.1	50.2
5.5	52.9	69.1	76.6	60.3	32.1	77.5
5.0	60.2	73.6	79.1	70.9	32.1	71.3
Within Champlain Valley						
Crossing Rating	% road sample	% of Bear (12)	% of Moose (73)	% of MATS Roadkill (not deer) (96)	Amphibians and Reptiles (27)	MATS Deer (23)
9.0	0.0	0.0	0.0	0.0	0.0	0.0
8.5	0.0	0.0	0.0	0.0	0.0	0.0
8.0	0.3	8.3	0.0	0.0	0.0	0.0
7.5	1.6	8.3	1.4	2.1	0.0	0.0
7.0	3.5	25.0	6.8	3.1	7.4	0.0
6.5	11.5	33.3	13.7	18.8	18.5	0.0
6.0	22.1	41.7	23.3	20.8	18.5	17.4
5.5	32.9	41.7	38.4	28.1	18.5	34.8
5.0	42.4	41.7	42.5	44.8	22.2	39.1

Results of the road-mortality comparison to the WLH analysis illustrate these differences among biophysical regions and within the Champlain Valley region in particular. In order to address the different environmental factors in the Champlain Valley, the GIS model was adjusted to reflect more accurately the landscape conditions that may influence wildlife movement.

Contiguous conserved lands

Similar to the Core Habitat layer, the Contiguous Conserved Land layer attempts to value conserved lands in terms of size and proximity to areas identified as potentially significant WLH. However, whereas in the Core Habitat layer buffer zones are non-additive, zones in Contiguous Conserved Lands layer are additive. Thus this layer prioritizes both areas near the boundaries of pre-existing conserved land and areas that are located between two or more areas of conserved land. This component of the GIS project identifies areas for conservation/acquisition that may have the greatest value for wildlife in terms of connecting other important patches of habitat and ensuring the movement of wildlife through the landscape.

In the previous version of the analysis, this layer was removed. The reason for the removal was that the analysis was designed to locate wildlife corridors based strictly on the environmental factors of the site. To use the Conserved Lands information would then bias the corridors to follow already conserved corridors. One might argue that corridors will change and will eventually follow conserved lands anyway, but for the sake of this analysis the Conserved Lands information was best left out. With that said, however, Conserved Lands information should be used in conjunction with the wildlife-corridor information. This means the Wildlife Corridors would be described without the use of the Conserved Lands information, but decisions made regarding the corridor should not be made with existing conserved land information.

Conclusions and Recommendations

This project represents an important initial effort towards identifying and understanding significant WLH throughout the state of Vermont. This information will prove useful for identifying wildlife-habitat issues that may be associated with transportation-development projects in a timely fashion and thus reduce the time necessary to address those issues in the planning and permitting processes. It will also enable the Department and Vtrans to make informed decisions regarding the appropriate degree of mitigation necessary to address impacts to WLH or other significant habitats, as well as to make financially responsible decisions regarding the locations of wildlife crossing infrastructure.

It is important to note that this is only a preliminary, landscape-scale assessment of WLH in Vermont. Additional field investigations will be necessary to confirm, on a site-by-site basis, the significance of any given WLH identified as a result of this project. Site-specific considerations for understanding the functions and values of WLH include guardrails, bridges, culverts, fence openings, areas of dense vegetation near road edges, sharp curves in the road alignment, and ridgelines along roads, among others (Hammond 2002). Based on this information, a field-investigation protocol should be developed. We recommend that the Department and Vtrans continue to focus on a refined assessment of WLHs in areas throughout the state that are targeted for transportation improvement, new infrastructure, land conservation, or other issues of mutual interest.

We recommend that this GIS project continue to be refined with any new applicable data that may become available in the foreseeable future. This model deserves a broader scientific peer review. We recommend that other experts outside of Vermont be asked to review the GIS project and the underlying assumptions that guide it.

Finally, it is essential to maintain the wildlife road-mortality database that was developed as a result of this project. We strongly recommend that this database and associated data-collection efforts be maintained by both agencies. A modest financial commitment is necessary for an annual update of the database and the corresponding GIS data layer.

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Controlling Transportation and Wildlife-Habitat Linkages Through Partnerships, Planning, and Science Near Los Angeles, California

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Abstract

Beginning in 1996, the National Park Service, Caltrans, and other agencies and organizations have worked together collecting, analyzing, and sharing data about regional wildlife- movement corridors within the Santa Susana Mountains, Simi Hills, and Santa Monica Mountains, near Los Angeles, California. This region is characterized by intense urban development, several major multi-lane highways, and large expanses of protected open space supporting abundant wildlife.

Scientific studies include radio telemetry of coyotes, bobcats, and mountain lions, monitoring of undercrossings and culverts to evaluate wildlife utilization, assessment of wildlife mortality along selected roadway segments, and geographic information system (GIS) analyses of potential wildlife-movement corridors adjacent to and across major highways. Results from these studies demonstrate that regional wildlife viability will depend on identifying and protecting habitat linkages and wildlife-movement corridors, particularly across major highways that bisect remaining open space.

In addition, the studies confirm that opportunities do exist to retain landscape connectivity, with many species found to utilize a variety of roadway-crossing structures. By combining the results of the science with transportation planning, Caltrans, the National Park Service, and other partners are now integrating on-the-ground conservation actions with needed transportation-improvement projects and regional transportation plans. Recent successes include the formation of a multi-agency and local participant group to identify and prioritize regional wildlife-movement corridors and to create plans for implementing enhancements.

Agencies and organizations are also sharing information about collaborative opportunities to fund and implement wildlife-corridor enhancement projects. GIS analyses, including least-cost path-linkage analysis, have been used to identify regional wildlife-connectivity requirements. These data will then be available to help to identify priority sites for on-the-ground enhancements.

Along one highway segment (State Route 23), National Park Service scientists are working with Caltrans planners and designers to install wildlife-proof fencing where mortality frequencies are high, enhance existing culverts and undercrossings to facilitate safe wildlife movement, and conduct detailed animal monitoring both before and after improvements to evaluate the success of various actions.

These improvements and monitoring are all linked to lane additions along the highway to improve transportation efficiency. In another location (Highway 101), National Park Service scientists are collaborating with Caltrans environmental specialists to design and install a wildlife-crossing structure along one of the last remaining habitat linkages between the Simi Hills and the Santa Monica Mountains.

Overall, we demonstrate that by sharing expertise and experiences and by linking science and planning, regional wildlife-habitat connectivity can be enhanced in combination with needed transportation projects. This model of partnership and collaboration can be applied to other areas facing similar wildlife-conservation and transportation challenges.

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Sierraville (California) Highway 89 Stewardship Team: Ahead of the Curve

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Abstract: Highway 89 stretches from north to south across California, through Sierra County from Sierraville to Truckee. The highway bisects an important portion of the Loyalton-Truckee deer herd, as well as important habitat for forest carnivores, amphibians and other wildlife on the Tahoe National Forest.

By 2002, several groups were working independently to investigate different aspects of animal-vehicle collisions along the highway. These independent efforts were the:

- Continuation of a 20-plus year collection of carcass information on SR 89 by Caltrans
- Investigation of the effects of roadside forest thinning on roadkill by University of California-Davis Agricultural Extension Service
- Investigation of radio-collared deer movements across the highway by California Department of Fish and Game
- Applications to study the effects of deicing salt on deer attraction by the Sierra County Fish and Game Commission
- Long-term connectivity and habitat planning by the USDA Forest Service

These groups and their efforts were brought together in 2002 when they were catalyzed by the USDA Forest Service into a stewardship team to work together collaboratively to improve the high wildlife mortality and increasing habitat fragmentation on the highway. Most efforts to mitigate similar highway impacts are precipitated by a department of transportation project.

In the case of SR 89, no improvement for SR 89 was planned by Caltrans. Thus, instead of responding to a tight project timeline and budget, the Stewardship Team was able to proactively develop a connectivity and mitigation plan using Caltrans' large roadkill database, the Forest Service's large-scale habitat maps, and the other cooperators' information.

In 2004, Caltrans independently funded a $720,000 wildlife-mitigation project on SR 89, thus allowing the Stewardship Team to use its connectivity plan as the basis for decisions on prioritizing wildlife crossing structures. The Stewardship Team is using the connectivity plan to propose further mitigation to Caltrans after the initial structure is constructed. The Stewardship Team has also secured grant funding to involve the local high school in a long-term investigation of how habitat connectivity and highway impacts are related.

This presentation traces the efforts of the Stewardship Team member agencies and how their diverse contributions, once coordinated, supported a grass-roots effort to mitigate highway impacts on SR 89.

Introduction

California State Highway 89 follows the east side of the Sierra Nevada Mountains for hundreds of miles through high sagebrush desert, rural ranching communities, and National Forest System lands (figure 1). Sierra County, California, has only a handful of small towns including Sierraville, none larger than 200 residents. North of Lake Tahoe, from the towns of Truckee to Sierraville, the Loyalton-Truckee Mule Deer Herd crosses the highway in large numbers during upslope and down-slope seasonal migrations. Resident deer cross within their home ranges numerous additional times.

Within the last five years, several groups of people independently recognized and tried to solve aspects of the deer/vehicle collision problem on Highway 89. Once these people were brought together into a cohesive team (the Sierraville Highway 89 Stewardship Team (Team)), their passion and skills resulted in a model example of grassroots accomplishments. This paper relates some of the Team's accomplishments to date and anticipated accomplishments for the future.

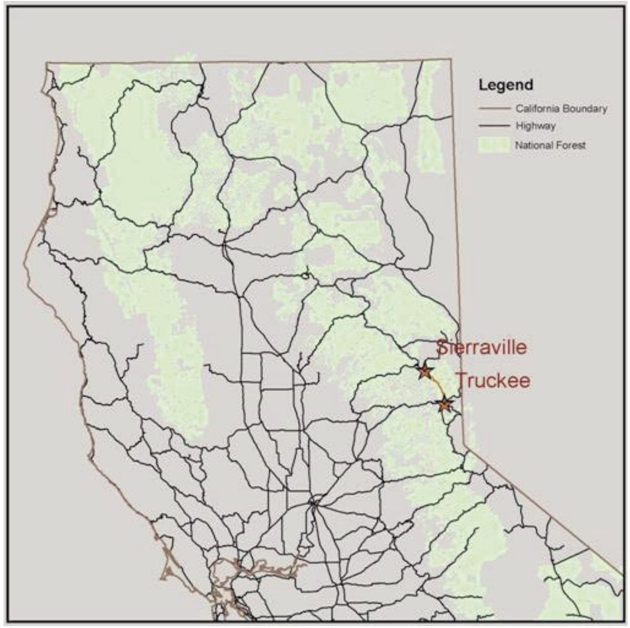

Figure 1. Northern California's State Highway 89 from Truckee to Sierraville.

The Team's experience is valuable to others because the combined efforts of several individuals and agencies have resulted in substantial accomplishments. The Team's contributions can be summarized in these areas:

1. No highway project is planned on Highway 89 for the foreseeable future. Therefore, any mitigation for highway impacts could not be rolled into another project, but instead must be a standalone. This determined the approach the Team would take to identify and promote mitigation opportunities.
2. Caltrans has consistently collected carcass data on Highway 89 for 23 years. While not unique, it is extremely unusual to have the longevity of a carcass database in an area that has seen few human developmental changes along a 16-mile distance (of the 33 miles total), thus allowing testing of the database for use in other situations.
3. The Team conducted a mid-scale habitat connectivity 'rapid assessment' (Ruediger and Lloyd 2003) of the lands within approximately 15 miles on each side of Highway 89. This connectivity assessment was based on readily available information gathered from local agencies, including USDA Forest Service habitat maps and the Caltrans carcass database. All species were considered, although the initial impetus for the Team's interest was deer/vehicle collisions.
4. The Team modified a process in use by Caltrans for some of its projects, the Value Analysis process (Caltrans 2003). This process helped select and prioritize opportunities for mitigation within the 33-mile stretch of Highway 89 between Truckee and Sierraville.

Stewardship Team Members

The Stewardship Team (figure 2) was formed when individual members realized others were working towards similar goals. Interestingly, prior to 2002 several agencies and individuals were independently working on aspects of the problem of deer/vehicle collisions. The California Department of Fish and Game (CDFG) had an ongoing research project to identify factors affecting the Loyalton-Truckee Mule Deer Herd. Among the issues were deer/vehicle collisions on Highway 89 and other highways within the herd's range. Sierra County Fish and Game Commission had inquired of Caltrans on the possibility of reducing deicing agents, which may attract deer to roadside edges. Caltrans was continuing to collect carcass data along highways in several counties.

Among the most complete and continuously collected databases was Highway 89, resulting in an excellent database. The University of California (Davis) Agricultural Extension Service had begun to use the Caltrans carcass database to investigate whether a relationship existed between forest fuels treatments along highway edges and deer/vehicle collisions. The USDA Forest Service's Pacific Southwest Research Station had begun to use Caltrans' carcass database to investigate how to extract the maximum amount of useful information out of it and similar databases used elsewhere.

The Sierra County Board of Supervisors submitted a grant to the Caltrans Transportation Enhancements for 'wildlife mitigation' along Highway 89. The USDA Forest Service was interested in the effects of Highway 89 and others on the connectivity of several wildlife species between widespread units of the Tahoe National Forest.

Figure 2. Sierraville Highway 89 Stewardship Team reviewing mitigation options in the field. Representatives are pictured from USDA Forest Service Tahoe National Forest and Pacific Southwest Research Station, Caltrans, California Department of Fish and Game, and Sierra Country Fish and Game Commission. Not pictured, Michael DeLasaux, UC Davis Agricultural Extension Service, photographer.

The Tahoe National Forest recognized that a combined effort would be needed to organize these disparate efforts and also that specialized expertise in wildlife and highway issues would be needed to tackle the challenges. The Pacific Southwest Research Station was requested to organize, lead, and teach the Stewardship Team until local individuals could take over.

Individuals working on all these efforts convened in spring 2003 and the Sierraville Highway 89 Stewardship Team was formed to more efficiently reach mutual objectives. The Team agreed on these primary objectives:

1. Increase traveler safety by decreasing deer/vehicle collisions.
2. Reduce vehicle-caused mortality to all species of wildlife.
3. Maintain or improve habitat connectivity for all species across the highway, especially as highway traffic volume increases over time.

Although many of the Team members originally became interested in the topic because of deer/vehicle collisions, the Team wholeheartedly agreed that multiple species were affected by Highway 89 and needed to be included in any mitigation efforts.

As the Team progressed towards identifying the problem and potential solutions, more people became interested in the project. The California Highway Patrol and the Sierra County local government became involved. Sierra County applied for a Title III Grant to involve local schools in the research and solution-finding efforts of the project, resulting in a grant of $132,000. The California Deer Association granted the Team $5,000 for team members' expenses.

Stewardship Team Assumptions and Agreements

The Stewardship Team agreed to take a comprehensive, large-scale approach to mitigate Highway 89's impacts to wildlife. First among these agreements was to consider multiple species rather than define the issue as a deer/vehicle safety issue. This agreement led to the understanding that habitat connectivity was as important to consider as vehicle-caused mortality. The Team further agreed that any mitigation would be a very long-term process, likely spanning two decades, and agreed to continue to champion mitigation efforts as long as needed.

At the time of the Team's formation, no budget existed for mitigation. The Team considered the lack of a constraining budget as an opportunity, because then we could choose mitigation based on its efficiency and priority, rather than by a project's budget limitations. Because Highway 89's impacts would require many individual mitigation solutions even as parts of an integrated mitigation package, the Team expected to promote improvement projects incorporating our recommendations or seek grants for separate mitigation projects.

Although formal agreement vehicles such as memoranda of understandings or the like have been discussed, to date the Team has no formal agreements.

Team members are seeking ways to use current accomplishments to leverage future research and mitigation opportunities. The Sierraville section of Highway 89 offers an unprecedented opportunity to conduct Before-After/Control-Impact studies, particularly using the long-term carcass database.

Initial Accomplishments

The Stewardship Team conducted a mid-scale connectivity analysis for all terrestrial species likely to be affected by Highway 89 using the general rapid assessment protocol of Ruediger and Lloyd (2003). We used available resources including local experience, habitat quality maps from USDA Forest Service data, the Caltrans carcass database, and mule deer movement information from the California Department of Fish and Game's ongoing research.

The connectivity analysis revealed few identifiable 'hotspots' where typical mitigation methods such as underpasses would work. Primarily this was because the topography allows for unconfined movements of many species, including deer, and the vegetation is homogeneous for long distances adjacent to the highway. Nevertheless, after field review, the Team identified five high priority locations between the Sierra/Nevada County line and Sierraville (16 miles).

The Caltrans carcass database is currently being used for several ancillary investigations. These will be the topics of future papers and are briefly described later in this paper.

Currently, no published tool exists to help transportation planners prioritize wildlife-mitigation sites within a highway stretch or to identify the tradeoffs among competing variables at each potential location. In a construction project, planning teams have a defined distance, timeline, and budget to constrain decisions. Often, interagency agreements define which species (if any) may receive status as worthy of mitigation. In the Sierraville Highway 89 project, no such constraints existed, therefore the choice of which target species, mitigation method, and location was unconstrained.

The connectivity analysis thus provided an excellent starting tool to identify and prioritize general locations and the species associated with those locations (figure 3). The species affected determine the range of mitigation options at a given site. Since the Team had no budget, cost was not a constraint, although we rejected solutions that were not cost effective. For example, the only mitigation solution currently available as a feasible engineering design in some of the hotspots would be an overcrossing; we rejected this option due to its high cost relative to the traffic volume expected in the next 50 years.

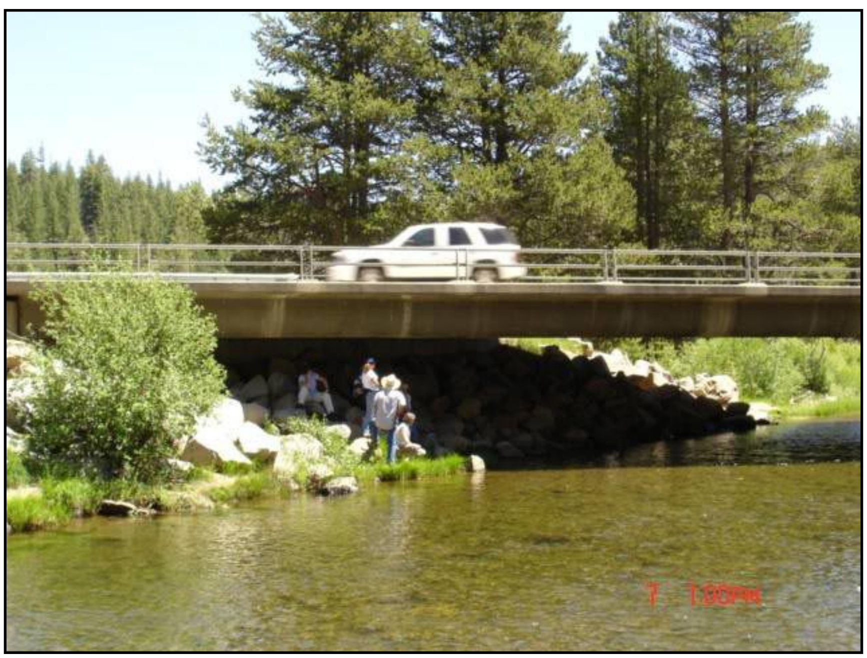

Figure 3. This bridge was determined by the connectivity analysis to be an opportunity for improving wildlife passage if the riprap could be made more wildlife-friendly. Image by Michael DeLasaux.

Transportation Enhancements Grant

At the time the Stewardship Team had completed the connectivity analysis and identified several potential mitigation options and specific locations, Caltrans notified us that the Sierra County Board of Supervisors Transportation Enhancements (TE) grant submission had been funded. The grant designates $720,000 for 'wildlife mitigation.' Caltrans has the authority to choose the mitigation option. However, the agency has relied heavily on the Team's connectivity analysis and knowledge of the mitigation needs of the area in their required analysis stages.

Caltrans uses a Value Analysis study process on some of its projects (Caltrans 2003). This process helps improve the value of highway projects in several ways, including when multiple alternatives are identified or consensus is needed among stakeholders. The Stewardship Team modified the process to identify the best choice of location and mitigation type based on several variables defined by the Team. This process will be outlined briefly below and will be the subject of a future paper. Based on the connectivity analysis, field review, and the Value Analysis process, the Team recommended three locations and structure types to Caltrans as potential projects for the TE grant and requested a review from the agency to determine which of the options would be within the budget.

Caltrans agency engineers reviewed the Team's recommended options and determined that one of the options would be within the TE budget. This option was the Team's highest priority option (of the three chosen for this TE grant) as well (figure 3).

Figure 3. This site was chosen as the highest-priority location for an improved underpass suitable for all local species. Instead of replacing this box culvert, Caltrans engineers suggested installing an additional underpass 5 meters to the right of this view because of reduced installation costs. Image by Michael DeLasaux.

As of the date of this writing, the final decision on the type of mitigation option has not been chosen by Caltrans. However, it is likely to be an underpass at Kyburz Flat. In addition to an underpass, three small water-conveyance culverts were identified within the area to be fenced that could also be retrofitted to be suitable for small terrestrial fauna (figure 4).

Figure 4. The highest-priority mitigation option (a large underpass about 10 miles from this location) will need diversion fencing. The fencing will enable several other suitable, existing small culverts to function as small fauna passages because of the diversion. Image by Michael DeLasaux.

Funding for monitoring was included in the TE grant. This funding leveraged with other funds (including those from USDA Forest Service) will allow us to investigate experimentally for effectiveness several commonly used retrofitting options as well as new concepts, particularly with regards to noise moderation within the underpass.

Construction is planned for 2007. The Stewardship Team is prepared to continue to identify and seek funding for the remaining mitigation projects.

Modified Value Analysis

The Stewardship Team modified Caltrans' Value Analysis process so that we could have an objective, transparent, and repeatable means of identifying which mitigation project to fund first. Because the TE was submitted by Sierra County, we narrowed the choices to the mitigation projects within Sierra County.

We further narrowed the choices to the stretch on the Truckee (south) side of a side road that diverted a considerable amount of traffic from Sierraville because the rate of increase in traffic volume would likely be greatest in this stretch. Within the remaining stretch, five major areas for mitigation projects remained.

The Value Analysis process allowed us to identify criteria for choosing among the remaining mitigation options, rank those criteria to determine how close each criterion met the Team's objectives, and then rate each mitigation option for fit to the criteria. However, while the Team believed the Value Analysis process we used was very helpful in illuminating our decision rationale, we also believed the process needed additional work to be fully useful as a standardized approach elsewhere.

For example, feasibility ranked highest among all 11 criteria (figure 5). Aesthetics ranked lowest. In this case, aesthetics were never more important than any of the other criteria. Although aesthetics would therefore not be a decisive factor in choosing a mitigation option, the Team felt it was important to include it because several stakeholders mentioned aesthetics during Team discussions.

For purposes of our analysis, we did not include cost because the Team decided that if the TE grant would be insufficient to pay for our highest priority, we would seek additional funds, rather than choose a less functional option.

Performance Criteria Evaluation

	Criteria	A Feasibility	B Aesthetics	C Maintainability	D Environmental Impact	E Cost-effectiveness	F Land ownership	G Urgency	H Habitat Quality	I Multiple-species	J Safety	K Human Disturbance	Total	Percent
A	Feasibility		A	A	A	A	A	A	A	A	A	A	10	19
B	Aesthetics			C	D	E	F	G	H	I	J	K	0	0
C	Maintainability				C	E	F	G	H	I	J	K	2	4
D	Environmental Impact					E	F	G	H	I	J	K	1	2
E	Cost-effectiveness						E	G	H	I	J	K	4	7
F	Land ownership							G	H	I	J	K	3	6
G	Urgency								H	I	J	G	7	13
H	Habitat Quality									H	H	H	10	19
I	Multiple-species										I	I	9	17
J	Safety											J	2	4
K	Human Disturbance												6	11
												Total	54	102 <- rounding erro

Figure 5. Modified Caltrans Value Analysis process performance criteria used for evaluating the priority of each potential mitigation option along Highway 89. Each criterion is compared to all others and ranked in relative closeness in meeting the Stewardship Team's objectives.

The 11 criteria we used, in order of importance, were:

1. Feasibility
2. Adjacent habitat quality
3. The capability of the mitigation option to meet multiple species needs
4. Urgency (are conditions changing or are ephemeral opportunities available?)
5. Presence of human disturbance
6. Cost effectiveness
7. Adjacent land ownership
8. Maintainability
9. Safety
10. Environmental impact (of the mitigation itself)
11. Aesthetics

Safety ranked relatively low because the Team reasoned that functional mitigation would provide safety benefits and that mitigation options that provided safety benefits (but not ecological benefits) were less desirable. Many of these criteria are similar to those identified in the decision matrix used in Florida (Neal et al. 2003).

Caltrans Carcass Database

Carcass databases over unbroken, long-duration timespans are rare, particularly with consistently collected data. Further, carcass databases are more useful for information on wildlife issues than animal/vehicle collision data because many vehicle owners do not report animal/vehicle collisions.

Caltrans has collected information on carcass locations throughout many locations in California. However, the quality of the data is dependent on numerous factors, including the relative importance placed on it by maintenance supervisors over the years. The Sierra County section of Highway 89 is unusually complete and of long duration. Nevertheless, it was collected by crews of typical highway maintenance workers untrained in statistics. It is therefore an excellent database to use to determine how useful such databases are to inform decisions on mitigation options.

Pacific Southwest Research Station is currently developing a Microsoft Excel-based tool to help transportation planners answer some first approximation questions. One such question is how long it may be necessary to collect carcass data to identify ‘hotspots’ on a given stretch of highway under user-identified circumstances. The definition of ‘hotspot’ is user identified as well because some DOTs may have guidelines already.

This tool can also be used as a first approximation of hotspots if users have little or no habitat information available for greater interpretation. Hotspot locations have limited utility for informing decisions on mitigation options; however, a first approximation with a simple tool may help transportation planners determine if further investigation of hotspot data with a more sophisticated tool may be useful.

The Caltrans Highway 89 carcass database is being used as one of several similar databases from around North America as part of the National Coordinated Highway Research Program’s project 25-27: Evaluating the Effectiveness of Wildlife Crossing Structures. These databases will be used to develop and refine much more sophisticated tools for carcass and vehicle-collision databases, especially those with GIS-based habitat information available.

These results and tools will be available in a future publication.

Biographical Sketch: Sandra L. Jacobson is a wildlife biologist/research and management liaison at the Pacific Southwest Research Station, Redwood Sciences Laboratory, Arcata, California. Education: B.A. in zoology (1983), Humboldt State University, Arcata, California; M.S. in natural resources/wildlife (1986), Humboldt State University. Jacobson has served as a wildlife biologist for the USDA Forest Service since 1980, working on three national forests at the district and forest levels in California and Idaho. She has worked for the USDI Fish and Wildlife Service, California Department of Fish and Game, and the USDA Soil Conservation Service. As the district wildlife biologist for the Bonners Ferry Ranger District on the Idaho Panhandle National Forests for 13 years, she managed grizzly bears, woodland caribou, and other threatened or endangered wildlife in an interagency and international setting. Ms. Jacobson is the lead biologist for the Wildlife Crossings Toolkit website. She is a charter member of the Transportation Research Board’s Task Force on Ecology and Transportation and a team member for NCHRP 25-27’s Evaluating the Effectiveness of Wildlife Crossing Structures. She is a member of the UC Davis Road Ecology Center’s Scientific Advisory Committee. Currently, Ms. Jacobson is providing project-level technical expertise and training on wildlife and highway issues for several agencies around the country while acting as a research/management liaison at the Pacific Southwest Research Station.

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WSDOT Highway Maintenance: Environmental Compliance for Protected Terrestrial Species

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Abstract: Protected plant and wildlife species that grow, forage, nest, roost, or migrate near the Washington State Department of Transportation (WSDOT) highway system may be susceptible to impacts from routine maintenance activities. In response to community-driven concerns related to the conservation of protected terrestrial species and due to the lack of existing guidance for maintenance personnel when protected-species conflicts arose, WSDOT biologists and maintenance personnel worked together to develop new guidance. The purpose of the guidance is to provide maintenance personnel with resources that identify which projects occur in sensitive plant and wildlife areas and identify best management practices (BMPs) that can be implemented to minimize or avoid impacts to protected terrestrial species in Washington State.

Existing sensitive-species data and aerial photographs were used to identify locations of sensitive species and habitats and to develop guidance. To verify habitat presence, biologists conducted site visits to areas identified as possible sensitive habitats. The guidance document is in the form of a field handbook presented in a step-by-step format to facilitate use by WSDOT maintenance personnel. The guidance document provides maps and descriptions of sensitive areas, each identified by state route and milepost. Species information, such as species name, nest sites, wintering sites, or locations of sensitive habitats, are not identified in the guidance document. Alternatively, biologists placed the species into groups based on habitat needs and identified only the state-route mileposts that fall within each sensitive area. This process helped WSDOT prevent publicizing sensitive wildlife data in the guidance documents and avoided the need for evaluation of habitat by maintenance personnel.

Common maintenance functions were also broken down into groups. For each sensitive location and maintenance function group, a list of BMPs is provided. BMPs may include timing restrictions, equipment use restrictions, or overall activities that should be avoided during certain seasons. The document does not address all possible conditions that may arise during maintenance operations that could affect protected terrestrial species. Maintenance staff consult with their Regional Maintenance Environmental Coordinator prior to initiating any activity that is not addressed by the guidance document or if there is any uncertainty about the applicability of the guidance. Maintenance activities that are not able to comply with the guidance typically require a field review by a biologist and the development of site-specific BMPs. Maintenance personnel do not follow this guidance for emergency actions because separate procedures were previously developed that adequately address protected species compliance for emergency maintenance actions.

This project is currently being piloted with the Olympic Region Maintenance Program. Training courses conducted at individual maintenance sheds have provided opportunity for discussion and question and answer sessions. Biologists and maintenance personnel have had the opportunity to work together to learn each other's programs, perspectives, and observations to improve the effectiveness of the environmental compliance guidance. The WSDOT Highway Maintenance Environmental Compliance Guidance for Protected Terrestrial Species Program has helped the Maintenance Program conduct their projects in a timely fashion without unnecessary delays and to remain good stewards of the environment.

Introduction

Washington State is well known for its diverse species and unique environments. Washington State is also home to many of the species protected by the Endangered Species Act (ESA) and the Migratory Bird Treaty Act (MBTA). Washington State laws or the Washington Administrative Code (WAC) also provide protection for many of these species. The Washington State Department of Transportation (WSDOT) maintains thousands of miles of roadway within our state that bisect terrestrial habitats occupied by these protected species. Protected plant and wildlife species that grow, forage, nest, roost, or migrate near the WSDOT highway system may be susceptible to impacts from routine maintenance activities. WSDOT is presented with the challenge of maintaining the public-transportation systems while protecting plant and wildlife species that occur along or near the WSDOT highway right-of-way (ROW). WSDOT maintenance personnel must prevent harm or harassment to species protected by the ESA, MBTA, or WAC when implementing highway-maintenance activities.

Section 7 of the ESA allows certain activities to be conducted that may impact an ESA-listed species. However, Section 7 provisions are limited to actions that have a federal nexus. Existing rules under Section 4(d) of the ESA provide limited coverage for projects that require in-water work and may have impacts to some ESA-listed fish species under the jurisdiction of the National Marine Fisheries Service (NMFS). WSDOT coordinates with NMFS for approval and permitting when 4(d) activities arise. WSDOT also coordinates with the U.S. Fish and Wildlife Service (USFWS) when conflicts arise with MBTA-listed birds nesting on WSDOT bridge structures and time-sensitive highway-maintenance activities are required that may harm the species. However, the majority of WSDOT maintenance activities that could impact terrestrial species protected under the ESA, MBTA, and WAC have no compliance provisions. Therefore, it is critical to provide guidance to maintenance personnel in the field, as well as to supervisors involved in the planning of activities to assure that WSDOT conducts their highway maintenance in compliance with laws that protect terrestrial species.

The unique environments of Washington State provide a home to a variety of protected terrestrial species and a large number of them regularly encounter the WSDOT highway system. Currently, Washington State is home to 14 ESA-listed endangered species, 32 threatened species, 14 species that are candidates to be listed, three proposed to be listed, 20 species with designated critical habitat, and two species with critical habitat proposed to be designated. Many of these species and habitats overlap or are regular inhabitants of the WSDOT highway ROW.

In response to community-driven concerns related to the conservation of protected terrestrial species and due to the lack of existing guidance for maintenance personnel when protected-species conflicts arise, WSDOT biologists and maintenance personnel worked together to develop a new program. The objective of the program is to determine where protected terrestrial species and habitat coincide with state routes, develop guidance that allows maintenance personnel to avoid or minimize impacts to these species and habitats, and ultimately facilitate project delivery with minimal delay.

Maintenance Activities

Maintenance activities that have the potential to disturb protected terrestrial species or impact habitat were grouped by function. Within each maintenance function group, we identified various pieces of equipment or activities and describe their applicability and how they may potentially impact species or habitat. Table 1 provides a list of the maintenance function groups, the equipment or activities within that group, and their applicability to the environmental guidance.

Table 1. Maintenance activities and potential environmental impact

Maintenance Function Group	Applicability*
1. Roadway Maintenance	Environmental guidance applies due to potential: ❑ Disturbance impacts from pavement grinding, jack hammering, grader patching, shoulder re-grade (pulling shoulders), and chip seal operations.
2. Drainage Maintenance and Slope Repair	Environmental guidance applies due to potential: ❑ Disturbance impacts from operation of excavators, back hoes, vactor trucks, jackhammers, and ❑ Habitat impacts from vegetation clearing outside of the developed right-of-way.
3. Roadside and Landscape Maintenance	Environmental guidance applies due to potential: ❑ Disturbance from brush cutting, hazard tree removal, operation of chain saws, and ❑ Habitat impacts from hazard tree removal, herbicide application, mowing, and vegetation clearing outside of the developed right-of-way.
4. Bridge and Tunnel Maintenance	Environmental guidance applies due to potential: ❑ Disturbance from common regional maintenance activities, and ❑ Nest removal from cleaning and washing activities.
5. Snow and Ice Control	Exempt.
6. Traffic Control Maintenance and Operations	Exempt.
7. Rest Area Operations	Exempt. Not applicable to the current rest areas in the region.
8. Support Operations	Exempt.
9. Third Party Damage and Disaster Operations	Exempt.

* Regardless of the maintenance function group, all emergency actions are exempt from this guidance.

Sensitive areas
Sensitive areas are sections of state routes that coincide with occurrences of protected terrestrial species or habitat. These sensitive areas are provided to maintenance personnel in the form of milepost sections of a state route. This approach allowed us to avoid publishing the precise locations of protected species. We located sensitive areas based on species or habitat presence, distance of the species or habitat from the state route, and suitability of the habitat.

Species groups
We grouped species based on their habitat requirements. All species included in this guidance are protected by the ESA, MBTA, or WAC. However, the guidance emphasizes ESA-listed species and habitat. Table 2 summarizes the species groups located in the WSDOT Olympic Region and their associated habitat.

Table 2. Summary of species in the Olympic Region and their assigned groups based on habitat requirements

Species Group	A	B	C	D	E
Habitat Type	Old-growth Forests	Riparian or Marine Forest	Ocean Beaches or Salt-spray Meadows	Prairie or Open Grasslands	Bridges
Species Names	❑ Northern Spotted Owl ❑ Marbled Murrelet	❑ Bald Eagle	❑ Brown Pelican ❑ Western Snowy Plover ❑ Oregon Silverspot Butterfly ❑ Streaked Horned Lark	❑ Golden Paintbrush ❑ Kincaid's Lupine ❑ Nelson's checkermallow ❑ Whulge Checkerspot ❑ Valley Silverspot ❑ Mardon Skipper ❑ Puget Blue ❑ Streaked Horned Lark ❑ Mazama Pocket Gopher	❑ Peregrine Falcon ❑ Osprey

Species Group A

Species Group A includes those species associated with old-growth forests. Species included in Species Group A are northern spotted owl (*Strix occidentalis caurina*) and marbled murrelet (*Brachyramphus marmoratus marmoratus*). The USFWS has determined that the destruction, modification, or curtailment of habitat for these species is a significant factor in their decline (Federal Register 1990; Federal Register 1996). The northern spotted owl is a federally threatened species under the ESA (Federal Register 1990) and a Washington State endangered species (WAC 232-12-014). The marbled murrelet is a federally threatened species under ESA and Washington State threatened species (Federal Register 1992a; WAC 232-12-011). Critical habitat has also been designated for both species (Federal Register 1992b; Federal Register 1996). Both northern spotted owls and marbled murrelets are protected under the MBTA (50 CFR 10.13).

Northern spotted owls are nocturnal forest-dwelling owls that nest from March to June (Federal Register 1990) in stands with structural components typical of old-growth forests. Fledging occurs from mid-May to late June, with parental care continuing into September (Federal Register 1990). Nesting generally occurs in cavities of large (>30 inches diameter at breast height [dbh]) coniferous trees and snags (Federal Register 1992b). Adult northern spotted owls require sufficient open space below the canopy to forage (Thomas et al. 1990 in Federal Register 1992b). Use of chainsaws, the sound of falling trees, and the sound of cutting downed wood have the potential to adversely affect northern spotted owls in western Washington between March 1 to July 15 if the sound occurs within 65 yards of the species (USFWS 2003). Use of heavy equipment and motorized tools has the potential to affect northern spotted owls adversely in western Washington during this same timeframe if the sound occurs within 35 yards of the species (USFWS 2003).

Marbled murrelets are seabirds; however, nesting occurs in stands with the structural components typical of old-growth forests usually located within 50 miles of saltwater (Rodrick and Milner 1991). All of the WSDOT Olympic Region falls within the range of the marbled murrelet. The marbled murrelet nesting season takes place in Washington from April through August and juveniles begin to fledge in June (Hamer and Nelson 1995a). These murrelets nest on "platforms" in the upper canopy of large coniferous trees (i.e. large or forked limbs, dwarf mistletoe [*Arceuthobium spp.*] infections, witches' brooms, deformities, etc.) (Hamer and Nelson 1995b). They may fly over 50 miles from nest sites to coastal waters to forage for fish and return to the nest once a day (one visit by both parents), usually during dawn or dusk, to deliver prey to the juvenile (Nelson and Hamer 1995). Due to this unique foraging strategy, any interruption during prey delivery could have severe consequences. Murrelets generally follow streams, roads, and other open areas on their flights to and from the nest (Nelson and Hamer 1995). Use of chainsaws, the sound of falling trees, and the sound of cutting downed wood have the potential to affect marbled murrelets adversely between April 1 and August 5 if the sound occurs within 45 yards of the species (USFWS 2003). Use of heavy equipment and motorized tools has the potential to affect marbled murrelets adversely during this same timeframe if the sound occurs within 35 yards of the species (USFWS 2003).

Species Group A also includes designated critical habitat for northern spotted owls and marbled murrelets. Northern spotted owls require habitat suitable for nesting, roosting, foraging, and dispersing (Federal Register 1992b). Currently, 20 critical habitat units for northern spotted owls have been designated in Olympic Region; 18 of them are adjacent to or are intersected by WSDOT highways that are maintained by Olympic Region maintenance personnel. Based on this information, approximately 38 miles of WSDOT highway are classified as sensitive due to the presence of critical habitat and potentially being within 0.25 miles of nesting northern spotted owls.

Marbled murrelet critical habitat includes only those primary constituent elements that provide suitable nesting habitat (Federal Register 1996). Currently 541 critical habitat units have been designated in Olympic Region; 18 of them are adjacent to or are intersected by WSDOT highways that are maintained by Olympic Region maintenance personnel. Based on this information, approximately 39 miles of WSDOT highway is classified as sensitive due to the presence of critical habitat and potentially being with 0.25 miles of nesting marbled murrelets.

Due to the increased home range of northern spotted owls and marbled murrelets outside of the nesting season and the decreased threat of disturbance and habitat impacts outside of the nesting season, we are only providing guidance for activities that occur within nesting areas during nesting seasons. We have established guidance for the various maintenance activities that could affect nesting northern spotted owls and marbled murrelets or destroy northern spotted owl or marbled murrelet nesting habitat. Guidance for sensitive zones for Species Group A includes avoiding noisy activities that occur for more than one hour and are between March 1 and September 30. Guidance is also provided for tree removal in sensitive areas, with maintenance personnel contacting the Regional Maintenance Environmental Coordinator prior to removing any trees great than 12 inches dbh.

Species Group B

Species Group B is designated for bald eagles (*Haliaeetus leucocephalus*). Bald eagles are terrestrial raptors that are generally associated with aquatic habitats for foraging purposes. The USFWS has determined that the decline of bald eagles was largely attributed to the widespread use of organochlorine insecticides, habitat loss, harassment and disturbance, shooting, electrocution from power lines, poisoning, and a decline in prey base (Federal Register 1978). The bald eagle is currently listed as a federally threatened species under ESA (Federal Register 1978) and Washington State threatened species (WAC 232-12-011). The bald eagle is also protected under the MBTA (50 CFR 10.13), and the Bald and Golden Eagle Protection Act (16 USC 668a-668c). Protection of nesting and wintering habitats are critical to the continued survival of the bald eagle (Federal Register 1999) and availability of suitable trees for nesting and perching is critical for maintaining bald eagle populations (USFWS 1986).

Biologists have characterized suitable bald eagle habitat as accessible foraging areas and trees that are large enough for nesting and roosting (Stalmaster 1987). Food availability, such as aggregations of waterfowl or salmon runs, is a primary factor attracting bald eagles to wintering areas and influences nest and territory distribution (Stalmaster 1987; Keister et al. 1987). Bald eagles generally nest in the same territories each year and often use the same nest repeatedly, although alternate nests in the territory may be used as well. Bald eagle nests in the Pacific Recovery Area are usually located in uneven-age stands of coniferous trees with old-growth forest components (USFWS 1986) that are located within 1 mile of large bodies of water (Stalmaster 1987). Factors such as relative tree height, diameter, tree species, form, position on the surrounding topography, distance from the water, and distance from disturbance influence nest-site selection. When foraging, bald eagles generally select perches in the tallest trees that provide an unobstructed view of the surrounding area.

Wintering bald eagles typically congregate in large aggregations where, most importantly, food is abundant. Suitable perch sites adjacent to foraging areas and winter-roost habitat are also necessary. In Washington, these criteria are typically met where waterfowl and salmon populations are present, as well as marine areas (Stinson et al. 2001). Communal night-roosting sites are traditionally used year after year and are usually the largest trees with the most open structure (Keister and Anthony 1983; Watson and Pierce 1998). These sites are often located in areas that provide a more favorable microclimate during inclement weather (Keister et al. 1985; Knight et al. 1983; Watson and Pierce 1998).

Human disturbance is a continuing threat to nesting and wintering bald eagles (USFWS 1986). Use of heavy equipment and motorized tools between January 1 and August 15 or October 31 and March 15 and within 0.25 miles (no line of sight) or 0.50 miles (line of sight) of bald eagle nesting or winter-roost sites is expected to result in an adverse effect (USFWS 2003). Bald eagles can occur in the Olympic Region throughout the year as both resident and wintering populations. Information obtained from the Washington Department of Fish and Wildlife (WDFW) indicates the presence of over 984 bald eagle nest sites distributed throughout Olympic Region, with 96 of the nest sites within 0.25 miles of a

WSDOT highway. We have provided guidance for maintenance activities that may be disruptive to nesting and wintering bald eagles or activities that may alter bald eagle nesting, roosting, or wintering habitat. Highway-maintenance activities do not pose a threat to eagles outside of the nesting and wintering periods. Therefore, no guidance is provided for non-nesting/wintering eagles. Guidance includes minimizing noisy activities on highways occurring within 0.25 miles of bald eagle nest sites between January 1 and August 15 and within 0.25 miles of bald eagle wintering roost sites between October 31 and March 31.

Species Group C

The species in group C are associated with ocean beaches or salt-spray meadows and include brown pelican (*Pelecanus occidentalis*), western snowy plover (*Euphydryas editha taylori*), streaked horned lark (*Eremophila alestris strigata*), and Oregon silverspot butterfly (*Speyeria zerene hippolyta*). Currently, the brown pelican is listed as a federally endangered species under ESA (Federal Register 1970), is a Washington State endangered species (WAC 232-12-014), and is also protected under the MBTA (50 CFR 10.13). The western snowy plover is a federally threatened species under ESA (Federal Register 1993a), a Washington State endangered species (WAC 232-12-014), and is also protected under the MBTA (50 CFR 10.13). The streaked horned lark is a candidate to be federally listed under ESA (Federal Register 2005), a candidate to be protected by Washington State law (WDFW Policy M-6001), and is already protected under the MBTA (50 CFR 10.13). The Oregon silverspot butterfly is a federally threatened species (Federal Register 1980) and a Washington State endangered species (WAC 232-12-014).

The brown pelican is a coastal seabird that requires terrestrial habitat for communal roosting. Biologists have determined that the primary reason for the decline of brown pelicans is the past widespread use of organochlorine insecticides. These pelicans are also threatened by oil spills, disturbance at post-breeding roosts, entanglement with fishing lines, and disease outbreaks resulting from overcrowding in harbors. Protection of major roost sites was included among the primary objectives for the recovery of the species (USFWS 1983).

Brown pelican nesting is restricted to southern California during March and April. Northward seasonal movements begin after breeding, beginning as early as mid-May. Roosting and loafing sites in Washington State provide important resting habitat for these birds. These sites are located around good marine fishing areas with offshore rocks and islands, river mouths with sand bars, breakwaters, pilings, and/or jetties. Aerial surveys along the Washington coast from 1987 to 1991 have documented the presence of large numbers of pelicans from the mouth of the Columbia River north to Cape Flattery. Pelican numbers have increased each year of the survey from 922 observed in 1987 to 7,610 observed in 1991 (Jaques et al. 1996).

Brown pelicans are diurnal and roost on land at night. Roosting pelicans are extremely susceptible to disturbance. Human activities such as walking, jogging, fishing, dog walking, and hunting have all been documented as being very disturbing to pelicans (Jaques et al. 1996). Headlights flashing across roosting birds have been observed to cause a flushing reaction. Construction and maintenance activities resulted in several cases of disturbance at a roost at Mugu Lagoon in Southern California, but operating heavy equipment and installing riprap along the edge of the lagoon, approximately 330 feet from the birds, was not observed to cause a disturbance (Jaques et al. 1996). Thus disturbance appears to be dependent on the type and duration of the activity.

Brown pelicans are likely to occur along the outer Washington coast with the greatest concentrations of pelicans in and around bays and estuaries. Brown pelican concentrations are documented in Grays Harbor areas (Jaques et al. 1996). We have provided guidance for maintenance activities that may be disruptive to night-roosting brown pelicans. Guidance includes avoiding disturbance near brown pelican night roost sites (from an hour before sunset to an hour after sunrise) between June 1 and October 31, such as from the use of chainsaws and heavy equipment. Highway-maintenance activities pose no other potential threat to brown pelicans.

Western snowy plovers are coastal seabirds that breed on coastal beaches from southern Washington to southern California. Biologists have determined that the primary reason for the decline of the western snowy plover is due to loss of nesting habitat and disturbance of breeding western snowy plovers (i.e. crushing eggs) by humans and domestic animals (USFWS 2001a). Nesting season on the Washington coast occurs from early March through late September. Eggs are present from early March through the third week of July. Nest sites are generally flat, open areas with sandy or saline substrates. Vegetation and driftwood are present, but sparse. Nesting usually occurs within several hundred meters of water. To minimize disturbance to breeding and nesting western snowy plovers, the USFWS recommends preventing disruptive activities from occurring near nesting habitat and preventing off-road pedestrian or vehicular traffic through nesting habitat (USFWS 2001a). Therefore, we provided guidance for maintenance activities that may be disruptive to breeding and nesting western snowy plovers and activities that may impact western snowy plover habitat.

Most western snowy plovers remain in Washington State year round, while others migrate. In 1995, the breeding population in Olympic Region was restricted to one site, the Damon Point/Oyhut Wildlife Area at Ocean Shores (WDFW 1995); however, suitable habitat occurs at other coastal sites in Olympic Region. Recent estimates indicate the population at Damon Point and Oyhut Wildlife Area may have increased to up to nine nesting adults (Federal Register 2004). Due to the small population and documented concentrated use areas in Olympic Region, road projects are expected to have a very minor impact on this species.

Streaked horned lark are terrestrial songbirds that were once abundant in Puget Sound prairies and open coastal habitats (Stinson 2005). During nesting season, these larks are closely associated with spacious grasslands containing a significant amount of bare ground (i.e. bunchgrass-type habitat) but have adapted to nesting in grasslands at airports and on sandy coastal spits (Stinson 2005). Biologists have determined that the primary reason for the decline of streaked horned lark populations in Washington is due the extensive destruction of native grasslands and disturbance during nesting season (Pearson and Hopey 2005).

Nesting season for the streaked horned lark is very long, typically beginning in early April with nest building and breeding displays, and seems to exhibit two peaks in clutch initiation, with the first peak from late April until early June and the second peak from late June to late July (Pearson and Hopey 2005). Biologists working towards the recovery of this species and others species associated with grassland and beach-dune habitat discourage the introduction of non-native plant species (i.e. European beachgrass [*Ammophila arenaria*]), off-road vehicle operation, pedestrian presence, and land-management activities (i.e. mowing) while eggs are in nests (Pearson and Hopey 2005). In conjunction with these management recommendations, we provided guidance for maintenance activities that may be disruptive to nesting streaked horned larks or may impact nesting habitat. According to Pearson and Hopey (2005), management activities that benefit the western snowy plover will likely benefit the streaked horned lark. In Washington, suitable nesting habitat for western snowy plovers typically is occupied by nesting streaked horned larks. Therefore, the guidance we designed to minimize impacts to western snowy plovers will likely be protective of streaked horned larks.

The Oregon silverspot butterfly is a coastal subspecies of the widespread Zerene fritillary butterfly in montane western North America. Biologists believe that this subspecies is now extirpated from its historical range along the Washington coast (USFWS 2001b). The Oregon silverspot butterfly depends on a diverse wildflower habitat, including known caterpillar host plants and a variety of adult nectar plants and that are associated with fescue-dominated (*Festuca* spp.) montane grasslands, stabilized dunes, and marine salt-spray meadows (USFWS 2001b). Current efforts by WDFW and USFWS include conserving existing habitat, rehabilitating marginal habitat, and possibly reintroducing the species into its historical range along the Washington coast (USFWS 2001b). Management recommendations for the recovery of the Oregon silverspot butterfly include timely land-management activities (i.e. mowing) that foster growth of native species and prevent the spread of invasive plant species (USFWS 2001b).

The only known larval host plant for the Oregon silverspot butterfly is the early blue violet (*Viola adunca*). The early blue violet is a low-growing plant that needs open spaces or bare ground, which is common in fescue-dominated grasslands, dunes, and meadows. The adult Oregon silverspot has a late-summer flight period (July through September). Therefore, it depends on late-blooming nectar plants such as common California aster (*Aster chilensis*), western pearly everlasting (*Anaphalis margaritacea*), dune goldenrod (*Solidago spathulata*), yarrow (*Achillea millefolium*), and dune thistle (*Cirsium edule*).

The potential habitat for this species in the Olympic Region is limited to coastal areas along Grays Harbor County. We provided guidance for maintenance activities that may alter suitable Oregon silverspot habitat. Disturbance is not considered a limiting factor. Therefore, no guidance specific to limiting disturbances near Oregon silverspot butterflies is provided. Guidance includes avoiding clearing vegetation (grading, grubbing, filling) and applying herbicides outside of the vegetation-free zone (zone 1) of the WSDOT highway ROW along stretches adjacent to suitable habitat. Also, mowing is not recommended outside of zones 1 and 2 (zone 2 is the operational zone and is typically maintained for erosion, sight distance, vehicle recovery, and other purposes) of the WSDOT highway ROW during May and between July 1 and September 31 along highway segments with suitable habitat. Mowing is encouraged at these sites during the months of April, June, and after September.

Species Group D

Species in group D are located in glacial outwash prairies and alluvial valley meadows and include golden paintbrush (*Castilleja levisecta*), Kincaid's lupine (*Lupinus sulphureus kincaidii*), Nelson's checkermallow (*Sidalcea nelsoniana*), whulge checkerspot butterfly (*Euphydryas editha taylori*), mardon skipper butterfly (*Polites mardon*), Mazama pocket gopher (*Thomomys mazama*), and the streaked horned lark. Currently, golden paintbrush, Kincaid's lupine, and Nelson's checkermallow are all listed as federally threatened under ESA (Federal Register 1997, 2000, 1993b). The whulge checkerspot butterfly, mardon skipper butterfly, and Mazama pocket gopher are candidates to be listed as threatened or endangered under ESA (Federal Register 2005). The mardon skipper butterfly is also endangered under Washington State law (WAC 232-12-014).

Golden paintbrush, Kincaid's lupine, and Nelson's checkermallow are native wildflower species that are believed to have once flourished in the expansive native prairies of the Puget and Willamette Trough. Over time, the destruction of this habitat by development, the introduction of competitive non-native species, and the conversion of native grasslands for agricultural purposes has threatened the continued existence of these species (Caplow 2004, Federal Register 2000, USFWS 1998). Biologists involved with the recovery of these species recommend protecting remaining native grasslands, providing guidance for appropriate roadside-management techniques in areas with documented plants, and managing for invasive species (Caplow 2004, Federal Register 2000, USFWS 1998). Therefore, we provided guidance for maintenance activities that may directly impact golden paintbrush, Kincaid lupine, and Nelson's checkermallow flowers or permanently alter their habitat.

The whulge checkerspot and mardon skipper butterflies require a diverse habitat with a wildflower population supportive of adult foraging and larval development (Fimbel 2004). Suitable habitat for these species also includes appropriate topography and sparse deciduous trees or forest "nooks" that create complex microclimates throughout the seasons (Fimbel 2004). This diverse and complex habitat is characteristic of native fescue-dominated grasslands of the Puget and Willamette Trough (Fimbel 2004).

Both of these butterflies have an early spring flight period, typically occurring from May through June. This timing is consistent with the bloom time of the early blue violet (*Viola adunca*), an important nectar plant for the adult mardon skipper and the bloom time of the common camas (*Camassia quamash*), desert parsley (*Lomatium* spp.), and broad-petal strawberry (*Fragaria virginiana*), known nectar plants for the adult whulge checkerspot. Also an important habitat component for these butterflies is the presence of summer food resources for pre-diapause larvae. Diapause for butterfly larva is a "sleep time" that begins before harsh winter conditions arrive and during which the larva does not grow. Fescue (*Festuca* spp.) is the primary larval host plant for the mardon skipper, while harsh paintbrush (*Castilleja hispida*) and English plantain (*Plantago lanceolata*) are important larval host plants for the whulge checkerspot. Protection of these native species and other species that make up native grasslands is critical for the recovery of these butterfly species (Fimbel 2004). Therefore, we provided guidance for maintenance activities that may alter mardon skipper or whulge checkerspot habitat.

The Mazama pocket gophers need open meadows, prairie, or grassland habitat with friable soils that are not too rocky (Stinson 2005). They are generally associated with glacial-outwash prairies in western Washington (Hartway and Steinberg 1997). Mazama pocket gopher habitat has been lost to development and succession to forest. What remains continues to be degraded by the invasion by Scotch broom (*Cytisum scoparius*) (Stinson 2005). These gophers do not usually occur where grassland has been taken over of dense Scotch broom (Steinberg 1996). Given these requirements, we provided guidance for maintenance activities that may permanently alter mazama pocket gopher habitat. Disturbance is not identified as a potential limiting factor. Therefore, no guidance that pertains to limiting disturbance was provided for Mazama pocket gophers.

The streaked horned lark was placed in species group C and D due to its overlap into both habitat types. Information on this species was provided in the previous species group. Management recommendations for the streaked horned lark coastal habitat represented in species group C also apply to its upland grassland habitat represented in this species group.

The guidance manual highlights sensitive areas where suitable habitat exists adjacent to the state route for Species Group D. Recommended guidance that may minimize impacts to habitat for Species Group D includes avoiding vegetation clearing (grading, grubbing, filling) and application of herbicides outside of zone 1 of the WSDOT highway ROW. Also, the guidance signals maintenance personnel to contact the Regional Maintenance Environmental Coordinator prior to mowing outside of roadside management zones 1 and 2 between March 15 and September 1.

Species Group E

Species in group E are those species that commonly nest on WSDOT bridges. Included in this group are American peregrine falcon (*Falco peregrinus*), osprey (*Pandion haliaetus*), and pelagic cormorant (*Phalacrocorax pelagicus*). American peregrine falcons have been delisted from protection under the ESA since 1999 (Federal Register 1999). However, they are still classified as an endangered species in Washington State (WAC 232-12-014) and are also protected by the MBTA (50 CFR 10.13). Osprey population declines have been noted (Levenson and Koplin 1984), but their population has not decreased to the point that they are endangered or threatened with becoming extinct. Regardless, they are protected under the MBTA (50 CFR 10.13) as are pelagic cormorants.

American peregrine falcons in Washington State may begin courtship displays at the nesting site as early as February (Hayes and Buchanan 2002). Eggs may be present at the nest site from April to June (Hayes and Buchanan 2002) and juveniles fledge by the end of July (Hayes and Buchanan 2002, Wilson et al. 2000). Like most falcons, peregrines do not build nests, instead, nesting pairs form a hollow, or a "scrape," in loose rock or gravel (Hayes and Buchanan 2002). During the breeding period, these peregrines will protect their nest, eggs, and young from predators (including humans) at varying levels of intensity (Hayes and Buchanan 2002). Limited data suggests that peregrines have a tendency to return to the areas where they nested the previous year (Mearns and Newton 1984).

Established pairs of osprey also use the same nest year after year unless it is destroyed. If the nest is destroyed, the osprey pair usually rebuilds a new nest as close to the old site as possible (Westall 1986). Although constructed primarily of sticks, the osprey incorporates just about anything into its nest that is not tied down (Westall 1986). Osprey generally nest mid-May through June (Bent 1937 in Westall 1986), with juveniles fledging after eight weeks (Westall 1986), or by the end of September.

Pelagic cormorants are colonial-nesting seabirds and are year-round residents of some WSDOT bridges. They appear to be nesting on the underside of bridges as early as mid-March (Carey pers. comm. 2005). Nests are made from seaweed or other plant debris (Baicich and Harrison 1997). All juveniles fledge the occupied bridges by mid-October (Carey pers. comm. 2005).

Due to the susceptibility of American peregrine falcons, osprey, or pelagic cormorants to disturbances at nest sites, we provided guidance for highway-maintenance activities that may disturb nesting. A list of bridges with documented nests from these birds is provided in the guidance manual. We recommend avoiding noisy highway-maintenance activities (i.e. pavement grinding, jack hammering) during the nesting season. The sensitive seasons provided in the guidance manual for nesting American peregrine falcons, osprey, and pelagic cormorants are February 1 through July 15, April 1 through September 30, and March 15 through October 15, respectively.

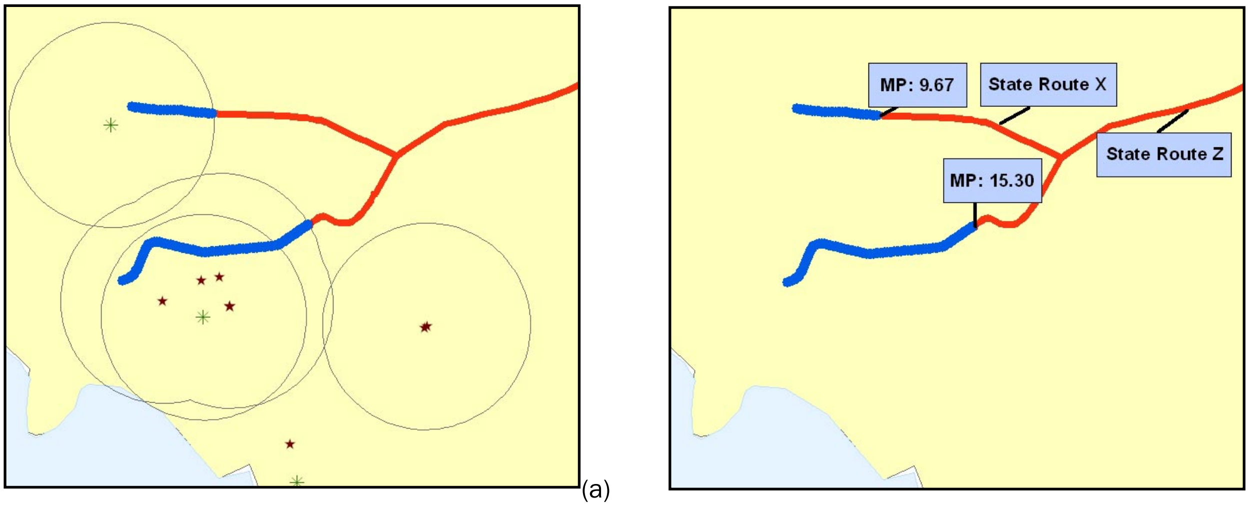
The three bird species discussed above are the only identified species in Species Group E that may be impacted by common highway-maintenance activities. However, the Olympic Region Maintenance Program also conducts some bridge-structure maintenance and inspection activities that could, depending on the extent and location of the maintenance activity on the bridge, cause injury to other wildlife species nesting on bridges. In an effort to provide regional bridge-maintenance personnel with the ability to plan in advance and conduct work without injuring nesting wildlife species, we added a bridge appendix to this guidance manual. The appendix was written to be a stand-alone document and is provided only to regional bridge-maintenance personnel to minimize distribution of this sensitive information. This appendix identifies the species and the bridges where nesting is likely occurring. We included those species that WDFW and USFWS have asked WSDOT to protect. Maintenance personnel are signaled to inspect the bridge for nesting status prior to conducting the work. Inspecting the bridge first will prevent unnecessary implementation of BMPs if the species is not nesting. Species included in the appendix are American peregrine falcons, osprey, pelagic cormorants, golden eagles (*Aquila chrysaetos*), owls (*Order Strigiformes*), bats, (*Order Chiroptera*), swallows (Family Hirundinidae), American dippers (*Cinclus mexicanus*), and pigeon guillemots (*Cepphus columba*). Guidance includes inspecting the bridge for nesting status of the identified wildlife species and if the species is nesting, contacting the Regional Maintenance Environmental Coordinator prior to conducting work to determine the least-invasive means of conducting the activity.

Identifying Sensitive Areas

WSDOT Geographic Information System (GIS) and Biology staff queried Priority Habitat and Species (PHS) and other sensitive species databases to identify wildlife nest and roost sites, historical and current sensitive-plant locations, old growth, and critical habitat in the vicinity of WSDOT highway ROWs. State route sections that overlap with a 0.25-mile buffer around nest and roost sites were highlighted and mileposts identified for mapping purposes. Aerial photographs were used to identify possible prairie or open grassland areas that are adjacent to the state route. WSDOT Bridge and Structures staff assisted in the development of a list of WSDOT bridges with documented nesting/roosting wildlife based on bridge-inspection reports and personal communications.

WSDOT biologists conducted site visits to verify sensitive habitat presences. The habitat was delineated by a Global Positioning System (GPS) and data was converted into state route milepost sections by the GIS staff.

In the guidance document, WSDOT presents the location of sensitive areas (identified by state route and milepost) in map and table formats. Both formats are provided for each species group (assignment of species into groups is discussed above). Species information, such as species name and locations of nest sites, wintering sites, or sensitive habitats, are not identified in the guidance document. WSDOT developed this system to prevent publicizing or distributing PHS and other sensitive species data. Figure 2 provides an example of this system.



(a) (b)

Figure 1. Example of the process used to determine sensitive zones of state routes. (a) PHS data overlaid with state routes. The figure shows the nest sites with a 0.25-mile buffer and its overlap with the state route. (b) Example from the guidance document. The guidance document only identifies the state route and mileposts that overlap with the buffer.

Guidance implementation

The guidance document is in the form of a field handbook presented in a step-by-step format to facilitate use by WSDOT maintenance personnel. The guidance document provides maps and descriptions of sensitive areas for each species group, identified by state route and milepost, as illustrated in figure 2. The first step for maintenance personnel is to determine if a maintenance activity will take place in one of these sensitive areas prior to conducting the work. If the activity will not occur within an identified sensitive area, the action may proceed without implication from this guidance. If the activity will occur within a section of state highway identified as sensitive, the reviewer identifies which species group(s) occur(s) in that highway section, then proceeds to Step 2.

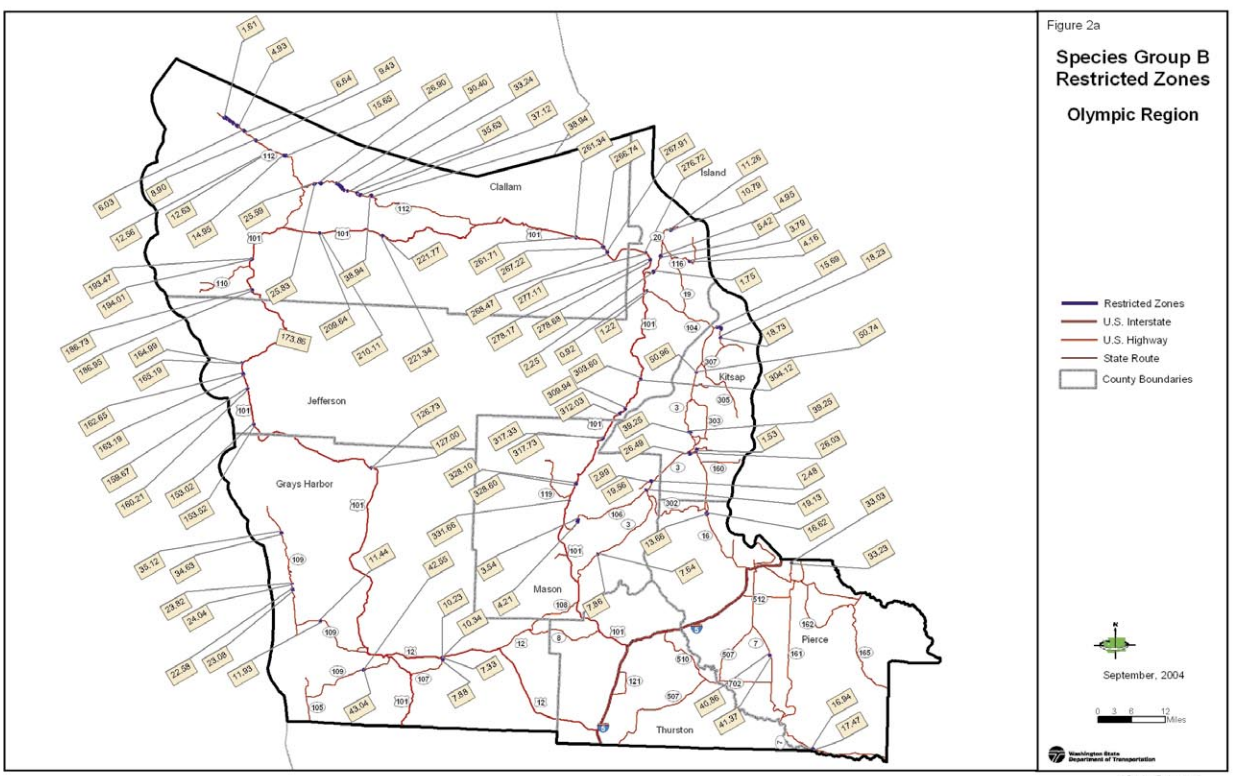


Figure 2. Example of the sensitive areas for Species Group B in map format.

The second step for maintenance personnel is to determine if the proposed maintenance activity is applicable to the guidance. (No guidance was developed for those maintenance actions that pose no potential threat to sensitive species. Those actions were identified as "exempt".) If a maintenance activity is not exempt, Best Management Practices (BMPs) will be assigned to the activity based on the species group(s) that are present, as illustrated in figure 3.

Maintenance Activity	Best Management Practices														
	Species Group A		Species Group B			Species Group C					Species Group D			Species Group E	
	A-1	A-2	B-1	B-2	B-3	C-1	C-2	C-3	C-4	C-5	D-1	D-2	D-3	E-1	E-2
Group 1															
Pavement grinding	X		X	X					X	X				X	X
Grader patching	X		X	X					X	X				X	X
Shoulder re-grade (pulling shoulders)	X		X	X					X	X					
Chip seal	X		X	X					X	X				X	X
Jack hammering	X		X	X					X	X				X	X
Group 2															
Maintenance Activity	**Best Management Practices**														
	Species Group A		**Species Group B**			**Species Group C**					**Species Group D**			**Species Group E**	
	A-1	**A-2**	**B-1**	**B-2**	**B-3**	**C-1**	**C-2**	**C-3**	**C-4**	**C-5**	**D-1**	**D-2**	**D-3**	**E-1**	**E-2**
Excavator / backhoe operation (over 1 hour duration)	X		X	X					X	X					
Vactor truck operation (over 1 hour duration)	X		X	X					X	X					
Jack hammering	X		X	X					X	X					
Vegetation clearing		X			X	X					X				
Group 3															
Brush cutting	X		X	X					X	X					
Mowing							X					X			
Hazard tree removal	X	X	X	X	X				X	X					
Chain saw use	X	X	X	X	X				X	X					
Herbicide application								X					X		
Vegetation clearing						X					X				

Figure 3. BMPs for selected Olympic Region Maintenance Program activities. BMPs are defined in the guidance manual provided to Olympic Region Maintenance Program personnel and are based on management recommendations discussed in the "Species Groups" section of this paper.

BMPs are grouped based on management recommendations and guidance discussed in the previous section under individual species groups. A table (see figure 3) is provided in the guidance document to designate the appropriate BMP(s) that is recommended within a proposed work area. BMPs may include timing restrictions (i.e. during nesting season for birds, flight season for butterflies, or flowering season for wildflowers), equipment use restrictions (i.e. noisy equipment such as pavement grinding or jackhammering), or activities that should be avoided (i.e. vegetation clearing).

BMPs are guidance and are to be used as a planning tool. BMPs are not meant to stop projects from occurring. If a project cannot comply with the applicable BMPs, then maintenance personnel are signaled to contact their Regional Maintenance Environmental Coordinator to develop site-specific BMPs. Site-specific BMPs are designed to allow the project to continue while minimizing impacts to protected terrestrial species. Site-specific BMPs are developed cooperatively by maintenance personnel, the Regional Maintenance Environmental Coordinator, and a biologist.

The document cannot address all possible conditions that may arise during maintenance operations that could affect protected terrestrial species. Maintenance staff consult with their Regional Maintenance Environmental Coordinator prior to initiating any activity that is not addressed by the guidance document or if there is any uncertainty about the applicability of the guidance. The guidance documents are not applicable to emergency actions because separate procedures have been developed that address protected species compliance for emergency actions.

Due to the success implementing this new guidance document in the Olympic Region, maintenance staff reformatted the guidance handbook to facilitate data entry into the existing Personal Data Assistant system that documents statewide WSDOT environmental compliance. This BMP Field Guide has been printed and distributed to Olympic Region maintenance personnel and we are now beginning to work with other regions to implement the program in other areas of Washington State.

Biographical Sketches: Tracie M. O'Brien has been a wildlife biologist for WSDOT since January 2004. She has been involved in the creation and implementation of the *WSDOT Highway Maintenance: Environmental Compliance for Protected Terrestrial Species* project. She has been actively involved in creating site-specific BMPs for various maintenance projects. She will be leading the completion of this project statewide.

Bret Forrester, while working for David Evans and Associates, was a place-based biologist at WSDOT where he worked on a variety of tasks including Programmatic Biological Assessments and the initial draft of the *WSDOT Highway Maintenance: Environmental Compliance for Protected Terrestrial Species*. He has since moved on to work in the wildlife-management arena and is working for Tacoma Public Utilities.

Marion Carey is the fish and wildlife program manager for the Headquarters office of WSDOT. She is responsible for developing and implementing statewide policies like Programmatic Biological Assessments and the *Highway Maintenance Manual for Terrestrial Species*.

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Chapter 6

Streamlining, Stewardship, and Sustainability

Streamlining in Washington State

Measuring the Performance of Multi-Agency Programmatic Permits for Washington State Department of Transportation Activities

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Abstract

In 2001, the Washington State Legislature established the Transportation Permit Efficiency and Accountability Committee (TPEAC) to identify measures to streamline permit procedures for transportation activities and improve environmental outcomes. A programmatic subcommittee was created to develop a multi-agency approach for developing programmatic permits that would cover 60 to 70 percent of Washington State Department of Transportation (WSDOT) activities (mostly maintenance and preservation work). The subcommittee envisioned that the process for developing programmatic permits would involve establishing common conditions between jurisdictional agencies for similar categories of transportation-related activities. Agreement on common conditions would lead to programmatic permit approval issued by each agency that would cover the subject activities as they occur throughout the state. Agencies involved in this effort included NOAA Fisheries, USFWS, Corps, Washington State Departments of Ecology and Fish and Wildlife, local agency representatives and tribe representatives.

In July 2004, the subcommittee had completed developing multi-agency programmatic approval for bridge and ferry terminal painting and washing, bridge and ferry terminal deck replacement, bridge and ferry terminal maintenance and repair, fish way maintenance, channel maintenance, culvert maintenance, culvert replacement, LWD removal from bridges, beaver dam removal, sediment test boring in all state waters, and 40 pile replacement in marine water. Much of this work was performed in the field during 2004 using programmatic permit coverage.

In January 2005, WSDOT received and compiled information regarding the performance of these programmatic permits during the 2004 calendar year. This presentation compares the performance results from 2004 with the initial goals and expectations established by the subcommittee (mainly focusing on percent activities covered). The presentation further expands on results including time and cost savings for both WSDOT and permit agencies, environmental benefit, and other lessons learned.

Streamlining Transportation Permitting in Washington Through use of Integrated Web-Based Permitting Tools and Applications

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Abstract

The State of Washington, under the sponsorship and leadership of the State Office of Regulatory Assistance (Agency of the Governor's Office), has embarked on a multi-agency, multi-phased effort to integrate permitting and regulatory requirements across the state for Washington State Department of Transportation (WSDOT) projects through use of innovative web-based technologies, applications, and leveraged partnerships. Partner agencies involved in this multi-agency, multi-jurisdiction integration effort include:

- **Federal**. US Army Corps of Engineers for Section 10 and Section 404 permits; US Coast Guard for Section 9 permits; and Federal Highways (WA);
- **State**. Washington State Department of Fish and Wildlife for HPA permits; Washington State Department of Ecology for Section 401, CZM consistency, and shoreline permits; Washington State Department of Natural Resources for Aquatic Use Authorizations; Washington State Department of Health for on-site septic approvals; Washington State Department of Transportation; Washington State Office of Regulatory Assistance; Washington State Office of Financial Management; and Washington State Natural Resources Information Portal Project; and
- **Local**. King County for local shoreline, critical areas, and zoning permits.

Key elements of the web-based permitting approach include:

- One-Stop JARPA Permitting Site. Interactive web application providing WSDOT and others with: (i) a single, integrated source of local, state, and federal permitting and regulatory guidance, glossary, tips, FAQs, examples, and step-by-step instruction from the above permitting and regulatory agencies; (ii) downloadable "one-stop" permitting forms (e.g., web-enabled multi-agency Joint Aquatic Resources Permit Application (JARPA) form); (iii) secure upload functionality to ensure all regulatory agencies are looking at and seeing the same application materials and environmental discipline reports; and (iv) on-line search, retrieve, and archive capability.
  See http://www.one-stop-jarpa.org
- On-Line Permit Assistance System (OPAS). Interactive, query-based application designed to help applicants and WSDOT determine permitting requirements based upon answers given to select project questions and the extent to which certain regulatory thresholds are met or exceeded. Conclusion of query session is a customized, narrative report of applicable permits and their descriptions. See http://apps.ecy.wa.gov/opas/
- Permit Process Schematics. Interactive process and timeline flowcharts depicting sequence and steps associated with select permitting and regulatory processes, including Section 404, Section 10, HPA, Shoreline, CZM, SEPA, NEPA, NPDES Stormwater, Air Operating, Water Rights, NPDES, and more. Permit Process Schematics coupled with customized OPAS narrative reports provide applicants and WSDOT with a comprehensive overview of applicable permit and regulatory requirements. See http://www.ecy.wa.gov/programs/sea/pac/ppds_info/review.htm

Project Purpose Statement: The purpose of the Office of Regulatory Assistance's effort to work with WSDOT and others to advance integration of permitting and regulatory requirements through the above described web elements is largely to:

- Provide clear, accessible, and uniformly presented information in a similar format and level of detail;
- Enhance and promote permitting and regulatory accountability and transparency;
- Provide a means to foster and enable continuous process improvement and innovation; and
- Improve by lessening decision-making review and transaction times and increasing overall quality of submitted application materials and documentation.

Brief Project Overview and Methodology: Development of the above described web elements has largely occurred through cooperative agreement and participation from the above agencies. Leadership and staffing from the Office of Regulatory Assistance has provided the vision and sense of direction necessary to unify and secure the engagement and participation from the agencies. Development occurs through a consultant, agency IT staff, and a multi-agency steering group.

Explanation of Current or Anticipated Results: Beta testing to date has resulted in higher quality permit applications being submitted to local, state, and federal regulatory agencies (via the Washington State Multi-Agency Permitting Team for Transportation). Additionally, web elements have generated productive process improvement and process clarity changes within the regulatory agencies. Clear and accurate information, acquired and factored in early in the process, results in greater attention to regulatory and permitting requirements as well as better and more fully informed compliance (or better yet, impact avoidance as a result of likely regulatory obligation).

Recommendations for Future Research: Advance thinking and planning is underway for merging and linking work done in the environmental and natural resources realm with the work occurring in parallel with State Departments of Licensing, Revenue, and Community, Trade, and Economic Development.

The Use of a Multi-Agency Permitting Team (MAP Team)

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Abstract

Environmental permitting for transportation projects is complex and time consuming. Communication and sharing of information between permitting agency staff can be inefficient, partially due to staff location in different geographic areas. The establishment of a Multi-Agency Permitting (MAP) Team is a project to demonstrate the advantages of co-locating regulatory staff from multiple agencies in a common office to enhance interpersonal communication and interagency coordination. Effective communication early in project development is key to risk identification and project management and consequently, maintaining the planned schedule and budget. The purpose of the MAP Team is to cooperatively process environmental permits for Washington State Department of Transportation (WSDOT) transportation projects while protecting natural resources in the public interest. Participating agencies hope to demonstrate the efficiency and cost effectiveness of this new concept of focused governmental cooperation. The primary goal is to provide thorough, expedited review of permit applications to ensure that transportation projects are consistent with environmental regulations and agency agreements and policies.

Project overview and methodology
The State of Washington is investing in strategies intended to streamline environmental regulatory and permit processes. The creation of the MAP Team is one such strategic investment that is designed to demonstrate how WSDOT and regulatory agencies can work together to meet transportation and environmental goals. The MAP Team charter agencies include: WSDOT, Washington State Department of Ecology, Washington Department of Fish and Wildlife, United States Army Corps of Engineers, and King County Department of Development and Environmental Services. MAP Team members are co-located together a minimum of one day a week at the Department of Ecology's Northwest Regional Office in Bellevue. The MAP Team concept is being tested on approximately 52 transportation projects primarily in western Washington. The MAP Team has been up and running since early November 2003 and is scheduled through June of 2007.

After initially defining how to work together, the team began communicating with their customer base in an attempt to make permitting processes more consistent and predictable. The MAP Team has been using this feedback to initiate streamlining opportunities to: define complete application(s), create early project coordination and MAP Team permit processes, identify improvement opportunities within each agency, and to create model business practices that will use existing project experiences to deliver future projects. These investments in early project coordination are being tracked through eight performance measures. The MAP Team model is based on developing a foundation of trust and open communication between a diverse, highly capable group of decision makers from the five agencies. This formula provides an accountable, transparent process that is able to identify risks and opportunities and to address and avoid conflicts early, thereby achieving permit decisions in a predictable and timely manner.

Current results
To date, the MAP Team has been involved in reviewing permits for over 25 transportation projects. The MAP Team work is being evaluated against a number of performance standards. These include permit processing time, baseline comparisons, agency investments, initiating change, conflict resolution, and meeting customer expectations. Evaluation of these performance standards will be used to determine the success of the MAP Team concept.

Recommendations for the future
Based on the initial stakeholder feedback from this pilot project, the MAP Team business model appears to be a good investment toward the delivery of transportation improvement projects. Because of this feedback, the MAP Team pilot project, which was to sunset in June 2005, was extended to June 30, 2007. After further evaluation, it is possible that Washington State may institute the MAP Team concept as a permanent business practice with the potential for growth in other transportation, intergovernmental, and private venture applications.

Washington State's Transportation Permit Efficiency and Accountability Committee (TPEAC)

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Abstract: Washington State is about to complete a five-year effort to improve the environmental-permitting process for transportation projects. From its start in 2001, the Transportation Permit Efficiency and Accountability Committee (TPEAC) sought to streamline the environmental-permitting process for transportation projects in Washington State. Some of the goals of TPEAC are to reduce mitigation cost, increase environmental benefit, reduce the redesign of transportation projects, and reduce time required to obtain permits. Passage of the Transportation Streamlining Act by the Washington State Legislature in 2001 began the work of this committee. TPEAC has provided a valuable forum to bring together representatives of all entities involved in transportation permitting. TPEAC participants recognize the relationship between their individual roles and the importance of working together to bring about a more streamlined and integrated permitting process in order to use public resources more efficiently and achieve better environmental results. Several technical subcommittees established by TPEAC have developed some important transportation-streamlining tools and policies that help reduce costs and increase environmental benefits. TPEAC's work to improve Washington State's transportation permitting process serves as a model for collaborative, multi-stakeholder efforts to increase regulatory efficiency while maintaining high environmental standards.

Introduction

This paper is intended to share the experience and lessons learned from Washington State's five-year effort to improve the environmental-permitting process for transportation projects. From its start in 2001, the Transportation Permit Efficiency and Accountability Committee (TPEAC) has sought to streamline the environmental-permitting process for transportation projects in Washington State. One of the basic assumptions of TPEAC was that successful streamlining activities were thought to be those that balanced transportation permit delivery goals and environmental protection and could be measured by the following four criteria:

- Reduced project delivery time
- Reduced project delivery costs
- Increased environmental performance
- Customer/stakeholder satisfaction

The TPEAC experience serves as a case study of a collaborative, multi-stakeholder effort to reform environmental permitting for transportation projects. TPEAC has provided a valuable forum for bringing together representatives of all entities involved in transportation permitting. There now exists a much better understanding of the challenges faced in environmental permitting of transportation projects and solutions needed to improve and simplify the process. TPEAC fosters a cooperative relationship where WSDOT works together with other state and federal agencies, local governments, and tribes in establishing common goals to minimize project delays, develop consistency in the application of environmental standards, and maximize environmental benefits. TPEAC's greatest success has been the creation of a forum for airing issues and developing relationships between agencies. TPEAC's work to improve Washington State's transportation permitting process serves as a model for collaborative, multi-stakeholder efforts to increase regulatory efficiency while maintaining high environmental standards.

How the Process Began

WSDOT and the Washington State Legislature recognized the need for transportation-permit reform. The Legislature established TPEAC to create a forum to discuss, develop, and test innovative approaches for permit streamlining. The goal of the TPEAC is to develop a streamlined approach to environmental-permit decision making in order to optimize limited public resources for transportation system improvements and environmental protection.

In 2001, the Washington State Legislature passed Engrossed Senate Bill 6188 – Streamlining the Environmental Permit Process for Transportation Projects to ensure that transportation dollars are used efficiently and effectively while increasing the environmental benefit. The act mandated the creation of a Transportation Permit Efficiency and Accountability Committee (TPEAC). TPEAC was extended by the 2003 legislature until March of 2006. Goals of the new act are to reduce environmental mitigation costs, increase environmental benefits, and increase WSDOT's performance in meeting environmental regulations.

The TPEAC committee includes senators and representatives from the state legislature, state agencies, local government, business, trade, and environmental organizations. Federal and tribal agencies also participate. TPEAC funding is used to support technical staff participation from the Departments of Ecology, Fish and Wildlife, the Northwest Indian Fisheries Commission, the Upper Columbia United Tribes, the Columbia River Intertribal Fisheries Commission, the Association of Washington Cities and the Washington Association of Counties. These agencies are working with WSDOT in technical and policy development to improve regulatory processes. TPEAC funding is also used for consultant services for research and policy work in support of permit development and creating better project-mitigation alternatives. Other resource agencies dedicate staff time for participation in TPEAC activities.

Explanation of Current Results

TPEAC has provided a valuable forum to bring together all those involved in transportation permitting. All participants now recognize the relationships between their roles and the importance of working together to bring about a more streamlined permitting process to use government resources more efficiently and achieve better environmental results. Some of the TPEAC innovations have been institutionalized (such as a variety of programmatic permits) and more are planned, including watershed characterization; improvements to environmental mitigation; and on-line permitting tools to improve permit applications.

Work of TPEAC's Technical Subcommittees

TPEAC Legislation directed the establishment of several technical subcommittees to evaluate and develop streamlining tools and policies. The following sections provide examples of some of the work of TPEAC's technical subcommittees.

Watershed-based mitigation

TPEAC tasked the Subcommittee with creating a watershed approach to environmental mitigation. The TPEAC legislation directed that the subcommittee undertake specific activities, including:

- Developing technical tools that use a watershed-based approach to identify mitigation sites
- Developing a multi-agency watershed-based mitigation policy guidance document to expedite environmental permitting
- Completing a test of the policy and technical tools
- Developing a schedule to integrate watershed tools, policies, and procedures.

A watershed approach seeks to understand natural resource impacts, assess the condition of environmental processes, and evaluate restoration options in a landscape context. Using a watershed approach to permitting ensures that decisions on mitigation opportunities are evaluated based on their potential to provide measurable environmental benefits at landscape scales, rather than just an on-site replacement of habitat lost in the transportation project. The subcommittee developed a methodology to characterize the ecological health of a watershed and to use that information to identify areas that would provide the greatest environmental benefit for impacts caused by transportation projects.

The watershed characterization method outlines a scientific framework and set of procedures for identifying, screening, and prioritizing a suite of options for mitigating environmental impacts on large transportation projects with complex environmental issues. The method includes:

- Characterizing the condition of the watershed to support, maintain, and improve restoration and mitigation efforts
- Assessing potential environmental impacts of a project
- Optimizing avoidance and minimization opportunities
- Identifying, assessing, and prioritizing potential mitigation sites

A watershed characterization technical team has developed a landscape-scale method for evaluating watersheds in association with a transportation corridor and identifying and prioritizing potential mitigation opportunities that have the greatest potential to mitigate transportation impacts and maximize environmental benefits. The team has completed four projects located in Snohomish, King, and Pierce counties to develop, test, and refine the methodology. On the I-405/SR 520 project, the team used the watershed characterization tool to identify 4,888 potential wetland, riparian, and floodplain mitigation sites.

Multiple mitigation sites provide opportunities to maximize environmental benefits and reduce project costs. For example, treating stormwater flow control through the restoration of degraded wetlands provides a new mechanism for meeting mitigation needs and increasing environmental benefits. A wetland restored upstream of a highway project can provide the same stormwater flow control benefits as a detention pond next to the project or a stormwater vault built underneath the highway. Meanwhile, it has many other benefits: wildlife habitat, groundwater recharge, water quality improvement, etc. At the same time, the wetland option may be far less expensive than the engineered option.

The Watershed Subcommittee also developed a transportation-screening tool to help engineers identify projects with the potential for excessive mitigation costs early in project planning. Work is currently underway to automate and integrate the screening tool into WSDOT's Environmental Work Bench. The Environmental Work Bench is a geographical information system (GIS) that includes several layers of environmental information so that project engineers can| readily access relevant information for project locations across the state. Automating the screening tool will make it more convenient for project engineers and others to analyze environmental risks and the need for watershed-characterization work.

Permit compliance and training subcommittee
TPEAC was interested in improving permit compliance. The subcommittee was formed to meet that need and addressed this issue by adopting clear reporting procedures for construction and operations managers. This was combined with enhanced environmental training for staff to ensure that permit terms and conditions are understood and enforced.

Environmental compliance includes planning, designing, building, maintaining, and operating a transportation system while:

- Avoiding, minimizing, or mitigating environmental impacts
- Meeting federal, state, and local legal requirements
- Meeting permit conditions
- Being accountable for results

The purpose of the subcommittee was to develop tools to improve on these items for WSDOT construction and hired contractors. The goal of the subcommittee was to Develop a compliance, training, and reporting framework that:

- Meets environmental requirements
- Clarifies assignment of responsibilities
- Protects the environment while building, maintaining, and operating the transportation system

The objectives follow:

- Improve and demonstrate impact avoidance and minimization from project scoping through construction, operation, and maintenance.
- Ensure dedicated and adequate compliance, training, and reporting funding for DOT and NR agencies.
- Establish system to develop, track, and analyze environmental performance and create a feedback loop using monitoring results.
- Respect the differences of missions and operational approaches of DOT and NR agencies while recognizing that all agencies need to be willing to change in order to cooperate and collaborate effectively.
- Increase accountability by using timely clear communication. This will improve trust among all parties and the public.
- Define the roles and responsibilities of all WSDOT staff, contractors, and NR agencies relative to environmental compliance.

The subcommittee established enhanced environmental training for staff to ensure that permit terms and conditions are understood and enforced. While the policy issues for this Subcommittee have been resolved, training efforts are still ongoing with new classes still in development.

To date, TPEAC has funded training of over 2,000 staff members in a variety of areas including Endangered Species Act compliance, permit training for design engineers and environmental practitioners, field application of best management practices, conflict resolution, environmental-compliance assurance procedures, permit compliance for inspectors, environmental-justice regulation, and river mechanics.

Permit delivery
This subcommittee was created to streamline the permitting process. When the environmental review and permit-decision process is duplicative and uncoordinated, projects are delayed, which increases project costs and decreases service levels without necessarily improving environmental protection. The subcommittee looked at ways to coordinate environmental review and permit decision-making among federal, state, and local agencies while involving stakeholders more efficiently and effectively. The objectives of the work on permit streamlining were to:

- Develop a new process focused on streamlining.
- Apply new process to pilot projects.
- Evaluate the pilots' process for usability.
- Institutionalize those identified improvements.

Current activities focus on ensuring that the permit applicant knows what the regulations require, ensuring that initial permit applications are complete, and ensuring that permit review are coordinated among resource agencies. This committee is currently working on developing an electronic web-based permit-application process.

The Permit Delivery Subcommittee's work has supported development of on-line permitting tools for WSDOT projects. Key elements of the web-based permitting approach for WSDOT projects include the One-Stop Joint Aquatic Resources Application (JARPA) Permit Site. Development of a web-based JARPA application has included the creation of a web-based worksheet and guidance database designed to help WSDOT offices complete permit applications. The site provides WSDOT and others with a single, integrated source of local, state, and federal permitting and regulatory guidance, glossary, tips, FAQs, examples, and step-by-step instructions from the permitting agencies. The permit application consists of a downloadable source of "one-stop" permitting forms. It has a secure upload functionality to ensure all regulatory agencies are looking at and seeing the same application materials and environmental-discipline reports.

Programmatic subcommittee
TPEAC created the Programmatic Subcommittee to develop permits for routine transportation maintenance and construction activities. A programmatic permit is a consistent set of permit conditions for environmental protection that are used whenever a certain type of project is constructed. The approach is best suited for simple or often-repeated activities.

The Programmatic Subcommittee and WSDOT completed the following programmatic permits:

- Bridge and Ferry Terminal Structure Washing
- Bridge and Ferry Terminal Painting
- Bridge Structure Repair
- Channel Maintenance
- Fish Way Maintenance
- Culvert Maintenance
- Culvert Replacement in Non-Fish Bearing Streams
- Bridge Deck and Drain Cleaning
- Bridge and Ferry Terminal Deck Overlay and Replacement
- Pile Replacement in Marine Waters

Programmatic-permit coverage is suitable for low-impact and routine activities that are typically funded by the highway maintenance and preservation program. Programmatic permits provide coverage for approximately 90 percent of WSDOT's Maintenance Program, 30 percent of WSDOT's Preservation Program (e.g., bridge painting and washing, bridge deck replacement, and pile replacement), and less than 3 percent of WSDOT's Improvement Program (e.g., culvert replacement and sediment-test boring). The current programmatic coverage reflects the initial expectation of the programmatic subcommittee: that programmatic permits were suitable for low-impact activities.

Local government task force
TPEAC directed a small task force to look at the collective experiences of local governments and WSDOT as they relate to permitting transportation projects at the local government level. The purpose of the Local Government Task Force is to:

- Identify one or more county and city permits for activities for which uniform standards can be developed for application by local governments.
- Identify strategies for local governments to adapt standards and best practices to include in local permits.

A case-study approach was used to review joint WSDOT and local government projects that have been delayed during the past biennium. At the end of the 2001-2003 biennium, WSDOT recorded 89 construction projects with deferrals. Only 11 of the 89 projects were attributed to a city or county. Based on the case study, the task force met with representative staff from all six WSDOT regions, the Washington State Ferries environmental office, WSDOT Maintenance, WSDOT Bridge, and WSDOT Hydraulics. Using the survey as a platform for discussion, the meetings focused on:

- What is working well with local jurisdictions?
- What challenges do you have with local jurisdictions in obtaining permits?
- Of the identified challenges, what potential solutions would you like to see?

As part of the balance of the discussion, local jurisdictions were compared to state and federal agencies as part of the overall project delivery. In addition, local governments were asked to identify potential uniform standards and identify process improvements with WSDOT.

Feedback from WSDOT and local governments was extensive and generally positive from both perspectives. Overall, they found that the relationships with local governments are good and that cities and counties were found to be small part of the concern for construction delays. The following findings, categorized under some general-topping headings, were identified as issues:

- Staff turnover and understanding of transportation issues at the local level can be a problem (revisiting prior decision, new staff tends to be more conservative in analysis, lack of experience dealing with larger transportation projects, etc.).

- Both WSDOT and a jurisdiction's own public-works staff may not fully understand what is required in a permit.
- There is a continued desire for more locals to use the Joint Aquatic Resources Permit Application (JARPA).
- In larger jurisdictions, working with a city or county's public-works department and planning office is key to project delivery.
- Pre-application process with WSDOT is supported and frequently used.
- Early involvement on WSDOT projects with locals usually occurs; the exceptions tend to be with cities/counties that operate their permits on an enterprise-fund basis.
- Permit issuance was relatively fast, but WSDOT did not approach the jurisdiction until after the other permits had been obtained.
- The actual permit is issued relatively quickly, but negotiations leading to a permit can take months.
- Better clarification of emergency or imminent maintenance work is needed, e.g., preventative bank stabilization before flood events.
- Clarification is needed on WSDOT mitigation requirements as they relate to critical area ordinances.
- Watershed mitigation has potential but requires continued development.
- Greater review of local government planning processes (ordinance updates etc.) Better Internet access to local ordinances is needed.

Further clarification is provided for the following three issues that were highlighted by the task force:

1. Developer Services Manual: During the interview process, the task force received feedback from both local government and WSDOT staff referencing a manual that has proved to be a useful tool for permitting transportation projects. State agency and local government staff found the manual useful, particularly in the case of staff turnover. It was suggested that:
    - The draft WSDOT Developer Services Manual be institutionalized.
    - Local utilities-notice requirements be incorporated as part of the NEPA hearing process to reduce one public-outreach loop.

2. Development of programmatic and noise permits:
    - Consistency in noise variances or exemptions is desirable.
    - Programmatic permits have potential for high benefit since counties/cities have similar maintenance activities.

3. Shoreline Management Act:
    - Shoreline Management Act exemptions are being applied inconsistently by local jurisdictions throughout the state. Streamlining an exemption process for routine roadside and ferry service maintenance activities would be beneficial.
    - Notification of WSDOT activities that are occurring within the jurisdiction, even if it is an exempt activity within WSDOT right of way, is desirable.

How Successful Has TPEAC Been?

The Transportation Permit Efficiency and Accountability Committee was established by the Legislature in 2001, reauthorized in 2003, and is now mid-way through its fourth year of developing and demonstrating efficiency and accountability measures to improve transportation-project permitting. TPEAC is scheduled to sunset in March 2006 and while several of the technical subcommittees established by TPEAC have concluded their work, many of the streamlining tools and products developed by the subcommittees are being used and are starting to be evaluated. The use of multi-agency programmatic permits, web-based permit applications, watershed-based mitigation, and local permitting improvements are some of the TPEAC tools that are being implemented by WSDOT and resource agencies to increase both efficiency in transportation-project permitting and environmental benefits.

In addition to developing streamlining tools and products, TPEAC has continued to provide a valuable forum to bring together all of those involved in transportation permitting. Participants recognize the relationship between their roles and the importance of working together to bring about a more streamlined permitting process in order to more efficiently use government resources and achieve better environmental results.

As with any process aiming to foster collaboration between a diverse group of stakeholders, the TPEAC experience was not without its challenges. Participants' individual perceptions varied, but there were several commonly identified issues that can be captured in general lessons about the TPEAC process and its products.

The TPEAC experience serves as a case study of a collaborative, multi-stakeholder effort to reform environmental permitting for transportation projects in Washington State. Reflecting on the Committee's Process, Products, and Lessons Learned reveals tips, tools, and resources to assist both in the implementation of transportation streamlining tools and in the pursuit of future collaborative efforts.

Since its start in 2001, the Transportation Permit Efficiency and Accountability Committee has sought to improve the permitting process for transportation projects while maintaining high standards for environmental protection. The permitting tools developed and enhanced by TPEAC and its subcommittees are a testament to the value of this endeavor. However, as evidenced by lessons from the TPEAC experience, the committee was not without its limitations. TPEAC participants have identified several areas/issues where further progress could be made and/or where efforts are ongoing.

As with any process aiming to foster collaboration between a diverse group of stakeholders, the TPEAC experience was not without its challenges. Participants' individual perceptions varied, but there were several commonly identified issues that can be captured in general lessons about the TPEAC process and its products.

TPEAC Process Lessons Learned

- Clearly understanding and defining the problems(s) is crucial to developing an effective approach.
- Building effective relationships is both the challenge and the reward of the collaborative process.
- Appropriate participation at all phases in the process is critical to the overall effectiveness of a group's efforts.
- There needs to be a clear, collective understanding of the roles and responsibilities of participants.
- Effective and appropriate meeting management is critical to ensuring engagement and productivity.

Recommendations for the Future

TPEAC created a Successes Steering Committee to develop a vision for the future after TPEAC sunsets in March 2006 and to strategize on how to communicate results that have been achieved through TPEAC. There is an interest and a need identified by TPEAC for resource agencies, Tribes, local governments, and WSDOT to have an ongoing relationship and to continue to implement and expand on the work of TPEAC after TPEAC formally sunsets in March 2006. On the topic of how to maintain momentum on improving the regulatory process, the group agreed that the Office of Regulatory Assistance (ORA) could take the lead. This office is well positioned to bring state agencies, along with federal, local, and tribal government representatives together to continue to streamline regulatory processes. This new structure could offer the opportunity to broaden the regulatory focus for improvements beyond the transportation sector.

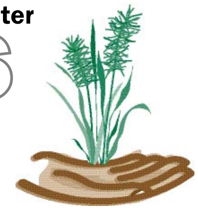
The Steering Committee identified ideas and strategies to communicate TPEAC successes including:

- Developing a TPEAC website
- Holding streamlining workshops
- Using other workshops/conferences as a forum to talk about streamlining.

Additional Information on TPEAC can be found at WSDOT's TPEAC website:
http://www.wsdot.wa.gov/environment/streamlineact/default.htm

Biographical Sketch: Barbara Aberle serves as the Transportation Permit Efficiency and Accountability (TPEAC) Implementation Manager for the Washington State Department of Transportation in Olympia, Washington. Previously she has developed wetland mitigation banks and managed WSDOT's retrofit programs for fish passage and chronic environmental deficiencies. She also has experience working at the Washington State departments of Fish and Wildlife, Natural Resources, and Ecology. Barbara has a B.S. degree in ecosystems analysis from Huxley College as well as a Master of Environmental Studies degree from the Evergreen State College.

Chapter 6



Other Innovations Across the Country

Convert Natural Resource Liabilities Into Business Assets

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Abstract

Market-based approaches to managing natural resources are becoming increasingly popular. In contrast to traditional command-and-control approaches, federal agencies are shifting to incentive-based structures where landowners are rewarded for activities that support vital ecosystem services such as clean water, clean air, healthy habitat, and biodiversity. Now, instead of tracking down and punishing those who do not comply with federal laws, government agencies are sitting at the same table with business managers to sign mutually beneficial land-management agreements.

Consensus for this approach has solidified in the past few years; recently, the Millennium Ecosystem Assessment, an international effort by nearly 1,400 scientists to determine human impacts on the environment, expressed encouragement for market-based systems as one tool for “taking nature’s value into account” and achieving a more sustainable future (Millennium Ecosystem Assessment, Statement from the Board. Living Beyond Our Means: Natural Assets and Human Well-being. March 2005 (available at http://www.maweb. org/en/products.aspx).

Market-based strategies enable landowners to buy and sell ‘credits’ for conserving ecological features such as wetlands, endangered species habitat, water-quality reduction (nutrients, oxygen, turbidity, etc.), carbon sequestration, and mercury reductions (specific to electric utilities). These credits that represent natural-resource values are banked for internal use or sold on the open market.

In its most common application, a property owner agrees to preclude development on a sensitive tract of land in exchange for a cash payment. Under government-sanctioned guidelines, the property owner then collects payments from companies who need mitigation for impacting sensitive land elsewhere. EPRI Solutions has found that new niche markets have resulted in valuations of up to $125,000 per acre for land that supports rare plant and animal species (Fox, J. and Nino-Murcia 2005), up to $250,000 for an acre of wetland (Fox, personal communication), and over $25 for a ton of carbon in European markets (Carbon Finance Magazine). In this way, ecological resources are converted into financial assets, increasingly referred to as “eco-assets.” A summary of eco-asset types and their regulatory instruments is presented in Table 1.

Table 1. Eco-Asset Credit Types

Eco-Asset Credits	Federal Guidance/Policy Generating Credits	Year Guidance/Policy Released
Wetlands	Mitigation Banking	1995
Endangered Species	Conservation Banking	1995 CA /2003 Federal
Water Quality	Water-Quality Trading	2003
Mercury	Clean Air Mercury Rule	March 15, 2005
Carbon Emissions	Pending in the U.S.	Pending in the U.S.

While the federal government determines the number of credits granted, the competitive market sets the price. Credits can be used or sold in order to comply with mitigation requirements of U.S. federal environmental laws, including the Clean Water Act, Clean Air Act, and the Endangered Species Act. The system is attractive to landowners, developers, and biologists because it is simple, cost-effective, and ecologically more promising than other mitigation options. Many of the first-generation banks are owned by for-profit organizations, established for financial motives rather than driven by environmental activism. Consequently, these approaches foretell a solution to the historically intractable con?icts between business profitability and environmental concerns.

There are several business benefits for engaging in market-based strategies and developing eco-assets on corporate property. These include:

- Reducing environmental-compliance costs by applying natural resource values on surplus land towards internal mitigation needs
- Increasing revenues either from selling eco-assets credits or the lands that underlie these assets based on their eco-asset value
- Improving public relations by taking steps to protect natural resources on corporate lands

There may also be opportunities to reduce corporate taxes by utilizing those portions of federal and state tax codes that provide substantial tax benefits to companies who donate assets to qualifying non-profit organizations or public agencies. While this approach has been used, it is generally less common than the benefits listed above.

Currently, there are about 300 wetland banks, 75 endangered species banks, and an active international market for carbon credits with the Chicago Climate Exchange already facilitating trading in the United States. Several business sectors are actively utilizing wetland and endangered-species banking. For example, departments of transportation have already banked more than 44,000 acres of wetlands in the United States (Extracted from Banks and Fees 2003). Eighteen different DOTs are active in wetland mitigation banking, with an additional six having established endangered species credits.

The pulp and paper industry is also enjoying business benefits from market-based approaches. In contrast, electric utilities and oil and gas companies have been slow to engage. As of 2002, electric utilities had established three wetland banks covering 4,263 acres (Table 2) and only one conservation bank covering 101 acres for the Coastal California gnatcatcher owned by Southern California Edison (Fox and Nino-Murcia 2005). With federal guidance only recently released for water quality trading and mercury trading, and carbon trading still awaiting official U.S. sanctions, these markets are less established across all business sectors, compared to wetland and endangered species banking.

Table 2. Wetland Banks Owned by Electric Utilities (Banks and Fees 2002)

Bank Name	Year Established	Total Acreage	Bank Sponsor
Everglades Mitigation Bank-Phase I	1996	4215	Florida Power and Light Company
Ohio Edison Grand River	1996	42	Ohio Edison Company, subsidiary of First Energy
ODEC-Virginia Power Wetland Mitigation Bank	1997	6	Old Dominion Electric Cooperative

Factors limiting participation by some industries include uncertainties related to using eco-asset credits to address mitigation needs, concern over the 'thinness' of markets, lack of knowledge of opportunities, and concerns about revealing ownership of natural resources that have traditionally been considered legal liabilities. Many of these issues are tractable and when resolved, will likely lead to an influx into the eco-asset markets.

To support market-based environmental practices for electric utilities and other companies, EPRI Solutions has launched a new program called the Eco-Asset Strategic Service. This information service helps companies understand the benefits of market-based environmental protection, an approach that is expected to grow significantly over the next five years. As one of the first deliverables of the Strategic Service, EPRI Solutions is organizing the first multi-industry eco-asset workshop to discuss hurdles, opportunities, and successes in utilizing market-based approaches. The event will bring together businesses, federal agencies, and environmental groups to hear case studies, recent research, and brainstorm on how to integrate eco-asset opportunities into primary corporate goals. We will identify synergies and collaborative opportunities between at least four industries – electric utilities, transportation, oil and gas, and pulp and paper. The Ecological Assets in Business Workshop will be held in Palo Alto, CA, on March 13 and 14, 2006. Visit www.eprisolutions.com/eco-assets for up-to-date information.

Biographical Sketch: Jessica Fox is a certified Associate Ecologist by the Ecological Society of America with a master's degree in conservation biology from Stanford University. She is currently a senior scientist at EPRI Solutions Inc. in Palo Alto, California providing financially attractive solutions for protecting natural resources on corporate property. She has conducted benchmark research in conservation banking and published multiple peer-reviewed articles on the subject of market-based natural resources protection. She frequently presents her academic and practical experience with market mechanisms for ecosystem protection.

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Managing Environmental Compliance for ODOT's OTIA III State Bridge Delivery Program: Many Regulations–One Framework

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Abstract

The OTIA III State Bridge Delivery Program is part of the Oregon Department of Transportation's 10-year, $3 billion Oregon Transportation Investment Act (OTIA) program. In 2003, the Oregon Legislature enacted the third Oregon Transportation Investment Act, or OTIA III. The package includes $1.3 billion for bridges on the state highway system. During the next eight to 10 years, ODOT's OTIA III State Bridge Delivery Program will repair or replace hundreds of aging bridges on major corridors throughout Oregon.

Oregon Bridge Delivery Partners (OBDP) is a private-sector firm that has contracted with the Oregon Department of Transportation to manage the $1.3 billion state bridge program. OBDP, a joint venture formed by HDR Engineering Inc. and Fluor Enterprises Inc., will ensure quality projects at least cost and manage engineering, environmental, financial, safety, and other aspects of the state bridge program.

During the first 12 months of execution, OBDP has developed a framework to integrate the myriad of tools previously developed by ODOT for the Program, including environmental-performance standards, a joint batched-programmatic biological opinion, environmental and engineering baseline reports, a comprehensive mitigation and conservation strategy, and a web-based GIS. The purpose of this framework is to identify environmental concerns early in the project-development process and communicate these concerns to design teams and regulatory agencies to promote environmental stewardship through impact avoidance and minimization.

Innovative and creative use of technology has been a keystone to the framework. Environmental professionals input the relevant environmental data for a project in a comprehensive, online Pre-Construction Assessment (PCA) that links to a GIS database. The data are used to identify project challenges (e.g., archaeological sites or wetlands within the project footprint) and compile electronic reports to the regulatory agencies. Environmental metrics (such as exempted T and E species "take" and wetland mitigation debits/credits) are tracked using the GIS database. One system meets the needs of multiple stakeholders.

Three "levels" of the PCA have been developed that coincide with the stages of project development. The initial submittal (Level 1 PCA) identifies critical environmental concerns and permitting constraints. The second submittal (Level 2 PCA) outlines the solutions to the earlier concerns. The final submittal (Level 3 PCA) includes the project specifications necessary to comply with the Program-specific and standard environmental permits. Phasing the submittals in this way allows early and continuous communication between the design teams and the regulatory agencies, thereby promoting environmental stewardship through collaboration and coordination.

This electronic system allows the OBDP Environmental Team to verify that each environmental regulation is addressed, identify environmentally sensitive projects and project elements, track critical environmental metrics, and communicate with the regulatory community. The technological component of this framework has been a cornerstone of the Environmental Management System (EMS) developed for the Program. This system can be easily applied to other programs within ODOT and other DOTs.

Oregon Department of Transportation's OTIA III State Bridge Delivery Program: 400 Bridges One Biological Opinion

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Abstract: The Oregon Department of Transportation (ODOT) concluded a study in 2001 of the condition of Oregon bridges nearing the end of their design life—those built in the late 1940's to the early 1960's. Funded under the first two phases of the Oregon Transportation Investment Act (OTIA I and II), this study found varying degrees of shear (diagonal cracking) in a large number of the state's bridges. In July 2003, Oregon Governor Ted Kulongoski signed legislation authorizing OTIA III, a $2.5 billion transportation package, including $1.3 billion to repair or replace over 400 bridges under the OTIA III State Bridge Delivery Program (Bridge Program) over the next 10 years.

Timely completion of environmental regulatory permitting was critical to meet the Bridge Program's aggressive construction schedule. To facilitate this, ODOT and the Federal Highway Administration (FHWA) began working with a number of federal and state regulatory and resource agencies in late 2002 to develop permitting strategies that would meet the dual goals of timely review of individual permitting and protection and enhancement of fish and wildlife habitat.

In addition to coverage under the Federal Endangered Species Act (ESA), the preferred regulatory compliance approach needed to ensure compliance with other state and federal statutes designed to protect fish, wildlife, and plant species and their habitat, including the Oregon ESA, Migratory Bird Treaty Act (MBTA), Marine Mammal Protection Act (MMPA), Magnuson-Stevens Fishery Conservation and Management Act (MSA), and Fish and Wildlife Coordination Act.

As a contractor to ODOT, Mason, Bruce & Girard, Inc. (MB&G) worked closely with ODOT and other state and federal agencies from 2003 through 2004 to prepare a programmatic Biological Assessment (BA) for the Bridge Program. Critical to the BA was the development of a set of environmental performance standards designed to minimize and avoid impacts to ESA listed species. In addition, a fluvial performance standard was developed to ensure that bridges replaced under the OTIA III Program would enhance, not simply maintain, geomorphological features at the bridge site.

The BA was submitted to the regulatory agencies in March 2004. In June 2004, ODOT received a joint Biological Opinion from NMFS and the USFWS addressing 73 threatened, endangered, proposed, and selected sensitive species and their designated or proposed critical habitat. In addition to listed fish, wildlife, and plants, the BA also satisfied the requirements of the MMPA, MBTA, FWCA, and MSA.

ODOT expects that 85 to 90 percent of the bridges under the OTIA III Bridge Program will be permitted using the programmatic approach, resulting in significant time and cost savings. ODOT anticipates that the programmatic approach to environmental compliance will, program-wide, result in time and cost savings of two years and $54 million over the 10-year program, exclusive of time saved on the part of state and federal resource agencies. Bridge design using the environmental performance standards developed for the program is now underway.

Introduction

The Oregon Department of Transportation (ODOT) concluded a study in 2001 of the condition of Oregon bridges nearing the end of their design life—those built primarily between 1947 and 1961. Funded under the first two phases of the Oregon Transportation Investment Act (OTIA I and II), this study found varying degrees of shear (diagonal cracking) in a large number of the State's bridges. In July 2003, Oregon Governor Ted Kulongoski signed legislation authorizing OTIA III, a $2.5 billion program to repair or replace over 400 bridges statewide under the OTIA III Statewide Bridge Delivery Program (Bridge Program) over the next 10 years.

One of the principal requirements to meet the Bridge Program's aggressive construction schedule was the timely completion of environmental regulatory permitting. To facilitate this, ODOT and the Federal Highway Administration (FHWA) began working with a number of federal and state regulatory and resource agencies in late 2002 to develop permitting strategies that meet the dual goals of providing timely review of individual permit applications, and protecting or enhancing the natural and built environments. A number of criteria were identified as being relevant to developing a permitting approach for the Bridge Program, including:

- Efficiency. A primary goal of the "streamlining" effort was to minimize redundancy of permitting hundreds of similar projects, reducing the duration of consultation with the Federal permitting agencies, the National Marine Fisheries Service (NOAA Fisheries) and the U.S. Fish and Wildlife Service (USFWS) (collectively referred to as the Services), and the State permitting agency, the Oregon Department of Fish and Wildlife (ODFW).
- Legal Defensibility. The higher the risk of liability and legal challenge, the less desirable the approach to ODOT.
- Simplicity. Approaches that reduce the regulatory process to the simplest method possible were favored.
- Stewardship. A key objective for ODOT was to demonstrate commitment to the stewardship component of the Agency's transportation mission through building green bridges with minimal effect to the environment.
- Agency Relations. Maintaining excellent agency relations was of paramount importance to ODOT. A collaborative approach was deemed critical to the success of this effort.

ODOT's development of an approach to environmental compliance was a collaborative effort and relied on three key elements: 1) extensive communication with regulatory and resource agencies, 2) national review and incorporation of existing consultations and strategies, and 3) use of a Geographic Information System (GIS) database designed to screen for and describe potential effects of the Bridge Program on federally listed fish, wildlife, and plant species.

In addition to coverage under the federal Endangered Species Act (ESA), the regulatory compliance approach needed to ensure compliance with other state and federal statutes designed to protect fish, wildlife, and plant species and their habitat: the Oregon ESA, Migratory Bird Treaty Act (MBTA), Marine Mammal Protection Act (MMPA), Magnuson-Stevens Fishery Conservation and Management Act (MSA), and Fish and Wildlife Coordination Act (FWCA).

A Vision of Green Bridges

ODOT's history of proactive environmental stewardship provided the credibility needed to assure the regulatory agencies of ODOT's commitment to "green bridges" (i.e., bridges designed to not only maintain, but improve habitat quality for fish and wildlife). Support of ODOT at the executive level of state government was also clear. Governor Kulongoski's Executive Order No. EO-03: A Sustainable Oregon for the 21st Century required enhancement and protection of the natural and built environments. ODOT therefore had both a culture of environmental stewardship as an agency and a mandate provided by executive order that essentially required ODOT to implement their vision. This proved to be a powerful combination and helped considerably to increase comfort on the part of the resource agencies in developing an overarching approach to environmental permitting.

Approach to the Consultation

In developing the ESA consultation approach for the Bridge Program, ODOT engaged the help of the private consulting community to review existing streamlined, programmatic ESA consultations and to obtain "lessons learned" information from other DOT and agency staff involved in these consultations. The purpose of this research was to learn from these previous experiences, specifically, to determine what worked, what did not work, what contributed to the success of a consultation, or what lead to delays and problems.

ODOT's consultants also requested information from entities involved in programmatic consultations regarding the level of effort (i.e., percent of their time and staff resources) and number of staff that were required from the action agency and the services for a successful consultation. This information further aided the development of ODOT's consultation strategy. The general consensus among entities contacted was that a large amount of staff time and commitment was extremely important to the success of the consultation. Low turnover of staff working on the consultation was another important success factor. An emphasis was placed on the importance of very committed service staff familiar with transportation issues, willing to make decisions, and who thoroughly understood the ESA.

The need for close collaboration between the action agency and the services was identified as an overarching trend throughout all programmatic processes and documents reviewed by ODOT. The Colorado DOT, USFWS, and FHWA collaborated on a successful Section 7 programmatic consultation that addressed over 20 species. These agencies collaborated early in the process and concluded that addressing species' needs on a project-by-project basis would have yielded scattered and fragmented habitat conservation or improvement, contributing little to the viability of individual species or to the habitat and ecosystems on which they depend. These agencies envisioned that contributing to multi-species recovery in an integrated and comprehensive fashion would aid in recovery of the species, alleviate some of the need for additional listings under the ESA, and improve predictability in the project development process.

The California Department of Transportation (CalTrans) also had considerable experience with programmatic consultations. Primary lessons learned from their Desert Tortoise and Valley Elderberry Longhorn Beetle consultation (USFWS 1996) were to seek buy-in from state resource agencies to avoid later complications, to keep agreements simple, and to incorporate adaptive methods to allow change by mutual agreement. These "lessons learned" from past programmatic consultations were incorporated into the Bridge Program consultation to help avoid pitfalls and to help ensure a successful consultation.

Based on this and other research, MB&G, other private consultants, and representatives from ODOT determined that a formal, streamlined batched-programmatic Section 7 Federal ESA Consultation would be the most effective and efficient approach to environmental compliance for the Bridge Program. In contrast to a strictly programmatic approach, a batched programmatic was deemed appropriate since the proximity, distribution, duration, and disturbance frequency of the proposed action were known (these are formally recognized batched elements) and the timing, nature of the effect, disturbance, intensity, and severity are controlled through measures administered throughout the Bridge Program (these are the programmatic elements) (USFWS and NOAA Fisheries 1988). This consultation approach has been used in previous Section 7 consultations such as the Wildland Urban Interface Fuel Treatment batched-programmatic BA prepared by the Southwestern Region of the U.S. Forest Service (USFS 2001). Formal consultation with the federal agencies was necessary due to the potential adverse effects to federally listed fish, wildlife, and plants. This batched-programmatic approach met both streamlining requirements and the goals of species conservation and environmental protection mandated by existing environmental laws.

The services formally recognize streamlining as a consultation approach and provide guidelines in the Endangered Species Consultation Handbook (NOAA Fisheries and USFWS 1998) and for certain types of projects (USFWS and NOAA Fisheries 2002). Streamlined consultations typically involve interagency teams that work together early in the process to narrow the scope of issues within consultation documents. ODOT recognized that early coordination and cooperation among ODOT/FHWA and the services would be essential to this streamlining process.

Programmatic consultations typically evaluate the potential for groups of related agency actions to affect listed and proposed species and designated and proposed critical habitat. Implementation of these actions is guided by established standards, guidelines, or governing criteria to which they must adhere. Programmatic consultations may be conducted on an action agency's proposal to apply specified standards or design criteria to future proposed actions. The NOAA Fisheries Standard Operating Procedures for Endangered Species (SLOPES) Programmatic Biological Opinion (NOAA Fisheries 2003) is an example of a widely used programmatic approach to ESA consultation.

ODOT's selection of a batched-programmatic consultation also assured the services that the level of effects analysis would provide the detail needed to adequately assess overall program impacts. This approach would provide numbers of bridges, acreages of affected habitat, and species-specific effects analysis. A strictly programmatic approach, lacking this level of detail, would not have allowed a no jeopardy determination under Section 7 of the ESA.

Framework for Collaboration

ODOT recognized early in this project that 1) a collaborative effort was key to success, 2) collaboration must be sustained, and that 3) a framework was needed to ensure that, if necessary, policy issues or conflicts could be identified early and resolved at the appropriate level. As described below, a tiered approach was used to guide the process and to ensure access to agency staff with decision-making authority.

A Tiered Development Team Approach

As a result of a fall 2002 planning and brainstorming workshop hosted by ODOT, representatives from FHWA, USFWS, NOAA Fisheries, ODOT, and private consultants concluded that a three-tiered review system would provide the highest likelihood of success. Roles and responsibilities of each of the three levels are described below.

Level 1 working group

The Level 1 Working Group was comprised of representatives from USFWS, NOAA Fisheries, ODFW, ODOT, and private consultants who were selected based on their understanding of the ESA and their familiarity with potential biological and physical (geomorphological) impacts at bridge projects. The "core" Level 1 Group adhered to a rigorous schedule of meetings (weekly from June 2003 through April 2004) and was responsible for the day-to-day work necessary to produce the batched-programmatic Biological Assessment (BA).

The Level 1 meetings were productive, lively, and technically challenging. These meetings resulted in key work products that were either directly incorporated into the BA or served to refine the analytical approach and methods. Products included 1) a consultation approach and outline, 2) an action area definition, 3) species ranges for effects analysis, 4) metrics to calculate potential project effects on species and habitats, 5) design- and construction-based environmental performance standards, and 6) a process to administer the Bridge Program, including monitoring strategies, a process for handling non-conforming activities, and continued communication between the action agency and the services.

Products of Level 1 meetings also included Effects Screening Layer (ESL) memos that documented assumptions used in assessing project impacts and Environmental Performance Standards (EPSs). The latter are a set of guidelines for bridge repair or replacement designed to minimize or avoid adverse effects to the species covered in the consultation. Effects of the project were ultimately considered assuming compliance with the EPSs within assumed areas of impact and given assumptions documented and approved by the services in ESL memos.

The primary role of MB&G for the Level 1 Group was to coordinate activities and schedules, compile and distribute meeting notes to all team members (at all tiers), develop the ESL memos, and develop the BA (MB&G 2004). Resource-agency members provided critical input throughout the Level 1 meetings and would later draft the project Biological Opinion.

Level 2 reviewing group

A Level 2 Reviewing Group met on an as-needed basis to resolve conflicts and receive progress reports and updates on important issues. The Level 2 Group was comprised of senior representatives from USFWS, NOAA Fisheries, and ODOT. The Level 2 Reviewing Group also provided feedback and approval to the Level 1 Work Groups regarding the consultation direction. The Level 2 Group met twice during the drafting of the BA.

Level 3 executive group

The Level 3 Executive Group was comprised of state and/or regional director-level representatives of USFWS, NOAA Fisheries, ODFW, and ODOT. The Level 3 Group was available to provide high-level policy direction and to provide input as needed to resolve policy conflicts. The Level 3 Group remained briefed through Level 1 meeting minutes and met once during the drafting of the BA and once during the drafting of the Biological Opinion (BiOp).

Development of the BA

Development of the Bridge Program BA was a collaborative effort that began with the first Level 1 Team meeting in the spring of 2003 and concluded with delivery of the BA to the services in March 2004. While the bulk of the analysis and writing of the document took place between November 2003 and February 2004, work on the BA was ongoing throughout this period.

All major activities critical to completion of the BA were conducted with active participation and support of federal agency staff that would ultimately write the Biological Opinion (BiOp). As noted, the Level 1 Group met on a weekly basis over much of this project. In addition to development and refinement of EPSs (see below), the focus of many of the Level 1 meetings was to review and approve the assumptions and approach used to assess potential impacts of the Bridge Program on individual species or on species groups. Agreements reached at these meetings on data sources, species ranges, habitat preferences, and analytical approach were captured in Effects Screening Layer (ESL) memos. These 2 to 3 page documents were submitted to the Services as they were developed by the Level 1 Group. Once approved, they served to guide and frame the Effects Analysis and became appendices to the BA. Major activities and milestones in the development of the BA are described below.

Definitions of the Action Area

Activities under the Bridge Program that may affect fish, wildlife, and plants included in the ODOT OTIA III Bridge Program BA (MB&G 2004) cover a wide range of actions ranging from direct physical injury to an individual fish, wildlife, plant, invertebrate, or plant species to visual disturbance of nesting birds. Even broader, the action area may justifiably encompass the entire state of Oregon given the broad geographic scope of this program and the programmatic nature of consultation with the federal agencies. Considering all of these factors, the Level 1 Group determined that the action area with respect to potential mitigation needs would encompass all areas within the same sixth field hydrologic unit code (HUC) of a particular program bridge. However, project-specific effects analysis would be conducted within a defined Area of Potential Impact (API). The API is a much smaller subset of the action area that varies from bridge to bridge.

Effects Analysis

The Bridge Program BA and BiOp addressed 73 threatened, endangered, proposed, and selected sensitive (TEPS) species and their designated or proposed critical habitat (Table 1). In addition to listed fish, wildlife, and plants, the BA also satisfied the requirements of the MMPA, MBTA, FWCA, and MSA.

The potential effects of the Bridge Program were considered based on the combined effects of all 430 program bridges, allowing the services in their BiOp to reach a conclusion as to the likelihood of jeopardy on a programmatic basis. This was accomplished in part by first defining the possible effects pathways, or avenues by which effects to species may be delivered. Effects may be in the form of habitat-altering actions, such as wetland impacts; effects to individuals (e.g., fish injury during work area isolation); or to entire populations, (e.g., effects to isolated plant populations). Effects pathways include soil (e.g., because soil can be the medium through which a species is affected), air, water, vegetation, and chemicals. Direct effects and incidental take of individuals of a species were also considered effects pathways.

Once the pathways of effects were defined, a series of environmental performance standards (EPSs) were developed to serve as barriers to or constrictions of these pathways with regard to their ability to deliver effects of project actions to species of concern. The overarching goal of the EPSs was to avoid and/or minimize effects to listed species and to create a net benefit of the program in terms of improved habitat conditions within the action area. Effects of the Bridge Program were thus evaluated assuming implementation of EPSs necessary to avoid and minimize effects, improve habitat for listed species, and to enhance their recovery. In essence, the EPSs provided a design framework describing desired outcomes and allowing creativity and innovation on the part of the bridge design and construction teams. This approach uses a "tell them what you would like to see" philosophy rather than the traditional "tell them what they cannot do."

Table 1. List of TEPS species addressed in ODOT's Bridge Program consultation

Common Name	Scientific Name	Federal Status	State Status	Critical Habitat
Terrestrial Mammals				
Canada lynx	*Lynx Canadensis*	Threatened	Threatened	
Columbian white-tailed deer (Columbia River DPS)	*Odocoileus virginianus leucurus*	Endangered		
Kit fox	*Vulpes macrotis*		Threatened	
Wolverine	*Gulo gulo*		Threatened	
Washington ground squirrel	*Spermophilus washingtoni*		Endangered	
Marine Mammals				
Steller sea lion (Eastern population)	*Eumetopias jubatus*	Threatened		
Sei whale	*Balaenoptera borealis*	Endangered		
Blue whale	*Balaenoptera musculus*	Endangered		
Finback whale	*Balaenoptera physalus*	Endangered		
Right whale	*Eubalaena jubatus*	Endangered		
Humpback whale	*Megaptera novaeangliae*	Endangered		
Sperm whale	*Physeter macrocephalus*	Endangered		
Birds				
Marbled murrelet	*Brachyramphus marmoratus marmoratus*	Threatened	Threatened	Designated
Western snowy plover (Pacific Coast population)	*Charadrius alexandrinus nivosus*	Threatened		Designated
Bald eagle	*Haliaeetus leucocephalus*	Threatened	Threatened	
Northern spotted owl	*Strix occidentalis caurina*	Threatened	Threatened	Designated
Western snowy plover (Interior population)	*Charadrius alexandrinus nivosus*		Threatened	
Peregrine falcon	*Falco peregrinus anatum*		Endangered	
Short-tailed albatross	*Phoebastria albatrus*	Endangered		
Brown pelican	*Pelecanus occidentalis californicus*	Endangered		

Table 1 (continued)

Common Name	Scientific Name	Federal Status	State Status	Critical Habitat
Reptiles and Amphibians				
Loggerhead sea turtle	*Caretta caretta*	Threatened		
Green sea turtle	*Chelonia mydas*	Threatened		
Leatherback sea turtle	*Dermochelys coriacea*	Endangered		Designated
Olive (Pacific) Ridley sea turtle	*Lepidochelys olivacea*	Threatened		
Resident Fish				
Foskett speckled dace	*Rhinichthys osculus*	Threatened		
Shortnose sucker	*Chasmistes brevirostris*	Endangered	Endangered	Proposed
Lost River sucker	*Deltistes luxatus*	Endangered	Endangered	Proposed
Warner sucker	*Catostomus warnerensis*	Threatened		Designated
Oregon chub	*Oregonichthys crameri*	Endangered		
Hutton tui chub	*Gila bicolor*	Threatened		
Borax Lake chub	*Gila boraxobius*	Endangered		Designated
Lahontan cutthroat trout	*Oncorhychus clarki henshawi*	Threatened		
Bull trout	*Salvelinus confluentus*	Threatened		Proposed
Cutthroat trout (SW Washington/Columbia River DPS)	*Oncorhychus clarki clarki*	Species of Concern		
Pacific lamprey	*Lampetra tridentata*	Petitioned	Sensitive	
River lamprey	*Lampetra ayresi*	Petitioned	Sensitive	
Western brook lamprey	*Lampetra richardsoni*	Petitioned	Sensitive	
Anadromous Fish				
Chum salmon (Columbia River ESU)	*Oncorhynchus keta*	Threatened		
Coho salmon (Southern Oregon/Northern California Coasts ESU)	*Oncorhynchus kisutch*	Threatened		Designated
Coho salmon (Oregon Coast ESU)	*Oncorhynchus kisutch*	Threatened		
Coho salmon (Lower Columbia River ESU)	*Oncorhynchus kisutch*		Endangered	
Steelhead (Upper Columbia River ESU)	*Oncorhynchus mykiss*	Endangered		

Table 1 (continued)

Common Name	**Scientific Name**	**Federal Status**	**State Status**	**Critical Habitat**
Steelhead (Lower Columbia River ESU)	*Oncorhynchus mykiss*	Threatened		
Steelhead (Middle Columbia River ESU)	*Oncorhynchus mykiss*	Threatened		
Steelhead (Snake River Basin ESU)	*Oncorhynchus mykiss*	Threatened		
Steelhead (Upper Willamette River ESU)	*Oncorhynchus mykiss*	Threatened		
Sockeye salmon (Snake River ESU)	*Oncorhynchus nerka*	Endangered		Designated
Chinook salmon (Snake River Spring/Summer-run ESU)	*Oncorhynchus tschawytscha*	Threatened		Designated
Chinook salmon (Snake River Fall-run ESU)	*Oncorhynchus tschawytscha*	Threatened		Designated
Chinook salmon (Upper Willamette ESU)	*Oncorhynchus tschawytscha*	Threatened		
Chinook salmon (Upper Columbia River Spring-run ESU)	*Oncorhynchus tschawytscha*	Endangered		
Chinook salmon (Lower Columbia River ESU)	*Oncorhynchus tschawytscha*	Threatened		
Invertebrates				
Vernal pool fairy shrimp	*Branchinecta lynchi*	Threatened		Designated
Fender's blue butterfly	*Icaricia icariodes fenderi*	Endangered		
Oregon silverspot butterfly	*Speyeria zerene hippolyta*	Threatened		Designated
Plants				
McDonald's rock-cress	*Arabis mcdonaldiana*	Endangered		
Applegate's milk-vetch	*Astragalus applegatei*	Endangered	Endangered	
Golden paintbrush	*Castilleja levisecta*	Threatened	Endangered	
Willamette daisy	*Erigeron decumbens var. decumbens*	Endangered	Endangered	
Gentner's fritillary	*Fritillaria gentneri*	Endangered	Endangered	
Water howellia	*Howellia aquatilis*	Threatened		
Western lily	*Lilium occidentale*	Endangered	Endangered	
Large-flowered wooly meadowfoam	*Limnanthes floccosa ssp. grandiflora*	Endangered	Endangered	
Bradshaw's Lomatium	*Lomatium bradshawii*	Endangered	Endangered	

Table 1 (continued)

Common Name	Scientific Name	Federal Status	State Status	Critical Habitat
Cook's Lomatium	*Lomatium cookii*	Endangered	Endangered	
Kincaid's lupine	*Lupinus sulphureus ssp. kincaidii*	Threatened	Threatened	
MacFarlane's four-o'clock	*Mirabilis macfarlanei*	Threatened	Endangered	
Rough popcornflower	*Plagiobothrys hirtus*	Endangered	Endangered	
Nelson's checker-mallow	*Sidalcea nelsoniana*	Threatened	Threatened	
Spalding's catchfly	*Silene spaldingii*	Threatened	Endangered	
Malheur wire-lettuce	*Stephanomeria malheurensis*	Endangered	Endangered	Designated
Howell's spectacular thelypody	*Thelypodium howellii ssp. spectabilis*	Threatened	Endangered	
Marsh sandwort	*Arenaria paludicola*	Endangered		

E = Endangered, T = Threatened, Can = Candidate, CH = Designated Critical Habitat, Prop = Proposed for listing, Prop CH = Proposed Critical Habitat.

Effects Screening

Based on agreed-to assumptions documented in ESL memos (e.g., preferences for specific habitat types, species ranges, etc.), all 430 program bridges (with their respective APIs and effects buffers) were mapped and entered into a GIS database. The bridges were then screened to describe and estimate the effects of the proposed action on listed species and their habitats. Results of this analysis were documented in Evaluation of Effect (EOE) memos submitted to the services for review and approval. Like the ESL Memos, the EOE memos became appendices to the BA memorializing critical decisions and assumptions used in analyzing program effects and summarizing results in terms of the number of bridges, if any, affecting particular species.

Environmental Performance Standards

ODOT/FHWA, in collaboration with the services involved in this consultation, developed Environmental Performance Standards (EPSs) to guide project design and construction. The EPSs were a critical component of the BA that ensured avoidance of potential long-term adverse effects and minimization of short-term, unavoidable effects. The EPSs require that unavoidable long-term effects be offset with restorative or mitigative actions that result in no net long-term adverse effect to listed species and their habitats. In addition, the EPSs were developed to maximize the potential for short and long-term beneficial effects to listed species, non-listed species, and their habitats. Bridge replacement or repair activities that cannot conform to the EPSs are not covered under the BiOp and therefore require individual consultation under Section 7 of the ESA.

The EPSs developed for the Bridge Program are summarized below. As noted earlier, the SLOPES Programmatic BiOp is currently in use for U.S. Army Corps activities that may impact listed species. ODOT/FHWA and the Services built on many of the performance standards developed for SLOPES and developed new EPSs as necessary based on the unique goals and objectives of the Bridge Program.

Program administration

The Program Administration EPS includes requirements for monitoring and reporting, program-management guidelines, environmental documentation, communication protocols, and variances. In short, this is the "accountability" EPS.

The Program Administration EPS describes the required content of the Pre-Construction Assessment (PCA). The PCA is prepared in lieu of a BA and ensures that the effects of activities at a particular bridge or group of bridges are within the range of effects considered in the BiOp. The PCA also quantifies project-level take estimates, verifies that program-level permitted take is not likely to be exceeded, and that all appropriate EPSs are being properly followed. The PCA is submitted to the services at least 30 days prior to starting construction activities.

Another critical element of the Program Administration Standard is the protocol for variances. For purposes of this consultation, variances are defined as actions not clearly addressed within the environmental performance standards, but that do not result in greater effects or greater take than provided in the BiOp. An example of a variance in this context is an extension of an in-water work window to avoid the need for a second year of construction. The PCA is used to formally request a variance.

Species avoidance and adverse effect minimization
The Species Avoidance EPS consists of a comprehensive set of actions and measures required to avoid and minimize incidental take of listed fish, wildlife, and plant species resulting from construction activities. Measures required of construction contractors are described in detail in the BiOp and cover timing of in-water work (for activities below the Ordinary High Water (OHW) elevation), work-area isolation, fish-screen criteria and installation, and noise attenuation for steel piles driven through water when listed fish may be present.

For wildlife, this EPS is designed to minimize incidental take and harassment of listed wildlife species and adverse effects to wildlife and migratory birds from high-noise producing activities. Wildlife species addressed specifically in the OTIA III BiOp include marbled murrelet, bald eagle, and northern spotted owl. Timing restrictions for blasting and non-blasting high noise producing construction activities are limited to regionally specific non-nesting periods for these species and to times of day that were developed in close coordination with ODFW and USFWS biologists.

For listed plants, the Species Avoidance EPS requires surveys for state and federally listed plants and their occupied habitat during appropriate flowering periods and within the geographic range of listed plants as described in the BA. If listed plants are found, a management buffer is established to protect the population from construction activities or as a result of indirect effects such as herbicide drift.

Habitat avoidance
Technically referred to as Habitat Avoidance and Removal Minimization, this EPS provides specific guidance to avoid and minimize adverse effects to natural stream and floodplain function by limiting streambank protection actions to those not expected to have long-term adverse effects on aquatic habitats. This EPS provides a wide range of approved bank-protection techniques for use individually, or in combination at a particular bridge site.

Actions that could potentially result in habitat removal or that may impair the ability of threatened, endangered, proposed, or selected sensitive species to complete essential biological behaviors, such as breeding, spawning, rearing, migrating, feeding, and sheltering, are restricted via this EPS. Specifically, activities are restricted that may adversely affect nest trees of listed species (e.g., bald eagle, marbled murrelet, or northern spotted owl) and non-listed species. Avoidance of adverse effects on breeding and functional habitat is also required under this EPS unless protocol surveys show the area is not occupied or except in cases where public safety takes precedence.

Water quality/quantity
A critical concern of ODOT/FHWA and the Services was: 1) the potential transfer of pollutants (via spills, equipment leakage, etc.) to soils and waters of the U.S. caused by construction operations and 2) an increase in impervious surface that may result from replacement of program bridges. The Water Quality EPS requires development of a pollution and erosion control plan which specifies measures to prevent delivery of contaminants, and containment of pollutants (including petroleum products, contaminated water, silt, welding slag, sandblasting abrasive, green concrete, or grout cured less than 24 hours) to contact any area within 150 feet of waters of the U.S. unless approved by the Services and the appropriate regulatory authorities. Control of drilling discharge and drilling fluids is addressed in detail in this EPS, as is removal of treated wood piles.

With respect to stormwater management, this EPS requires that adverse effects resulting from changes to the quality and quantity of stormwater runoff be avoided or minimized for the life of the project by improving or maintaining natural runoff conditions within project watersheds. Protection of groundwater is also addressed; stormwater runoff from pollution generating surfaces requires pretreatment (using described approaches) before infiltration to groundwater or discharge into waters of the U.S.

Site restoration
The Site Restoration EPS requires renewal of habitat access, water quality, production of habitat elements, channel conditions, flows, watershed conditions, and other ecosystem processes that form and maintain productive habitats. A site-restoration plan is required to ensure that all habitats (e.g., streambanks, soils, large woody material, and vegetation) disturbed by the project are cleaned up and restored. Detailed guidance and recommendations on the use of pesticides, fertilizers, streambank shaping, as well as recommended materials and methodologies to achieve site restoration, are presented in the Site Restoration EPS. A site-restoration work plan is required that includes: boundaries for the restoration area; restoration methods; timing and sequence; an irrigation plan, including water supply source; and a five-year monitoring and maintenance plan.

Compensatory mitigation
Effects that are not offset by site restoration must be addressed through compensatory mitigation. The compensatory mitigation EPS requires that the Bridge Program meet the goal of no net loss of habitat function by offsetting unavoidable permanent and temporary adverse effects to habitats. Activities that reduce or remove habitat function or that delay or prevent development of desired function or condition of habitat will trigger the need for a Compensatory Mitigation Plan. The Compensatory Mitigation EPS requires that these plans be based on a functional assessment of adverse effects of the proposed project and functional replacement (i.e., 'no net loss of function') whenever feasible, using a minimum one-to-one linear foot or acreage-replacement ratio. Mitigation actions associated with the Bridge Program must comply with the USFWS' Conservation Banking for Threatened and Endangered Species (May 8, 2003, 68 FR 24753), and the Corps' Regulatory Guidance Letter on Compensatory Mitigation (USACE 2002).

Fluvial
A critical goal on the part of ODOT/FHWA and the services for this consultation was a performance standard that would prevent adverse effects on geomorphic features of streams and rivers crossed by program bridges, thus precluding corresponding effects on their floodplains. The Fluvial EPS is designed to allow normative physical processes within the stream-floodplain corridor. This EPS requires that program bridges span the functional floodplain (determined as specified within this EPS), thereby promoting natural sediment transport patterns for the reach and providing unaltered fluvial debris movement. In essence, this standard requires that program bridges go unnoticed by passing water bodies, that natural sediment and wood loads are maintained, and that localized scour of streambanks and likely spawning areas is prevented. From a maintenance perspective, this standard reduces the need for removal of large wood resting against bridge-support structures.

Bridging the BA and BiOp

The Bridge Program BA was completed in March 2004, which was approximately one year after the first meeting of the Level 1 Team and three months prior to the desired June 1 signing of the BiOp. Recognizing that design work could not be initiated without a signed BiOp and faced with looming construction deadlines, ODOT and the Level 1 Team continued to meet on a weekly basis while the services drafted the BiOp. Despite the familiarity of the services with the BA (the same staff attending Level 1 meetings drafted the BiOp), more detailed review by senior NOAA and USFWS staff led to questions and policy issues which, if not immediately addressed, could have threatened the project timeline. Meetings throughout this period included Level 1 Team members, ODOT, and, as necessary, senior staff from the services.

The Conservation Conundrum

While relatively minor issues arose and were resolved during preparation of the BiOp, it was clear that ODOT's required level of commitment to Section 7(a)(1) of the ESA and varying expectations regarding conservation within the Bridge Program were not minor issues. Section 7(a)(1) of the ESA directs federal agencies to utilize their authorities to further the purposes of the ESA by carrying out conservation programs for the benefit of threatened and endangered species. Conservation recommendations are discretionary measures suggested to minimize or avoid adverse affects of a proposed action on listed species, to minimize or avoid adverse modification of critical habitat, or to develop additional information. *The Environmental Law Reporter Endangered Species Deskbook* (Liebesman and Peterson 2003) states that there are currently no regulations directly interpreting or implementing 7(a)(1). Further, they note that Section 7(a)(1) emerged from a Ninth Circuit Decision as "a little something extra" and "in the absence of firm guidance by the biological agencies, there is considerable leeway as to what that something will be." The issue of conservation within the Bridge Program proved considerably difficult, but was resolved in large measure due to the trust that had been developed among ODOT and the services over the previous 12 months of collaboration.

Central to the discussion on conservation was the role of ODOT's Comprehensive Mitigation and Conservation Strategy (CMCS) within the Bridge Program. The CMCS may be considered a net beneath the Environmental Performance Standards, designed to ensure application of an ecologically-based approach to mitigating unavoidable impacts on both a site-specific and a regional basis. While the CMCS was not specifically designed to address Section 7(a)(1) of the ESA, it was ODOT's opinion that it ensured mitigation well above that required on strictly a compensatory basis. Moreover, the CMCS emphasizes species' habitat relationships and functional values to determine mitigation needs, an approach that greatly increases the probability of success on many levels. In short, use of the CMCS, in ODOT's opinion, ensured that conservation needs within the Bridge Program would be more than met.

The Services agreed that the CMCS process offered substantial benefits over the traditional, ratio-based approach to mitigation. However, the CMCS program had yet to be implemented at the time the BiOp was being prepared and a great deal of uncertainty existed regarding issues such as impact assessment and mitigation tracking and development of a combined mitigation/conservation credit and accounting method. Given these uncertainties, the USFWS requested that program-level conservation targets be based on one of the following three methods (in order of preference):

1. Estimates of permanent and temporary take provided in the BA, regardless of actual loss;
2. A collaborative approach developed through the CMCS; and
3. Permanent and temporary take, modified as follows:
   - 1.5:1 mitigation to impact ratio for marginal or low quality habitat;
   - 2:1 mitigation to impact ratio for higher quality habitat; and
   - Various time-dependency ratios based on time to achieve desired future condition, ranging from 1.5:1 for 5 to 10 years and 5:1 for greater than 50 years.

Take estimates presented in the Bridge Program BA represented the upper limit of anticipated take. ODOT had not anticipated their use as mitigation targets. However, ODOT recognized the difficulty on the part of the USFWS in basing conservation and mitigation requirements solely on the yet-to-be implemented CMCS approach. Negotiation on this point led to considerable discussion within the text of the BiOp on the application and benefits of the CMCS to the

Bridge Program. The final, signed BiOp ultimately provided the assurances needed by the Services, a commitment on their part to continue to work within the CMCS framework, and a commitment by ODOT to stewardship, regardless of the means of defining mitigation and conservation requirements.

Lessons Learned

A meeting in July 2004, one week after the signing of the Bridge Program BiOp, was held among those actively involved in the Bridge Program ESA consultation, including senior staff from NOAA, USFWS, ODOT, FHWA, and consultants. While this was a working meeting to discuss program implementation and continuing expectations/roles for the services, there was a discernable celebratory tone. A joint, batched programmatic BiOp for repair and replacement of over 400 bridges in the State of Oregon had just been signed by both NOAA and USFWS, requiring "extreme collaboration" among a large number of individuals for over a year. Participants at this meeting acknowledged that many were skeptical of the batched-programmatic approach and of the likelihood of the signing of a joint BiOp. Thus, there was a sense of relief, pride, and camaraderie at the accomplishment.

Acknowledging the value of a discussion on lessons learned, participants voiced several factors that, in combination, allowed a successful outcome of this project. These included:

- Visionary Senior Staff. This program was the vision of ODOT senior policy advisors who actively encouraged and nurtured it from inception of the BA to final signing of the BO.
- Team Continuity. No single member of the project team (ODOT, USFWS, NOAA, other agency staff and consultants) ever left the project; all core members who began remained actively involved throughout.
- Productive Meetings. As stated earlier in this document, meetings among ODOT and the services were held on virtually a weekly basis over the course of a year, with subgroup meetings occurring as needed throughout this period. Each of these had clear agendas, defined products, and most importantly, guided the analysis of project effects. Project meetings were extremely productive, lively, and technically challenging, and were building blocks to the Biological Assessment.
- True Collaboration. Participants in this consultation, particularly the Level 1 Group, worked together for a sufficient period of time to establish close working relationships. While roles remained well defined, distinctions among regulators, consultants, and ODOT staff were blurred. All were team members with a clear mission: develop a Bridge Program that would allow creative engineering, but within a framework that avoided environmental impacts.
- Trust. Mutual trust was key to the successful conclusion of this consultation. This was embodied by the decision, reached late in the consultation, to do without a Memorandum of Agreement initially discussed as necessary to provide the services the assurances they sought with respect to conservation. Without this level of trust on both sides, it is unlikely a joint BiOp would have been possible.

In summary, ODOT's collaborative approach to ESA consultation met the agency's goals of compliance with the Federal ESA, Oregon State ESA, MBTA, MMPA, MSA, and FWCA. Adherence to the EPSs that are the basis for this consultation will further ODOT's vision of green bridges and ensure that the Bridge Program is clearly in line with the Governor's Executive Order No. EO-03 to promote sustainable actions among all Oregon state agencies. Collaboration, trust, and creative solutions characterized this consultation from the outset. ODOT looks forward to implementing this program and to the benefits it will provide to the traveling public and the natural resources they so value.

Biographical Sketches: Michael B. Bonoff, MB&G, Senior Aquatic Scientist/Project Manager. Mike is an aquatic scientist in MB&G's Portland, Oregon office with 25 years of experience in surface water impact assessment and mitigation. He has worked closely with resource agencies, utilities, and local governments throughout the U.S. on Clean Water Act and ESA issues. Mike has served as a technical reviewer for the Oregon DEQ and the Governor's Office, and has published peer-reviewed technical papers on topics including reservoir limnology, watershed/stream enhancement, stream ecology, and field methods for sample collection in lakes, streams, and rivers.

Robert G. Carson, MB&G, Principal/Manager, Environmental Services Group. Bob has served as project manager for over 200 projects involving Endangered Species Act permitting, biological resource studies, wetland delineation/mitigation projects, and due-diligence analyses for land transactions. He has authored numerous publications on ecology, wildlife habitat, and wetlands and is a frequent speaker at conferences and workshops dealing with endangered-species issues.

Zachary O. Toledo, OR Bridge Delivery Partners. Zak is the Endangered Species Act Discipline Leader and a project manager for the Environmental and Resource Management group in the Portland, Oregon office. He has prepared and managed wetland and Endangered Species Act (ESA) documents for more than 100 transportation projects, including the batched-programmatic biological assessment described in this paper. He has experience obtaining and overseeing receipt of federal and state approvals and permits under the federal ESA, Fish and Wildlife Coordination Act, Clean Water Act Section 404, Oregon Removal-Fill Law, Migratory Bird Treaty Act, Marine Mammal Protection Act, and Magnuson-Stevens Fishery Conservation and Management Act. Zak has conducted environmental analyses throughout Oregon including monitoring of nesting seabirds, intertidal communities, and marine mammals; sampling of riparian vegetation, water quality, stream invertebrates, and fish; as well as Rosgen Level II channel cross-sections in headwater streams.

William A. Ryan, Oregon Department of Transportation. Bill has 16 years of experience in the environmental and transportation fields and has been with ODOT since 1996. As Permitting and Mitigation Manager and later Environmental Program Manager, Bill directed and oversaw development and implementation of the environmental stewardship and streamlining strategy for the OTIA III State Bridge Delivery Program, including the programmatic-batched BiOp that is the subject of this paper.

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Species Conservation in Idaho—Going Beyond the ESA

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Abstract

Results of listing species under the Endangered Species Act (ESA) have been less than inspiring. Since enactment of the ESA, slightly over 1300 species have been listed as threatened or endangered. Only 12 of these species have recovered to the point of being delisted. Roughly 40 others have been removed from listing due either to extinction, errors in the original listing decision, or other reasons. Congress directs that 75 percent of funding for recovery of species goes to about 10 species, leaving the remaining 25 percent to be applied to all the remaining listed species. A major focus of the Endangered Species Act is on listing of species. Once a species becomes listed, time-consuming and complex consultation is often required to avoid liability under the act. That consultation process can discourage and delay implementation of actions beneficial to the species. In Idaho, efforts have been made to utilize Candidate Conservation Agreements (CCAs) and Candidate Conservation Agreements with Assurances (CCAAs) to avoid the need to list additional species and provide direct beneficial effects for species.

Slickspot Pepppergrass (*Lepidium papilliferum*, or SSPG) is an annual or biennial white flower thought to occur only in southern Idaho. It is found in the sagebrush habitats of the Snake River Plain and possesses an unusual habitat requirement ("slick spots" of clay soils). Information on the plant's historical range, habitat needs, and population trends had been limited and largely anecdotal. On and off, SSPG was designated as a candidate species under ESA for over a decade. Threats to the species include grazing, non-native plants, development, recreation, wildfire, fire suppression, and fire-prevention activities.

A lawsuit was initiated in 2001 demanding emergency listing of SSPG under the ESA. In settlement of that that suit, the Fish and Wildlife Service (FWS) was under a court order for a decision to list SSPG as threatened or endangered by July 2003. In early 2003, the state Office of Species Conservation was made aware that FWS believed that an endangered listing was appropriate based on the information available and that significant changes in land use would result from this listing. Through negotiation by interested parties including the Office of Species Conservation, Idaho Department of Fish and Game, Idaho National Guard, Idaho Bureau of Land Management (BLM), and a consortium of ranching interests, efforts were made to avoid listing of the species through development of a CCA. In July 2003, FWS delayed their listing decision by six months in order to allow for completion of the CCA and resolution of some final issues. FWS and NOAA's Policy for Evaluation of Conservation Efforts (or PECE policy) was applied as a guideline for the development of this CCA; this was the first application of the PECE policy in development of a CCA. Conservation measures prepared to address each threat to SSPG were included in the CCA. A FWS-facilitated scientific review panel validated conclusions reached by the SSPG partnership and found that the CCA would substantially delay risks of extinction of SSPG. In January 2004, FWS issued a determination that the proposal to list SSPG was not warranted because of the management plans developed and instituted under the CCA.

This was a win-win solution for all parties to the agreement and for the species. The benefits include: 1) conservation measures to benefit the covered species are developed and put into place on both public and private lands across a large geographic area, 2) users such as grazing permittees get routine processing of renewals, assuming the terms of the CCA are being met, 3) landowners and state agencies get Section 10 incidental take coverage and assurances that additional restrictions will not be placed on their lands or operations, and 4) federal agencies get reduced consultation requirements.

Since this CCA was developed, another CCA has been developed for the Southern Idaho Ground Squirrel (*Spermophilus brunneus endemicus*). A programmatic CCA is currently being completed for the Southern Idaho Ground Squirrel that will allow other parties to enter into the CCA and participate in the benefits by agreeing to implement the conservation measures described. A multi-species CCA for Idaho is also currently under development.

More applications of this concept are possible, but they can be challenging to develop. Early establishment of a baseline of the "best available scientific information" for a species is one of the most important early steps that can be taken to facilitate development of a CCA and/or CCAA.

Biographical Sketch: Brent Inghram is the environmental program manager for the Federal Highway Administration's Idaho Division office in Boise, Idaho. Mr. Inghram holds a bachelor's degree in environmental planning and management from the University of California, Davis, and a master's degree in geology from the University of Nevada, Reno. He works with environmental program and policy issues, including wetlands and endangered species, for transportation projects.

Temporal Loss of Wetlands as Justification for Higher Mitigation Ratios

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Abstract

"Temporal loss," or the time between initiation of mitigation and maturation of anticipated ecological functions on a compensatory mitigation site, is a concept which has long been used by regulatory and commenting resource agencies as justification for higher mitigation ratios in compensatory mitigation Also, preservation is typically given as the last alternative in a sequence of mitigation options in regulatory guidance, which runs restoration, enhancement, establishment, then preservation. This is in spite of the fact that preservation of exceptional resources at risk can provide full ecological functions over the period of time which would be required for establishment of a full suite of ecological functions on a restoration, enhancement, or establishment site. This time can be significant on sites such as bottomland hardwoods, scrub-shrub, or salt marshes, if indeed a full suite of functions is ever established.

If "temporal loss" is recognized, then it is logical that "temporal gain" of functions attendant to a preservation site in high functional condition should be similarly recognized. A more complete rationale for recognizing "temporal gain" is given, and alternative methods for measuring this gain are given.   The concept of temporal gain provides a rational approach for accepting more reasonable mitigation ratios on preservation sites at risk. Absent the recognition of temporal gain by regulatory and resource management agencies, the concept of temporal loss should be abandoned in regulatory determination of mitigation needs.

Chapter 7

Transportation Corridor Vegetation Management

High-Altitude Revegetation Experiments on the Beartooth Plateau Park and Carbon Counties, Montana, and Park and Bighorn Counties, Wyoming

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Abstract: The Federal Highway Administration (FHWA) Central Federal Lands Highway Division is conducting a comprehensive study to identify techniques that maximize the opportunities for successful revegetation along high altitude portions of U.S. Highway 212, the Beartooth Highway. A portion of the Beartooth Highway that travels through alpine and subalpine areas is proposed for reconstruction by the FHWA. FHWA has conducted revegetation experiments in the form of test plots and seed-increase experiments since 1999 to identify the most successful revegetation techniques for revegetating alpine areas.

Over a period of four years, four revegetation experiments have been placed on the Beartooth Highway to investigate the most effective revegetation techniques for subalpine and alpine disturbances. Variables tested include topsoil placement, organic amendments, surface mulches, seeding rate, and seed source (locally collected or commercial sources).

In addition, three seed-growout experiments have been conducted at a nearby farm in Manderson, Wyoming, to assess whether seed collected on the Beartooth Plateau can be produced in large quantities and used to revegetate disturbed areas associated with construction. These seed-growout experiments tested the potential to commercially produce a variety of alpine and subalpine forb, grass, and sedge seed. The results from this study will assist highway departments, mining, oil and gas, and utility companies, and other land-management agencies in revegetating high-altitude disturbances to meet requirements of various state, local, and federal permits. The study makes conclusions about the effectiveness of several revegetation items, such as seeding rate, type of organic amendment, fertilizer reapplication, and topsoil placement and makes recommendations for further study regarding native-seed propagation.

Key words: alpine revegetation, native-plant restoration, highway revegetation, soil amendments, seeding rates, topsoil.

Introduction

The FHWA proposes to reconstruct portions of U.S. Highway 212, the Beartooth Highway, in Park County, Wyoming. The Beartooth Highway is a scenic highway that traverses subalpine and alpine areas on the Beartooth Plateau. In anticipation of the proposed reconstruction, FHWA and ERO began a series of revegetation tests in 1999, to determine the most appropriate revegetation techniques for alpine portions of the Beartooth Highway. ERO conducted and extensive literature review, which was summarized in the proceedings of the 15th annual High-Altitude Revegetation Workshop (Payson 2002). ERO consulted with several people knowledgeable in the reclamation of sensitive naturals areas, including Ray Brown (formerly with the Rocky Mountain Research Station), Dale Wick and Joyce Lapp of Glacier National Park, Eleanor Williams Clark of Yellowstone National Park, Mark Majerus of the USDA Bridger Plant Materials Center, Steve Parr of the USDA Meeker Plant Materials Center, and suppliers of plant materials seed, soil amendments and surface mulches. The revegetation tests examine seed mix densities, seed sources, topsoil salvaging, organic amendments, surface mulches, the planting of nursery stock, and growout of seed collected on the Beartooth Plateau.

1999 Montana Borrow Area Revegetation-Test Plots

In September 1999, ERO placed revegetation-test plots in an existing gravel-borrow area along the Beartooth Highway. Design of the test plots was based on studies of revegetated disturbances in Rocky Mountain alpine environments. Three variables were tested: soil salvaging, seeding rates, and soil amendments. On half of the plots, fertilizer and Kiwi Power (a soil amendment) were reapplied for 2 years after the revegetation plots were originally constructed. Native seed was collected on the plateau and used for direct seeding of the revegetation-test plots and for production of plant materials (Tables 1 and 2). Additional revegetation-test areas (planting test plots) were created to determine the feasibility and cost effectiveness of planting greenhouse-grown seedling plant materials from locally collected seed. The plants included in the planting test plots are shown in Table 2. The four variables tested on the plots were:

- Composted organic matter plus fertilizer versus surface application of Kiwi Power and Fertil-Fibers NutriMulch
- High seeding rate versus very high seeding rate
- Topsoil salvaging and replacement versus no topsoil
- Reapplication of fertilizer or Kiwi Power versus no reapplication of fertilizer or Kiwi Power

Table 1. Seed Mixes for the 1999 Montana Borrow Area Plots

1999 Montana Borrow Area Seed Density					
Scientific Name	**Common Name**	**Lower Density Plots**		**Higher Density Plots**	
		PLS†	**Seeds/ft^2**	**PLS**	**Seeds/ft^2**
Deschampsia caespitosa	Tufted hairgrass	0.88	45	1.75	90
Poa alpina	Alpine bluegrass	1.48	45	2.95	90
Phleum alpinum	Alpine timothy	1.25	25	2.5	50
Festuca ovina	Sheep fescue	1.75	32.5	3.5	65
Trisetum spicatum	Spike trisetum	0.38	12.5	0.75	25
Antennaria lanata	Wooly pussytoes	0.40	45	0.8	90
Artemisia scopulorum	Rocky Mountain sage	1.02	45	2.05	90
Lupinus argentea	Lupine	7.50	4.5	15	9
Total		**14.66**	**254.5**	**29.3**	**509**

†PLS = Pure Live Seed

Table 2. Nursery-Grown Species Transplanted in 2000

Scientific Name	**Common Name**	**Number Planted**
Graminoids		
Carex scirpoidea	Downy sedge	40
Carex paysonis	Payson sedge	40
Deschampsia caespitosa	Tufted hairgrass	40
Poa alpine	Alpine bluegrass	40
Phleum alpinum	Alpine timothy	40
Festuca ovina	Sheep fescue	40
Trisetum spicatum	Spike trisetum	40
Forbs		
Antennaria lanata	Woolly pussytoes	40
Artemisia scopulorum	Rocky Mountain sage	40
Geum rossii	Alpine avens	40
Sibbaldia procumbens	Sibbaldia	40
Trifolium parryi	Parry's clover	40
Total		**480**

2000 Gardner Headwall and West Summit Slope Plots

The test plots created at the Gardner Headwall and West Summit Slope plots in 2000 address additional issues identified for the proposed project, such as new types of organic amendments, slope, and seed source. The 2000 Gardner Headwall and West Summit Slope revegetation-test plots were designed for observation and some quantitative analysis and were not designed to be statistically repeatable. This decision was made in an effort to limit disturbances to fragile alpine areas, but still permit evaluation of variables such as slope and aspect. The four variables tested in 20 revegetation-test plots (12 at the West Summit and eight at the Gardner Headwall) for their effect on revegetation success were:

- 1:2 slope versus 1:3 slope (vertical:horizontal)
- Seed collected from the Beartooth Plateau versus commercially supplied seed (Table 3)
- Surface application of BioSol Mix versus surface application of Kiwi Power and Fertil-Fibers NutriMulch
- Slope aspect

For the West Summit Slope plots, the test plots were on the south-, southeast-, north-northeast, and east-facing slopes of an old gravel-borrow area north of the parking lot. Twelve revegetation-test plots were established at the West Summit Slope plots. Four experimental 14.86 m2 (160 ft2) plots and two 7.43 m2 (80 ft2) control plots were placed on approximate 1:2 slopes. Four 14.86 m2 (160 ft2) experimental plots and two 7.43 m2 (80 ft2) control plots were placed on approximate 1:3 slopes.

At the Gardner Headwall pullout, eight revegetation-test plots were established. The test plots at the Gardner Headwall were on a north-facing slope adjacent to a pullout on the south side of the Beartooth Highway. Four test plots, two organic-amendment test plots, and two control plots, all measuring 7.43 m2 (80 ft2), were established on 1:2 slopes. Four experimental test plots, two organic-amendment test plots and two control plots, all measuring 7.43 m2 (80 ft2), were established on 1:3 slopes.

Table 3. Seed Mixes for the 2000 West Summit Slope Plots and Gardner Headwall Plots

2000 Gardner Headwall and West Summit Slope Plots Seed Mix Density			
Scientific Name	**Common Name**	**PLS**	**Seeds/ft^2**
Deschampsia caespitosa	Tufted hairgrass	0.87	45
Poa alpina	Alpine bluegrass	1.48	45
Phleum alpinum	Alpine timothy	2.40	45
Total		**4.75**	**135**

2001 West Summit Flat Plots

In September 2001, 32 test plots 6.25 m2 (67 ft2) in size were placed in a flat portion of the borrow area at the West Summit. This location was selected for its uniform topography and existing disturbances on the site. Also, topsoil and subsoil removed from the 2000 test plots was placed here, leaving an ideal growing medium for placement of additional revegetation-test plots.

The 2001 West Summit Flat plots tested three surface mulch treatments, two seeding rates, two methods of transplanting soil plugs, and one organic amendment. The treatments were:

- Two-thirds cedar/one-third fir wood chips versus bonded fiber matrix versus 70:30 straw:coconut-fiber erosion-control blanket
- Very low versus moderately low density seeding rate
- Sod transplants placed immediately versus sod transplants placed after one-month stockpile
- Organic-amendment application versus no organic amendment

Table 4. Seed Mixes for the 2001 West Summit Flat Plots

2001 West Summit Flat Plots Seed Mixes					
Scientific Name	**Common Name**	**Moderate Density Rate**		**Low Density Rate**	
		PLS	**Seeds/ft^2**	**PLS**	**Seeds/ft^2**
Deschampsia	Tufted hairgrass	0.35	20	0.175	10
Poa alpina	Alpine bluegrass	0.90	20	0.45	10
Phleum alpinum	Alpine timothy	0.85	20	0.425	10
Trisetum spicatum	Spike trisetum	0.35	20	0.175	10
Total		**2.45**	**80**	**1.23**	**40**

Seed-Growout Experiment

In anticipation of potential impacts to alpine and subalpine vegetation along the Beartooth Highway associated with the proposed reconstruction of the highway, the FHWA implemented a seed-growout experiment to evaluate the effectiveness of collecting the seed of reclamation plant species on the Beartooth Plateau and farming it as a seed crop. This process is called seed increase or seed growout. Seed was collected from both alpine and subalpine habitat on the Beartooth Plateau. The FHWA wanted to determine if seed growout is a cost-effective and reliable method of obtaining seed to revegetate disturbed alpine areas.

Two seed-growout experiments are now underway. Seed was collected for the first seed growout in 2000 (2000 Growout) and then seeded/planted in the spring of 2001. Seed was collected for the second growout in 2001 (2001 Growout) and seeded/planted in spring 2002.

2000 growout

In fall 2000, Wind River Seed collected seed from four alpine species on the Beartooth Plateau (Table 5). Two crops of weed were established in 2001, one in the spring and one in the fall. A portion of the 2000 growout crop was direc-seeded and a portion was planted from nursery stock that Bitterroot Restoration Inc. grew from seed collected by Wind River Seed. Wind River has been growing out these species since 2001.

2001 growout

An additional seed-growout experiment was undertaken in the fall of 2001. Wind River Seed and Sabine Mellman Brown collected seed from the Beartooth Plateau in the fall of 2001. The seed was planted in 2002. Again, a portion of the growout crop was direct seeded and a portion was planted from nursery stock that Bitterroot Restoration grew from seed collected by Wind River Seed. The 2001 Growout experiment is divided into two parts.

First, a small-scale supplemental seed-growout experiment (Supplemental Growout Experiment) was conducted to test forbs and sedges for use in revegetation. The purpose of this experiment was to test the effectiveness of growing out forbs and sedges to add diversity to revegetation-seed mixes and plantings.

Second, a large-scale growout experiment was conducted to see if it is possible to grow enough seed for construction in 2004 (2004 Construction Experiment). The purpose of this experiment is to determine whether it is possible to grow seed that is not commercially available, has sporadic or limited commercial availability, or is better genetically adapted to subalpine environments than available commercial stock.

Summary

ERO and the FHWA are conducting revegetation experiments on the Beartooth Plateau as part of planning for proposed reconstruction of portions of the Beartooth Highway in Park County, Wyoming. Monitoring of these revegetation-test plots is ongoing and is expected to yield valuable information about revegetation of alpine areas in the Rocky Mountains.

Biographical Sketch: Liz's areas of expertise include revegetation, wetland delineation, permitting, and mitigation. She is knowledgeable in the restoration of natural habitats, riparian, and disturbed land reclamation and has over 11 years experience conducting vegetation inventories at project sites in a variety of ecosystems. Liz has designed and supervised construction of restoration sites, wetland mitigation sites, and trout and duck ponds. She also has experience in revegetation, weed control, plant taxonomy, threatened- and endangered-plant surveys, and wildlife-habitat assessments.

Reference

Payson, L. 2002. High-Altitude Revegetation Experiments on the Beartooth Plateau, Park County, Montana and Park County, Wyoming. First Year Monitoring Results. *Proceedings: High-Altitude Revegetation Workshop No. 15*. Colorado State University. Fort Collins, Colorado.

Table 5. Seed and Plants for 2000 Growout Experiment

Scientific Name	Common Name	Spring 2001 Direct Seeding		Fall 2001 Direct Seeding		Area Planted*	
		Proposed	Actual	Proposed	Actual	Proposed	Actual
		Ac.	Ac.	Ac.	Ac.	Ac.	Ac.
Deschampsia caespitosa	Tufted hairgrass	0.20	0.78	0	0.51	0.20	0.73
Poa alpine	Alpine bluegrass	0.20	0.36	0	0.30	0.20	0.43
Phleum alpinum	Alpine timothy	0.20	0.36	0	0.30	0.20	0.43
Festuca ovina	Sheep fescue	0.20	0**	0	0	0.20	0.06
Total		**0.8**	**1.5**	**0**	**1.11**	**0.8**	**1.65**

*No. of transplants of each species: tufted hairgrass = 8,600; alpine bluegrass = 5,350; alpine timothy = 5,100.
**Insufficient seed was collected of this species to direct seed.

Table 6. Seed Amounts for the 2002 Supplemental Growout Experiment

Scientific Name	Common Name	Amount Seeded	Transplants	Transplants
		Lbs (PLS*)	Proposed	Planted
Agoseris glauca	False dandelion	0.25	0	783
Anaphalis margaritacea	Pearly everlasting	0.10	625	380
Aster foliaceus	Aster	0.25	625	625
Carex nigricans	Black alpine sedge	0.25	0	600
Carex paysonis	Payson sedge	0.25	625	691
Carex scirpoidea	Downy sedge	0.02	625	0
Phacelia hastate	Whiteleaf phacelia	0.20	625	11
Polemonium viscosum	Sky pilot	0.03	0	97
Potentilla diversifolia	Varileaf cinquefoil	0.20	625	985
Total		**1.55**	**3,750**	**4,172**

*PLS = Pure Live Seed.

Table 7. Seed Planned for the 2004 Construction Seed Increase

Scientific Name	Common Name	Amount	Transplants	Transplants	Area to	Additional	2003	2004	Total
		Lbs	Proposed	Planted		Spring 2003	Lbs (PLS)*		
Danthonia	Timber oatgrass	0.485	6,060	1,800	0.08	100	15	15	30
Calamagrostis	Bluejoint	-	800	-	-	-	-	-	-
Deschampsia	Tufted hairgrass	1.091	460	460	0.03	-	5	5	10
Elymus glaucus	Blue wildrye	0.551	7,212	7,200	0.02	455	108	108	216
Elymus scribneri	Scribner's	0.919	7,884	8,000	0.62	650	119	119	237
Festuca idahoensis	Idaho fescue	-	-	-	-	-	-	-	-
Festuca ovina	Sheep fescue	0.023	-	1,000	0.02	200	4	4	8
Koeleria pyrimidata	Prairie junegrass	-	-	-	-	-	-	-	-
Penstemon procerus	Penstemon	4.536	530	396	0.02	-	4	4	8
Phleum alpinum	Alpine timothy	0.430	1,580	790	0.11	-	20	20	40
Poa alpina	Alpine bluegrass	0.662	-	1,750	0.26	-	74	74	148
Poa nevadensis	Nevada bluegrass	0.970	-	4,500	0.26	330	50	50	100
Stipa nelsonii	Nelson's	0.551	-	2,997	0.08	195	12	12	24
Total		**10.375**	**25,210**	**29,593**	**1.88**	**1,930**	**416**	**416**	**832**

Mitigation for Dormice and Their Ancient Woodland Habitat Alongside a Motorway Corridor

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Abstract: The M2 motorway-widening scheme in Kent, England was set within a constrained, environmentally sensitive corridor. Ecologists were involved from the earliest stages of the project and throughout the planning, development, and implementation phases they worked alongside the design engineers to develop pragmatic solutions to the potential impacts of the scheme.

One of the most significant impacts was on the areas of ancient woodland that abut the existing motorway. Since the widening was on-line or adjacent to the existing motorway, the widening proposals sought to minimize the ancient woodland land-take, but some loss was inevitable.

The scheme was discussed at length with the statutory consultees. One option considered was a contribution to off-site habitat creation (mitigation banking). Instead, a scheme for the creation of new woodland adjacent to the scheme was developed. However, rather than simply planting trees onto a bare site, an ambitious proposal to translocate the existing ancient woodland soil to the new site was implemented.

From the outset, the ancient woodland topsoil was identified as a valuable resource, having developed in shaded conditions for hundreds of years and containing a considerable diversity of woodland seeds, bulbs, micro-organisms, and invertebrates. The majority of the woodlands affected by the scheme were commercial sweet chestnut coppice of little intrinsic nature conservation value, but all of the woodlands supported the protected hazel dormouse.

Over a year before the contract to widen the M2 was let, the ecological advance works began on site. The trees within all of the strips of woodland where the motorway widening would take place were coppiced during winter, using hand-held tools and without permitting vehicles onto the ancient woodland soil. This work was timed to coincide with the period when dormice would be hibernating on the ground. On waking from hibernation in spring, the dormice moved into the canopy of the remaining woodland, where their habitat had been enhanced by the provision of artificial nest sites and woodland-management techniques, including selective coppicing and replanting.

The following autumn, the ancient woodland soil (with its seed-bank intact) was carefully excavated and re-spread on a specially prepared ‘receptor site.’

One hundred mature coppiced hazel trees were transplanted from the area of the widening to the new site to provide food for dormice. Also, 60,000 new trees of an appropriate diverse species mix and of local provenance were planted. Piles of decaying timber were also assembled to provide a habitat for fungi and dead wood invertebrates.

The new woodland that has been created connects three existing woods, enhancing their nature conservation value and providing a linking function as a substantial ‘wildlife corridor.’ There is also a public footpath and bridleway, suitably fenced throughout the length of the site so that the new woodland can be enjoyed by local people.

The translocated ancient woodland soil will give the new woodland a valuable start in its development by providing many of the important components of a woodland ecosystem. The site is being monitored closely for at least the next 10 years, and each successfully transferred element of the habitat is being carefully logged and its progress to full establishment recorded. Five years on, the woodland is developing well. There is a distinct woodland ground flora, with carpets of bluebells in the spring, and woodland invertebrates are still present. The tiny fragment of retained woodland in the center of the site still holds a population of dormice. The translocated and new Hazel are beginning to fruit heavily so that a further eight hectares of habitat will soon be available to the population.

Introduction

This paper describes works to mitigate the effects of a motorway-widening scheme in the South-East of the UK on a species protected by national and international policies and legislation, the hazel dormouse (*Muscardinus avellanarius*), along with its ancient woodland habitat.

Advance mitigation works for this project began in 1998; construction took place between 2000 and 2003; and monitoring is intended to extend until 2013. This paper presents a summary of the results of the pre-construction surveys, outlines the main elements of the works to mitigate impacts on both dormice and valuable woodland habitats, and summarizes the interim results of the scheme.

Background to the Project

Authorization for the construction of the A2/M2 Widening between Cobham and Junction 4 in Kent was obtained as part of the Channel Tunnel Rail Link Act (1996). The Highways Agency (which is the Government Agency responsible for the trunk road network in England) agreed to a landscape- and ecological-mitigation strategy with English Nature (the Government's advisor on nature conservation issues) to address the loss of ancient woodland and impacts on populations of protected species adjacent to the road. These ancient woodlands had been fragmented when the motorway was originally constructed. Whilst the widening proposals sought to minimize the ancient woodland land-take, some loss was inevitable. The distribution of the woodland and related habitats along the route is shown on figure 1.

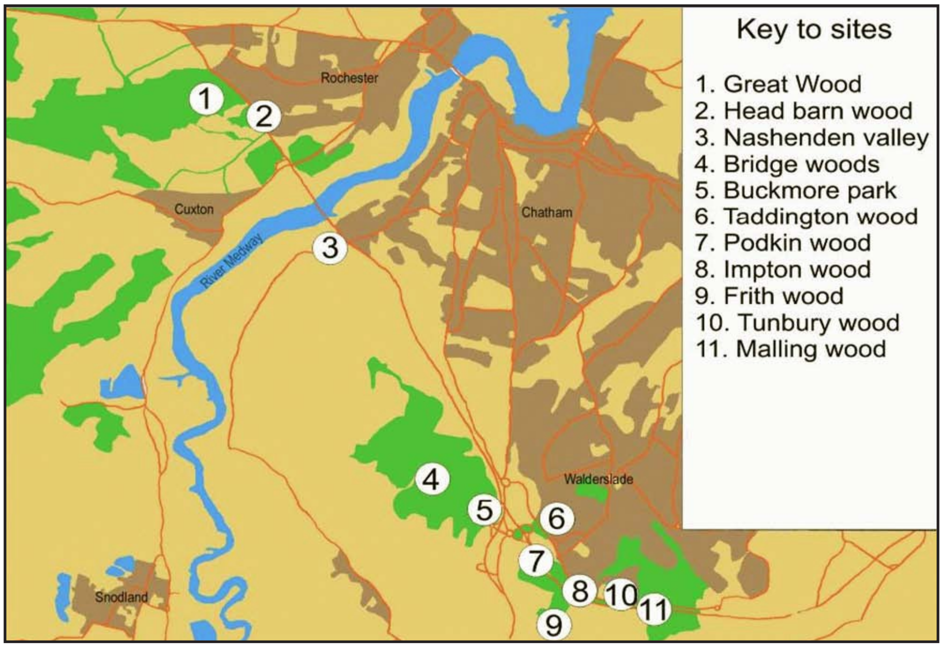

Figure 1. Distribution of woodland and related habitats along route.

The woodlands and some associated habitats were known to support populations of hazel dormice. Proposals were made to ensure the maintenance of these populations and the protection of individual dormice. Allied to this were measures to create replacement woodland habitat. Rather than simply plant new woodland areas, a proposal to translocate the existing ancient woodland soil to a new site was implemented along with a new planting scheme. The principal aim of this soil translocation, along with the translocation of coppice stools, was to create a new broad-leaved woodland of nature conservation value which would support a diverse fauna and flora, including plants, animals, and invertebrate species present in the original woodlands prior to translocation. Whereas from the outset, the ancient woodland topsoil was identified as a valuable resource (having developed in shaded conditions for hundreds of years and containing a considerable diversity of woodland seeds, bulbs, micro-organisms, and invertebrates), the majority of the trees were not. These largely comprised commercial sweet chestnut (*Castanea sativa*) coppice of little intrinsic nature-conservation value.

Nevertheless, each of the woodlands supported dormouse populations. The new woodland creation proposals formed one of three principle elements of a mitigation strategy for these animals:

- Displacement of dormice from the working areas
- Capture and release of dormice from isolated sub-populations into woodlands managed to benefit them
- Creation of the new woodland site

Attention to detail was paramount in this scheme and a partnership between the employer, contractor, engineers, landscape architects, and ecologists was crucial in developing the detailed working methods on site, using standard civil engineering plans.

Background Information on the Hazel Dormouse

Status and protection in the UK

The hazel dormouse is listed on Annex IVa of the EC Habitats Directive. The requirements of this directive are implemented in the UK by the Conservation (Natural Habitats &c) Regulations (1994). The species is protected under Schedule 5 of the Wildlife and Countryside Act 1981 (added in 1988) and Schedule 2 of the Conservation (Natural Habitats & c.) Regulations 1994. The hazel dormouse is also identified as a species of principal importance for biodiversity in England under Section 74 of the Countryside and Rights of Way (CRoW) Act (2000), which requires government departments to take or promote steps for its conservation. The hazel dormouse is identified as a Priority Species in the UK Biodiversity Action Plan, for which a Species Action Plan (SAP) has been produced (JNCC 2004; UKBAP 1995). The plan aims to maintain and enhance dormouse populations in all the counties where they still occur and to re-establish self-sustaining populations in at least five counties where they have been lost. The dormouse is also identified as a Priority Species in the Highways Agency Biodiversity Action Plan (HABAP). The main aim of the SAP for dormice is to ensure that new road developments avoid or adequately mitigate any potential impacts on dormice (Highways Agency 2002).

Due to the effects of habitat loss and fragmentation, dormouse numbers and distribution have declined significantly as a result of the isolation of their woodland habitats and inappropriate woodland management. The animals are reluctant to cross open ground and consequently, are vulnerable to local extinctions when woodland is lost. In addition, the 'grubbing-out' of hedgerows in recent decades has removed wildlife 'corridors' between woods that might have allowed dormice to move more freely to alternative sites. As a result of its serious decline, dormice are classified as 'Lower Risk-near threatened' by the IUCN and 'Vulnerable' in the UK.

Characteristics and ecology

Hazel dormice are small, arboreal rodents, which can easily be distinguished from mice by their long, fluffy tails. They have golden fur on the back and a pale, cream-colored underside. The dormouse has large eyes that betray its strictly nocturnal existence. Dormice tend to weigh between 10 and 30 g, with a head and body length of approximately 50 mm and a tail length of a further 50 mm. They are relatively long-lived for small mammals, surviving up to five years in the wild (Corbett and Harris 1991; Bright et al. in press).

In the UK, dormice are largely restricted to the south of England and Wales, where they live in dense, deciduous woodland, coppice, dense areas of shrubs, and hedgerows. Hazel coppice is a preferred habitat. During their active period, dormice build spherical nests situated a few feet from the ground. Here dormice spend the greater part of the day before emerging after dark to forage in the woodland and understory canopies. They eat flowers and pollen during the spring and fruit in the summer and nuts, particularly hazelnuts in autumn. It is thought that insects are also important components of their diets. This variety of food must be available within a relatively small area, a requirement which limits the suitability of some sites for dormice. Good quality dormouse habitat will comprise a variety of species that will ensure availability of food throughout the period of dormouse activity (April to late October/early November). Furthermore, because dormice tend to feed in the upper branches of their woodland or scrub habitat and they do not make use of food sources available on the ground, this availability of sequentially flowering and fruiting species linked by arboreal route-ways, is crucial (Morris 2004). Bright (1998) also demonstrated the importance of habitat connectivity for dormice.

Recent studies have indicated that the majority of hazel dormice seek suitable places to hibernate on the ground in late-October or early-November (Morris 2004; Bright et al. in press). The majority of animals found active after this time are thought to have been aroused from hibernation, either to search for food, if their fat reserves are not adequate enough to sustain them though the hibernation period, or as a result of mild temperatures (Bright et al. in press; Juskaitis 2005; Csorba 2003; Bright et al. 1996). Hazel dormice in the UK normally hibernate until mid to late April (although, once again, mild conditions and warm locations can induce dormice to become active earlier in the year). As a result, their breeding season occurs relatively late in the year compared to other small mammals and litters are less likely to be found before mid-June. Females generally give birth to one successful litter a year. This usually consists of no more than four young (Juskaitis 1999; Morris 2004).

Methodology and Results of Pre-Construction Investigations

Dormouse surveys

There were existing records of dormouse populations in several of the woodlands that were unavoidably to be affected by the widening works (see figure 1). Additional surveys by consultants during earlier stages of scheme development revealed the presence of dormice in additional locations.

Prior to the advance mitigation works in 1998 and 1999, further investigations of areas of landscape planting were undertaken to confirm the presence/absence of dormice in remaining areas of potentially suitable habitat. This comprised a combination of searches for characteristically-chewed hazelnuts, searches for dormouse nests, and inspections of artificial nest boxes (Bright et al. in press).

The surveys confirmed that dormice were present in each of the areas of established woodland bordering the scheme. In addition, dormice were found to inhabit strips of landscape planting and roadside hedgerows along and within the highway boundary. In several locations, these narrow 'belts' of landscape planting (planted approximately 30 years previously when the motorway was first built and comprising a diversity tree and shrub species) appeared to represent particularly suitable habitat for dormice. In one section of the motorway, along the Nashenden valley, the subsequent mitigation operation for dormice involved a comprehensive capture operation, which served to produce reasonably reliable data on the numbers of dormice present (see below). Transects were walked through this vegetation in order to record its structural and species diversity. The results of these are presented in Appendix I.

Surveys of woodland habitat

Eight woods along the route of the A2/M2 were included in the woodland soil-translocation scheme as 'donor sites' (Brewers Wood, Great Wood, Head Barn Wood, Bridge Wood, Taddington Wood, Frith Wood, Tunbury Wood, and Malling Wood). Quadrat-based surveys of seven of these woodlands were undertaken by consultants during earlier stages of the project in October through November 1997 and repeated in July 1998. Analysis of these data revealed that these would be classified as *W10 Quercus robur-Pteridium aquilinum-Rubus fructicosus* woodland, but some individual quadrats supported a slightly different flora which showed strong affinities to W8 Fraxinus excelsior-Acer campestre-Mercurialis perennis woodland (Rodwell 1991). Malling Wood was not surveyed at this time, but a brief walkover survey undertaken in spring 1999 revealed that it would also be classified as W10 woodland.

Brewers Wood, Great Wood, Bridge Wood, Tunbury Wood, and Malling Wood all comprised neglected sweet chestnut (*Castanea sativa*) coppice, whilst Taddington Wood and Frith Wood comprised neglected hornbeam (*Carpinus betulus*) coppice. Most of the woodlands were shown to support a limited range of woodland ground flora species. This was, in part, due to the time of year that the baseline surveys were undertaken (e.g. wood anemone (*Anemone nemerosa*) was not recorded in any of these woodlands, although it has been recorded post-translocation) and in part due to heavy shading by dense growth of the coppice stools. Nevertheless, most of these woodlands supported ground-flora herbs associated with ancient woodland, together with those associated with disturbed/more open habitats.

Dormouse Mitigation and Habitat Translocation Works

Dormouse mitigation works

These advance mitigation works began more than a year in advance of construction. The measures to mitigate impacts on the resident dormice were designed specifically around seasonal variations in dormouse behavior and habitat use. The works were undertaken under license as appropriate.

Vegetation clearance during the hibernation period

Along the majority of the widening scheme, where the adjacent areas of woodland and associated 'belts' of landscape planting were well connected, the following approach was adopted:

During the winter prior to construction (1998/9), all of the trees and shrubs within the working width were coppiced (cut back to ground level) using hand-tools and avoiding ground disturbance as far as possible. A narrow haul route was 'sacrificed' in terms of preserving the ancient woodland soils and a finger-tip search of this also ensured that hibernating dormice were not killed accidentally. From this haul route, felled timber was extracted using an appropriate lifting plant and lighter material was moved by hand.

A further strip of vegetation was also subject to selective coppicing with the intention of establishing a more 'natural' new woodland edge to help limit the problems of wind throw in subsequent years and to maximize the fruiting capacity and hence productivity of young trees and shrubs within the edge of the woodland into which dormice would be displaced. A total of approximately 250 artificial dormouse nest boxes were also established along these woodland boundaries to provide additional shelter and breeding sites.

Earthworks in these areas were then delayed until late summer/early autumn of the following year (1999). This not only allowed any dormice hibernating within the working width to emerge, but also meant that vegetation translocated at that time of year (see the following) had the best chance of survival.

From the point of view of the resident dormice, the rationale behind this element of the mitigation works was as follows: In any one location, the width to be cleared tended not to exceed approximately 50 m and thus the home ranges of most of the resident dormice were likely to extend beyond the vegetation to be removed (Bright et al. in press). For this reason, the intention was to retain the animals in situ rather than attempt translocation. Cutting the vegetation back in winter avoided the probability of killing or injuring dormice using the tree and shrub canopies, particularly breeding animals and young, and working practices were adopted which sought to avoid the mortality of any animals which would be hibernating within the working width.

Previous studies of dormice released into open areas have shown them to be able to orientate themselves and regain access to cover over distances of this kind (Bright 1998). In addition, shortly after emergence the organization of dormouse home ranges and territorial behavior tends to be in a greater state of flux than at other times of the year (partly as a result of the effects of over-winter mortalities) and thus animals displaced into adjacent habitat would be expected to have a greater distance of establishment and survival in late spring than later in the year.

Capture and Release of Dormice from Isolated Sub-Populations

Capture operations

In certain locations along the route, areas of landscape planting were identified that supported dormice but which were not well connected to the suitable habitat that would be retained post-construction. Thus any animals which might hibernate in these locations would have had difficulty in regaining access to suitable habitat once the vegetation had been removed. Every attempt was made to capture and remove dormice from these isolated areas prior to construction.

A total of approximately 200 artificial nest boxes (Bright et al. in press) were installed within these isolated areas of landscape planting. These were checked regularly during the summer and autumn of 1999. Any dormice found were captured and relocated to a number of release sites (see below). Towards the end of the dormouse 'active' season in 1999 (during October and early November), the vegetation in these isolated areas was cleared with care and under close supervision, with the intention of capturing any remaining individuals.

A total of 36 individual dormice were captured and relocated during this operation. It has been possible, on the basis of these capture data, to estimate population densities in some of the 'belts' of species-rich landscape planting. An overall late season (post-breeding) average of approximately 10 individuals/Ha was estimated, although in the more suitable areas, locally higher densities up to the equivalent of 30/Ha were recorded.

Dormouse receptor site selection, preparation and subsequent management
A proportion of the dormice captured (where very small numbers were encountered in a particular location that was fairly close to suitable retained habitat) were simply released into the retained habitat nearby. However, the majority were released into selected areas of woodland where dormice were either uncommon or absent, but where the habitat appeared to be potentially suitable and worthy of improvement.

Two areas of woodland in particular were chosen as 'dormouse receptor' sites: Impton Wood and Podkin Wood. Impton Wood was a relatively large, isolated area of woodland, largely comprising sub-optimal habitat for dormice, which was thought to support a small, declining population. Podkin Wood was a small area of woodland, again supporting sub-optimal dormouse habitat, but linked to a larger area of more suitable habitat (Frith Wood) with its own large and healthy dormouse population.

During the season prior to release of relocated dormice, both woodlands were subject to woodland-management operations (largely selected felling and coppicing) designed to increase the fruiting capacity of selected shrubs in an effort to increase their productivity for dormice in the shortest time possible. No further works were then undertaken in Podkin Wood, whereas a comprehensive management plan was produced for Impton Wood and is being implemented. This seeks to reduce the dominance of sweet chestnut coppice and to increase structural and species diversity within the woodland through a phased treatment of selective felling, coppicing, and replanting over the next two decades.

In addition to the monitoring scheme for dormice (see the following), the effects of the management works on the woodland vegetation are also subject of a monitoring scheme, with the intention of informing subsequent phases of management.

Creation of the 'New Woodland' site
The location of the new woodland site is shown in figure 2.

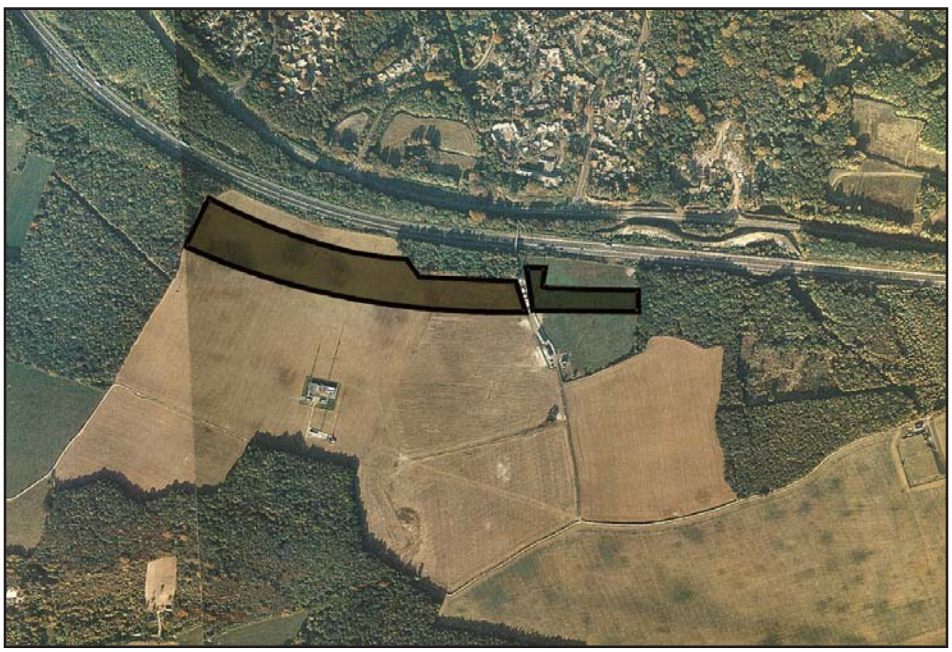

Figure 2. Location of new woodland site.

Soil Translocation Works

Receptor site
The receptor site for the translocated soil comprised a large arable field that links three of the 'donor' woodlands (Frith Wood, Tunbury Wood, and Malling Wood). This site was chosen because it provides a link between existing woodland blocks that will form a substantial wildlife corridor and enhance the nature-conservation value of the existing areas of woodland. In addition, the isolated fragment of woodland that comprises Tunbury Wood was found to support a small, vulnerable population of dormice. Linking these animals to those in the adjacent woodlands offered a chance of long-term survival for this population.

Preparation of the receptor site for ancient woodland soils
In September and October 1999 topsoil was stripped (to a depth of approximately 300 mm) from the receptor site and used elsewhere on the widening scheme as a planting medium for landscaped areas. To ensure that there was no loss of function in the subsoil (in particular over-compaction which would lead to a reduction in drainage through the soil profile) the works were carefully planned, including the use of predefined haul routes to minimize the number of vehicle passes over the subsoil surface. To ensure that there was no deterioration in subsoil drainage capacity, the subsoil was also 'ripped.' Subsoil characteristics were also assessed and found to match well with more of the different donor sites.

Excavating soil from the donor sites
The soils on the donor sites were silty clay loams and clay loams. These soil textural types have low plastic limits and are prone to structural degradation if traversed by vehicles or handled when too wet. To avoid problems of soil compaction (which can have consequent effects on drainage, nutrient cycling, and microbial function) site works were only permitted when the soil was at or below field capacity (i.e. the soils did not contain any freely draining water). Haul routes were predefined to ensure the minimum number of vehicle passes over the majority of the site. In total, 10,000 tonnes of topsoil of varying depths were removed using tracked excavators and transported by dumper truck to the receptor site. Depths of excavation and soil horizons were identified on site and care was taken to avoid mixing topsoil and subsoil layers. Large roots (those over 50 mm in diameter) and foreign materials were removed from the soil prior to transportation. A proportion of the cut timber was retained for use in the creation of large dead wood piles on the edge of the new woodland to create habitat for fungi and invertebrates. The remainder of the cut material was disposed of off site.

Transferring the soil and coppice stools
The receptor site was zoned so that soil from the individual woodlands was not mixed together and was spread in well-defined separate areas. No tracking over the newly laid soil was permitted. Soil was loosely tipped (to avoid compaction or smearing) and spread to depths varying between 150 mm and 300 mm to replicate the topsoil depth at the donor sites. Approximately 125 hazel (*Corylus avellana*) coppice stools were also moved from two of the donor woods using a 'tree spade' and placed to create a linear link across the receptor site in order to promote the early development of a corridor of more-mature vegetation to connect the currently isolated fragments of woodland.

Establishing the woodland habitat
A diverse mix of nursery-grown native trees and shrubs of local provenance was planted across the site at 1-m spacings, with a total of 60,000 trees and shrubs being planted. A planting mix was developed to produce the tree and shrub flora typically associated with W8 *Fraxinus excelsior-Acer campestre-Mercurialis perennis* woodland. The adjacent woodlands were each known to support dormice. The new woodland block was intended to form a valuable link for these isolated populations, as well as providing habitat for other wildlife. The mixture used was therefore biased to include a large number of fruit- and nut-bearing species to enhance the value of the developing woodland for dormice.

Woven plastic mulch mats were placed around the bases of the trees and shrubs to prohibit the growth of weedy species and help retain soil moisture. A piped irrigation system, fed by a large tank filled with rainwater, was also installed as an additional water source for the new habitat. Dead or diseased trees and shrubs were replaced as part of a maintenance contract. The use of herbicides and pesticides was prohibited to prevent any damage to the developing flora and fauna. Large clumps of vegetation (mainly grasses) that grew over the mulch mats were pulled away from the tree and shrub stems to reduce the likelihood of field vole damage. To reduce costs, tree shelters were not used, but the larger trees were staked. Rabbit-proof fencing was installed around the boundaries of the site and on the edge of the footpaths created through parts of the site. The trees and shrubs were planted densely in order to create shade as quickly as possible. It was identified that thinning would be required in future years to create suitable light conditions for the woodland ground flora.

Methodology and Results of the Monitoring Activities to Date

Monitoring the effects on dormice
This monitoring scheme began in 2000 and is intended to continue until 2013.

Dormice in retained woodlands
Using the artificial nest boxes installed as part of the mitigation operations for dormice in the retained woodlands close to the scheme where management to improve their productivity for dormice was/is being undertaken, one aim of the monitoring strategy was to monitor the status of dormouse populations in these areas.

To achieve this, the dormouse nest boxes have been inspected monthly between July and October of each year. Several boxes have been vandalized and sequentially replaced to maintain a total of approximately 220. To date, dormouse have been found still to be present in each of the areas in question, with (in most years) evidence of breeding in each area.

Dormice in the two release sites
As explained above, dormice were captured from isolated habitats along the route and released into Impton Woods and Podkin Woods, each of which having been the subject of initial management to increase their productivity for dormice and with Impton Wood being the focus of on-going management operations. As with the retained woodlands, artificial nest boxes were installed in these woods to provide suitable alternative nesting and breeding sites and to facilitate monitoring.

In Podkin Wood, 21 nest boxes were initially installed, then an additional 25 new dormouse boxes were installed in May 2002. For Impton Wood, the majority of originally installed boxes were removed and/or vandalized over the course of the first two years of monitoring. Fifty new boxes were installed in 2002.

As with the retained woodlands, dormouse nest boxes in Podkin Wood and Impton Wood were checked and cleaned on a monthly basis between mid June and mid October each year. Nests belonging to rodents other than dormice and old, disused birds' nests were removed from the boxes to minimize competition for nesting sites. To date, occupancy of the boxes by dormice has remained fairly constant since 2000, fluctuating between an annual average of 6 percent and 11 percent. So far, breeding has not been recorded in any of the boxes, although on the basis of the ages of the animals captured, it is clear that dormice are breeding elsewhere within the woodlands.

Monitoring the Development of the New Woodland Area

Methodologies

The monitoring program involved five elements. The first element was an annual survey to assess the survival and success of translocated hazel coppice stools. For this, the height, canopy spread, fruiting abundance, and level of die-back was recorded every September.

Secondly, surveys to monitor the composition and structure of ground flora on the created site were undertaken to give an insight into the successional processes within the woodland and to determine the success the woodland creation in terms of its similarity to the surrounding woodland communities. During the first year of monitoring (April 2000), permanent quadrats were established in each of the sub-areas of the receptor sites corresponding to the different woodland soils that had been translocated. In each woodland sub-area, a series of five nested quadrats of 10 x 10 m and 4 x 4 m were established to record the scrub and field-layer vegetation. When developed, canopy layer trees will be assessed in five 50 x 50 m quadrats across the site. In each quadrat, the percentage cover of each species was recorded, a general species list compiled to record species outside of the permanent quadrats, and a permanent photographic record taken. These data were recorded each year.

The third element of the monitoring program focussed on invertebrates. By monitoring the composition of invertebrates at the receptor site, the presence and absence of 'indicator' species was to be used to assess whether the created woodland was developing appropriately. To date, two such surveys have been carried out, one in 2000 and one in 2004, with further surveys to be carried out in 2009 and 2013. During these surveys, the ongoing development of the newly created woodland was assessed by monitoring invertebrates associated with dead wood habitats. For this, log piles created on site were sampled using flight-inception traps. In addition, pitfall traps were used to monitor the success of the translocation of the invertebrate fauna from donor woodlands to the receptor site and the subsequent colonization by woodland invertebrates from neighboring habitats.

The fourth and fifth elements of the monitoring program related to fungi and birds: Fungal surveys have also been undertaken annually during the autumn to investigate the value of the dead wood habitat features and the developing woodland generally for these groups. A survey of breeding birds was undertaken in 2004, with further surveys to be undertaken in 2009 and 2013 to assess the value of the developing habitats for these species.

Summaries of Results to Date

Hazel coppice fruiting and re-growth

The results of this element of the mitigation have been very encouraging. Canopy width and height of the translocated stools has increased steadily between 2000 and 2004, with approximately 50 percent of the stools now over 2 m in height. Approximately 95 percent of the plants fruited in the year following their translocation. The majority of the plants have exhibited no die-back. The corridor of translocated coppice shrubs now forms a continuous, potentially functional link between Tunbury Wood and Frith Wood, which would be expected to permit the dispersal of individual dormice to and from Tunbury Wood.

Development of woodland ground flora

The composition of the developing ground flora has been monitored for four consecutive years. As might be expected, the woodland ground flora species varied in abundance across the site. Some areas were dominated by woodland ground flora species, including Bluebell (*Hyacinthoides non-scripta*) and Wood Anenome (*Anenome nemorosa*). Other areas supported, and in places were dominated by, grassland species and plants associated with open, unshaded habitats, including Common Bent (*Agrostis capillaris*), Creeping Bent (*Agrostis stolonifera*), and Yorkshire Fog (*Holcus lanatus*).

The relative abundance of woodland plants appears to be correlated with the level of wind and sun exposure across the site. The more sheltered areas supported larger numbers of woodland plants and the exposed areas contained more plants characteristic of open habitats and disturbed ground. These included a number of invasive weeds, including Common Ragwort (*Senecio jacobaea*), Broad-leaved Dock (*Rumex obtusifolius*), and Spear Thistle (*Cirsium vulgaris*).

By 2003, the abundance of woodland herbs had increased in parallel with the growth and establishment of the shrubs and trees on the site. As the canopy develops further, it is expected that the abundance of woodland herbs, grasses, and weeds will progressively change over time to become more characteristically similar to surrounding woodlands.

Development of invertebrate communities
The most recent results have indicated that the area is still in an early stage in its development as woodland ecosystem, but there were indications that the faunal composition may be changing. For example, a number of grassland species had been lost or their abundance had diminished since the first survey. These include *Calathus fuscipes* and *Pterostichus melanarius* (both Common ground beetles; Carabidae), *Liogluta pagana* (a Notable B rove beetle; Staphylinidae), *Staphylinus fortunatarum* (a Notable B rove beetle; Staphylinidae), and *Enicmus transverses* (a Common mold beetle: Lathridiidae). However, only a small number of the woodland specialists recorded in the donor sites in 2000 and 2001 were present in the receptor site. In particular, many species typical of woodland habitats were not recorded in the receptor site in 2004, including *Calathus piceus* (Carabidae: a Common ground beetle), *Cychrus caraboides* (Carabidae: a Local ground beetle), *Acalles misellus* (Curculionidae: a Local litter weevil), *Acelles roboris* (Curculionidae: a Notable B litter weevil), *Platycis minuta* (Lycidae: a Notable B net-wing beetle), *Euophryum confine* (Curculionidae: a Naturalised woodworm beetle), *Dirrhagus pygmaeus* (Eucnemidae: a RDB3 false click beetle), and *Orchesia minor* (Melandryidae: a Notable B false darkling beetle).

Despite the absence of a large proportion of the donor site invertebrate community, the presence of some woodland or woodland edge species in the created woodland and, particularly, the colonization of certain species appeared to be a good indication that a woodland succession is occurring. For example, although *Acelles ptinoides* (the least specialist of the three woodland species of *Acelles*) was the only one currently present in the created woodland, it is reasonable to expect that the other two (*A. roboris and A. misellus*) will be recorded in the receptor sites in the future as the woodland matures. In addition, the survival of *Plinothus* spp. (a genus of predatory rove beetles) and *Tropiphorus elevatus* (a broad-nosed weevil commonly linked to Dog's mercury) is encouraging. It is to be hoped that increases in such species will be observed in the future.

Use of the developing habitats by breeding birds
The first of the monitoring surveys in 2004 recorded a total of 26 species using the new woodland site. The majority of these species were not found to be nesting within the site boundary, but did appear to use the new woodland for foraging and/or roosting. Four UK BAP species were recorded within or near the site: Skylark (*Alauda arvensis*), Linnet (*Carduelis cannabina*), Song thrush (*Turdus philomelos*), and Grey partridge (*Perdix perdix*).

The newly created woodland is still very much a developing feature and at present offers nesting opportunities for few woodland species. However, it is likely that as this woodland develops, the nesting and foraging opportunities that it offers to the local breeding-bird population will increase and the species that it attracts will change through the successional process. Its proximity to other woodlands should ensure that it is colonized by woodland bird species at an earlier stage than might otherwise be the case.

The results of the fungal surveys are not yet available.

Discussion and Conclusion

The results to date of the monitoring of dormouse populations along the boundaries of the retained woodlands, along with the results of the careful supervision during the pre-construction and construction works, indicate that the operations to protect dormice during construction and to relocate the dormice were successful.

Similarly, although the populations in question still appear to be in the process of becoming established, the short-distance translocation of dormice to woodlands that are being managed to benefit them also appear to have been successful.

With regard to the establishment of the new woodland site, the interim monitoring results also appear encouraging. It is possible to confirm that many of the woodland ground flora plants recorded in the 'donor' woodlands have been successfully translocated. In addition, most of the woodland species recorded in the first monitoring year, post-translocation, have persisted across the site, although their growth has been more luxuriant in the most sheltered parts of the site. The growth of trees and shrubs across the site appeared to be slower than expected and thus offered only limited shelter. Where woodland plants were present, they appeared to be maintaining a similar proportion of ground cover as they did in the first year of monitoring, despite having to compete with increasingly vigorous grasses.

Studies of mature woodland soils have revealed that the seedbank is largely comprised of opportunistic species associated with more open habitats and that, unless the woodland contains open areas which support these species, it does not reflect the composition of the stable woodland-plant communities above ground (Buckley 1989). Disturbance of woodland soils and an increase in light levels at the ground surface through woodland clearance or translocation operations would be expected to cause dormant seeds to germinate. The increase in the number of 'ruderal' herbs recorded following the translocation of these woodland soils is, therefore, an inevitable consequence of the soil disturbance associated with transference. However, the occurrence of these species does not appear to have had a detrimental affect on the typical woodland ground flora species associated with ancient woodlands.

Species that have failed to appear following soil translocation are those few woodland species that require a degree of shading to germinate, notably the bryophytes and ferns. These species have also failed to appear six years after the soil translocation exercise associated with the CTRL (Helliwell et al. 1996). It was anticipated that the ferns would not survive translocation and it was for this reason that mature mail-fern (*Dyyopteris filix-mas*) plants that were found in the areas of woodland affected by the road scheme were translocated directly into the retained areas of woodland.

The new woodland that has been created connects three existing woodlands, enhancing their nature conservation value and providing a linking function as a substantial wildlife corridor. The translocated ancient woodland soil is providing the new woodland with a valuable start in its development by providing many of the important components of a woodland ecosystem. The site will continue to be monitored closely and each successfully transferred element of the habitat will be carefully logged and its progress to full establishment recorded. The data gathered will provide important guidance for similar projects in the future.

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Appendix 1

Typical transects through embankment vegetation (maturing landscape plantings and self-seeded scrubs)

Transect 1

Trees: very open canopy 10-16 m (expressed as total number per 30m section)

Betula pendula	6
Fraxinus excelsior	4
Carpinus betulus	2
Sorbus aria	2
Pinus sylvestris	1
Malus domestica	1

Understorey: very dense 1.5-3 m (expressed as DAFOR scale)

Cornus sanguinea	A
Viburnum lantana	F
Acer campestre	F
Rosa spp.	F
Betula pendula	F
Sambucus nigra	O
Salix spp.	O
Euonymus europaeus	O
Crataegus monogyna	O
Ligustrum vulgare	O
Prunus spinosa	R
Quercus robur	R
Acer pseudoplatanus	R
Fraxinus excelsior	R

Climbers etc: throughout understorey and up to 5 m into trees

Rubus fruticosus (agg.)	A
Clematis vitalba	F

Transect 2

Trees: no large trees (expressed as a total number per 30 m section)

Understorey: very dense 1.5-3.5 m (expressed as DAFOR scale)

Cornus sanguinea	D
Viburnum lantana	O
Acer campestre	R
Rosa spp.	F
Betula pendula	O
Salix spp.	F
Crataegus monogyna	R
Ligustrum vulgare	R
Fraxinus excelsior	R
Rhamnus cathartica	O

Climbers etc: throughout understorey and up to 5 m into trees

Rubus fruticosus	F
Clematis vitalba	F
Lonicera periclymenum	R

Transect 3

Trees: scattered trees (expressed as a total number per 30 m section)

Fraxinus excelsior	3
Sorbus aria	1
Malus domestica	1
Salix spp.	1
Acer pseudoplatanus	1

Understorey: dense, very dense in places (expressed as DAFOR scale)

Malus domestica	R
Cornus sanguinea	D
Viburnum lantana	O
Acer campestre	O
Rosa spp.	F
Betula pendula	O
Sambucus nigra	R
Salix spp.	F
Euonomys europaeus	A
Crataegus monogyna	O
Ligustrum vulgare	R
Acer pseudoplatanus	R
Fraxinus excelsior	R
Rhamnus cathartica	O
Corylus avellana	R
Buddleja sp.	R

Climbers etc: throughout understorey and up to 5 m into trees

Rubus fruticosus	F
Clematis vitalba	F
Lonicera periclymenum	R

Response of *Acacia* Species to Soil Disturbance by Roadworks in Southern New South Wales, Australia

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Abstract: Heavy machinery is regularly used throughout the world to maintain infrastructure corridors. The purpose of this study is to investigate the response of roadside populations of three *Acacia* shrub species to soil disturbance from roadworks. Results were highly variable. However, resprouting and seedling emergence led to a 6.2 percent population increase at four road reserves. Two years after grading, there was significant resprouting of *A. decora* and resprouts reached a mean height of 72 cm. One year after disturbance, 71 percent of *A. decora* resprouts flowered and 49 percent also set viable seed. In contrast, there was patchy seedling emergence of *A. pycnantha* and *A. montana*. These results show that grading of roadsides appears to favor plants with strong resprouting ability and that the scale of response depends on the plants life-history attributes and the prevailing disturbance regime. Further studies of individual plant responses to soil disturbance can only better our understanding of plant dynamics in road and other transportation corridors.

Introduction

Heavy machinery (such as the Caterpillar grader) is commonly used throughout the world to construct and maintain roads and transport corridors (Forman et al. 2003) (figure 1). Recently, a number of studies have considered the effects of disturbances from heavy machinery on plant populations (Webb et al. 1983; Olander et al. 1998; Milchunas et al. 2000). As soil disturbance from heavy machinery is highly intensive and extremely variable, local extinctions of roadside plant populations often occurs (Lugo and Gucinski 2000).

Figure 1. A Caterpillar grader, which is commonly used for roadworks in southern NSW.

However, recent evidence suggests that in some situations, disturbance-tolerant plants can proliferate in transportation corridors (Forman and Alexander 1998). The purpose of this study is to investigate the response of three *Acacia* species to soil disturbance from roadworks in roadside environments in southern New South Wales, Australia. In this study, roadside populations of three *Acacia* species were monitored to test the hypothesis that soil disturbance from grading will facilitate resprouting and seedling emergence of *Acacia* species, depending on the life-history attributes of each species (e.g., Noble and Slatyer 1980; Clarke 1991).

Background: importance of roadside vegetation

Temperate woodlands are the most extensively cleared vegetation type in southern Australia. In many regions, these woodlands have almost been completely eliminated, with as little as 1 percent remaining in some areas (Prober and Thiele 1993; Sivertsen 1995; Benson 1999). On private farmlands, there are few remaining woodlands, which are mostly confined as small remnants on less fertile soils, more rugged outcrops, or hard to access areas (Yates and Hobbs 1997) (figure 2a).

However, in the development of agriculture in NSW in the 1870s, a network of road reserves was developed to provide access to fields, most of which contain a narrow strip of native vegetation (Breckwoldt 1990; Spooner 2005a). Road reserves are areas of public land, where clearing of vegetation has been restricted to road-construction purposes. As many reserves are over 60-m wide, this has resulted in the development of an extensive network of vegetated corridors, often referred to as 'roadside vegetation' (figure 2b).

In 1991, it was estimated that the network of road reserves (i.e., the total strip of land reserved for transportation purposes) occupied over 80 percent of the equivalent combined area of national parks in NSW (Bennett 1991). Yet despite the fortuity of past land-use decisions in creating such corridors, the importance of road reserves to conservation has mostly been undervalued, perhaps due to the ubiquitous nature of roads in the landscape (Cooper 1991).

Figure 2. (a) Typical cleared agricultural landscape of southern NSW, where most woodland vegetation is located in narrow road reserves, and (b) a wide stock route containing a large tract of roadside vegetation (images courtesy of NSW Land Information and CSIRO).

In Australia, the principle managers of road reserves are local government authorities (councils). Although the main function of road reserves is to provide a transportation corridor, most councils have become increasingly responsible for the maintenance of the conservation, historical, aesthetic, and amenity values of road reserves. Many councils have now completed biodiversity surveys of road reserves in their jurisdiction and promulgated roadside-management plans which highlight the conservation value of each reserve. As consequence of this process, many road reserves are now listed as high conservation status (Dennis 1992; Bull 1997; Spooner 2004a).

Although roadside vegetation is important for conservation of biodiversity in rural landscapes, many reserves are still under threat from human disturbances such as roadworks. Due to growth in human settlements and increases in intensive farming practices, there are greater demands to develop rural-transportation networks. Narrow 20.12 m (1 chain)-wide road reserves that were originally surveyed for farm access, were not designed to facilitate modern heavy transport, and are under most threat (Prichard 1991). One of the future challenges for local councils and government environment agencies is to reconcile transportation and conservation values of roadsides (figure 3).

Figure 3. A typical narrow 20.12 m (1 chain) road reserve in southern NSW where a gravel road and adjacent table drains have been recently graded as part of a regular maintenance program. In the process, all previous vegetation (approx 2 m x 1.7 km) has been removed, apart from a narrow strip of native vegetation (mostly *Acacia* and *Senna* species) along the fenceline.

Lockhart study area

This study was conducted from 2001-2004 in the Lockhart Shire council area (35.12° S, 146.43° E), a rural local government area of 365 km^2 which is located in southern NSW, Australia (figure 4). The area has a cool temperate climate, with mean annual rainfall ranging from 500-600 mm and altitude ranging from 200-450 m. Topography consists of low undulating hills and flat riverine plains with occasional granitic outcrops. Over 95 percent of native vegetation has been cleared for agriculture. Less than 1 percent has been formally protected in conservation reserves (Benson 1999). In many regions, roadsides provide vital refuge for many threatened species.

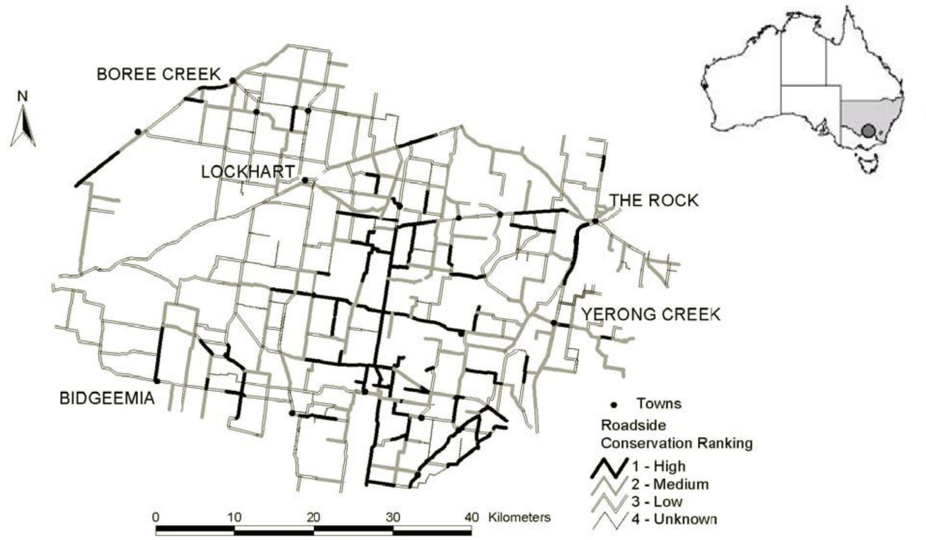

Figure 4. Location of the study area in southern NSW, Australia showing roadside conservation rankings for the Lockhart Shire council area (based on data in Bull 1997).

Study *Acacia* species

Acacia species (Mimosaceae) are woody shrubs and small trees that are widely distributed in temperate woodlands in southern Australia (Maslin and Pedley, 1998) and are commonly recorded species in many segments of roadside vegetation (McBarron 1955; Bull 1997). Most *Acacia* species are highly adapted to fire by hard-coated seed and re-sprouting ability. Though the post-fire response of *Acacia* species has been well documented, little is known of how soil disturbances affect *Acacia* populations.

Three widespread *Acacia* shrub species with different life-history attributes were selected for study, based on previous roadside survey reports in the Lockhart region:

1. Golden Wattle (*Acacia pycnantha*) is a loosely branched shrub 3-8 m tall found on a wide range of sandy or red-loamy soils. It is fast growing, with leathery dark-green phyllodes or 'leaves', large golden flower heads in showy racemes, brown flattish seed pods 5-12 cm x 5–7 mm, and is an obligate seeder (figure 5a).
2. Mallee Wattle (*A. montana*) is a dense and rounded green shrub 1-3 m tall and found on well-drained sandy red earths or heavy clay soils. It is also fast growing, with small narrow and 'sticky' green phyllodes, golden-yellow flower heads along branches, distinctive white-woolly seed pods 2–5cm x 3–4 mm, and is a facultative seeder and resprouter (figure 5b).
3. Western Silver Wattle (*A. decora*) is a rounded spreading shrub 1-4 m tall and found on well-drained light to heavy soils. It has grey-green thick phyllodes, bright golden flower heads on short racemes in branchlets, dark straight seed pods 5-10cm x 4-8 mm, and is a facultative seeder and vigorous resprouter (Costermans 1981; Tame 1992) (figure 5c).

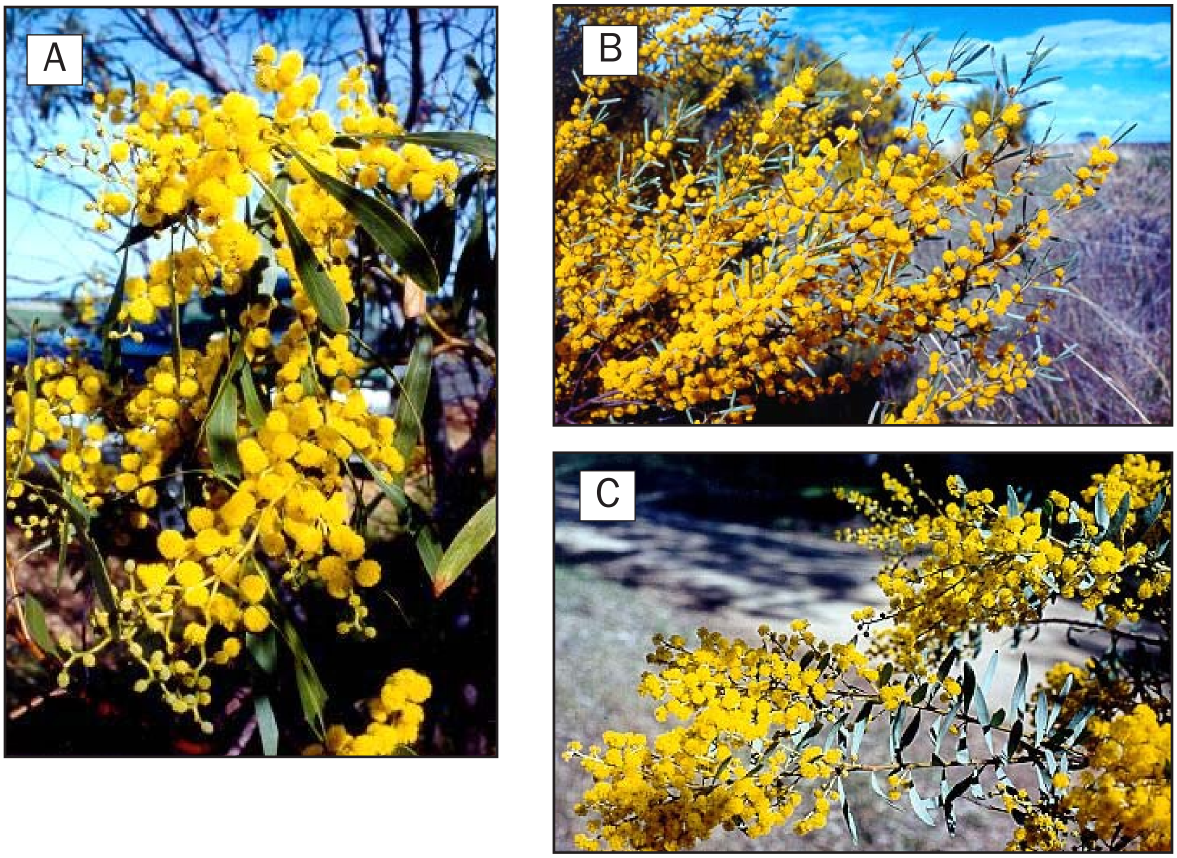

Figure 5. Model *Acacia* shrubs in the Lockhart study area, showing flowering branches of (a) *Acacia pycnantha*; (b) *A. Montana*, and (c) *A. decora*.

Methods

Studies were conducted from 2001 to 2003 in the Lockhart Shire Council area (figure 4). Many roads in the area are minor rural roads of gravel construction. These roads need periodic maintenance. Gravel road surfaces are usually graded every five years or so (Spooner et al. 2004b). It is common practice to regularly clear vegetation adjacent to gravel roads with a grader to maintain table drains. In 2001, a regional survey of the three study *Acacia* species was carried out, using existing roadside survey reports as a baseline (Bull 1997; Spooner et al. 2004b). Roads were then monitored for grading activities that impacted upon *Acacia* populations and wide road corridors were targeted (> 20 m) so comparisons could be made between graded areas and adjacent, ungraded (control) areas.

In total, four wide road corridors were selected where recent roadworks activities had occurred (table 1). Two road reserves were selected for sampling in 2001 and two further road reserves were selected in 2002; both had similar soils, topography and disturbance from grading activities. In all cases, grading occurred parallel to the road, extending approximately 2.5 m (one angled blade width) into adjacent native vegetation. After grading operations, transects were placed parallel to the road along the edge of the impact area. Transect length varied depending on the extent of grading along each road. Transects were divided into 'populations' and 'gaps.' The number of acacia plants in each population was re-counted and stem densities calculated.

Table 1. Site data for four road reserves impacted by soil disturbance from grading and number of sub-sample acacia populations monitored on each roadside

Road reserve	Date of impact	Road verge width (m)*	Impact length (km)	Populations (n)
Soldier Settlement road	Sep 2001	14	5.76	13
Pat Gleesons road	Sep 2001	17	3.92	7
County Boundary road	Nov 2002	14	2.70	7
The Rock-Lockhart road	Oct 2002	42	3.85	8

* Width of roadside vegetation at one side of roadway. Not entire road reserve width.

Based on the difference between population censuses before and after grading, an estimate of the number of stems that existed prior to disturbance was made and verified by visual inspection of stumps in the impact area. Emergence of basal resprouts, root suckers and seedlings in acacia populations and gaps was monitored three months after impact and then at one-year intervals until September 2003, coinciding with the spring flowering of *Acacia* species. For all sites, the total number of acacia resprouts and seedlings that emerged was recorded. In each shrub zone, a random sample (maximum of 20) of resprouts and seedlings was tagged. Stem heights and plant reproductive outputs were recorded using methods described in Spooner (2005b).

Results

Physical evidence of damage to acacia populations was obvious at all four road reserves, with approximately 100 percent of all above-ground biomass removed by grading and only stumps and damaged roots remaining. Despite the catastrophic nature of this disturbance, resprouts of *Acacia* species emerged almost immediately in September 2001 in two road reserves, often with vigorous growth of basal resprouts and root suckers.

Prior to the grading-disturbance events, the area had experienced below-average monthly rainfall. However, subsequent to resprout and seedling counting, a thunderstorm event resulted in approximately 140-mm rainfall (24-32 percent of yearly average), which may have contributed to resprout establishment and growth. However, monthly rainfall throughout 2002 and early 2003 was well below average, resulting in a declared drought for the summer of 2002/03. Rainfall did not return to average levels until July 2003 (Bureau of Meteorology 2004).

Recovery of acacias to grading was highly variable. However, basal resprouting, root suckering, and seedling emergence led to an overall 6.2 percent population increase for all road reserves combined (table 2). At Soldier Settlement and Pat Gleesons roads, grading resulted in significantly ($P < 0.05$) more resprouting of A. decora populations in the impact areas compared to control areas. However there was no resprouting of *Acacia* species observed at County Boundary and the Rock-Lockhart roads.

Table 2. Number of acacia resprouts and seedlings recorded at four road reserves post-disturbance and net population change

Road Reserve	Number of acacias prior to grading		Resprouts		Seedlings		Net change[2] (%)
	C	I	C	I	C	I	
Soldier Settlement	826	166	0	276	0	0	+ 11.1
Pat Gleesons	274	55	0	88	0	0	+ 10.0
County Boundary	308	45	0	0	0	52	+ 2.0
The Rock-Lockhart	556	27	0	0	0	16	- 1.9
Total	1964	293	0	364	0	68	**+ 6.2**

[1] Where C = control, I = impact areas.
[2] Assumes 100 percent survivorship of resprouts and seedlings.

In two road reserves, *A. decora* resprouts reached respective mean height of 72 and 74 cm two years after the grading event (figure 6). Seedlings only emerged at County Boundary and the Rock-Lockhart roads. By 12-13 months after disturbance, mean seedling heights were 42.0-52.5 cm respectively (figure 6). The tallest seedling had attained a height of 100 cm (*A. pycnantha*). Somewhat surprisingly, 71 percent of *A. decora* resprouts flowered and 49 percent also set viable seed. Similarly, 65 percent of resprouts of the facultative seeder *A. montana* flowered but only 10 percent set viable seed, which appeared to be more affected by prevailing drought conditions. In contrast, there was patchy seedling emergence of the obligate seeder *A. pycnantha* and (to a lesser extent) *A. montana*, and seedlings did not reach reproductive maturity one year after disturbance. Results for seedling emergence were not statistically significant.

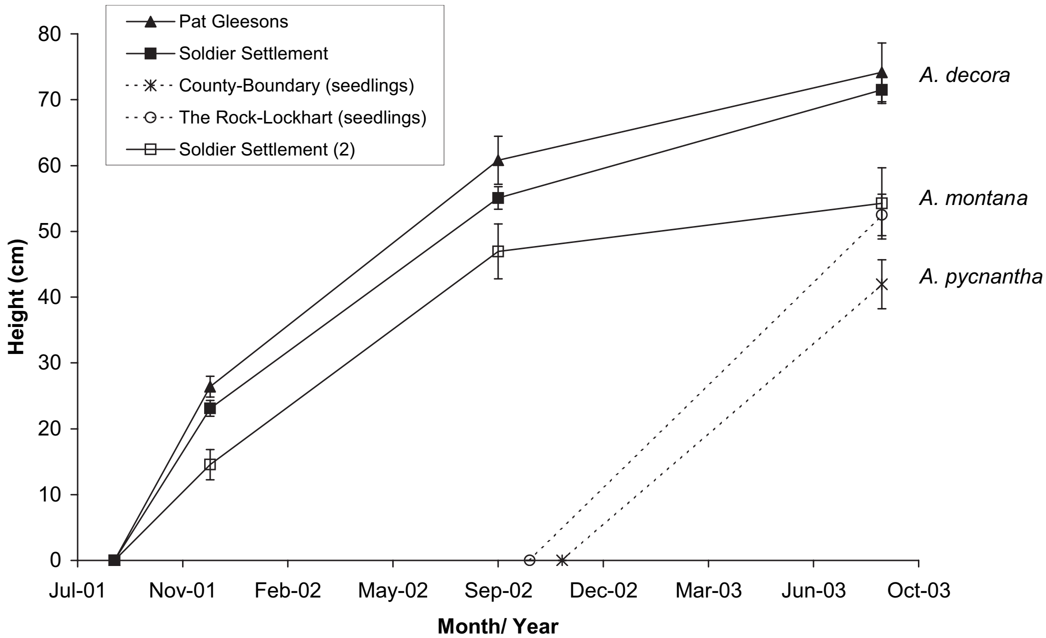

Figure 6. Mean height of acacia resprouts (solid lines) and seedlings (dashed lines) following grading at four road reserves. Species listed on LHS. Bars indicate +/- 1 standard error (SE). SS(2) indicates one population of *A. montana* resprouts at SS.

Discussion

Soil disturbance from grading activities reduces plant biomass by causing its partial or complete destruction and provides a diverse set of new conditions for seedling establishment and plant growth (White and Pickett 1985). It has been commonly accepted that for most *Acacia* species, fire is required to stimulate germination from hard-coated seed and that a lesser proportion of species rely on resprouting ability for recruitment (Hodgkinson 1979; New 1984). However, the results of this study show that for some acacias, soil disturbance from roadworks acts as a surrogate disturbance agent for small-scale natural-soil disturbances and fire, which is now mitigated in most agricultural areas (Hobbs 1987; Benson 1991). Grading activities led to vigorous resprouting of the facultative seeder *Acacia decora* in most populations. Vegetative reproduction from damaged roots greatly aided the ability of this species to colonize a site.

Resprouting is a common response in woody plants subject to disturbance regimes of high severity, which destroy most or all above-ground biomass (Hodgkinson 1998; Bellingham and Sparrow 2000). Similar studies have shown how plants can resprout after repeated damage from heavy machinery (Gibson et al., 2004). These results suggest that in areas affected by roadwork activities, known as the 'road-effect zone' (Forman et al. 2003), soil disturbance by grading is an important process impacting roadside acacia populations. The scale of response from resprouting species is dependent on a number of factors, including: (1) the frequency of grading events; (2) the timing of events e.g., season; (3) the intensity of grading e.g., depth of cut; (4) individual carbohydrate (starch) reserves prior to disturbance, which is related to past disturbances and seasonal factors; and (4) prevailing climatic conditions.

Soil disturbance is also known to promote the germination of *Acacia* species from seed (Farrell and Ashton 1978). Acacias produce hard-coated seed that is ejected out of seedpods in hot conditions, which then falls to the ground where it maybe further dispersed by wind, water or animals. Ants harvest the seed and bury it in soil seed-banks (Buckley 1982; New 1984). Germination of acacia seed is normally triggered by heat shock from fire (Mott and Groves 1981), and manual scarification of the seed coat is a common seed treatment of acacia seed (Cavanagh, 1987). Spooner et al. (2004b) suggested that soil disturbance by grading may assist establishment of *Acacia* species by disturbing soil seedbanks, scarifying the hard seed coat, and providing an ideal substrate for establishment. Although this could not be supported conclusively in this study, seedling emergence of *A. pycnantha* and *A. montana* only occurred in areas disturbed by grading.

Conclusions

Most studies of transportation corridors have usually focused on their deleterious effects. As this study has shown, frequent and intensive soil disturbance regimes appears to favor acacias with strong resprouting ability, whereas acacias that are obligate seeders may be eliminated from roadside environments. Future colonization, stability or decline of roadside acacia populations will depend on the timing of soil disturbances from grading operations in relation to species life-history attributes (Noble and Slatyer 1980; Clarke 1991).

For *Acacia* species, it could be argued that disturbances from road management activities are really no different to periodic natural disturbances, but in reality there are significant differences in extent, frequency, and severity (Lugo and Gucinski 2000). In contrast with natural disturbances, soil disturbance from grading may reach intensities rivaling the most severe natural disturbances and lead to local extinctions (Foster et al. 1998). As ecosystems may take centuries to recover after this form of soil disturbances (Webb et al. 1983; Olander et al. 1998), grading effectively maintains the road-effect zone of roadsides in a simplified transitional state. It is only the ability of acacias to quickly grow and reproduce which allows this species to persist in environments with disturbances regimes which may be catastrophic to most other plants.

Given that roadsides are graded every five years or so and that a roadworks disturbance regime can have a strong controlling influence on acacia structural dynamics (Spooner et al. 2004b, c), it is reasonable to predict that plants that persist in regularly maintained environments would possess strong resprouting ability or be able to rapidly establish and set seed (e.g., exotic weeds) (McIntyre et al. 1995). Further studies of plant life-history attributes in relation to human disturbance regimes can only better our understanding of plant dynamics in transportation corridors and assist in formulating appropriate management actions.

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Chapter
8

Wildlife Impacts and Conservation Solutions
Large Mammals

Effects of Highways on Elk (*Cervus Elaphus*) Habitat in the Western United States and Proposed Mitigation Approaches

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Why Elk?

Elk are an excellent species to use as a "terrestrial wildlife indicator" for highway impacts. First, they are widespread and exist in all western states as well as several midwestern and eastern states. They are prevalent on many National Forest lands, Bureau of Land Management lands, USDI Fish and Wildlife Service and National Park Service lands. Much elk habitat is on public lands in the western United States (Flathers and Hoekstra 1989, Peek undated, Thomas and Toweill 1982).

Elk are also one of the best studied animals in North America. This is particularly true in respect to the effects of roads on elk. Very few wildlife species have as much scientific literature directed at them. Information such as food habits, density, behavior, fecundity, migration patterns, home range sizes and other important scientific data also abounds.

Figure 1. Elk are important socially and economically in the western U.S. Billions of dollars have been expended to ensure their conservation and management. They also present dangerous highway hazards to motorists. (Photo by Alex Levy)

Socially, elk are almost universally accepted as important native wildlife. They are generally not controversial, and their presence is usually accepted or even cherished. Economically, elk are one of the most important wildlife species in the western US. The economics of elk includes revenues to state wildlife agencies, motels, restaurants, airlines, and sporting goods manufacturers and retailers. Elk are enjoyed by the public for hunting, for food value, for viewing, and other aesthetic purposes.

How Elk are Affected by Highways

Before transportation and other agencies can apply appropriate highway mitigation measures, they first must understand how highways affect elk. From these impacts, appropriate and effective mitigation measures can be applied, often benefiting many wildlife species. Figure 2 provides a map showing elk habitat and highways in the western United States. It is obvious from this map that elk habitat is affected by highways.

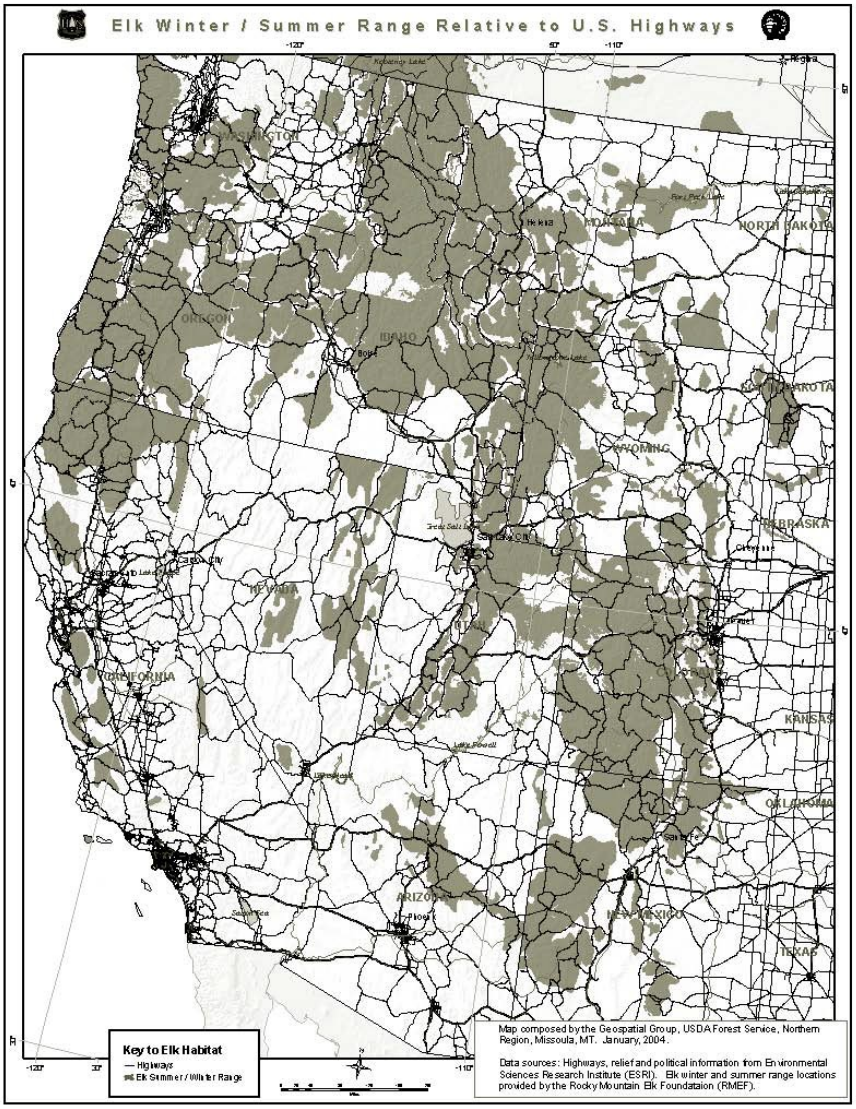

Figure 2. Overview of highway system with elk habitat in the western U.S.

Direct habitat loss

Direct habitat loss results from paving and fencing highway rights of way. This elk habitat is permanently lost as long as the highway is active. The direct loss of habitat in the highway right of way is easily assessed, but rarely mitigated. The significance of habitat loss is explained in the GIS assessment of this paper and is astounding. For a two-lane highway with a width of 150 feet (Basting 2005), the number of acres of elk habitat directly lost per mile of highway is 18.18 acres. For a four-lane divided highway with an average 300-foot pavement and right-of-way distance (Basting 2005), the number of acres of elk habitat lost is 36.36. For analysis purposes the authors call the habitat loss from direct loss of the pavement and right of way as Zone 1.

A 2005 geographic information system (GIS) analysis done by the authors indicates there are 21,285 miles of highways in mapped elk habitat and that over 387,000 acres of elk habitat have been lost to these highway developments. This estimate assumes a 150-foot right-of-way distance, which is common for two-lane highways. Undoubtedly, many four-lane highways exist in elk habitat and would increase the number of acres affected. Previous GIS analysis done in 2004 by the authors suggests that a majority (58%) of existing highways cross winter range habitat, generally the most critical range for elk.

Figure 3 provides a graphic estimate of the number of acres of elk habitat by state directly lost to highways in the western United States. The miles of highways in elk habitat by state can be found in table 3. Oregon leads the western states in both the number of miles of highways in elk habitat and the relative direct impact, with over 65,000 acres impacted. Colorado, Idaho, New Mexico, and Montana have all lost between 42,000 to slightly more than 50,000 acres of elk habitat to highways. California, Washington, Utah, and Wyoming have similar impacts of highways on elk habitat, ranging from nearly 26,000 acres to 33,000 acres.

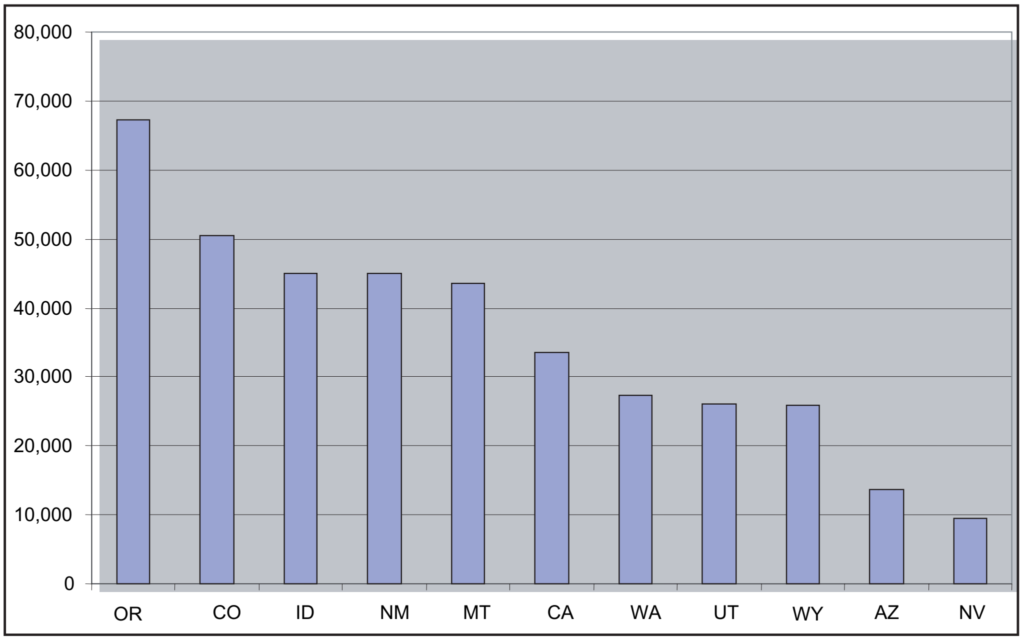

Figure 3. Estimated direct acres of elk habitat lost to highways by state.

Habitat fragmentation

Habitat fragmentation is one of the most serious impacts of highway development on elk and other wildlife. Habitat fragmentation of wildlife habitat is often a complicated issue with many causes and effects. Many of the effects of habitat fragmentation are poorly understood, such as the effects that noise and activity have on species' use of habitat near highways. Habitat fragmentation affects elk populations more profoundly than some other species because many elk herds are migratory, elk have relatively large home ranges, and elk dispersals can be long. Highways often limit how elk can move to and from summer and winter habitats; can separate cows from calves; and can affect breeding, water and food availability, mortality, and other biological factors. Recent expansions of highways from two to four lanes can increase fragmentation by making highways more difficult for elk to cross, by increasing elk mortality and by placement of cement rail, rip-rap, steep slopes, and other measures that encumber elk movements.

Although elk are economically and socially important to many western states, the issues with habitat fragmentation have been poorly studied with this species. Most impacts of habitat fragmentation have addressed carnivores and other species (Harris 1984, Noss et al. 1996, Noss 1987, Noss and Harris 1986, Noss 1983, Paquet and Hackman 1995, Quigely et al. 1996).

Displacement due to human disturbances

Elk responses to highways and roads vary by a number of factors, such as topography, vegetation, traffic volumes, how the highway is designed, and whether or not elk are hunted. Elk have been shown to use habitat adjacent to roads less frequently than similar habitat that is not affected by roads (Rowland et al. 2004, Wisdom 1998, Johnson et al. 2000, Ager et al. 2003, Perry and Overly 1977, Lyon 1979). Generally, elk use of habitat decreases as the proximity of that habitat to roads and highways increases. Rowland et al. (2000) found there was a measurable decline in elk use up to 1.8 kilometers (5,500 ft) from roads. Roloff (1998) and Rowland et al. (2000) suggest assessing using distance band approaches. Using distance band approaches from the Roloff (1998) and Rowland et al. (2000) and habitat effectiveness (HE) equations from Hitchcock and Ager (1992), the Wallow-Whitman National Forest calculated values of 0.17 to 0.83 for five distance bands of habitat moving from the roadside outward. Each of the five bands was 1,182 feet wide (394 yards) and exists on each side of the highway (Rowland et al. 2004). The authors of this paper simplified the Wallow-Whitman elk HE information into three zones as follows. Zone 1, highway right of way with HE = 0; Zone 2, roadside to 0.45 miles with HE = 0.25; and Zone 3, 0.45 – 1.1 mile with HE = .67. (Note: Zones 2 and 3 extend on both sides of the highway, so the total corridor of highway effects to elk is approximately 2.26 miles for a four-lane road, slightly less for a twoo-lane road. See table 1.)

Table 1. Acres of Lost Elk Habitat for Direct and Displacement Effects per Mile of Highway* for Two-Lane Highway

ZONE	SIZE*	HAB. EFFECT.	AC. HAB LOST/MI
Zone 1	150 ft* (.03 mile)	0	18.18 acres/mile/hwy*
Zone 2	0.45 mile (each side of hwy)	.25	432.0 acres/mile/hwy
Zone 3	0.65 mile (each side of hwy)	.67	282.0 acres/mile/hwy
Total*	2.23 miles*		732.18 acres/mile/hwy*

What are the strengths and weakness of assessing highway impacts and mitigation to elk habitat using such a system? The strengths include recognition that highways have a significant effect, even outside of the right of way. Current elk research is clear that the displacement effects to elk due to roads are significant. The weakness is that the research used to calculate the effects were based on forest roads and not highways in Oregon. When asked about how the effects of displacement for highways might compare to forest roads, some of the authors of the Rowland paper felt displacement effects would be more serious on highways. The only way to determine this definitively would be to do appropriate research.

The effects of displacement on elk and other wildlife are rarely displayed in highway environmental assessment documents, yet the displacement impacts may be the most important, or one of the most important, adverse effects of highways. The authors have taken the best available information and applied it on a broad-scale basis to look at how highways may be affecting elk and other terrestrial wildlife. Even if the approach only approximates the impacts of highways on terrestrial species, it indicates there are some large impacts that are currently not being assessed or mitigated.

Elk highway mortality

Highway mortality of elk has been studied very little. The extent that highway mortality adversely affects elk populations is minimal in most situations. Along with the other factors discussed in the paper, the long-term impacts are significant and increasing every year. The following is an estimate of known elk mortality by state. The estimate is low based on the responses provided. Almost all respondents mention that the actual number of elk killed on highways may be two to three times that reported. Better information about elk and other wildlife mortality on highways would greatly benefit wildlife effects analysis, wildlife mitigation, and highway safety.

Table 2. Reported Number of Vehicle Collisions with Elk (NA = Not Available)

STATE	APPROX._#_VEH._ELK_KILLS
Arizona	396
California	NA*
Colorado	560
Idaho	70
Montana	131
Nevada	NA*
New Mexico	195
Oregon	377
Utah	95
Washington	77
Wyoming	100
Estimated Total:	2,001

Highway Influences on the Spread of Exotic Plants

This paper is not an extensive review of the impacts of noxious weeds spreading into elk and other wildlife habitats. Roads and highways are a primary vector for introduction of non-native plants into parts of the West (Gelbard and Belnap 2003). The spread of noxious weeds has resulted in the degradation of many elk ranges, and roads and highways are a primary cause for noxious weed expansion.

Effects of Improved Highways on Secondary Human Developments

For years there has been an ongoing argument over the issue of whether improved highways accelerate secondary construction, such as housing and strip developments. The total effect of accelerated development created by improved highways is unknown, but in Colorado approximately 35,000 acres of elk habitat is being lost annually, most to real estate development. Colorado is only one of many states where elk habitat is declining rapidly. Most real estate development occurs at lower elevations, which are often within elk winter range.

Elk and Highway Safety

Obviously, elk are large animals, and collisions with vehicles are a serious matter. Elk average 600-850 pounds for adults (Arizona Game and Fish 2004), five to eight times larger than most deer species. This indicates that the average vehicle collision with an elk has the potential to be much more serious than with deer. Two of the most prominent wildlife crossing efforts in North America were built primarily to reduce collisions with elk. These include the Trans-Canada Highway wildlife crossings in Banff National Park, Alberta (Canada), and the SR260 elk crossings near Payson, Arizona (USA).

In Arizona, collision rates for elk were 1.22 collisions per mile yearly (Booth vs. State of Arizona 2003) for a 20-mile section of highway. The state of Arizona was found negligent for not keeping elk off the highway, a hazard that was well known in the area. Similar challenges to other state departments of transportation are likely in the future as information about methods to reduce elk/vehicle collisions becomes more widespread.

Figure 4. Elk are large animals that present significant road hazards. Survey information suggests more than 2,000 are killed annually in the West. (Photo by Lance/April Craighead)

It is common knowledge that collisions with wildlife are associated with the abundance of wildlife and the traffic volume (Gunson and Clevenger 2003, Fahrig et al. 1995, Boulanger 1999, Philox et al. 1999, Romin and Bissonette 1996). In all western states, elk appear to be increasing, traffic volume is increasing, and many respondents mentioned collisions with elk were increasing. In spite of increasing collisions with elk, it was difficult to find any quantifiable information specific to this species in regard to the seriousness of accidents, human loss of life, human injury rates, or costs per collision.

Mitigation Measures - Fitting to Appropriate Impacts

If wildlife mitigation measures are to be effective, they must address the issues created by the highway. Not doing so means that the problems become ever larger. While addressing impacts with mitigation focused on specific ecological issues caused by the road seems logical, many highway projects have not approached terrestrial mitigation in this manner. Often, terrestrial wildlife mitigation is seen as “optional” and is not addressed at all. This is in contrast to wetlands mitigation that focuses in minute detail on replacing the type or function of wetlands that were impacted.

If a highway is causing elk mortality, elk habitat fragmentation, or traffic safety issues, then mitigation measures that address these specific issues should be implemented, such as wildlife crossings and fencing. Certainly, wildlife crossings and fencing should be a standard mitigation measure for highways traversing deer or elk winter ranges or migration routes.

If there is a significant loss of habitat, then habitat acquisition and enhancements should be applied. This includes the loss of the habitat right-of-way acres, plus the loss of habitat due to displacement. Conversely, wildlife crossings and fencing do nothing to address habitat loss.

Mitigation is a management decision regarding what is appropriate. However, if terrestrial wildlife habitat is continually eroded by highway expansion, particularly for critical situations like elk winter range and habitat fragmentation areas, then serious losses will continue. Highway mitigation for terrestrial species like elk is inconsistently applied and oftentimes applied only if serious highway safety issues are involved. Current highway mitigation policy for terrestrial species was developed when highway rights of way were winding, narrow, two-lane roads; when safe speeds were often 30-50 miles per hour; and when traffic volumes were low and the impacts on many species poorly understood. These situations have now changed to multi-lane highways, with 65- to 75-mph speed limits, and traffic volumes that do not provide adequate time between traffic pulses for wildlife to safely cross highways. Also, the consequences on wildlife caused by highways are beginning to be better understood and quantified.

Unfortunately, many highway environmental documents fail to address the cumulative impacts of multiple "small" highway improvements or the effects of wider, faster roads with high traffic volume on elk and other species. This is one important reason why broad-scale or landscape-level wildlife habitat linkage analysis is critical to improving highway mitigation for wildlife. State departments of transportation need to know far ahead of highway projects the type and scope of mitigation measures needed, and they cannot do so late in the transportation planning phases. Statewide wildlife linkage analysis has recently been completed in Arizona, New Mexico, Utah, Colorado, and western Montana. It would greatly improve highway coordination for elk and other wildlife in the remaining elk states. In almost all cases, terrestrial highway mitigation would be more effective if "mitigation banks" were established that focused on large, important areas needing protection. The best mitigation practice for a given highway may be many miles from the project area.

Habitat acquisition
A myriad of potential habitat acquisition options are available to highway agencies. These include (1) replacement of all elk habitat on private and public lands, (2) replacement of all elk habitat affected on public lands, and (3) replacement of habitat in the most critical habitat, which for elk is often winter range. The loss of elk habitat to highway development is serious in terms of its effect on the carrying capacity of long-term elk habitat, and it is permanent in its duration. Highway, wildlife, and land management managers should remember that the rationale for acquiring habitat is for replacement of like lands lost directly (highway right of way) and indirectly (displacement loss) as a result of highways. Acquiring habitat does not affect habitat fragmentation, safety, or elk mortality caused by the highway, nor does it mitigate for loss of habitat caused by ancillary human developments encouraged by highway development.

To fully replace lost elk habitat, highway agencies should provide 750.4 acres of acquired mitigation habitat for each mile of highway in the project area for a four-lane highway and 732.2 acres (per mile of highway) for two-lane highway projects (see table 2).

Elk crossings and fencing
Wildlife crossings and fencing are mitigation for elk habitat fragmentation, elk mortality, and highway safety. News media occasionally take issue with the high costs of wildlife crossings as being poor expenditures of public funds. Actually, the opposite is true in high collision deer and elk areas. The cost of structures can often be offset in a few years by reductions in vehicle costs, human injuries, human fatalities, and a reduction in elk or deer mortality. Various types of wildlife crossing structures can be built that elk will use. Elk are large animals, and their size must be considered when planning appropriate crossings. The best highway investments in wildlife crossings are those that result in a high percentage of use.

Several elk crossing designs are effective. These include bridge extensions, wildlife overpasses or ecoducts, open-span underpasses, box culverts, and large elliptical culverts. Each has advantages and disadvantages and appropriate applications. Most effective for elk are large, wide wildlife overpasses, as seen on the Trans-Canada Highway in Banff National Park, Canada (Forman et al. 2003). Although very effective for elk and other ungulates, the downside of wildlife overpasses is their high cost and scarcity of appropriate location sites. For optimal use, wildlife overpasses may have to be approximately 50 meters wide (Pfister et al. 1997). Almost as effective and less expensive are open-span crossings. These are large bridge-like structures that are wide at the top and usually narrower at the bottom. Engineers and biologist in Canada and Arizona often recommend open-span wildlife crossings as both effective and cost efficient. Elliptical culverts (7x4 meters) are effective in some situations and are less expensive than open-span bridges. Bridge extensions and pathways are less frequently studied, but offer effective alternatives. These can be provided at existing bridge replacement projects, as is being done in Oregon (Bonoff 2005). Box culverts have less use in Canadian studies, and are smaller than other structures. Appropriate-sized box culverts for elk should be larger than for deer – such as 4x8 meters, or larger.

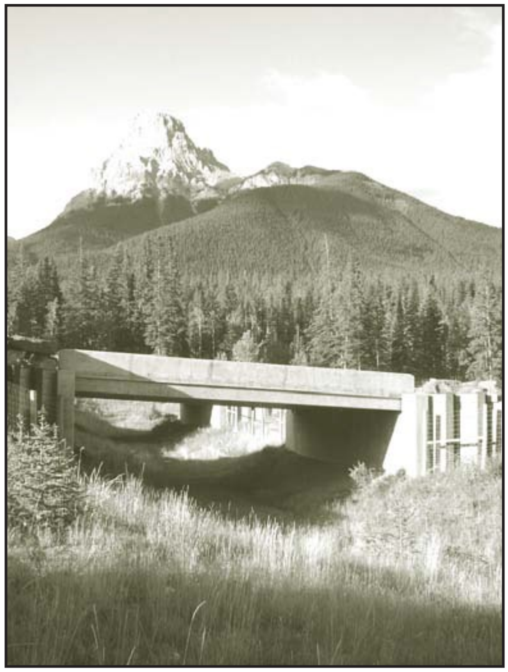

Figure 5. Single-span wildlife crossings, like this structure near Canmore, Canada, are effective for elk. (Photo by Tony Clevenger)

In general, under-crossing structures for elk should be 12 feet, or higher, to allow use by all sexes and age classes. The size of structures, location, type of structure, vegetative cover, noise levels, bottom material, “openness ratio,” human use patterns, and fencing configuration can influence elk use and structure effectiveness.

Fencing is an integral aspect of elk and other wildlife crossings. Fencing commonly increases elk use by 80 percent, or more. Even though large wildlife structures may appear excessively large by human standards, elk and other ungulates view many wildlife crossings as potentially threatening situations and may go considerable distances to cross over highway road surfaces. Fencing helps funnel animals into the crossing structure and provides a disincentive for avoiding it. Acceptance of structures is a highly individual trait with some animals accepting crossings at first encounter and some animals may avoid them entirely. As time goes by, use usually increases as animals become more accustomed to moving through them, especially young animals that are brought through the structures by their mothers.

Fencing for elk and other ungulates and large carnivores is usually 8-foot page wire. The bottom of the fence may need to be buried to prevent bears and coyotes from digging under the fence and providing access to the highway for them and other animals. Jump-out shoots or Texas gates can provide a means of escape for animals that may get into the right of way. Often, gates are used for this purpose, but they must be opened to allow animals out and closed afterwards.

Side road access is usually by gates, if traffic volume is low, or double cattle guards if traffic volumes are higher. Structures to prevent elk and other wildlife from accessing higher volume roads is problematic, as is snow compaction in cattle guards that may allow animals to walk across and into the roadway.

The cost of fencing is not incidental and may exceed the wildlife crossing costs. Maintenance is also expensive and critical, or animals will find openings and gain access to highways. Out-of-control vehicles, for example, commonly hit fences and create openings that require repair.

Wildlife warning signs

Wildlife warning signs are not appropriate for many highway situations. However, imaginative designs are being tried and studied. Most highway warning signs with a visual representation of an elk or deer have limited or no success in reducing elk mortality or vehicle accidents. Exceptions include large signs used in Canadian National Parks and “interactive” signs that flash warnings only when animals are in the right of way (Huijser 2005).

A GIS Assessment of the Amount of Elk Habitat Affected by Highways in the Western United States

The authors superimposed major highways with recently updated elk habitat mapping provided by the Rocky Mountain Elk Foundation. This information provides a number of interesting and pertinent data on how elk habitat is affected by highways. Highways were also assessed based on public land ownership including USDA Forest Service, USDI Bureau of Land Management, USDI National Park Service, USDI Fish and Wildlife Service, and others. These lands are critical for long-term elk conservation and should be protected, along with key other lands, if elk productivity is to be maintained. Most Federal and State lands are managed for multiple uses, including wildlife conservation. Conversely, many private lands in elk habitat are under pressure for development, such as housing. Many agencies and conservation groups are trying to purchase critical elk habitat, or buy conservation easements, but still elk habitat is declining rapidly in some areas. It is estimated that in Colorado over 35,000 acres of elk habitat is lost yearly to housing subdivisions.

A 2004 GIS assessment of elk habitat and highways by the authors indicates that most highways have been built in elk winter range because these lands are lower in elevation and more suitable for highway locations. Highways in winter range affect elk during the most stressful time of year when food is limited and elk are concentrated.

Table 3 provides information on highways in elk habitat for all western states. Included is the total miles of highways in all ownerships of elk habitat, the number of miles of highways in elk habitat on Federal Lands (public lands), and the number of acres of elk habitat affected in Zone 1 (highway right of way), Zone 2 (from the right of way to 0.45 miles on each side), and in Zone 3 (from 0.45 miles to 1.1 miles on each side). The total elk habitat loss for the eleven western states assessed is estimated to be over 15.5 million acres. Several individual states exceed or approach two million acres of elk habitat loss, including Oregon, Colorado, Idaho, New Mexico, and Montana.

Table 3. Miles of Highways in Elk Habitat by State, Miles on Federal Lands, and Estimated Acres of Habitat Loss for All Elk Habitat in Zones 1, 2 and 3

STATE	HWYS ELK HAB ALL (MI)	HWYS IN ELK HAB FED. LANDS (MI)	ACRES ELK HAB ALL
Oregon	3,696	910	2,706,044
Colorado	2,774	836	2,031,151
Idaho	2,475	591	1,812,031
New Mexico	2,471	650	1,809,008
Montana	2,395	624	1,753,760
California	1,839	581	1,346,481
Washington	1,506	391	1,102,601
Utah	1,434	360	1,050,242
Wyoming	1,425	607	1,043,190
Arizona	754	640	552,174
Nevada	517	49	378,472
TOTAL	21,285	6,238	15,585,155

Summary and Conclusions

Elk herds in the western United States are a national treasure that has taken many decades to establish and nurture since the early 1900s. Billions of dollars of public and private funds have gone into re-establishment of elk and other terrestrial wildlife species. While some highway agencies have begun to address elk and other terrestrial wildlife species in new highway projects, more progress is needed. Consistency is a problem. Some projects in elk habitat consider wildlife crossings, often for safety purposes only. Land management and state wildlife agencies need to be more involved in highway projects and wildlife mitigation.

Wildlife mitigation on highway projects could be vastly improved by integrating highway agency mitigation dollars, State and Federal wildlife agency conservation funds, Federal land management wildlife improvement funds, and private conservation efforts, such as land acquisition projects sponsored by the Rocky Mountain Elk Foundation. Integration of these funding sources would provide many benefits to elk and other wildlife, including synergies created from larger projects; larger habitat acquisition and habitat improvement projects with lower costs per unit; and the combined energies, specialties, and talents of conservation groups and agency personnel. Funding for transportation projects is increasing, in contrast to many wildlife and land management agency funding. Partnerships make sense from many perspectives.

Ideally, highway projects can result in improved wildlife habitat conditions as well as enhanced highway safety and less overall ecological impacts.

Highway policy needs to change, particularly for important public wildlife habitats, such as National Forests, National Parks, Bureau of Land Management lands, Department of Defense lands, and State lands, so that wildlife crossings, fencing, and habitat replacement mitigation measures are more consistently applied. Terrestrial highway mitigation policy is archaic and needs to be modernized to reflect social values, protection of significant ecological resources, and better integration with wildlife and lands managed to benefit wildlife habitat. European countries have done so for decades. The knowledge to improve highway coordination with wildlife and the environment, called *road ecology,* is one of the fastest growing natural sciences in North America and throughout the world.

Reducing elk and other wildlife habitat fragmentation and mortality caused by highways and vehicle traffic have human safety benefits as well. The time has come to address all the effects that highways have on elk and other species, and to apply the scientific knowledge we have gained over the last decade. It is a road we cannot afford *not* to take.

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Evaluation of Principal Roadkill Areas for Florida Black Bear

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Abstract: The high number of vehicle-bear collisions and the potential impact of these collisions on both humans and bears prompted a re-evaluation of principal roadkill areas for the Florida black bear (Ursus americanus floridanus). The Florida Fish and Wildlife Conservation Commission has documented an increasing statewide trend in the number of roadkill bears since 1976. Previous research indicates roadkills are concentrated in particular areas based on several habitat features (Gilbert and Wooding 1996). Additionally, Gilbert and Wooding (1996) suggest the areas with the largest bear populations (Apalachicola, Big Cypress, and Ocala) have accounted for the greatest number of roadkill, particularly Ocala National Forest. Most recently, Gilbert et al. (2001) prioritized "chronic" bear roadkill areas using roadkill data and habitat characteristics. A subset of black bear roadkill locations (May 2001-September 2003) was evaluated as part of a larger study focusing on several variables, including changes in patterns of principal roadkill areas. Using a simple density analysis (ESRI), principal roadkill areas were identified as those areas which have three or more roadkill instances within a distance of one mile. A one-mile buffer was established surrounding each of these identified areas to ensure that all roadkill locations were included. From the established criteria and analysis, principal roadkill areas were defined during the time frame May 2001 through September 2003. These principal roadkill areas were located in Apalachicola, Chassahowitzka, Ocala, and St. Johns. The majority of the principal roadkill areas, similar to previous research (Gilbert and Wooding 1996), were identified in Ocala. Although the results from the 2001-2003 analysis identified a number of principal roadkill areas documented by Gilbert and Wooding (1996) and Gilbert et al. (2001), several segments were no longer classified as principal roadkill areas, and a few new areas were documented. These new results prompted a re-evaluation of the data using the same time frame as Gilbert and Wooding (1996) as well as the full data set (1976-2004) to determine the causes of variation. These results identify trends in the occurrence of principal roadkill areas and determine re-occurring "chronic" areas. This evaluation provides information for managers and planners who must take direct management action in an effort to minimize road impacts on bears.

Introduction

The Florida black bear (*Ursus americanus floridanus*) is a subspecies of the American black bear (*Ursus americanus*) and occurs primarily in Florida, with evidence of Florida bears in southern Georgia, Alabama, and Mississippi. The Florida black bear is state-listed as threatened and occurs in six core and two small, remnant populations throughout Florida (figure 1). Historically and through today, intensive resource extraction and increased human population with associated development has impacted black bear and many other wildlife populations. The Florida black bear is not legally harvested in Florida; however, the number of transportation-related deaths (roadkill) is documented and monitored by the Florida Fish and Wildlife Conservation Commission (FWC). Since 1976, the number of black bear roadkills has increased. Understanding the impact of roadkill on bears prompted a statewide assessment of road impacts on bears in Florida, which was conducted in collaboration with FWC and the Florida Department of Transportation (FDOT) from 2001-2005. Results from the study indicated that overall, road mortality rates ranged between three and eight percent per year across the six core populations. Although the impact of road mortality differed by population, the roadkill rates sustained by these six populations were similar to roadkill rates sustained by black bear populations in other eastern U.S. states (Simek et al. 2005).

The road impacts study provided the opportunity to re-evaluate principal roadkill areas in Florida. Previous research by Gilbert and Wooding (1996) and Gilbert et al. (2001) identified chronic roadkill areas as areas that have eight bear roadkill within a distance of seven miles, using roadkill data from 1976 through 1995. Using historical roadkill data and habitat characteristics, the authors identified roadkill areas that needed to be addressed using conservation measures for the Florida black bear. For the road impacts study, more restrictive criteria were established to identify principal roadkill areas (three or more roadkill bear within a distance of one mile). These criteria were established to identify groupings of bears larger than a family unit within a tighter, more specific area. To align with the road impacts study time frame, roadkill data from 2001-2003 were analyzed. These analyses, and subsequent time frame comparisons, were accomplished using a simple density analysis with Spatial Analyst in ArcGIS (ESRI, Redlands, CA). Objectives of the re-evaluation were to establish whether these "chronic" areas were still apparent or had shifted, and whether different criteria and time frames would impact results and subsequent conservation recommendations using current and previously evaluated roadkill data.

Methods

The FWC bear roadkill data and a major roads shapefile available from the Florida Geographic Data Library (version 3.0) were used in these analyses. The major roads shapefile was created by the Florida Department of Transportation using their Roads Characteristics Inventory (RCI) dataset. Roads selected for analysis included interstates, state highways, county highways, highway access ramps, and major local and forest roads (as identified in the major roads shapefile).

The density analysis was performed in raster format with a pixel size of 30 m x 30 m. The simple density analysis creates a 2D raster grid of pixels calculating the total number of points (roadkill locations) that occurred within the search radius divided by the search area size. The resulting raster grid was reclassified to give a pixel value of one to those areas that had a density of three or more roadkill bear within a mile; all other pixel values were given no value. The areas with a value of one were identified as Calculated Roadkill Density Areas (CRDA).

To ensure that all roadkill locations that resulted in identifying the CRDA were included in the principal roadkill area identification process, a one-mile buffer of the CRDA dataset was performed. One mile is the maximum distance a roadkill instance from the CRDA. The buffer areas are called Principal Roadkill Buffer Areas (PRBA). Combined, CRDA and PRBA define the principal roadkill areas. Some manual removal of road segments which intersected the principal roadkill areas was performed due to inaccuracies of the major road shapefile construction and appropriateness for the current analysis. These analyses were repeated to identify the "chronic" roadkill areas using the criteria outlined by Gilbert and Wooding (1996) of eight roadkill bear per seven miles.

Results

The Gilbert methodology (8 bears/7miles) using data from 1976-1995 identified chronic roadkill areas in the Apalachicola, Ocala, Chassahowitzka, Glades Highlands, and Big Cypress black bear populations (figure 2). However, when using the current methodology of three or more bears per mile and data from 2001-2003, principal roadkill areas were identified in the Apalachicola, Ocala, Chassahowitzka, and St. Johns populations. With a few exceptions, most of the principal roadkill areas identified by both methodologies overlapped. When these two methods were overlaid, however, it became apparent that Glades Highlands and Big Cypress were no longer identified as principal roadkill areas while new areas were identified in St. Johns using the current methodology. The Gilbert methodology encompassed a much larger area, which included more roads, whereas the current methodology identified more specific principal roadkill road segments (figure 3).

Due to the differences exhibited in this first comparison, both methodologies were compared using a similar time frame (1976-1995) to determine if analyses using different time frames would impact the findings or, if, indeed, the principal roadkill areas had disappeared from Big Cypress, for example. The two methodologies identified very similar principal roadkill areas; however, the current methodology selected additional areas not found through Gilbert's method (figure 4a). Once again, Gilbert's method encompassed a larger area with a higher number of roads, whereas the current methodology selected more specific locations on fewer roads (figure 4b). Having tested the new methodology using Gilbert's time frame (1976-1995), it was now important to understand if the full database, including current data (1976-2004), would identify additional or different principal roadkill areas. Using both methodologies with roadkill data from 1976-2004, principal roadkill areas were identified in all six populations, including Eglin and Osceola, which had not been previously identified as containing principal roadkill areas (figure 5a and figure 5b).

As a result of these findings, the data from 1996-2004 were examined to determine if these new occurrences of principal roadkill areas in Eglin and Osceola occurred in the last 10 years or if the two methodologies were contributing to these differences. During this time frame (1996-2004), the current methodology identified the principal roadkill areas in Eglin and Osceola again, whereas the Gilbert method did not select these areas nor areas previously identified through Gilbert's method in Chassahowitzka and Big Cypress (figure 6).

Discussion

These findings illustrate the effect of different methodologies and different time frame scenarios on determining the locations of principal roadkill areas. Principal roadkill areas within the Big Cypress population clearly demonstrate the change in locations that can occur using the different methodologies and time frame scenarios (figure 7). Similar to Malo (2003), it is evident that the two methods consistently derive different results with respect to scale. Gilbert's method (8 bear/7mile) gives principal roadkill areas on a broader scale. The current methodology (3 bear/1mile) provides increased specificity on actual locations of "hotspots" within the broader framework. The time frame selected for analysis impacts the locations of the principal roadkill areas regardless of the spatial scale. For example, analyzing 28 years of data, using both methodologies, results in many roads being identified as problem roadkill areas. This may be an unrealistic scenario and logistically unfeasible for managers to address. On the other hand, using too few years of data can provide an inaccurate representation of what is really occurring. This raises the question of how many years of data should be used to accurately represent where principal roadkill areas occur.

A limitation to these analyses is that over time habitat and land use will change, thereby influencing the locations of principal roadkill areas. However, implementing conservation measures, such as wildlife crossings, signs, fencing, etc., is important in order to identify, address, and meet the immediate need of reducing the impact of the current "hotspot" on the target species. In addition, the average life span of the species of interest should be considered when selecting a specific time frame for analysis (Craighead et al. 2001). This will help to support the validity and relevance of identified principal roadkill areas. While other parameters, such as wildlife population dynamics, will influence the locations of concentrated roadkill, these parameters will also assist managers to interpret whether the impact of identified roadkill is of concern. In addition, factors such collision fatalities, insurance claims, and social perception may supersede the identification of principal roadkill areas from either methodology and may determine if action is necessary. Managers need to recognize that shifts may occur from a single factor or from a compilation of these factors. Therefore, both these methodologies will identify the specific locations for management actions to occur as well as identify larger areas of concern where comprehensive conservation planning needs to be implemented.

As previous research has identified, roadway features, habitat characteristics, population characteristics, etc., are critical to include in the assessment of where to implement conservation measures in response to areas with a high number of roadkill (Craighead 2001, Barnum 2003). However, when there are limited resources or opportunities to obtain these data, the methods described in this paper provide tools to identify principal roadkill areas using data that are readily and most commonly available (roadkill numbers and location). In addition, these methods provide the option to select the level of specificity required for the management objectives for a species or project.

Therefore, for different managers, a project's goals and objectives will influence the manager's choice of method to identify principal roadkill areas. For example, a transportation manager might consider the 3 bear/1mile method which will provide specific locations of road segments and principal roadkill areas that need to be addressed. However, a land manager might also select the 8 bear/7mile method, as this method will identify larger areas of concern to be targeted in developing land conservation measures, such as conservation easements, etc.

Depending on the method of choice, managers will need to select and prioritize which method to use based on each method's associated goals and results. For example, when choosing the Gilbert method, which selects broader areas of concern, techniques such as driver awareness/education measures through road design planning, which may include reduced speed zones and signs, can be used to reduce the number of roadkill. Selecting the current method may lead to implementing transportation planning, design, and redesign methods to reduce the number of roadkill and maintain or improve habitat connectivity (Servheen et al. 2003). These may include roadway design, enhancement, and construction; wildlife crossings (under and over passes); road closures, redirection of traffic, wildlife detection systems, signs, speed zones, line of sight improvements on roads, fencing, etc. The Gilbert and current methodologies, as illustrated in this paper, are useful in establishing both short- and long-term conservation measures to effectively address the negative consequences of roadkill on both wildlife and people.

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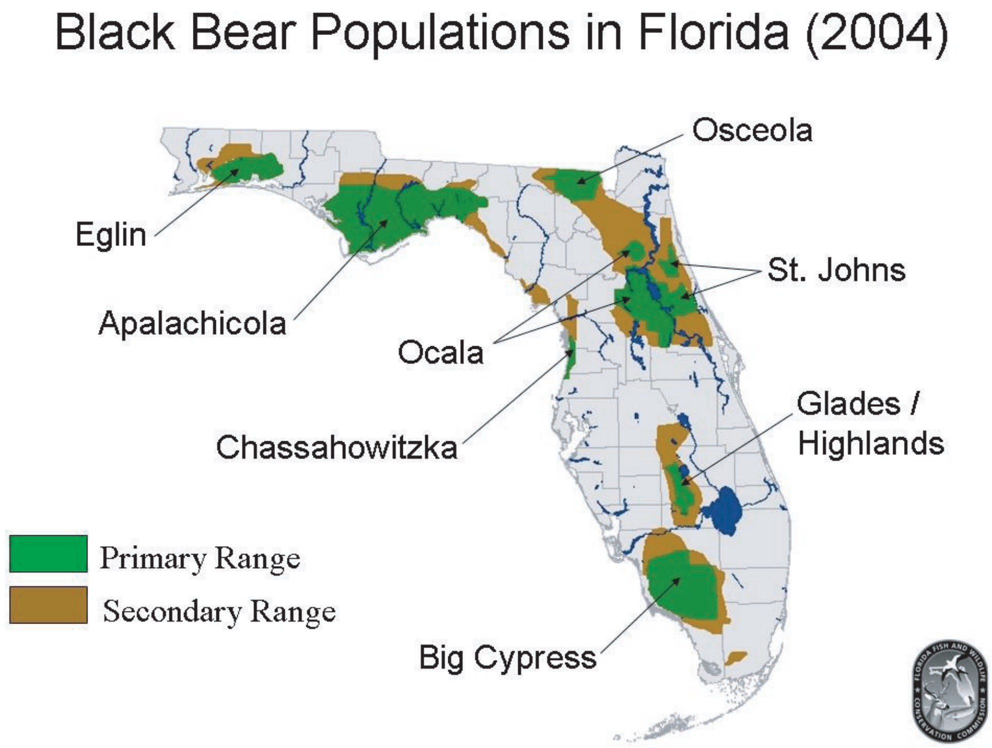

Figure 1. Black bear populations in Florida.

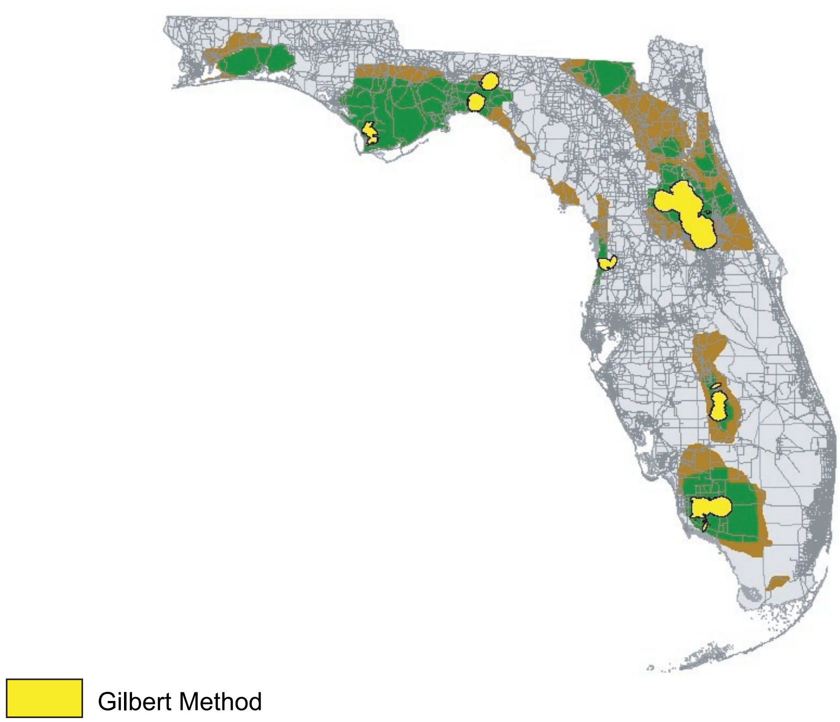

Figure 2. Principal roadkill areas using Gilbert methodology with data from 1976-1995.

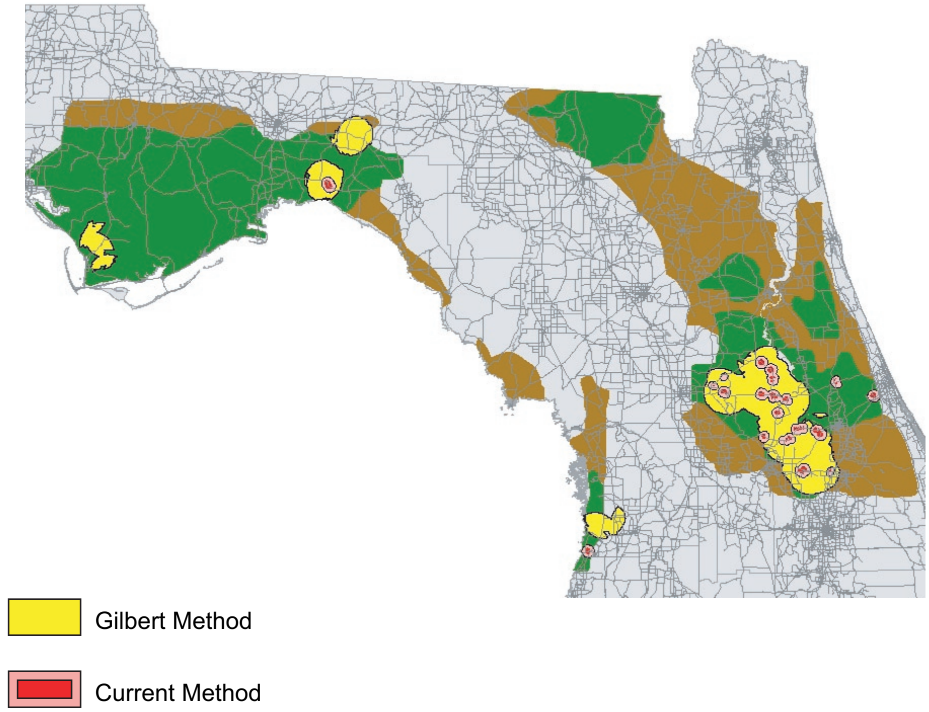

Figure 3. Overlap of principal roadkill areas using the Gilbert methodology (1976-1995) and the current methodology (2001-2003).

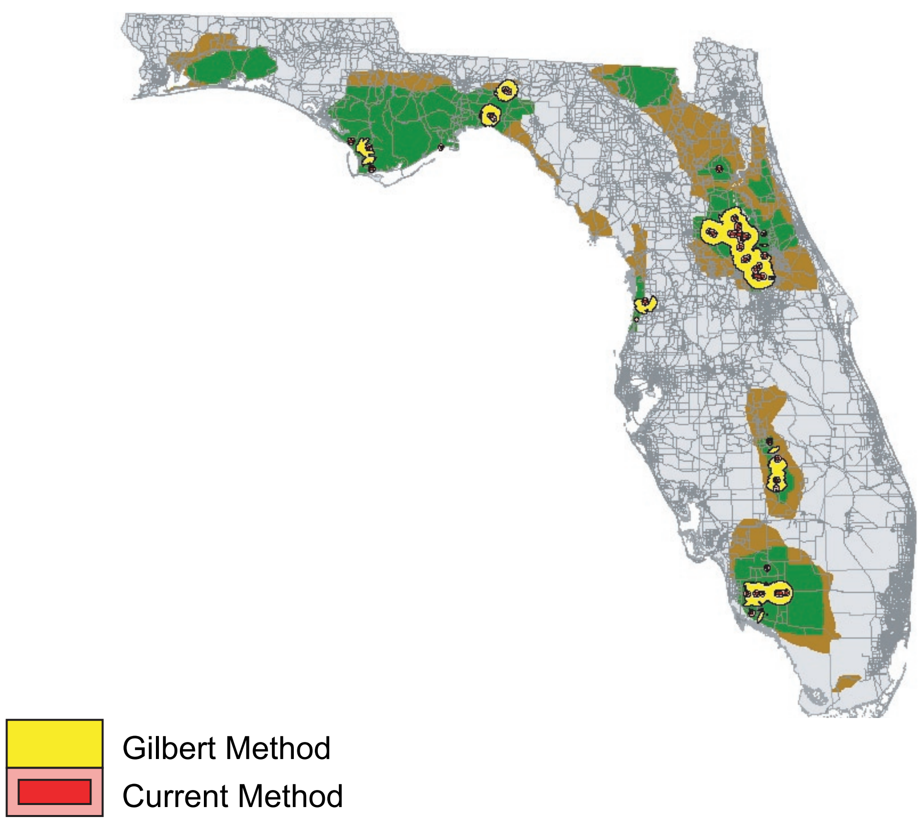

Figure 4a. Overlap of principal roadkill areas using the Gilbert and current methodologies with roadkill data from 1976-1995.

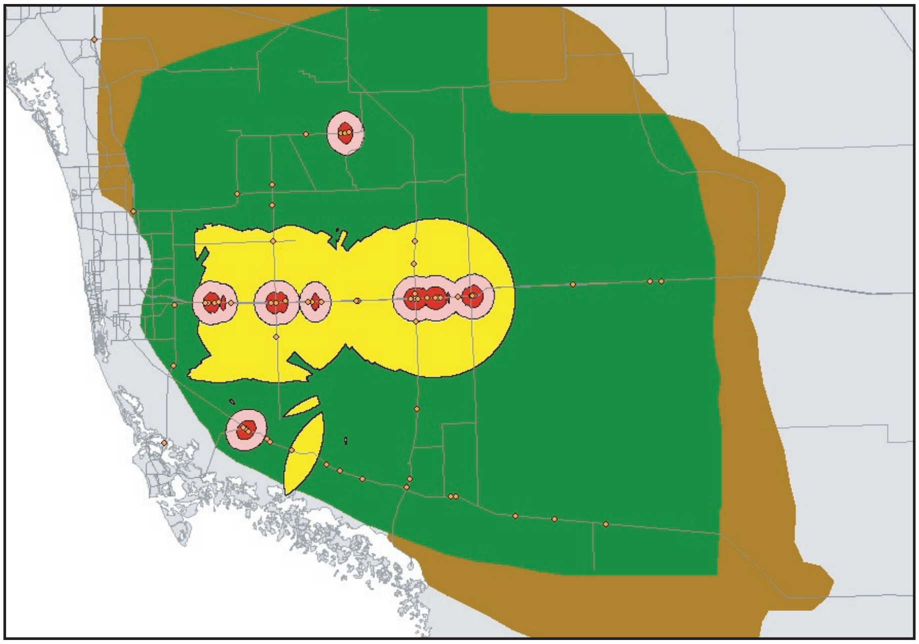

Figure 4b. Zoom view of Big Cypress population principal roadkill areas demonstrating the difference between the Gilbert and current methodologies.

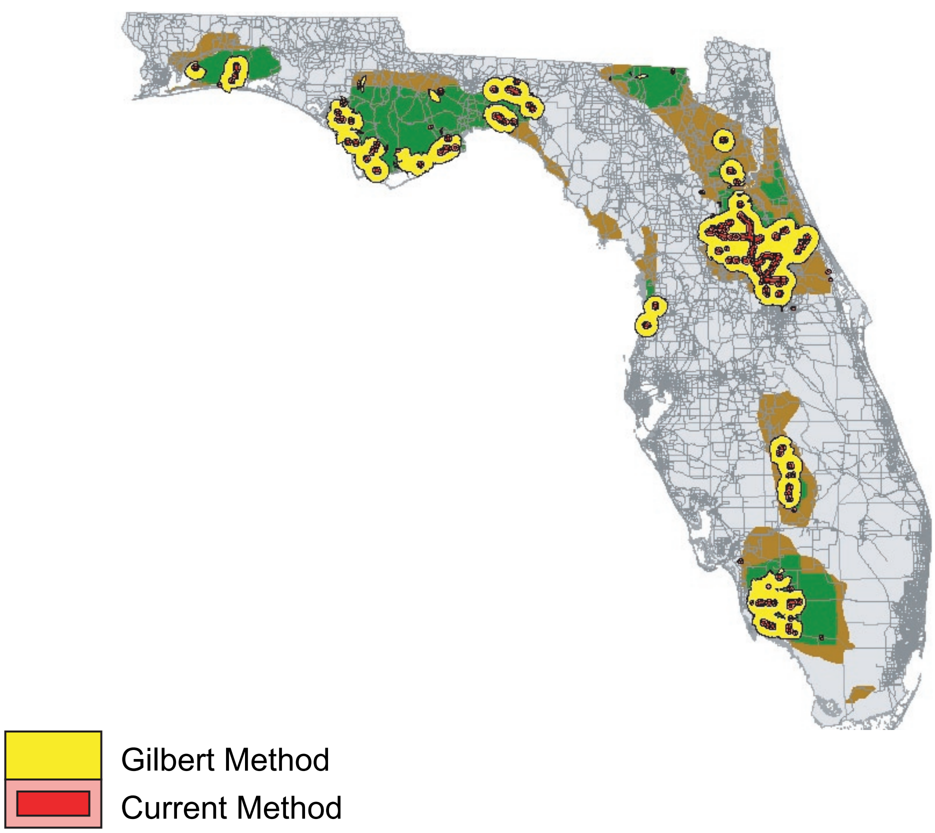

Figure 5a. Overlap of principal roadkill areas using the Gilbert and current methodologies with roadkill data from 1976-2004.

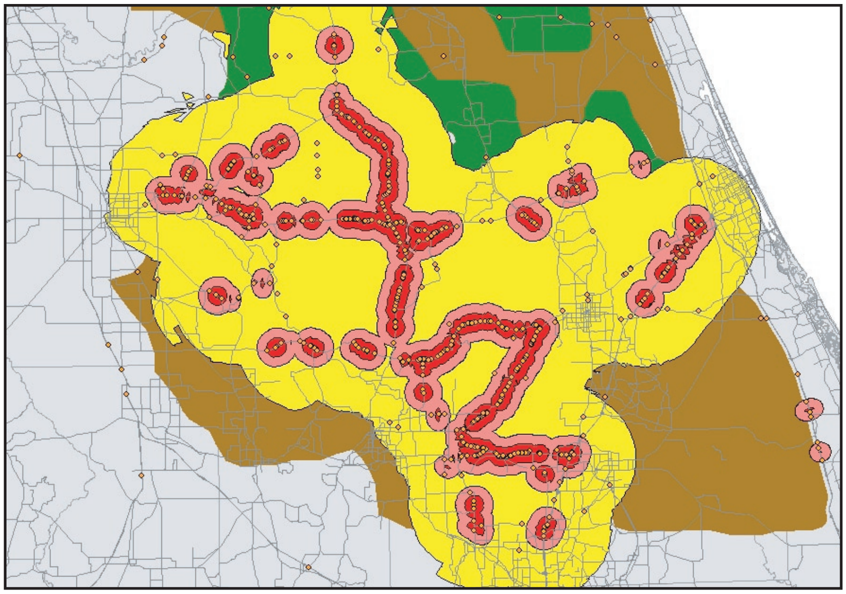

Figure 5b. Zoom view of Ocala population principal roadkill areas demonstrating the difference between the Gilbert and current methodologies.

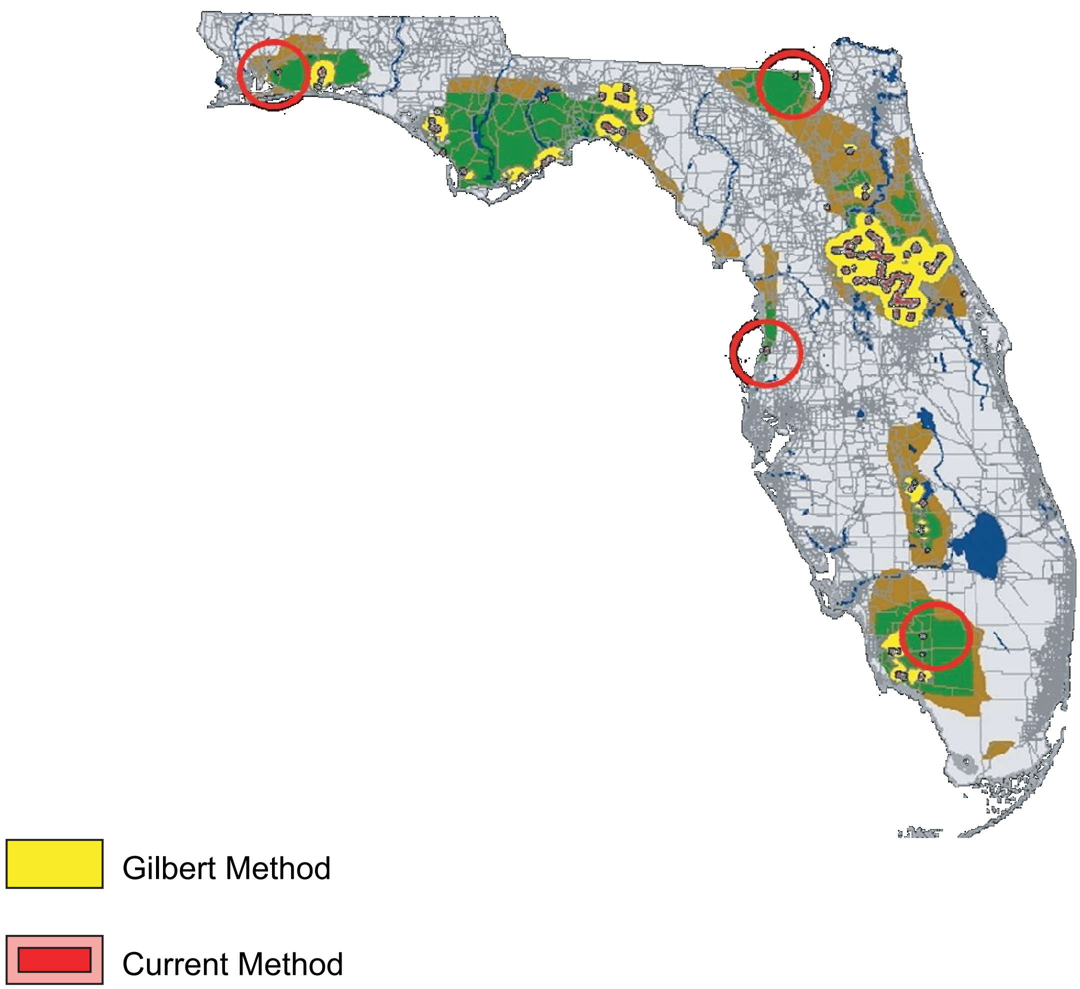

Figure 6. Overlap of principal roadkill areas using the Gilbert and current methodologies with roadkill data from 1996-2004, with major differences highlighted by red circles.

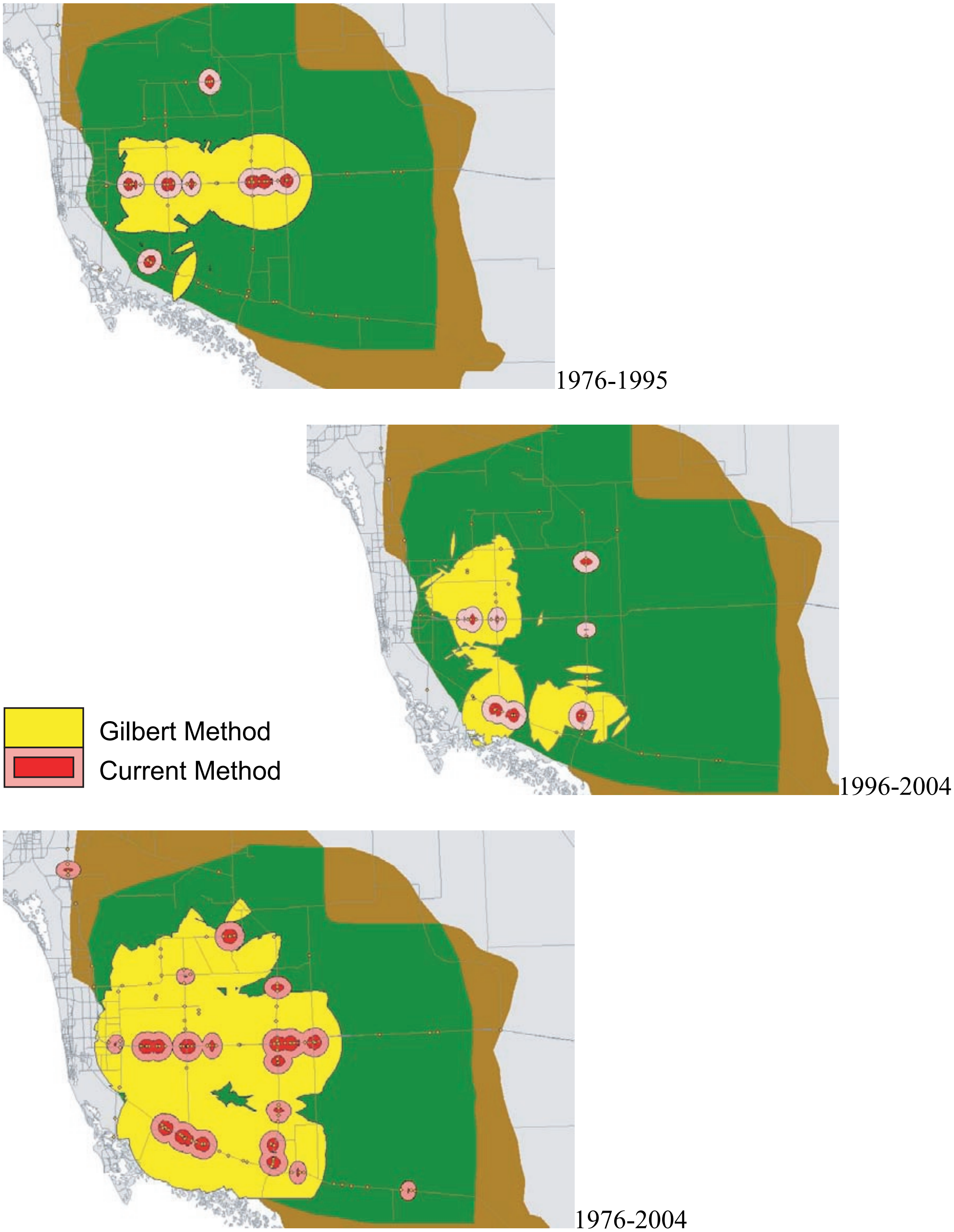

Figure 7. Effect of different methodologies and different time frame scenarios on determining the locations of principal roadkill areas using Big Cypress as an example.

Modeling Highway Impacts Related to Grizzly Bear Core, Living, and Connectivity Habitat in Idaho, Montana, and Wyoming Using a Two-Scale Approach

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Abstract: To address highway impacts on grizzly bear movements and population persistence (and by inference other wildlife species) a two-tiered modeling approach was used. At a coarse scale, highway segments were ranked in importance based upon their relative effects on grizzly bear core and connectivity habitat. At a fine scale, influences were examined by including highway features such as jersey barriers and bridges in the modeling process.

Grizzly bears are widely considered an "umbrella" or "focal" species whose protection and persistence will benefit a broad assemblage of plant and animal species; in general, maintaining grizzly bears will maintain biodiversity and the health and function of natural ecosystems. Highways have negative impacts on grizzly bears, biodiversity, and natural ecosystems that can be mitigated to some degree by reducing the fragmentation effects of the highway. To address fragmentation effectively, highway segments need to be prioritized based upon their relative impact on grizzly bear habitat and movement. Highway mitigation efforts and habitat conservation efforts can then be guided to address the areas of greatest impact.

Factors found to affect grizzly bear movement and habitat quality are road density, building density, land cover type, habitat heterogeneity, and amount of forest-grassland edge habitat. Within a geographic information system (GIS), habitat quality was modeled and used to define core areas (large enough area for a small population to survive), living habitat (large enough for an individual to survive), and connectivity habitat (connections between core habitat).

Highway impacts on grizzly bear habitat and movement were estimated at the coarse scale by estimating the total length of highway intersecting: (1) suitable grizzly living habitat, (2) core grizzly habitat, and (3) connectivity habitat. Highways were weighted to reflect their overall impact, and lengths of highway segments were estimated to reflect the relative impact of each highway on grizzly bear habitat.

Highway impacts on grizzly bear habitat and movement at the fine scale incorporated data on building locations, road sinuosity, slope, and global positioning system (GPS) locations of highway features such as jersey and/or texas barriers, and presence of guardrails. These features tend to affect animal and/or motorist behavior during attempts at highway crossings. At the fine scale, areas of secure habitat were delineated based upon contiguous areas of high quality habitat encompassing 10 km^2 or larger. A pilot modeling project was completed for the Bozeman Pass, Montana, area that should be applicable to other highway segments within potential grizzly bear habitat of Montana, Idaho, and Wyoming.

Our approach offers the ability to identify important areas at a coarse scale and then use fine-scale efforts to identify specific road segments of concern. Fine scale modeling should be done at all high-impact sites to help determine optimal locations where animals may attempt to cross highways. Additionally, other species may be modeled to examine locally important wildlife.

Introduction

Wildlife move across the landscape to meet daily, seasonal, and lifetime needs. Highways often intersect movement routes. Depending upon the location, topography, design, and traffic, highways can act as barriers and impede, injure, or kill animals. From a human perspective, animal-vehicle collisions are a serious source of injury and death to motorists and comprise a significant economic loss.

Many solutions are possible to mitigate these problems. The most effective solutions appear to be those that separate animals from traffic completely; they keep animals off the roadway. This solution involves construction of some sort of crossing structure — underpasses, overpasses, elevated spans, tunnels, etc., — associated with fencing to funnel animals to these structures and keep them off the roadway. Structures work most effectively when they are sited along natural travel routes for a variety of species. Different structures are more effective for different species, as are different locations (Clevenger and Waltho 2000).

It is important to determine the most appropriate site for crossing structures for economic and ecological reasons. One approach has been to develop models of wildlife habitat and movement to predict likely highway crossing sites. The US Fish and Wildlife Service has analyzed grizzly bear habitat through "linkage zones" between some of the large blocks of public land in the Northern Rockies using a habitat suitability approach with four GIS layers (road density, human developed sites, vegetative cover, and riparian zones) to score the habitat in terms of its relative value (Servheen and Sandstrom 1993, Servheen et. al. 2001). A similar approach was used to determine linkage zones across Canada's Highway 3 in Southeast British Columbia and Southwest Alberta (Apps 1997). Further, GIS-based analyses have been developed by Clevenger et al. (2000), Clevenger and Wierzchowski (2002), and Reudiger and Lloyd (2003). Least-cost-path approaches have been used at a fine scale to model probable highway crossing points for grizzly bears in Slovenia (Kobler and Adamic 1999), in Washington State (Singleton and Lehmkuhl 1999, Singleton et al. 2001), and in Montana (Davidson 2003).

This project addressed shortcomings in previous approaches, developed techniques to reduce or alleviate those problems, and evaluated model performance using empirical data. It should be noted that grizzly habitat is categorized upon habitat characteristics, not grizzly bear occupancy. Results reflect impacts upon habitat that can support grizzly bears as well as species utilizing similar habitat. Impacts upon actual bear populations need to be interpreted by knowledge of the current distribution of grizzlies.

Study Areas

The study area for coarse-scale analysis encompassed all of Idaho, western Montana, and western Wyoming. Included within the area are Yellowstone National Park (a World Heritage Site), Glacier National Park, and the Grizzly Bear Recovery Zone. Fine-scale analysis focused on approximately a 40 km stretch of Interstate 90 between Bozeman, MT, and Livingston, MT.

Methods

The initial basis of our habitat models was developed by Richard Walker and Lance Craighead (Walker and Craighead 1997, Craighead et al. 1997, 2001). Models have since undergone several iterations, including modifications of road and habitat coefficients and addition of building density. The basic model comprises separate sub-models: the first sub-model, the CERI Habitat Quality model (CERI HQ), is based on ranked habitat quality (using Montana GAP Analysis Project vegetation cover types) derived by expert opinion and adjusted for the amount of habitat heterogeneity. The second sub-model, the CERI Human Influence model (CERI HI), was developed from road and building density analysis. Cell values of the CERI HQ model were degraded by the values of the CERI HI model to produce a final Habitat Effectiveness (CERI HE) surface. Our methods for defining connectivity habitat were a modified approach to those reported in the literature (USDA Forest Service 1990, Walker and Craighead 1997, Singleton and Lemkuhl 1999, 2000, Singleton et al. 2002, 2003) where core areas of good habitat that offer security (little human disturbance) were selected and least-cost paths were calculated between pairs of core areas.

Habitat model validation

To determine whether current habitat models accurately predicted grizzly bear habitat selection and to compare relative accuracy of various models, we evaluated habitat models from four sources: Carroll et al. (2001), Merrill and Mattson (2003), the Yellowstone Grizzly Bear Cumulative Effects Model (CEM) (Weaver et al. 1986, USDA 1990), and modified models of Walker and Craighead (1997). All are grid-based mechanistic models. Each author provided a habitat quality model not including human disturbance and three of the four authors also provided a model incorporating human disturbance (Carroll et al. 2001 did not provide a model including human disturbance). Three of the four sources (Carroll et al. 2001, CEM, Merrill and Mattson 2003) used locations of radio-marked bears obtained during telemetry flights during 1975-1997 to develop models, while the CERI model was based on expert opinion from scientific literature to estimate parameter values. Mark Haroldson of the USGS used locations obtained from GPS collars on grizzly bears in the upper Madison River drainage of the Greater Yellowstone Ecosystem (GYE) to evaluate model performance using receiver operators characteristic (ROC) curves (Craighead et. al. *in prep.* 2005).

Course-scale analysis

For coarse-scale analysis of relative highway impacts on grizzly habitat we defined two types of "good" habitat: (1) living habitat – contiguous areas at least 50 km^2 in size of habitat equal to or greater than a minimum threshold value from our habitat effectiveness model (road influence included in it) that is within the extent of grizzly bear movement analysis, and (2) core areas – contiguous areas at least 250 km^2 in size of habitat equal to or greater than a minimum threshold value that is one magnitude higher than living habitat.

To address some of the limitations of least-cost path modeling, we developed a cost surface using reported techniques and then removed areas from the cost surface that were identified as unsuitable habitat; we defined "connectivity habitat" as results from least-cost path analysis (using 250-km^2 cores as a basis) that is below a maximum cost threshold for movement and where a patch of "acceptable" habitat (above the threshold defined for living habitat in the CERI HE model) is no further than 1 km away.

Boundaries of these three habitat types were used to clip the three classified ESRI roads layers, "Interstates," "Major Highways," and "Other Major Roads." Segment lengths were calculated and summed by route number and the type of habitat they intersected.

Fine-scale analysis

The fine-scale model is based on the assumptions that habitat will determine whether bears get close to roads, but specific highway variables determine if they will attempt to cross and also be successful in crossing (areas where barriers will not prevent a successful crossing and motorists can avoid potential collisions).

Habitat quality adjacent to the road, as rated by the Habitat Effectiveness model and distance to "good" habitat, considered to be 10 km^2 of core area, were the variables used to determine the chance a bear will approach the road. The following variables were considered highway specific: (1) road sinuosity as a measure of sightability for both animals and motorists, (2) magnitude and direction of slope adjacent to the road, e.g., is it uphill or downhill adjacent to the road and the slope angle, and (3) specific barriers to crossing, including guardrails, jersey barriers, and Texas barriers. The above variables were combined using a weighting technique for an initial output of continuous values. Continuous values were then classified using natural breaks to produce 10 classes that are specific to the road segment being analyzed. Final output in this manner thus allows road segments within an analysis extent to be prioritized.

Results

Using receiver operators characteristic (ROC) curves where 0.50 is the null hypothesis, the Merrill and Mattson (2003) model scored 0.615; the Carroll et al. (2001) model, 0.564; and the CERI model, 0.576. Results indicated there was no significant difference between models. The CEM models produce categorical outputs that cannot be compared directly with other models, but interpretation indicated similar results to other models.

Using the CERI HE model as a basis, which includes a reduction in habitat values due to the existence of roads, 25 routes with the greatest total lengths intersecting modeled grizzly bear habitat from coarse-scale analysis are presented in table 1. Table 2 lists the five routes with the greatest lengths of road intersecting each combination of road type and habitat type and the length of road segments within each category. Fine-scale analysis assigned ranked values from 1 to 10 for the ~40-km analysis extent, with segments ranging from 21 m to 9346 m in length.

The two highways with the greatest degree of intersection with grizzly bear habitat, Meadow Creek (Idaho) and Highway 93, impact habitat that currently does not support viable grizzly populations. These highways do, however, impact other wildlife with relative severity. Interstate 90 has the largest overlap of any four-lane route.

Our fine-scale model appears to provide sensitivity for predicting the most likely areas wildlife will succeed in crossing highways. Recent findings indicate that animal-vehicle collision locations are reliable indicators of preferred highway crossing sites for many species (Dodd 2005, these *Proceedings*). Using road-kill location data as a means to evaluate model performance should be valid for many crossing sites especially when traffic volumes are high. All our models are expert opinion models specific to grizzly bears and, therefore, difficult to validate because of little data on grizzly road-kill or known crossing locations. We are currently developing similar models for other species that can be evaluated using larger data sets and are also looking at using several models in conjunction with each other for predicting highway segments where vehicle-animal collisions of all types are most likely to occur.

Table 1. The 25 roads with the greatest total length (km) intersecting grizzly bear habitat and length of road within each habitat type (core, living, and movement habitat) for Montana, Idaho, and Wyoming

	Route number	Length of road (km) by habitat type			
Road class	or name	Core	Living	Movement	Total
Other	Meadow Creek (ID)		0.00	914.63	914.63
Major	93		35.60	438.82	474.43
Interstate	90		18.71	423.74	442.45
Major	12		40.79	363.28	404.06
Major	95		22.26	376.41	398.67
Major	2		51.95	345.10	397.05
Major	89		63.99	332.82	396.81
Major	200		66.18	298.45	364.63
Major	26	0.14	26.24	208.36	234.74
Major	20		26.76	170.69	197.46
Other	21		57.14	138.99	196.13
Interstate	15		0.52	192.42	192.94
Other	3		49.46	139.44	188.89
Other	78		5.81	182.79	188.60
Other	28		3.50	151.67	155.16
Other	83		43.12	106.72	149.83
Major	287		19.70	107.49	127.18
Major	191		27.13	97.47	124.60
Major	212		24.71	87.43	112.14
Other	55		18.06	88.37	106.43
Other	43		28.83	74.79	103.62
Other	37		1.24	89.10	90.34
Major	10		15.59	66.68	82.27
Other	41		1.70	78.60	80.29
Other	38		17.79	61.31	79.10

Table 2. Top 5 routes (when applicable) by road class and type of grizzly bear habitat they intersect. Road names used when route numbers are not available (lengths in km)

Interstate Highways			Major Highways			Other Major Roads		
Habitat	Route	Length	Habitat	Route	Length	Habitat	Route	Length
Core habitat			Core habitat			Core habitat		
	--			26	0.14		Un-Named	1.17
	--			--			75	0.08
	--			--			64	0.00
	--			--			--	
	--			--			--	
Living habitat			Living habitat			Living habitat		
	90	18.71		200	66.18		75	66.86
	15	0.52		89	63.99		21	57.14
	--			2	51.95		3	49.46
	--			12	40.79		83	43.12
	--			93	35.60		43	28.83
Movement habitat			Movement habitat			Movement habitat		
	90	423.74		93	438.82		Meadow Creek (ID)	914.63
	15	192.42		95	376.41		28	151.67
	12	0.30		12	363.28		3	139.44
	--			2	345.10		21	138.99
	--			89	332.82		78	130.65

Discussion and Conclusions

Results indicated none of the models we compared was significantly different from each other. However, the CERI model is the only one that was developed without the aid of telemetry data and may thus be improved if actual locations were used to adjust model parameters. It is also the only one that can be easily used to conduct sensitivity analysis.

The model used for our estimates of road impacts on grizzly bear habitat incorporates the influence of roads on habitat and reduces values in the vicinity of all roads. We have also set a minimum habitat value as to where bears can survive. Thus, estimates of roads intersecting grizzly bear habitat do not indicate or include roads that have reduced adjacent habitat value below the threshold that bears may utilize or attempt to cross. Estimates only indicate roads that exist in areas where the type and density of roads have not reduced value below this threshold point and bears may attempt to cross.

Biographical Sketches: Tom Olenicki is a wildlife biologist and GIS project manager at the Craighead Environmental Research Institute in Bozeman, MT. He received his bachelor's degree in 1989, his master's degree in fish and wildlife management in 1993, and is currently finishing his Ph.D. in ecology at Montana State University, Bozeman. His current research interests focus on wildlife habitat modeling at multiple scales, primary for conservation area design.

Dr. Lance Craighead has been the executive director of the Craighead Environmental Research Institute in Bozeman since 1994. He received his bachelor's degree from Carleton College in 1969. He completed a master's in wildlife ecology from the University of Wisconsin-Madison in 1977. Between his master's and doctorate he worked as a field biologist for about 10 years, primarily in Alaska working on various wildlife research projects, with state and federal agencies and consulting firms. Dr. Craighead completed his Ph.D. in biological sciences at Montana State University in 1994. He is currently an adjunct assistant professor of biology at Montana State. His research interests center on conservation area design and habitat analysis as well as field work related to carnivore ecology. Dr. Craighead has published numerous scientific papers, completed two book chapters, and published one book, *Bears of the World*, for Colin Baxter/ Voyageur Press.

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Monitoring Effects of Highway Traffic on Wild Reindeer

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Abstract: Some of the major wildlife problems associated with transport infrastructure development in Norway involve the negative effects on reindeer populations. Documented effects include barrier effects resulting in fragmented populations and indirect impacts on reindeer grazing caused by disturbance from road traffic and human activities in general.

Wild reindeer are sensitive to disturbance and are known to have high alertness ageinstagainsttend to be extremely shy of human activities. The disturbance caused by road traffic and human activities can reduce the reindeer h habitat use at relatively 's use of areas for large distances (several kilometreskilometers) on either side of roads. The result of this avoidance is a reduction in the available grazing resources, which during the winter consist mainly of lichens, in wide zones parallel to roads, and an equivalent increase in grazing pressure in a zone at some distance from roads in undisturbed areas. Because lichens needs 20 – 30 years to recover after periods of intensive grazing, the wild reindeer are regarded as especially vulnerable to barriers that reduce their possibilities to reach new grazing grounds.

At the Hardangervidda, the biggest mountain plateau in Southern Norway, the functional use of the wild reindeer area has probably changed from being a large-scale rotation in the use of the food resources and calving areas, to a more restricted use of a smaller and central area. become an overexploitation of a too small area. The northern parts of the Hardangervidda isparts of the Hardangervidda are, for example, functionally parted from the rest by Highway (Hw) 7 and the railroad. This situation is not unique to the northern parts of Hardangervidda, but appears to be a general problem for most of the edges , and many of the surrounding of the plateauareas that also happens to be most affected by humans and less are no longer used by the reindeer.

The Norwegian directorate for nature management has suggested closing down a stretch of about 40 km of Hw 7 crossing the Hardangervidda, during the winter months, hoping to . The aim is to resume reindeer habitat use in this partsthese parts of the areathe original use of the whole mountain plateau. Even if the road has very low traffic in the winter months (ADT 300-400), the suggestion has caused a lot of protests and discussions locally.

In 2002 scientists from the Norwegian Institute of Nature Research (NINA) were engaged by the Norwegian Public Roads Administration (NPRA) in a five-year study to undertake research on patterns of reindeer habitat use and utilization of the lichen grazing resources and on the movements of wild reindeer in the aareas believed to be influenced by the road close to the road. The main purpose of the project is to find out to which degree the road and/or the traffic generated by the road constitute a barrier for the wild reindeer, and if it has a repelling effect on the animals. The NPRA will draw up its recommendation to the Parliament on the future management of the road based on the results of the project.

The project has equipped a total of more than 20 animals with GPS transmitters, providing continuous detailed and accurate data on their habitat use and movementsposition. The GPS units are where programmed to register localize each animal every the localisation of the animal each third hour. The data are stored in the computer in the collar, which includes a possibility for remote data transfer, and the computer is programmed to deliver the data for the last two weeks every second week. The collar also sends out a VHF signal, so the animal can be tracked, and the data downloaded to a portable computer.

Since the expressed effects in reindeer behaviourbehavior and habitat use are Because the fragmentation is the result of the cumulative effects of different disturbance sources, the project also aims to disentangle looks into the relative contribution level of disturbance to disturbance from other sources than road traffic, e.g.,xamples as such are pPower lines, the settlement of cottages and alpine resorts, and recreational use by skiers and snow scooters. all contribute to the disturbance of the wild reindeer.

Maps of the distribution of different reindeer the food resources (e.g., lichens) have been produced both by using field surveys and by the use of satellite imagesphotos. When the preliminary GPS data are compared with the distribution of lichen resources, in the area, it is very appears that clear that the animals do not use the areas richest in lichens: oin the outskirtsfringe of the plateau and in a zone 5 – 7 km from the road. This zone of avoidance also strengthens the barrier effect of the road such that the migration routes to and from the North are more or less cut off. This is both a problem of reduced genetic flow, and the availability of winter grazing resources.

The field work closes in 2005, and the results will be presented in 2006. The data will hopefully also also give us valuable information about the relative disturbance from other all the different disturbance factors, so that action can be taken based on the right factors.

Future research should focus more on the relative and cumulative effects of different disturbance factors, and whether placing selected stretches of the road in tunnels can eliminate or reduce the negative effects on reindeerthe disturbance from the road.

Keywords: wild reindeer, roads, barrier, fragmentation, disturbance, GPS

Introduction

More than 60 percent of Norway's land area is situated above the timber line, which is approximately 1,000 meters above sea level in southern Norway. These alpine and sub-arctic tundra areas in southern Norway are a refuge for the remnant last populations of the European mountain reindeer (Reimers, Villmo et al. 1980). left in Europe. The Norwegian topography is from nature's side fragmented by long and deep fjords, with and narrow valleys surrounded by high and steep mountains. As our society has developed the natural barriers have become stronger, and the natural landscape has become more and more fragmented. Norway is still called the green lung of Europe, and the density of roads is only 0.6 km/km2 compared to tThe Netherlands at 3.8 km/km^2. (Trocme et al. 2002). (BJØRN; har du ref. til denne?) The densest developed areas are along the coast, and in the deep valleys.

The major road systems are relatively simple (fig. 1), and they follow the topographic patterns that naturally fragment the country into a matrix of forested and mountainous habitats. The possible impacts of roads on Norwegian wildlife can be illustrated by their distribution and traffic levels. The total road network, including private roads and forestry roads, constitute a rather close and dense network of roads covering larger parts of the landscape (fig. 2).

Figure 1. Main roads in Norway.

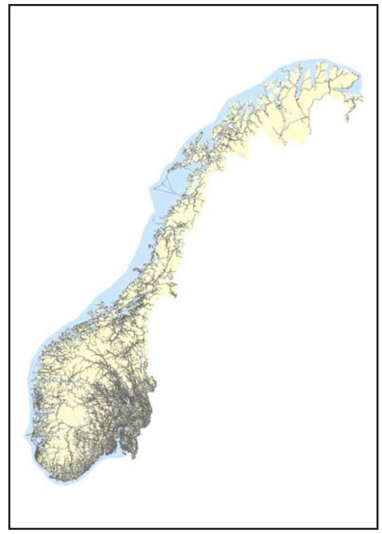

Figure 2. All roads in Norway.

The traffic density on Norwegian roads is relatively low compared to most western countries, and the average daily traffic (ADT) is highest in the south east part of the country and around the major cities (Fig. 3).

The traffic density on Norwegian roads is relatively low compared to most western countries, and the average daily traffic (ADT) is highest in the southeastern part of the country and around the major cities (fig. 3).

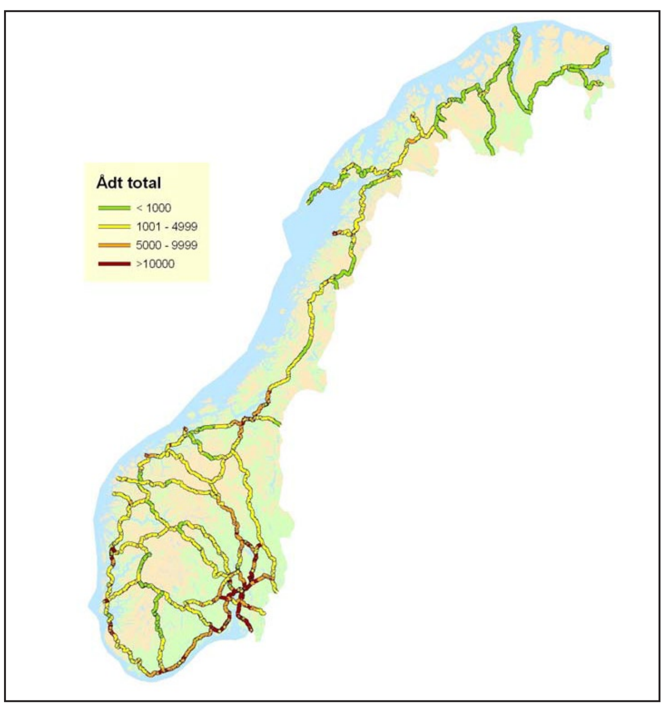

Figure 3. Average daily traffic density (ADT) on main roads in Norway.

Together with the network of power lines, dams, and regulated water courses, the result is that there are just a few spots of untouched nature left. This can be illustrated even further in maps classifying habitats into undisturbed and developed areas. Figure 4 shows that the distribution of areas more than 5 kilometreskm fromto larger technical installations (wilderness), be it roads, railways, power lines, built-up areas, or regulated water courses, has become greatly reduced since 1900. In fact more than 95 percent of the areas classified as "wilderness" in Southern Norway have disappeared during the last century. The remaining wilderness areas are mainly protected areas above the treetimber-line.

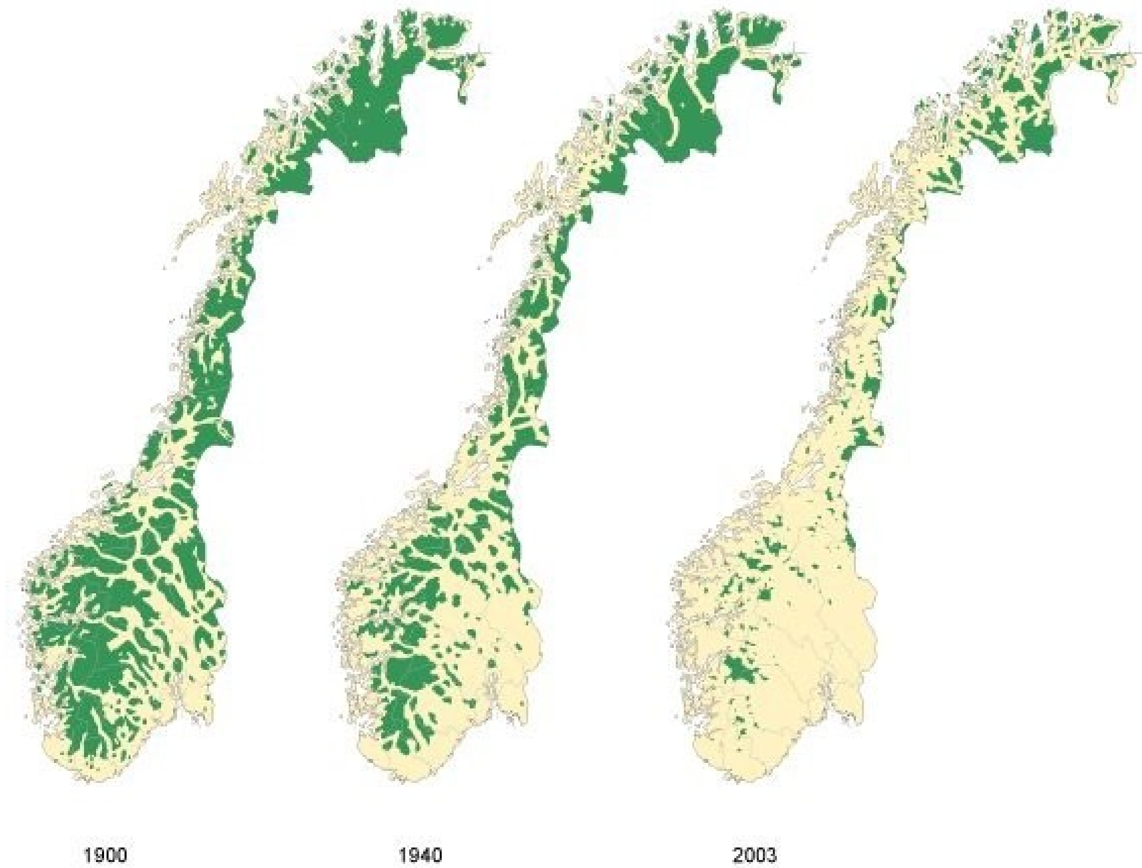

Figure 4. Changes in the area of undisturbed land between 1988 and 2003 (Source: Statens kartverk/DN).

Wild reindeer

When the glaciers withdrew at the end of the last Ice Age, some 10,000 years ago, reindeer and man migrated into these areas from at least two different directions. the reindeer were already here. Some reindeer came from the South and Central Europe, and they inhabit today the southernmost areas in Norway. A second immigration came from the East, and descendants from this immigration are mainly found in the northern reindeer areas (DN 1995; Andersen and Hustad 2005). (Knut røed). and some from the east. There is still a predominant and documented genetic difference between these two groups of reindeer.

Prior to the industrial development wild reindeer moved more or less freely in two to three defined areas in southern Norway, the major barriers being the deep valleys between the mountain plateaus. The present distribution of wild reindeer into 23 more or less isolated management units (fig. 5), is thus a result of both natural factors and the effects of human infrastructure (Reimers, Villmo et al. 1980; Skogland and Mø›lmen 1980).

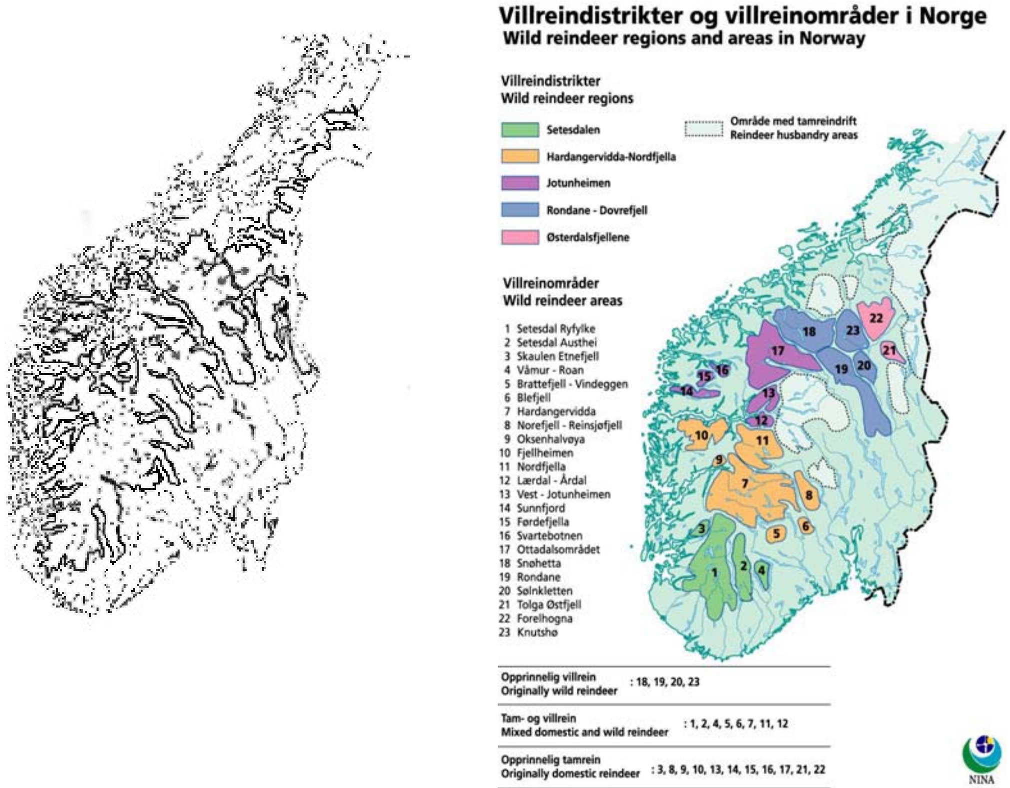

Figure 5. Wild reindeer areas in South Norway before and now.

Today the distribution of wild reindeer is limited to the southern parts of Norway, with approximately 30,000 animals left(Jordhøy, Strand et al. 1997). The hunting tradition is still strong, and the annual harvest out-take varies between 3,000 and 10,000, depending on the production and population levels. Hunting is of course strictly regulated by the means of annual population censuses and yearly adjusted hunting quotas.

Norwegian wild reindeer do not migrate over huge distances, like caribou or reindeer populations found in large arctic tundra areas, but they do have nomadic and seasonal movements at a smaller scale between winter, summer, and calving areas. Reindeer are also live in herd herds living animals and aggregate in relatively large groups. In evolutionary terms this herding behaviourbehavior is seen as an adaptation to co-existence with large predators (Skogland 1989). Today large predators are functionally extinct from the Norwegian wild reindeer areas, and hunting is the single most important factor acting limiting reindeer numbers and preventing populations from overgrazing their habitat (Skogland 1985). As a result of deep snow and limited access to other forage, reindeer in southern Norway utilize lichens as their main winter forage (Kojola, Helle et al. 1995; Gaare 1997). Unlike green plants, lichens keep all their biomass above ground (they have no roots), and have slow recovery rates (up to 20-30 50 years) following after periods with high grazing pressure (Helle and Särkelä 1993; Miller 2000). Management and conservation of wild reindeer is, therefore, directed both at population management through harvest, aiming to keep populations at reasonable levels in relation to available winter pastures, and to protect remaining habitats from further developments (DN 1995; Andersen and Hustad 2005).

Wild reindeer are known to be sensitive to disturbance caused by different kinds of human activity (Wolfe, Griffith et al. 2000; Nellemann, Vistnes et al. 2003). Even at long distances reindeer respond to skiers, hikers, snow scooters, and other vehicles. In the rather flat and open mountain areas reindeer are known to have a flight distance at several hundred meters, and sometimes escape disturbances by several kilometers (Reimers, Colman et al. 2000; Nellemann, Vistnes et al. 2001; Vistnes and Nellemann 2001; Reimers, Eftestol et al. 2003). Known effects of human disturbances and infrastructure on reindeer behavior and habitat use might be summarized on two different levels – first, at an individual or a direct level, corresponding to changes in behaviourbehavior or physiological state of single events where animals are disturbed by human activities. Second, effects of disturbances are demonstrated at the population level, where effects are documented through loss of important migration routes and grazing habitats (Wolfe, Griffith et al. 2000). The latter studies are more easily related to management questions (since they are documenting effects at the population or landscape level), but are less interpretable with respect to their underlying mechanisms and effects of single disturbances.

Methods and Materials

Study area

The Hardangervidda mountain plateau is the largest mountain plateau in Northern Europe, ~8200 km^2 (Skogland 1990), and can still be found as a rather large green spot in maps with classified wilderness areas (fig. 4). Hardangervidda is also the home for the largest population of the remnant European wild reindeer. A larger part of the Hardangervidda is today protected as a National Park (3422 km^2) and is still used for hunting, fishing, and other outdoor activities.

Hw 7 is one of several roads between the two major cities of Oslo (the capital) and Bergen, on the West Coast, and crosses the northern parts of Hardangervidda. The Norwegian directorate for nature management suggested closing down the part that crosses Hardangervidda, a stretch of about 40 km, during the winter months. The aim is to restore reindeer habitat use in the northern parts of Hardangervidda. Even if the road has very low traffic in the winter months (300-400 ADT), the proposal has caused a lot of protest and discussion locally. Due to the local protests, the road is still open, except during periods of winter storms. The Norwegian Public Roads Administration (NPRA), therefore, had to carry out a survey in 2001, including both the biological issues and the socio-economic effects of such a drastic measure. The survey lead to the establishment of a five-year study of the wild reindeer's use of the area in wintertime, based on the use of GPS collars attached to reindeer, and mapping of the grazing patterns of the wild reindeer. The project is financed by the NPRA and carried out by the Norwegian Institute for Nature Research (NINA), starting in 2002.

Data collection

In order to disentangle the effects of human disturbance on the habitat use of wild reindeer at Hardangervidda, the ongoing science project adopts a two-fold approach, focusing on both reindeer habitat use in relation to human disturbances and the relationship between reindeer grazing and vegetation. In addition to studies based on GPS-collared reindeer and the use of habitat maps, we have also collected historical data including pit fall systems and former reindeer migration routes.

Detailed data on reindeer habitat use (from GPS collars) are to be used together with habitat distribution maps in a GIS-based analysis of reindeer habitat selection. The rationality behind these types of studies is to generate models for reindeer habitat selection including standard parameters, such as seasonality, elevation, aspectaspect, and vegetation cover. Possible effects of human activities (and the road) will be tested as single elements in the models, and their ability to explain the residual variation in the models will be used in order to test the hypothesis regarding disturbance effects on reindeer habitat use.

Results and Discussion

During the last 50 years the density of reindeer at Hardangervidda has fluctuated more than five fold. During periods with high density (in the 1960s and the early 1980s) reindeer have found new and richer grazing areas in the outskirts of Hardangervidda and in neighboring areas (fig. 6). Available historical data thus indicate that reindeer habitat use is a dynamic process where population density and food competition are important elements. Bearing this and the rather obvious limitations of the historical data in mind, it appears that the functional use of Hardangervidda has changed from a large-scale rotation between complementary habitats and calving areas, to a more restricted occupation of central areas. The northern parts of Hardangervidda, including the glacier Hardangerjøkulen, appear to be functionally separated from surrounding areas to the South by Hw 7, and by the Oslo-Bergen railroad to the North.

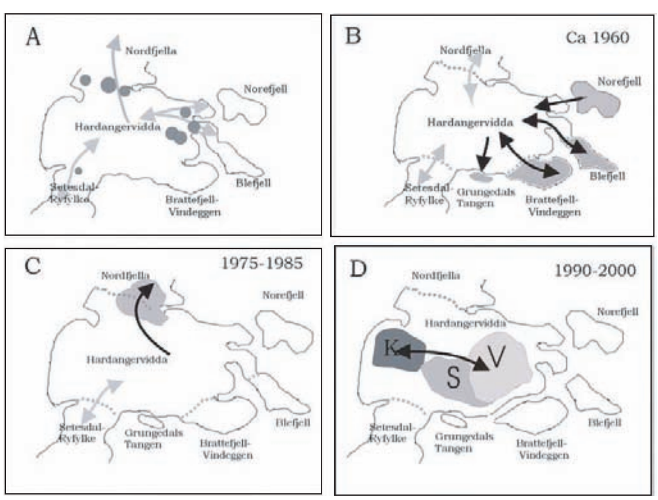

Figure 6. The past and present use of the Hardangervidda.
(K= calving areas, S= summer areas, V= winter areas).

Mapping of vegetation cover and reindeer pastures

Analyses of remotely sensed data show that we are able to map the vegetation cover on Hardangervidda with a reasonable accuracy for our purposes and that 75 percent of the total satellite images are correctly classified. So far, we have greatest success in classifying lichen heath communities where the classification accuracy is >90 percent. We have greater difficulties, however, with classification of mires and snow-bed communities. Preliminary analyses of the data show relatively large regional differences in vegetation cover and distribution of reindeer summer and winter habitats. Areas with a large proportion of lichen heath communities, which are important to reindeer in winter, are more frequent in central and eastern regions, whereas snow-bed communities and rich summer pastures are more frequently found in southern and western areas (fig. 7). These analyses also confirm that the area North of Hw 7 contains potentially important pastures for reindeer, and that habitats close to the glacier should be regarded as potentially important areas for summer grazing.

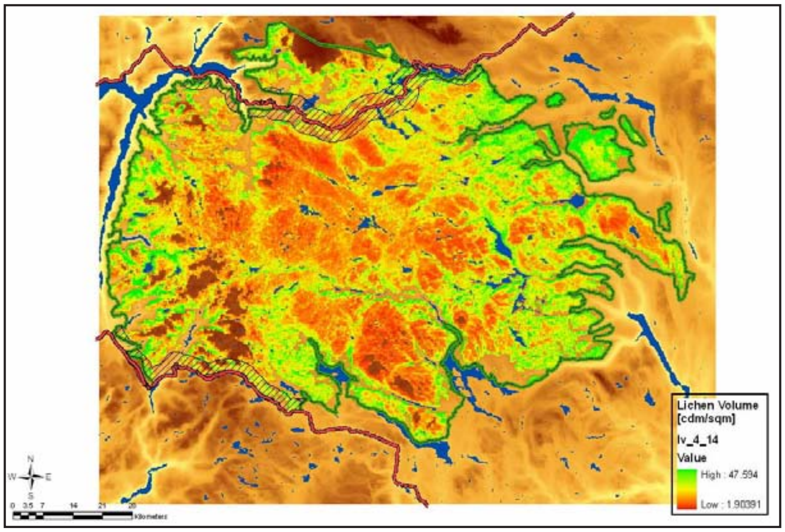

Figure 7. Vegetation cover maps describing the spatial distribution of important habitats. Areas with a large proportion of lichen heat communities, which are important to reindeer in winter, are more frequent in central and eastern regions, whereas snow-bed communities are more frequently found in southern and western areas.

Our studies on Hardangervidda have documented rather pronounced and large-scale regional differences in lichen biomass, suggesting a substantial increase in reindeer grazing pressure in central and undisturbed areas. Similar results were obtained in areas close to the road, and increasing levels of lichen biomass was observed in areas closer to the road (5-7 km), suggesting less reindeer grazing in these areas (fig. 8). The reduced biomass of lichens in remote areas further suggests that grazing has suppressed lichen biomass well below optimal levels in these areas, whereas lichens in the outskirts of the area probably have reached their un-grazed maximum biomass.

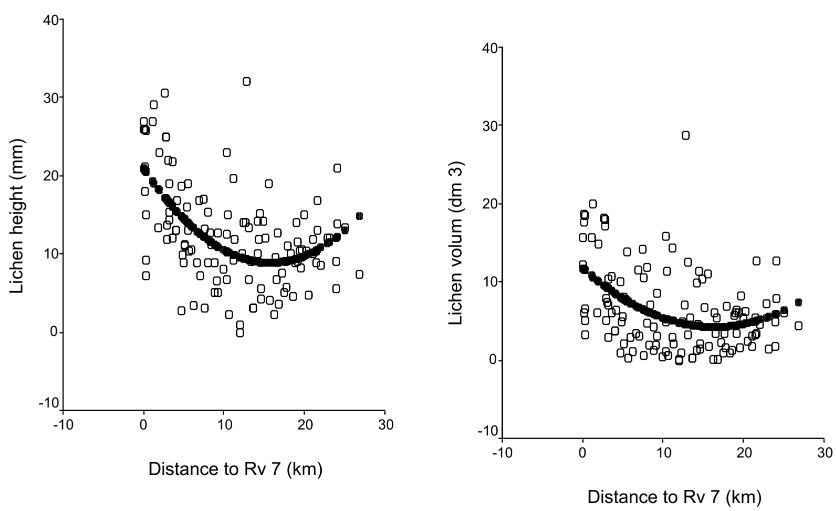

Figure 8. Measurements of lichen height and volume indicate an increase in reindeer grazing pressure at greater distances (5-7 km) from the road.

Using the Global Positioning System (GPS)

To be able to collect more detailed data of the movement of the wild reindeer, we initiated a GPS project, starting with six GPS transmitters (fig. 9).

Figure 9. Wild reindeer with GPS collar.

The GPS collars were programmed to register the location of each animal every third hour. The collar also sends out a VHF signal so that the animal can be tracked. The GPS system used on Hardangervidda also allows remote download of data and was used to collect a data sample at the start of the project. Due to high field costs we later abandoned this routine. Presently, we download data when collars are retrieved from hunters or by removing collars by a remotely triggered “drop-of” mounted on the collar.

Due to the satisfactory experiences with the GPS collars the project was expanded with another 10 GPS collars in 2002. Although we experienced some technical problems with some of the GPS collars most of them worked as scheduled. In late autumn 2004, however, we discovered that one out of a group of five similar collars had serious malfunctions. It was likely that all five collars had the same problems, and 10 new reindeer were collared. At most, we have had more than 20 GPS-collared female reindeer on Hardangervidda.

At this stage in the project (2005) we have been able to retrieve collars from 11 animals. From these collars we have extracted more than 40,000 data points with an average accuracy within 25 m. The rest of the collars will be collected during autumn 2005 and winter 2006.

Analyses of the GPS data so far indicate that collared females have had a rather uneven distribution and that the central areas have been extensively used (fig. 10). This effect seems to be especially strong in summertime (June, July, and August) when collared females have used less than 20 percent of the available area. During winter, reindeer seem to be more dispersed, and applications of Resource-Selection Function (RSF) models have confirmed a strong selection for lichen heath communities. We are now focusing our attention on refinement of vegetation maps and are developing different RSF models for reindeer habitat use, including parameters as vegetation cover, terrain properties (elevation and aspect), and density of human activities and distance from developed areas.

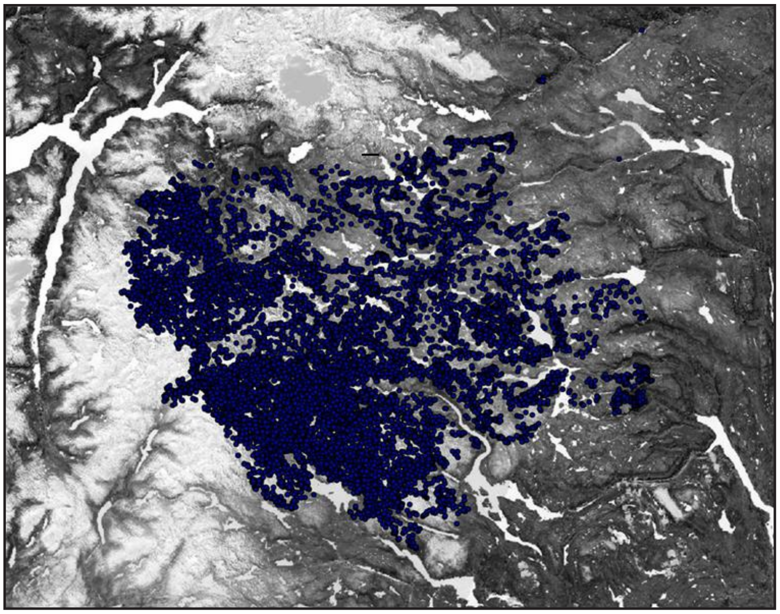

Figure 10. Example of GPS plots from eight female reindeer between 2000 and 2003 indicates a more frequent use of central areas, whereas outskirts and disturbed areas appear less used by reindeer.

Detailed studies of the GPS plots close to Hw 7 show a pattern of movement than can be described as fear or avoidance (fig. 11).

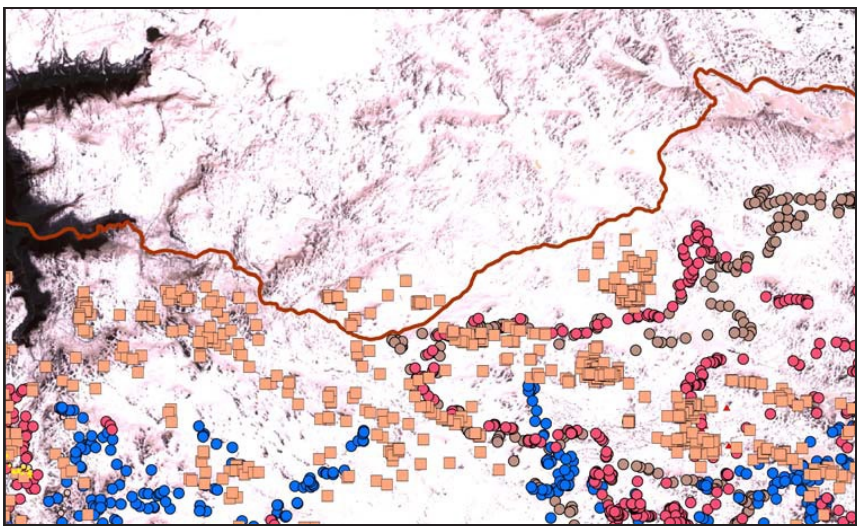

Figure 11. Movements of wild reindeer according to GPS registration of four different animals close to Hw 7 (red line).

Conclusions

In spite of some problems with the GPS collars, we expect to get the necessary data. The preliminary results suggest that we have been able to map habitat characteristics with necessary precision. The results from the RSF models are promising so far, although we still need to calibrate our models. We are probably ending up with a set of different models used to answer different questions (e.g., spatial scale, season; density of human installations vs. distance to GPS plots, etc.).

The field project ends in 2005, and the results will be presented in 2006. The data so far indicate that Hw 7 has an effect as a functional barrier, and that the appearance of human disturbance in general has a repelling effect on the reindeer.

The future management of Hw 7 in wintertime will depend on a political decision, which will also take into account factors other than wild reindeer. The analysis of the data from this project will document the effects of the Hw7 on the reindeer and provide a scientific basis to help enhance decision making about how to reduce the negative effects.

Biographical Sketches: Bjørn Iuell is a biologist from the University of Oslo (cand. scient., 1983). He worked as secretary general of WWF/Norway in the 1980s, and as environmental and planning officer for local communities in the 1990s. He has since 1997 been working as a senior engineer at The Norwegian Public Roads Directorate, mainly with questions related to wildlife, roads, and traffic. He serves as vice-chairman of the European project *COST 341 Habitat fragmentation due to transportation infrastructure*; coordinator of the COST 341 Handbook *Wildlife and traffic – a European handbook for identifying conflicts and designing solutions*; project manager of the Norwegian project *Highway 7 and the wild reindeer*; and member of PIARC technical committee 2.1 *Sustainable Development and Road Transport*.

Olav Strand is a biologist from the University of Trondheim. He has been working as a scientist at the Norwegian Institute for Nature Research (NINA) in Trondheim since 1991. He has a working experience from sub-arctic and arctic areas in Norway and Russia within the fields of population and behavioral ecology. His main research interests cover the conservation ecology of endangered arctic foxes and the management- and harvest-related issues of wild reindeer.

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Chapter 8

Small Mammals

Addressing Habitat Fragmentation Impacts from Construction of a New Highway

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Abstract: The purpose of this project was to develop methods to analyze impacts from and find solutions for habitat fragmentation resulting from the construction of a new highway across two military bases (McChord Air Force Base and Fort Lewis Army Base). The bases contain large blocks of rare terrestrial habitats. The need to maintain the security of the bases limits the ability to use on-site methods, such as underpasses and crossing structures.

In 2003, the Crossbase highway project, which had been a Pierce County-sponsored project, was identified as a new state highway, and thus became the Washington State Department of Transportation's (WSDOT) responsibility. The six-mile-long highway cuts through two adjoining military bases to connect a heavily developed urban/industrial area with Interstate 5. Both military bases have core areas containing airfields, housing, operational, and commercial areas that are surrounded by largely undeveloped natural habitats consisting of large wetlands, coniferous forests, rare oak woodlands, and rare native prairie areas. These natural areas are bisected by an extensive network of gravel and paved roads and are used for military training activities. These rare habitats support four federal candidate species, and one state-listed endangered species. Development activities surrounding the military bases have fragmented and eliminated much of the habitats outside of the bases.

The new highway is expected to result in three main ecological impacts: direct loss of rare habitat types, decreased use of surrounding habitat due to impacts associated with the operation of the highway (e.g., noise), and habitat fragmentation or isolation of habitats. While mitigation ratios exist to address the elimination of habitats such as wetlands, no ratios or methods exist to quantify impacts associated with operation impacts or habitat fragmentation. Working in conjunction with Washington State Department of Fish and Wildlife (WDFW), WSDOT developed a method to assess these impacts based on the level of function that would be lost. This method was used to determine what the total habitat enhancement and restoration package for the Crossbase highway should be.

The resulting habitat enhancement and restoration package that was developed consists of three parts: acquisition of a large parcel of rare habitat, restoration and enhancement of the acquired site, and providing funding for additional restoration, acquisition, and enhancement activities.

While construction of the highway has not begun, WSDOT is proceeding with acquiring the restoration and enhancement site and has provided funding for the additional acquisition, restoration, and enhancement activities. The developed method will be used on other new highway projects in the future.

Introduction

WSDOT creates very few new roadways. In the last 15 years, the few "new" roads that have been constructed were bypasses around small towns where traffic levels exceeded the capacity of the highway, and the majority of the road construction activities were associated with upgrading or replacing existing infrastructure. In the early 1990s Pierce County began planning for a new highway that would connect an industrial area with Interstate 5. As the project moved through the National Environmental Protection Act (NEPA) process, the state legislature designated it a state highway, and in 2003 the responsibility for the Crossbase highway project was assigned to WSDOT.

The Crossbase highway will be a four-lane limited access highway that is six miles long. The highway crosses two adjoining military bases – Fort Lewis Army Base and McChord Air Force Base. These two large bases comprise some 86,000 acres of land in the heart of Puget Sound, between the cities of Tacoma and Olympia. Due to the layout of the bases, portions of two counties lack easy highway access. The new highway will be a limited access highway to maintain the security of the bases.

Both military bases have heavily developed core areas containing airfields, housing, operation, and commerce areas that are surrounded by largely undeveloped natural habitats consisting of large wetlands, coniferous forests, rare oak woodlands, and rare native prairie areas. These natural areas are bisected by an extensive network of gravel and paved roads and used for military training activities. Development activities outside the military bases has fragmented and eliminated much of the habitats not located on the bases. The highway will cross several rare habitat types, including Oregon white oak woodlands and native prairies.

These rare habitats support numerous rare species, four of which are listed as candidates under the Endangered Species Act, and one that is listed as a state endangered species. These are in addition to the more "common" federally listed species that on-base habitats support, such as bald eagles (*Haliaeetus leuchcephalus*), water howelli (*Howelli aquatilis*), and Puget Sound chinook salmon (*Oncorhynchus tshawytscha*). The candidate species are all associated with the prairies or oak woodland prairies interface and include two butterflies – Mardon Skipper (*Polites* *mardon*) and the Whulge (Edith's) checkerspot (*Euphydryas editha taylor*); one bird – streaked horned lark (*Eremophila alestris strigata*); and one mammal – Mazama pocket gopher (*Thomomys mazama*). The western gray squirrel (*Sciurus griseus griseus*) is a state endangered species in severe decline in the Puget Sound Trough, which occurs in the oak, conifer, wetland interfaces on the bases.

There was strong opposition for the project from several environmental groups and public agencies during the NEPA process. The groups felt that the impacts from highway construction were too severe and that the no-build alternative should be selected. They were concerned that the highway would fragment the rare habitats and cause the extirpation of the western gray squirrel from the Puget Sound Region, and impact the three less mobile prairie-dependant species. There was less concern about the streaked horned lark as it is a very mobile species. Pierce County and its consultant worked hard to try to resolve the issues and created an extensive mitigation commitment in the Environmental Impact Statement (EIS). However, even when the Record of Decision was signed, there was still some opposition and disagreement on the project.

Since some of the more vocal opposition was from the WDFW, the Governor's office requested that WSDOT and WDFW come to resolution. Two teams were established: a policy team, consisting of executive level personnel from both agencies, and a team of technical experts from both agencies. The technical team worked together to develop the methods to assess impacts and also evaluated the suitability of the mitigation approach presented in the EIS. If that approach was insufficient, then the technical team was to develop a suitable habitat enhancement and restoration approach for review and approval by the executive level team. The executive level team would also settle any areas of disagreement between the two agencies that were presented by the technical level team. The technical team's methods for assessing impacts and evaluating the suitability of the mitigation approach are presented in this document.

Methods

There were two potential approaches that could be used to assess impacts: a species-based approach or a habitat-based approach. Since the EIS included extensive geographic information system (GIS) habitat information, the decision was made to evaluate impacts to habitats, rather than the species. The EIS had identified all of the habitat types in the project area and had determined the amount of each type of habitat. Habitat categories were grouped into five general categories: conifer forest, oak forest, other hardwood forest, savanna, and grassland habitat.

The first step was to identify the impacts from the project. Three impacts were identified: loss of habitat, permanently disturbed habitat, and fragmentation/isolation of habitat. The entire right of way was considered to fall under the loss of habitat category. This is habitat that the team felt would be altered to un-usable habitat even though there would still be native vegetation left intact in the outer zones of the right of way. The team determined that all areas within a half-mile of the new highway would be permanently disturbed by the presence of the highway. Disturbance from noise, stormwater, airborne pollutants, wind generated by traffic, and the edge effect were all considered when setting this distance. Only the area south of the new highway was placed into this category. The area north of the new highway was included in the third category, the fragmentation/isolation category. This included the entire non-altered habitat north of the proposed highway within the bases. Buildings, roads, parking lots and other developed areas were not included. Using GIS information, the amount of habitat (categorized by habitat type) in each of the impact categories was identified.

Table 1. Impact by Habitat Type

Habitat Type	Loss of Habitat (acres)	Permanently Disturbed (acres)	Fragmented/Isolated (acres)
Conifer forest	106	452	1208
Oak Forest	18	91	381
Other Hardwood forest	5	37	288
Savanna	7	31	318
Grassland	30	122	1332
Total Acres	166	733	3527

The technical team recognized that the habitats being evaluated were part of two very active military bases that managed their lands specifically for extensive year-round troop training exercises. Conifer forests are managed for open understories, and prairies are managed for parachute jumps, helicopter overflights, land navigational exercises, and as artillery impact areas. Since the habitat was not pristine, a functional value scale was applied to the habitat. The scale was set from 0 to 1, with 0 equaling no function (e.g., pavement), and 1 equaling intact, totally functional habitat. A value from 0.1- 0.3 was assigned to poorly functioning habitat, and a value of 0.4 –0.6 was assigned to disturbed, partially functioning habitat.

The technical team rated the function of each of the five habitats categories by evaluating the overall function based on aerial photos, site visits, and best professional judgment. The values for each habitat type were totaled in each of the three impact categories. A point value was determined for each habitat type based on the acres of habitat in the impact category multiplied by the assigned functional value (see table 2). After evaluating each habitat type, the average functional value for all the habitat in the area north of the proposed highway was calculated to be 0.5.

Table 2. Example of Calculation for Functional Value

Habitat Type	Functional Value	Loss of Habitat Impact Category (acres)	Loss of Habitat (functional value score)
Conifer Forest			
Poorly Functioning	0.1	56	5.6
Disturbed Partially Functioning	0.2	19	3.8
Intact Functioning	1.0	31	31
Total Acres		106	40.4

The next step was to evaluate the impact from the highway. Each of the three impact types was assigned a functional loss multiplier. Permanent loss of habitat was determined to be a total functional loss (100%), permanently disturbed habitat was determined to have a 10-percent loss of function, and fragmented habitat was determined to have a 20-percent loss of function. The existing functional value of the three impact categories was multiplied by the functional loss multiplier to determine the amount of habitat restoration and enhancement stewardship points that were to be provided by the project.

Table 3. Habitat Impact from Highway in Stewardship Points

Habitat Affected	Acres	Existing Functional Value	Functional Loss Multiplier	Stewardship Points
Permanently Lost	166	77	1.0	77
Disturbed	733	337	0.10	34
Fragmented	3527	2163	0.20	432
Totals	4426	2577		**543**

The team then evaluated the restoration package presented in the EIS. Since the highway was crossing two bases, Homeland Security concerns prevented the use of large under- or over-passes to help avoid fragmentation impacts. Thus, the majority of the impacts could not be addressed through on-site solutions, and needed to be addressed off site. The EIS identified a 364-acre restoration and enhancement site, and a conceptual restoration plan for the site. The site is located directly adjacent to Fort Lewis, providing an excellent opportunity to offset fragmentation and add to the total land area of the bases. The site is currently used for grazing and is degraded.

A functional assessment method was applied to the restoration site to determine its current functional value by habitat type. Then the functional value potential following restoration of the site was calculated. A functional level of 1.0 was used to represent the best possible functional value of the site. The current average functional value of the entire site is 0.36. The evaluation of the restoration site indicated that it would provide 356 habitat restoration and enhancement stewardship points, leaving a deficiency of 184 points.

Various options were discussed to finish the habitat restoration and enhancement package. The option favored by WDFW was to dedicate funding for other prairie and oak woodland habitat purchase, restoration, and enhancement efforts. This option required the assignment of a monitory value per point. Evaluation of the land prices in the area for large blocks of land helped establish a per point value of $8,152. Accordingly, $1.5 million was placed into an account under WDFW administration to assist in habitat procurement, restoration, and enhancement efforts.

Conclusions

The final habitat restoration and enhancement package for the Crossbase highway consists of the purchase of a 364-acre parcel adjacent to Fort Lewis, the establishment of a $3.5 million restoration budget with an additional $1 million contingency fund, and a $1.5 million contribution to other prairie and oak woodland habitat purchase, restoration, and enhancement efforts.

The method that the technical team developed to determine if sufficient habitat restoration and enhancement would occur to offset impacts from the highway provides a simple tool to assess habitat functions and impacts to habitats that will not be destroyed but will be impacted by disturbance or fragmentation. This method was created due to the lack of available approaches for operational and habitat fragmentation impacts to rare habitats and the limited availability of information about the species occupying the impacted habitats.

Biographical Sketch: Marion Carey is the fish and wildlife program manager for the Environmental Services Office of the Washington State Department of Transportation. Carey has been with the agency since 1994 working on a variety of fish and wildlife issues, including deer-vehicle collisions, Endangered Species Act consultations, Migratory Bird Treaty Act permits, and rare species surveys.

Effectiveness of Rope Bridge Arboreal Overpasses and Faunal Underpasses in Providing Connectivity for Rainforest Fauna

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Abstract: Rope bridge overpasses and faunal underpasses were effective in restoring rainforest habitat connectivity for many tropical rainforest species that suffer high levels of road mortality or that avoid large clearings, such as those for roads, and, therefore, suffer barrier effects.

Faunal underpasses furnished with logs and rocks to provide cover were constructed in 2001 at a hotspot for tree-kangaroo mortality. The narrow road and 120-m-wide strip of abandoned pasture divided two blocks of rainforest severing an important highland wildlife corridor through an agricultural landscape. No rainforest small mammals were recorded crossing the gap in six months of trapping prior to the road upgrade. During the upgrade, corridors of rainforest trees were planted through the pasture to connect with underpass entrances. Underpass use was monitored weekly using sand tracking beds complemented by infrared-triggered digital cameras. Weekly road kill data were collected for 12 months prior to construction and continues on two 0.5-km road transects in the vicinity of the underpasses and two transects along a highway dividing similar rainforest habitat 5km to the north. In 2004, bird and small mammal use of the planted corridors was investigated.

Many terrestrial rainforest species use the underpasses, including medium-sized and smaller mammals and terrestrial birds, together with two confirmed passages of the rare target species, Lumholtz's tree-kangaroo. Road mortality near the underpasses has remained low, whereas road kill rates are much greater along the narrow rainforest highway without underpasses. Community composition of rainforest birds within the corridors is approaching that of edge rainforest nearby, demonstrating effectiveness at this early stage of growth. However, although rainforest small mammals reside in the corridors, feral and pasture species still dominate, emphasizing the need for longer growth periods to encourage greater use by rainforest specialist mammals of the connectivity afforded by corridors and underpasses.

Several rope bridges erected 7m above narrow roads and designed for use by rare arboreal rainforest mammals have also proven effective and are regularly used by the obligate arboreal Lemuroid ringtail possum, which will not cross roads on the surface or via underpasses. Several other possums that rarely venture to ground level are also regular crossers. Structures also provide safe crossing routes for arboreal species that otherwise suffer road mortality. Monitoring using active infrared-triggered cameras, scat and hair collection, and spotlighting has shown all target rainforest ringtails and other possums using rope tunnel and cheaper rope ladder designs. Similar designs have since been installed elsewhere in Australia over four-lane highways. Subsequent rainforest studies will investigate use of longer rope bridges above a wide highway using mark-recapture and radio-tracking to determine home range and provide population information prior to construction, followed by systematic monitoring of the rope bridges.

Introduction

Fauna of the tropical rainforest understorey and ground layer are adapted to a structurally complex habitat with a cool, moist, and relatively equable microclimate and low light, whereas road clearings comprise an extreme contrast because they are structurally barren, suffer extremes of temperature, humidity and wind turbulence, and have very high daytime light levels (Siegenthaler and Turton 2000, Pohlman et al. 2005). Microclimate changes also permeate the edge of the forest and result in changes in species composition and structure of vegetation, altering faunal habitat at the edge (Siegenthaler et al. 2000, Goosem and Turton 2003, Goosem et al. 2005, Pohlman et al. 2005). Road clearings are, therefore, likely to form either partially permeable (Goosem 2001) or complete barriers (Goosem 2000) to the movements of specialized tropical rainforest fauna, an effect which may be exacerbated by traffic movement, headlights, pollution, and noise emanating from the road clearing. The degree of contrast between the road clearing and rainforest habitat means barrier effects are likely to be greater for many species of rainforest wildlife than for fauna of more open habitats (Goosem 1997, 2004). Barrier effects for tropical rainforest fauna are increased by several factors including wider clearings and microtopography, such as cuttings and embankments adjacent to the road that are difficult for terrestrial animals to traverse (Goosem 2000). Rainforest wildlife is also subject to high levels of road mortality (Goosem 1997, 2000). In areas of high traffic, mortality through vehicle-wildlife collisions can increase the road barrier effect, reducing success of road crossing attempts by less inhibited species (Forman et al. 2003). If effective, the inclusion of wildlife underpasses under roads for terrestrial rainforest wildlife could at least partially mitigate against the problems of mortality and fragmentation. Similarly, canopy overpasses could provide passage for species that are obligatorily arboreal.

Although the success of faunal underpasses for a variety of vertebrates including large mammals (Foster and Humphrey 1995, Clevenger and Waltho 2000, Gordon and Anderson 2003), small mammals (Mansergh and Scotts 1989, Mata et al. 2003, Servheen *et al.* 2003, Taylor and Goldingay 2003), reptiles and amphibians (Yanes et al. 1995, Aresco 2003, Mata et al. 2003, Taylor and Goldingay 2003) has been demonstrated for many roads through open habitats and temperate forests over the past decade, their effectiveness for tropical rainforest fauna has only recently begun to be examined (Goosem et al. 2001, Goosem 2003). Similarly, monitoring of structures provided for movement of arboreal fauna is relatively new (Becker 2003, Weston et al. 2005) and unique within rainforest ecosystems.

In the tropical rainforests of northeast Queensland, Australia, several highways traverse the mountain ranges from the rapidly expanding urban centers on the coast to connect with the mainly rural areas of the tablelands, dividing large blocks of rainforest in the process. Upgrade designs for one highway will straighten and widen the two-lane winding road to four lanes to cater for traffic volume increases from 6,500 to 10,000 vehicles per day. Iterative collaboration between the Queensland Department of Main Roads (QDMR) and researchers from the Rainforest Cooperative Research Center (Rainforest CRC) has ensured that the design of this upgrade incorporates all recent research into mitigation of impacts of tropical rainforest roads, including the two collaborative connectivity projects discussed in this paper. The first project concerns effectiveness of faunal underpasses for terrestrial rainforest species, and the second examines effectiveness of rope bridges in providing connectivity for arboreal rainforest fauna.

All study areas were situated within the rainforests of the Wet Tropics World Heritage Area, northeast Queensland, Australia (fig. 1).

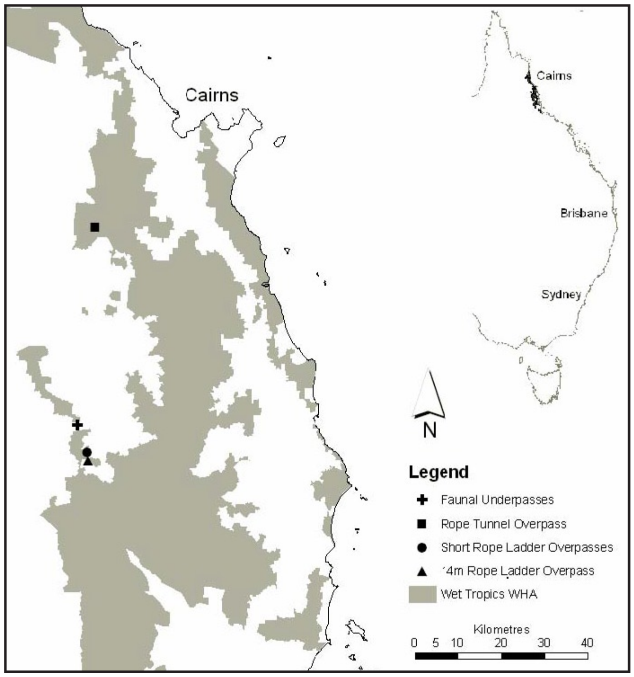

Figure 1. Location of study sites within the rainforests of northeast Queensland, Australia.

Faunal Underpasses

Study area

In 2001, QDMR upgraded a winding section of a one-lane, high-altitude (~1,100m) road to eliminate hairpin bends and provide two wide lanes. The former narrow road and adjacent abandoned pasture divided two important areas of highland rainforest (Goosem et al. 2001, Goosem 2003). Rainforest in this area is habitat for a suite of species with threatened or rare conservation status, including the endangered Southern Cassowary, *Casuarius casuarius johnsoni*, and the rare Lumholtz's Tree-kangaroo, *Dendrolagus lumholtzi*. The area was a hotspot for road mortality of tree-kangaroos (Kanowski et al. 2001, Izumi 2001).

Underpass design and siting: The road upgrade design incorporated four underpasses 3.4m high and 3.7m wide, constructed as galvanized steel arches with a concrete base (fig. 2). The height of the cassowary (1.5-2m) and the requirement to allow animals a direct line of sight to attractive rainforest habitat at either end of the underpasses were the reasons for choice of underpass size. Three underpasses were specifically for faunal use and were subsequently monitored using sand track beds complemented by infrared-triggered digital photography. Underpass design and siting were established in collaboration with QDMR, researchers from the Rainforest CRC, the Centre for Tropical Restoration in the Queensland Environmental Protection Agency, and community groups including the Tree Kangaroo and Mammal Group, Trees for the Evelyn and Atherton Tablelands and Wildlife Rescue.

The three faunal underpasses incorporate "furniture" (fig. 2), including escape poles erected vertically using stirrups in the concrete base. The base was then covered with a ground cover of soil, leaf and branch litter, and rocks and logs to simulate conditions on the forest floor, to reduce the open spaces that rainforest species tend to avoid, and to provide cover for smaller rainforest animals from predators such as dogs, cats and owls (Goosem 2003). A narrow pathway was retained through the centre of the underpass to allow easy movement of larger species. A thick rope was swung from hooks in the ceiling of the underpass through the tunnel and tied to trees near either exit for possible use by obligate arboreal species. Escape poles and ropes provide havens for arboreal species needing to escape from predators (Kanowski and Tucker 2002).

Figure 2. Faunal underpass showing furniture, including escape pole (vertical tree branch), sand bed, attractive habitat at exit, soil, litter, rocks and logs to simulate rainforest floor conditions.

Underpasses were sited as close to remnant rainforest vegetation as possible and rainforest trees were planted between these remnants, incorporating food plants to attract the target species. These "revegetated corridors" completed rainforest habitat connectivity between the main rainforest blocks, the disturbed remnant rainforest patches, and the underpasses. "Corridors" were designed to funnel animals towards underpass entrances and varied in width from about 10m at the underpass entrance to about 50m near rainforest remnants. Trees were planted at 3-m spacings. Erosion control revegetation works on the cut-and-fill embankments incorporated low plants that were less attractive forage and cover for rainforest animals.

Target species

The furniture of the underpasses and associated revegetated corridors were designed to encourage multi-species' use by provision of cover and escape routes from predators and by simulation of rainforest floor habitat. However, two species of conservation significance were carefully considered. The first was the rare Lumholtz's Tree-kangaroo (fig. 3) because of the threat posed to the species by road kill and the known hotspot of mortality at the underpass sites. Adult individuals weigh up to about 8kg, and juveniles disperse through cleared habitat between rainforest fragments. The second was the endangered Southern Cassowary (fig. 3) because road kill is recognized as a threatening process for the species which is estimated to have a total population of less than 1,000 animals remaining. Cassowary presence in the area was confirmed during pre-construction fauna surveys. The large flightless birds reach 1.5–2m in height. Both species are also subject to dog attack, which is considered to be a threatening process. Cassowaries can move easily and quickly through the tunnel using the clear central pathway, whereas tree-kangaroos can escape from dogs using the escape poles.

Pre-construction data collection

Road kill monitoring: For twelve months prior to construction, two 0.5-km road transects were surveyed weekly for road kill by walking on either side of the road. Traffic volume on the road was approximately 600 vehicles/day. Vertebrates were identified to species *in situ* or laboratory.

Figure 3. Lumholtz's Tree-kangaroo (left) and Southern Cassowary (right).
(Photos by Jonathon Munro, Doug Clague)

Small mammal habitat use: Between July and November 2000, small mammals were trapped monthly over three or four consecutive nights in two replicate sites of each of four habitats: abandoned pasture; pasture overrun by the woody weed, *Lantana camara*; rainforest on the edge of the north and south main rainforest areas; and interior rainforest more than 100m from the edge. At each site traps in a grid comprising 20 Elliot aluminum boxes placed at 5-m intervals and two 45 x 20 x 15-cm cages were baited with a mixture of rolled oats, vanilla essence, peanut butter, and honey. Animals were identified to species, weighed, sexed, marked with metal ear tags, and released at point of capture.

Post-construction monitoring methodology

Road kill monitoring: After construction was completed, weekly monitoring by walking continued on adjusted 0.5-km road kill transects. Two similar 0.5-km transects were established along a narrow rainforest highway carrying similar traffic volume (800 vehicles/day) and passing through similar rainforest habitat in the same north-south corridor, but 5km to the north.

Sand-tracking and camera trapping: Underpass use was monitored weekly by recording animal tracks in a 1-m-wide strip of fine sand 5cm deep placed across the centre of each of the three underpasses from one side to the other. Tracks were identified to species where possible or species group in the case of rodents and other groups having similar tracks. Each discrete track was recorded as one use by a taxon, and only one track per week for each species was used in data analysis of species composition. Track monitoring was complemented by occasional use of infrared-triggered digital cameras (Faunatech 110) to confirm identifications.

Corridor use by small mammals: In 2004, after three years growth, corridor trees were between 3m and 6m in height. However, rainforest understorey and ground layers had not yet established, leaving a relatively bare soil surface. Between May and August 2004, small mammals were trapped in three replicates of three habitat types using grids of 22 traps at interior and edge rainforest similar to the pre-construction trapping scheme. Each of the three corridors was divided into two sub-sites – one at the northern entry to the underpasses and one to the south. Grids of ten Elliot traps and one wire cage trap were established in each of the six sub-sites.

Corridor use by birds: Birds were point-censused at each of the nine sites in September 2004. Each site was visited once in the morning between 6am and 9am and once on a different day in the afternoon between 3pm and 6pm. Data were collected from the centre of the small mammal trapping grid over a 20-min period with all birds seen or heard within a 20-m radius being recorded. Birds were assigned to habitat guilds (rainforest, mixed habitat, grassland species and raptors) according to Crome et al. (1994) with data pooled over observation periods.

Data analysis: Road kill data were compared between years and highways for vertebrate groups and habitat guilds using chi-squared tests of homogeneity with Monte Carlo estimation (Lange 1997). Similar tests compared habitats for species composition of birds and small mammals. Kruskal-Wallis nonparametric analysis of variance examined abundance of small mammal species with comparisons performed using Mann-Whitney U-tests. Abundances of rainforest and non-rainforest bird groups were compared between habitats using analysis of variance. Underpass use data from June 2002 to November 2004 was divided into five six-month sampling periods according to wet (Dec-May) and dry (Jun-Nov) seasons and temporal variations compared using homogeneity tests. Relationships between presence of feral and native species were examined by correlation.

Rope Tunnel Arboreal Overpass

Study area

In 1995, a canopy bridge was erected 7m above a narrow (7m clearing) unsealed road carrying very low traffic (mean 4.2 vehicles/day) through highland rainforest 30km southwest of Cairns (fig. 1). The site chosen had no natural canopy connections across the road for 120m in one direction and 50m in the other (Weston 2000). The bridge was constructed in the style of a 50-cm wide x 50-cm deep rope tunnel made of 10-mm silver rope held taut with plastic spacers and attached to wooden poles erected amongst the trees on the road edge The total span of the overpass is 14m (fig. 4a). The tunnel design was used to offer protection from aerial predators. Several short ropes lead from the ends of the tunnel to trees near the support poles. This structure was erected as a collaborative effort by the Queensland Parks and Wildlife Service with assistance from the Far North Queensland Electricity Board using funding from the Wet Tropics Management Authority, but its effectiveness was not monitored until early 2000. In 2000, a single strand of rope was also erected nearby for a short period.

Figure 4a. Rope tunnel arboreal overpass.

Figure 4b. Rope ladder arboreal overpass over two-lane sealed tourist road.

Target species
The main target species for both the rope tunnel and ladder overpasses were the rainforest ringtail possums (fig. 5), including the Lemuroid ringtail possum (*Hemibelideus lemuroides*), the Herbert River ringtail possum (*Pseudochirulus herbertensis*), and the Green ringtail possum (*Pseudochirops archeri*). All three species have an adult weight of between 0.8-1.5kg and have a conservation status of rare (Queensland Nature Conservation (Wildlife) Regulation, 1994). The Lemuroid ringtail possum is highly vulnerable in fragmented forests, as it is an obligate arboreal species, never descending to ground level (Wilson 2000). The Herbert River ringtail possum also very rarely descends to the ground. Roads, therefore, constitute a severe barrier to movements of both of these species, with canopy connections over the road as the only means of movement across the road. Effective arboreal overpasses could provide a solution to the road barrier. Other less obligate arboreal species that could benefit from effective overpasses include several that suffer high levels of road kill, such as the Coppery brushtail possum (*Trichosurus vulpecula johstoni*) and the Striped Possum (*Dactylopsila virgata*), as well as a group of little-known species including the Long-tailed pygmy possum (*Cercartetus caudatus*) and an arboreal rodent (*Pogonomys mollipilosus*).

Figure 5. Target possum species for rope tunnel and ladder overpasses: left – Green ringtail, centre – Herbert River ringtail, right – Lemuroid ringtail. (Photos by WTMA, Mike Trenerry)

Monitoring methodology
Scat collection and hair analysis: A 1-m-wide net of fine mesh designed to intercept scats dropped by arboreal animals was installed under the rope tunnel overpass for several days each month from January to October 2000 and permanently from August to October 2001. Scat source was identified from gross morphology and presence of grooming hairs by an expert in trace analysis. Sections of self-adhesive double-side tape were fixed around the rope to collect hair, which was then identified by the expert using external morphology and microscopic transverse sections.

Remote photography: A passive infrared-triggered camera (Foresite Buckshot 35A or Foresite Bucshot RTV) with red filter to mask the camera flash was periodically installed inside the entrance to the rope tunnel between January and October 2000.

Direct observation by spotlighting: Between July 2000 and February 2002, 40 hours of spotlighting (30W, red filter) were undertaken over 10 randomly selected nights in both wet and dry seasons where any animal using the structure was recorded. Spotlighting observations of animals using natural canopy connections or the edge of the forest were also obtained by walking along both sides of the road.

Rope Ladder Arboreal Overpasses

Study area
Two 10-m-long arboreal overpasses of a less elaborate design than the tunnel were erected over a narrow forestry track in 2000. One emulated the dimensions of the top surface of the tunnel, i.e., 50cm wide. A second was half the width of the existing bridge, i.e., 25cm wide, and resembled a rope ladder. In 2001, this rope ladder was lengthened and erected 7.5m above a sealed two-lane tourist road that carries about 150 vehicles/day through highland rainforest (fig. 4b). All rope ladder overpasses were constructed of “silver” rope and were attached to robust trees, the first two about five meters above ground level with a span of seven or five meters between trees, respectively, in an area where canopy connections provided an alternative route for movement of arboreal species. The distance between trees for the rope ladder overpass above the tourist road was 14m, and the nearest natural canopy connections were more than 200m distant in either direction. A heavy rope held the bridge taut and led into the forest from the support trees.

Monitoring methodology
Remote photography and 40- (forestry track) or 70-hr (sealed tourist road) spotlighting observations were undertaken. For the rope ladder over the sealed road, nets could not be used, so scat collection used funnels of wire mesh funneled into a PVC pipe collector, placed in Sep 2001 and removed in Oct or Dec 2001. Hair samples were obtained between August and November 2001 using a curtain consisting of a wire frame of 55cm diameter draped with double-sided tape and attached centrally to the bridge with tie wire so that animals using the overpass had to pass through or over it, thus brushing against the tape (Weston 2003). Animals moving across the sealed road overpass were captured on video opportunistically.

Results

Faunal underpass project

Road Mortality

Table 1 summarizes mammal, bird, reptile, and amphibian mortality of species native to rainforest, mixed, or grassland habitats on the upgraded road in the 12 months before construction and the two years post construction. Numbers in each vertebrate group killed on the narrow rainforest highway 5km to the north for the two years post upgrade are also included. Vertebrate road mortality was always much greater on the rainforest highway than on the upgraded road (174, 270 vs 56, 43, respectively, for the two years post-construction).

Prior to construction, feral and grassland species were the most common amphibian casualties on the narrow road with rainforest species almost absent. Grassland amphibian casualties declined post upgrade. Feral and grassland species also dominated the amphibian statistics on the rainforest highway to the north, although rainforest species were more abundant there than on the upgraded road. In contrast, reptiles, birds, and mammals from rainforest habitats dominated the statistics for those groups on the rainforest highway. However, rainforest species from these groups were uncommon on the upgraded road. The exception occurred during the first year after upgrade when rainforest birds became a more common casualty on the upgraded road. However rainforest bird mortality declined thereafter. Feral predators (dogs/cats) never featured in the statistics.

Composition of vertebrate groups in the mortality statistics changed over the three sampling periods along the upgraded road (X^2=41.467, df=6, P=0.000) due to a significant decrease in the proportion of amphibians and the concomitant increase in the proportion of birds in the first year post upgrade, followed by an increase in the numbers of mammals in the second year. Habitat preferences of road victims also changed due to the decrease in grassland species (particularly amphibians) and the increase in rainforest species (particularly birds), in the first year post upgrade and the increase in feral species (particularly mammals) in the second year (X^2=38.959, df=6, P=0.000). Proportionally, more rainforest species and fewer grassland and feral species were killed on the rainforest highway to the north than on the upgraded road (X^2=37.955, df=9, P=0.000).

Table 1. Road mortality monitoring for 12 months prior to road upgrade and two 12-month periods after road upgrade at upgraded road and highway 5km to north.

Group	**Upgraded road**			**Rainforest Highway**	
	Pre-upgrade	**1 year post-upgrade**	**2 years post-upgrade**	**1 year post-upgrade**	**2 years post-upgrade**
Amphibia	**62**	**28**	**17**	**87**	**123**
Rainforest	1	1	-	13	7
Mixed	2	-	-	2	-
Grassland	23	4	1	25	56
Feral	20	23	16	31	60
Unidentified	16	-	-	16	-
Reptiles	**1**	**1**	**2**	**22**	**26**
Rainforest	1	1	1	17	19
Mixed	-	-	-	1	4
Grassland	-	-	1	-	1
Feral	-	-	-	1	-
Unidentified	-	-	-	3	2
Birds	**5**	**21**	**12**	**42**	**78**
Rainforest	2	17	6	39	61
Mixed	1	3	4	2	17
Grassland	1	1	-	1	-
Feral	-	-	2	-	-
Unidentified	1	-	-	1	-
Mammals	**2**	**6**	**12**	**23**	**43**
Rainforest	2	5	3	6	26
Mixed	-	1	1	3	2
Grassland	-	-	-	-	-
Feral	-	-	7	1	1
Unidentified	-	-	1	13	14
Total	70	56	43	174	270

Habitat Use by Small Mammals
Ten mammal species were captured during the trapping periods prior to road upgrade (2000) and after three years of revegetated corridor growth (2004). Three rainforest species dominated in the forest interior (94.1%, 96.7%) and edge forest (91.1%, 85.7%) during both trapping periods (fig. 5). Two rainforest species (87.3%) also dominated in the lantana habitat prior to road construction. The dense canopy afforded by this woody weed provided habitat for these less specialised rainforest species, although a few grassland individuals were also recorded there. In contrast, before the road was constructed the abandoned pasture habitat was dominated by three grassland (44.7%) and one feral (31.9%) species (fig. 5) with a few rainforest individuals found in small clumps of lantana scattered through the grass. During the 2000 trapping phase no tagged rainforest individuals crossed the road and abandoned pasture. After three years of tree growth in the revegetated corridors, the habitat was dominated by one feral species (the house mouse, *Mus musculus* – 48.6% of individuals), which was undergoing a population explosion in the area (fig. 5). However, a rainforest species that prefers the rainforest edge was also very common (36.9% of individuals), and only 9.9 percent of individuals were from three grassland species, demonstrating that the canopy in the corridor had greatly reduced the dominance of species preferring this habitat type. Species composition in the revegetated corridors was significantly different from that found in the forest edge (X^2=45.615, df=8, P=0.000) and interior (X^2=80.536, df=9, P=0.000), whilst species composition in edge and interior were similar. Abundances of non-rainforest individuals were significantly greater in the revegetated corridors than in the rainforest edge (Mann-Whitney U test P=0.001) and interior (P=0.000), whereas abundances of rainforest individuals were not significantly different between habitats. None of the captured small mammals was recorded as having crossed the road.

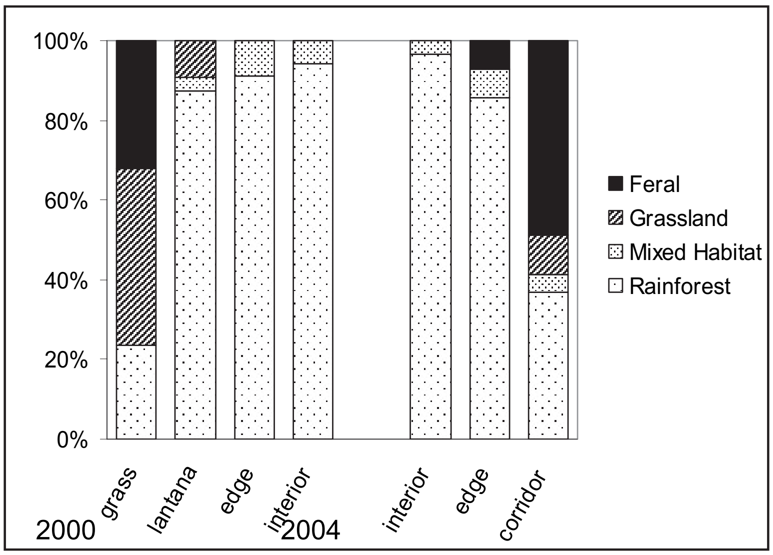

Figure 5. Use of habitats by rainforest, mixed habitat, grassland, and feral small mammals prior to road upgrade (2000) and after three years of growth of planted wildlife corridor (2004).

Corridor Use by Birds
Thirty-nine species were recorded using the planted corridors, edge, and interior rainforest, the majority of which were birds of rainforest habitats (27) with mixed habitat (9), raptors (2) and grassland species (1) less prominent. The rainforest edge was richest in species (29), with the rainforest interior (26) and revegetated corridors (25) having slightly reduced species richness. There was no significant difference in species composition between the three habitats (X^2-test), with all habitats dominated by rainforest species (fig.6). The revegetated corridors recorded the greatest proportion of mixed habitat species (36%) and lowest proportion of rainforest dependent species (52%), compared with 28 percent and 66 percent, respectively, at the rainforest edge and 19 and 81 percent, respectively, in the forest interior. However, this trend of greater guild diversity in the revegetated corridors was not significant. There were no significant differences in abundance of rainforest or non-rainforest birds across the three habitats (ANOVA P>0.15)

Use of Underpasses
Data obtained from sand-traps showed a variety of faunal groups using the underpasses (fig. 7). Two of the common species are rainforest dependent. The majority of the other groups comprised rainforest and mixed habitat species that could not be separated by tracks alone.

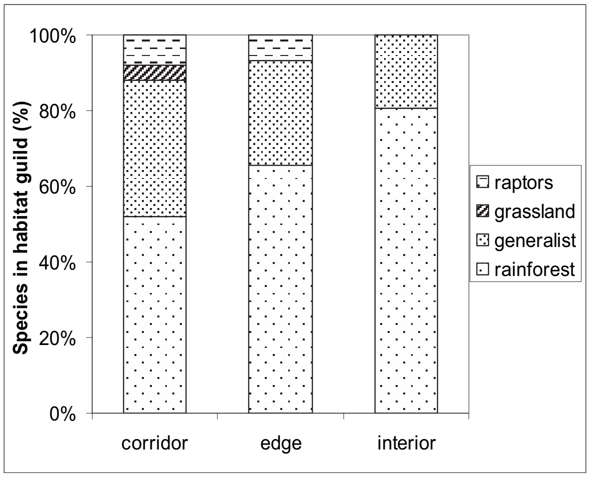

Figure 6. Use of habitats by rainforest, mixed habitat, grassland birds, and raptors after 3 years of growth of corridor trees (2004).

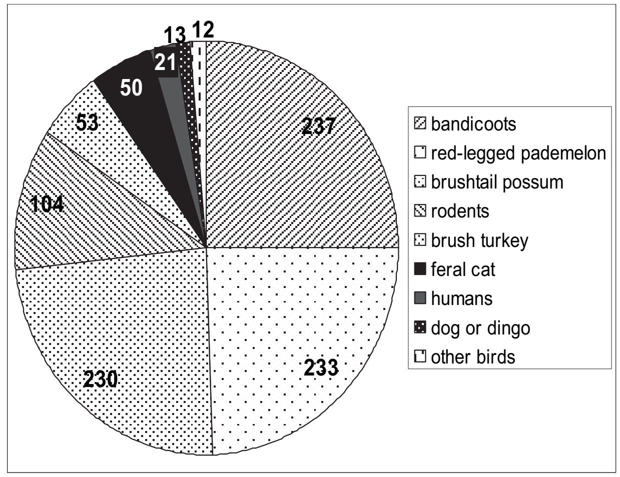

Figure 7. Sand-trapping records of use of underpasses by common faunal groups.
Note: Red-legged pademelon and brush turkey are rainforest species. The majority of recorded bandicoot, brushtail possum, rodents and other birds would be from rainforest with occasional individuals of mixed habitat species or possible grassland rodents

However, based on the proportion of rainforest species captured or observed during fauna surveys and the species identified during camera trapping (fig. 8), the majority of these are likely to be rainforest species. Even in the rodent group, for which trapping captures would suggest feral species predominated, the size of tracks suggested that these could only be rainforest or grassland species, as tracks of the feral house mouse tracks are too small to be recorded in the sand. Seasonal variations in use of underpasses were observed (X^2=31.755, df=20, P=0.046) and may demonstrate seasonal peaks in dispersal or breeding. Non-native species' use was relatively low (mean 13 tracks per 6 months) compared with native species' use (mean 164 tracks per 6 months). Feral predator (cat, dog/dingo) use varied with season (X^2=14.273, df=4, P=0.006), but no correlation was recorded with use of underpasses by native species overall or any of the common native species groups (P>0.25). Native and non-native species, including predators, regularly use the underpasses and also use the underpasses concurrently, either on different days, or at different times. Tracks of both have been recorded in all but three weeks over the three years. Only once has there been any sign of predation near an underpass.

Figure 8. Infrared-triggered digital camera photographs of underpass use. Left – pademelon, center – brushtail possum, right – brown bandicoot.

Target Species
The underpasses have been used on at least two occasions by the target Lumholtz's tree-kangaroo. One complete crossing was verified by following footprints from one entrance to the other. The species is often observed in trees near underpass entrances. The Southern Cassowary has yet to use an underpass, having become exceedingly rare in the area. However, on one occasion a bird was observed attempting to climb through fencing recently erected at an underpass entrance to deter cattle from resting in the tunnel.

Rope tunnel and ladder arboreal overpasses
Table 2 shows species recorded using the various crossing structures. After five years of habituation prior to monitoring, the rope tunnel was used by all target species. Use of the single rope strand over the 7-m road clearing was inconclusive without any direct or photographic evidence. Natural canopy connections above the narrow track were preferred over the 5- to 7-m spans of the narrow and wide rope ladders. However, where no canopy connections occurred nearby, the narrow rope ladder over the sealed tourist road was used by the majority of species. Fig. 9 shows a selection of animals using either rope tunnel or ladder style overpasses.

Table 2. Species identified as using the rope tunnel and ladder overpasses.

Species	Rope Tunnel 7m clearing	Rope single strand near tunnel 7m clearing	Wide rope ladder, canopy connections 7m span*	Narrow rope ladder, canopy connections 5m span*	Narrow rope ladder Sealed road 14m span
Lemuroid ringtail Possum	scat, photo, spotlighting	Scat	Scat	Scat	Spotlighting, scat
Herbert R ringtail possum	scat, photo, spotlighting	Scat	Scat, photo	Scat	spotlighting
Green ringtail possum	Photo		Scat	Scat	
Coppery brushtail possum		Scat, hair		Scat	Photo, hair, spotlighting,
Striped possum	Photo				spotlighting
Long-tailed pygmy possum				Scat**	
Lumholtz's Tree-kangaroo			Scat	Scat, hair**	Hair*
Fawn-footed melomys	scat, photo		Scat	Scat	

*As canopy connections were present, scats may have fallen from above the overpasses.
**These scat and hair samples were not from the centre of the overpass, so the species may not have crossed.

Target Species
All target rainforest ringtail possums have been observed using at least one of the structures (table 2). Additionally, species including brushtail and striped possums that are common in road mortality statistics have also been observed to use at least one of the structures. Use of the rope ladder overpass over the sealed tourist road is now common, with approximately one animal per hour now observed crossing. Multiple individuals of Lemuroid and Herbert River ringtail possums are also known to be prepared to use the same rope ladder overpass, verified by different coat patterns in Herbert River ringtail possums and individuals from different size/age classes of Lemuroid ringtail possums.

Figure 9. Ringtail possums using arboreal overpasses: left and right – Lemuroid and Herbert River ringtail possums on 14-m-span rope ladder over a sealed tourist road; center – Green ringtail possum in a rope tunnel over 7-m-wide unsealed road clearing.

Discussion

These studies have demonstrated the effectiveness of several structures for provision of connectivity above or below roads for rainforest fauna. Road mortality has remained low near the underpasses and many species are using both underpasses and overpasses. However, it must be recognized that natural connections rather than artificial structures are always preferred by rainforest species (Weston 2003), so avoidance of rainforest habitat should be considered the best option when considering road upgrading or new road construction (Goosem 2004). Where avoidance of rainforest is impossible, these mitigation methods have proven to be successful for many rainforest species including specialized rainforest species that avoid the open, disturbed spaces of road clearings.

Faunal underpasses

Use of underpasses and rainforest corridors
Not all terrestrial wildlife species found in these forests have been shown to use the underpasses. There are several potential explanations. The lack of sufficient time for habituation to the structures or the establishment of suitable rainforest habitat in the corridors is one explanation. Small mammal trapping in the corridors demonstrated that several mammal species require further tree growth and establishment of understorey and ground layer before colonization of the corridors is likely to occur and competition eliminates the feral and grassland species. Several years of habituation may be required prior to use of crossing structures (Clevenger and Waltho 2003) with long monitoring periods required to capture sufficient data and variability to provide satisfactory sampling of changing conditions (Hardy et al. 2003). The faunal

underpasses have now been monitored weekly for four years, with one generalist rainforest species commencing use of the structures within a week of their completion and two other groups appearing within four to six weeks. Abundance of individual tracks has increased in that time, together with increasing species richness. However, in the past year, the number of mammal species known to have used the underpass has remained relatively static (J. Munro pers. obs.), although the numbers of bird species observed flying through the tunnels continues to increase. It is proposed to continue underpass monitoring for at least another year and to again examine corridor community composition after a further period of growth.

Alternatively, failure to detect several terrestrial mammal species may be a function of rarity or our inability to distinguish them from others. Fauna surveys and trapping confirm that each of the missing species is very rare in the area and, therefore, may not have used the underpasses due to their low abundance. Also, distinguishing small species from more common mammals is difficult using sand tracking, and the complementary photography may be insufficient to capture rare species. It is planned to increase the use of photographic methods at the underpasses during the next 12 months. Fine-scale tracking methods, such as marble dust (Mata et al. 2003) or soot boards (Hardy et al. 2003), may also be trialed.

A third possibility is that the corridors are not wide enough (Laurance and Laurance 1999) and may consist entirely of edge habitat which fragmentation-sensitive species will not colonise. Restoration corridors already planted in the region, however, suggest that this is not the case for the majority of rainforest species (Simmons and Tucker 2002). Nevertheless, the species most vulnerable to fragmentation, such as the rare arboreal possums, seemingly remain fragmented with no records of attempted road or underpass crossings. For these species with strict habitat specialisations, it has been suggested that corridors should be floristically diverse and at least 30-40m in width (Laurance and Laurance, 1999). This would require further corridor plantings to close canopy gaps, particularly near underpass entrances, and also extend the width of the corridors (Bushnell 2004). For arboreal species, a rope bridge overpass may also be installed once trees attain sufficient height.

A fourth alternative is that the cover provided within the crossing structures may be insufficient to encourage habitat specialists to venture under the road, and the structures may not be used in their current form. Factors such as traffic noise and headlight disturbance of nocturnal species at underpass entrances may also restrict use of the structures. Traffic noise levels are known to be very high at the underpass entrances when large trucks pass by (Goosem et al. 2004). Encouraging greater growth of corridor plants near entrances may reduce such disturbance.

Many authors have demonstrated that wildlife can be selective in their choice of crossing type (Mata et al. 2003, Clevenger and Waltho 2003) and suggest that a variety of underpass designs are complementary for multi-species use. Some species, particularly large mammals, prefer open structures, such as ecoducts, and high, wide, short underpasses, while others prefer more constricted crossing structures and favor underpasses (Clevenger and Waltho 2005). In this study, the initial proposal was to include a range of small underpasses together with a larger structure because Australian rainforest fauna is generally small in size. However, in consideration of one target species, the 1.5- to 2-m-tall Cassowary, it was decided to design and construct larger structures that could be used by this endangered species. To encourage multi-species use and yet maintain the project within financial constraints, we simulated the forest floor within the underpasses as far as possible, and provided a range of cover and escape options for smaller species and those subject to predator harassment. The strategy appears to have been successful, as mammals and birds encompassing a range of sizes and levels of shyness have used the underpasses. However, the possibility remains that species yet to use the underpasses simply have not been provided with their preferred conditions within the crossing structures. This is certainly the case for the arboreal possums, which have not been observed within or near the underpasses. When it was decided to build large underpasses, consideration was given to installing smaller pipes within the underpasses for small species, if it was found that they do not use underpasses once the rainforest corridor understorey and ground layers have become established. This would be similar to the “vole tube” described by Foresman (2003).

Target Species

Lumholtz’s tree-kangaroo, one of the target species for the study, has been observed to use the underpasses twice and is often seen in trees near the entrances. The area which was previously a hotspot for tree-kangaroo mortality has also recorded one instance of road kill of the species, although this did not take place near the underpasses or the mortality transects. Insufficient time has elapsed to determine whether this reduction in road kill rate is significant. One cassowary (of very few remaining in the area) has been observed trying to reach an underpass but was deterred by fencing erected to repel cattle from resting there. This fencing can be removed now that cattle have been removed from the area.

Predators vs. Prey

An interesting aspect of this study was the finding that the occasional presence of feral predators did not appear to influence use by native species (Hunt et al. 1987, Little 2003). There was no correlation between use by any or all native species and the presence of cats or dogs/dingos. The inclusion of various strategies for escape from predators including rocks and logs for cover and poles for escape from dogs may have contributed to this result. Feral predators are considered most likely to pose a problem (Little 2003), as native prey have not co-evolved with these species and could be more susceptible to predation at passages because of failure to detect and avoid signs of predators. This was shown not to be the case. Native predators also have used the underpasses, including an owl roosting on the rope and snakes sunning themselves in the underpass entrances, and feral cats have twice sheltered from rain, but in no instance has underpass use been prevented. There has also been no evidence that the passages comprise traps for prey (Hunt et al. 1987) with only one observation of predation occurring near the underpasses.

Rope bridge arboreal overpasses

Canopy connectivity for obligate arboreal species was provided by the 14-m rope ladder style overpass in an area that did not have other canopy connections. This structure was used by different individuals of the same species and by multiple species, seven mammals in all. The majority of individuals observed using the initial tunnel design actually crossed along the top surface of the structure, prompting simplification of the design to a rope ladder for further trials. More than five months elapsed after construction of the rope ladder overpass over the tourist road before any possum species were photographed on the structure, and another six weeks passed before a target animal was spotlighted crossing the road via the structure (Weston 2003). Although this period of habituation was required, crossing events then became common. Crossing rates have risen to a current level of around one every hour.

Although a single thick rope structure was trialed, results were inconclusive, and the stability afforded by the rope ladder design, together with added safety, suggests that this easily affordable design is preferable. Safety aspects for wider highways suggest attachment to poles with concrete footings rather than attachment to trees. However, durability of the structures themselves is excellent. After 10 years, the original rope tunnel design made of silver rope with a high UV rating is showing little sign of decay, even without any maintenance.

Arboreal overpasses have been installed elsewhere in Australia, based on the designs shown to be successful in rainforest habitats. These are generally much longer structures than those we have monitored to date. The tree density of the forests which these new installations link is much more open than rainforest systems, so resident possums and gliders are expected to be less dependent on canopy cover and thus may be more prepared to move across the clearing using the arboreal overpasses. Little monitoring of these longer structures has been undertaken to date. However, a 70m-long tunnel-design overpass (fig. 10) has been monitored irregularly with digital infrared photography, and brushtail possums appear to be regular users (D. Bax pers. comm.). A glider has also been photographed. Rope ladder-style structures have been erected in Brisbane, Queensland, across a road dividing an urban habitat corridor (fig. 11). Monitoring will commence soon.

Figure 10. 70m-long tunnel-style overpass erected in open forest habitat near Newcastle, NSW. Brushtail possum using the interior of the structure. (Photos by David Bax)

Figure 11. 60m-long rope ladder-style arboreal overpass erected in open forest habitat in Brisbane, Queensland. (Photos by Pauline Fitzgibbon)

Our current research focus is on whether arboreal rainforest fauna will also use longer rope overpasses to cross highways. Ringtail possums are being radio-tracked to determine home ranges and, in particular, road frontage of home range, to ensure that rope overpasses are accessible to the home ranges of several individuals. Animals using adjacent habitat will be tracked and any movements across the road determined. Translocations to determine whether animals will return to home ranges via the overpasses may also be attempted after sufficient time for habituation to the crossing structures. Overpasses will again be monitored by photography, spotlighting, and scat and hair sampling.

Conclusions

Use of underpasses or overpasses is not necessarily proof that the structure of faunal populations has been sufficiently re-connected to maintain populations on either side of a road. Population studies are crucial in determining whether sub-populations of a metapopulation connected by crossing structures are of sufficient size and/or receiving sufficient recolonising individuals from other sub-populations to maintain themselves. However, such studies require a long-term financial commitment to provide in-depth information regarding survivorship, recruitment, and dispersal of juveniles, physical condition, short-term and long-term reproductive rates, sex ratios, and genetic exchange (Hardy et al. 2003). Information demonstrating isolation of populations resulting in reduced breeding opportunities, skewed sex ratios, decreased fitness and reduced probability of population survival takes many years to collect and is generally outside the levels of financial support supplied by road management agencies in Australia. However, evaluation of usage and road mortality by a relatively cheap monitoring system can provide a good indication of effectiveness, particularly if monitoring continues in the long term. Such studies provide answers to the most basic question posed by Hardy et al. (2003): Do crossing structures reduce mortality and allow animals to move safely across roads? If long-term monitoring demonstrates frequent use by a variety of wildlife and low mortality rates, the wildlife passages should at least be helping locally to preserve those species by connecting habitats and thereby restoring home ranges, genetic exchange, and the potential for recolonisation after catastrophes. These studies have demonstrated this for common rainforest terrestrial species and also for rare arboreal species. Longer-term monitoring is required to determine whether species which have not been recorded using the artificial crossing structures are actually displaying some sort of innate avoidance behavior and whether their exclusion will result in some form of long-term flow-on effect in ecosystem function.

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Biographical Sketches: Miriam Goosem is co-leader of a project examining sustainable linear infrastructure within the Rainforest Cooperative Research Center. She has been studying linear infrastructure impacts and mitigation in tropical rainforest since 1989 through master's, PhD, postdoctoral, and research fellowship stages. She is a senior research fellow based in the School of Tropical Environment Studies and Geography at James Cook University, Cairns, North Queensland, Australia, where the team of road ecologists is examining a diverse range of road impacts and mitigation measures in tropical rainforest ecosystems, including fragmentation, road mortality, edge effects, noise impacts, headlight disturbance, and mitigation through natural means and artificial structures, including bridges, purpose-built underpasses, culverts, and arboreal overpasses.

Nigel Weston is a research road ecologist within the Rainforest CRC sustainable linear infrastructure project at JCU, Cairns, whose master of science study investigated the mitigatory potential of rope tunnel and ladder overpasses for arboreal rainforest fauna. He is currently engaged in extending this work to encompass larger highways with Dr. Robyn Wilson undertaking distribution studies.

Sally Bushnell is a master's student of natural resource management at JCU, Townsville. Her master's project in the Rainforest CRC examined the effectiveness of faunal underpasses and associated revegetated corridors in mitigating road mortality and providing connectivity for rainforest fauna.

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Modeling the Effect of Roads and Other Disturbances on Wildlife Populations in the Peri-Urban Environment to Facilitate Long-Term Viability

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Abstract: Roads and traffic exhibit a multitude of impacts on wildlife populations. Most road ecology research seeks to assess the quantity and diversity of fatalities from collisions with vehicles, while studies documenting the impact of roads on the structure and sustainability of wildlife populations adjacent to roads have been lacking.

Populations of wildlife existing within the confines of fragmented reserves are particularly susceptible to fatalities on roads, especially those situated within peri-urban and semi-rural matrices.

We chose to examine the effects of disturbances, including fatalities on roads, using four case studies from Australia. These studies included a range of fauna, including the long-nosed bandicoot, the koala, and two studies of the swamp wallaby. To explore the impact of the various threats to wildlife living in peri-urban reserves, each case study utilized a population modeling approach. A combination of PVA modeling and sensitivity analysis was used to assess the impact of disturbances on the populations and identify appropriate management options to target disturbances. We discuss the utility of this approach in enabling conservation managers to assess the long-term viability of wildlife in these environments and in establishing management targets for improving viability in populations predicted to decline.

In all four cases road fatalities were a major disturbance, but the different landscape characteristics of each reserve and other threat levels altered the relative impact of roads. The findings suggest that the combination of a range of management options, such as road fatality prevention, control of predation, and improvements in immigration and fertility, are often necessary although the exact combination will be location specific.

Road management in the peri-urban environment can play a substantial role in ensuring the persistence of isolated populations in protected reserves that are surrounded by, and traversed by, roads. Given the broad geographic scale of roads, their effect on wildlife populations may be best understood from a landscape perspective, taking into account other disturbances that may be influencing population viability. We recommend the integration of PVA, sensitivity analysis, and GIS-based dispersion models as a suitable means for addressing both the temporal and spatial impacts of roads in order to successfully manage wildlife populations.

Introduction

Urban and peri-urban ecosystems include a multiplicity of anthropogenic disturbances, such as disruption by pets and habitat fragmentation and loss that impinge on the persistence of urban wildlife populations. Many of these disturbances are managed or planned for in management plans for peri-urban reserves (NSW NPWS 2000). Yet the impacts of roads on wildlife in these reserves are often given only cursory management consideration if any. This is a cause for concern as many studies indicate that roads can be a debilitating source of disturbance (Jones 2000; Lopez et al. 2003; Ng *et al*. 2004), particularly when road-impacts combine with other human-induced impacts to be the final blow to native wildlife living in semi-rural matrices of remnant bush land, agricultural lands, and urbanized areas.

Roads and the vehicles that traverse them have a multitude of effects on both the surrounding environment and the wildlife that persist there. A growing awareness of this problem has prompted a wide range of research that seeks to document the effects and develop programs to mitigate negative impacts (Forman et al. 2003; Sherwood et al. 2002). There have been numerous studies describing the pattern of road-based fatalities in different parts of the world, and yet relatively few studies have examined the impact of these fatalities on the conservation of roadside populations (Hels and Buchwald 2001; Lopez 2004). Frameworks for addressing the viability of roadside populations have to date received little attention, and exploration of this concept will provide conservation and road managers with the necessary tools for designing conservation strategies that best facilitate sustainable wildlife populations. Mitigation of road impacts will not always be the most beneficial conservation strategy, as it will depend on the impacts of other disturbances on the populations in question.

As a first step in this process, we use examples taken from Australia to indicate how currently available population models can be used to provide this framework. We examine the impact of roads relative to other disturbances, such as residential development, predation and fire, and discuss the potential benefits of managing roads in four different peri-urban reserves and how target-based conservation strategies can be developed. Four cases are explored, including two swamp wallaby populations on the outskirts of Sydney (Ben-Ami 2005; Ramp and Ben-Ami in press), a bandicoot population confined within Sydney (Banks 2004), and a koala population in northern New South Wales (Lunney et al. 2002). In all four cases road fatalities were a major disturbance, but the different landscape characteristics of each reserve and other threat levels altered the relative impact of roads. In all four cases population viability assessment (PVA) was used to model various management strategies aimed at improving the viability of the populations. These models were used to ascribe target-based objectives for conservation managers.

Case Summaries

Koalas at Iluka (NSW, Australia) – Lunney *et al*. (2002)

The Iluka Peninsula is situated at the mouth of the Clarence River in northern New South Wales. The peninsula contains two core natural areas: the World Heritage Iluka Nature Reserve, which is 136 ha, and the adjacent Bundjalung

National Park. The township of Iluka which lies directly adjacent to the reserve was settled in the 1870s. Early clearing, sand mining, urban subdivision, and population growth have reduced available koala habitat. The only road out of the township runs along one edge of the reserve and effectively bisects the peninsula along its length. The human population of Iluka is approximately 2,000, although there are an estimated 20,000 visitors per annum to Bundjalung National Park.

A two-year study of the koala population identified 17 individuals (D. Lunney, unpublished data), while it was estimated that the reserve had enough room for a population size of 50, much higher than was present. The major threats to the Iluka koala population were identified as habitat loss due to urban development, wildfire, fatalities on the road, predation by dogs, and low fertility due to disease (Ingersoll 1998; Lunney et al. 1996b; Lunney et al. 2000). Habitat loss and fatalities on roads were considered the most significant and immediate factors in the decline of the koala population, although low fertility was of concern. Movement of animals was known to connect the Iluka koala population to a larger population in Bundjalung National Park (Lunney et al. 1996a), forming part of a regional metapopulation (Haila et al. 1996). Two extensive bushfires in Bundjalung National Park in 1989 and 1994 were considered to have affected the mortality and fertility of the Bundjalung National Park koala population (NSW National Parks and Wildlife Service 1995). These fires also would have impacted the Iluka population through the drop in immigration from the national park.

Simulations conducted using PVA indicated that the population of koalas was heading for extinction. Investigation of the potential benefit of different management strategies aimed at preventing this decline indicated that a substantial reduction in fatalities on roads, either as a single mitigation strategy or even when considered with an improvement in fertility through disease control, was not sufficient to prevent the population from declining toward extinction (table 1). In contrast, the impact of even a low level of regular immigration was shown to dramatically improve the viability of the population in the long term, as the modeled population was particularly sensitive to immigration of females. A considerable improvement in fertility combined with regular immigration was predicted to provide the most effective population improvement, achieving both high probability of survival and an increased population size for this modeled population.

Table 1. Management scenarios explored for koalas within Iluka Nature Reserve. See Lunney et al. (2002) for more details.

Scenario	Initial Population	Fertility (%)	Probability of Survival	
			20 Years	50 Years
Basic model	20	20	0.25	0.01
Decrease fatalities 40%	20	20	0.58	0.06
Increase fertility 100%	20	40	0.69	0.12
Immigration 1M/1F per year	20	20	1	1
Immigration 2F per year	20	20	0.73	0.52
Fertility +20%, Fatalities -20%, Add 20 animals	40	24	0.71	0.05
As above, Immigration 1M/1F per 2 years	40	24	0.99	0.99
Fertility +35%, Immigration 1M/1F per 4 years	20	27	0.99	0.99

This outcome suggests that while fatalities of koalas on the road and predation by domestic dogs are of major concern and should remain as targets for mitigation, the viability of the population in the long term will be dependent upon improving immigration and fertility.

Bandicoots at North Head (NSW, Australia) – Banks (2004)

North Head is a 360-ha isolated pocket of remnant bushland at the opening to Sydney Harbor. A population of the threatened long-nosed bandicoot (*Perameles nasuta*) present on the headland is a small isolate of a once Sydney-wide population that has eroded, and now shows all the hallmarks of a fragmented population in danger from predation, road-based fatalities, and disease. Research into the ecology of the population over five years suggested that it was small and potentially declining (Chambers and Dickman 2002). The headland includes just over 40 percent of protected reserve and a mixture of residential, council, and private land holdings, none of which is free from potential development.

Major land use changes are already under way, and the primary reason for the modeling undertaken was the potential for a proposed development project on the headland. The PVA simulation considered a population size of 100 animals with a mean total carrying capacity of 120 individuals, allowing some scope for disease and natural mortality to hold the population below carrying capacity. It was assumed that the population had an even sex ratio (Scott et al. 1999), a stable age distribution, and also that all males were able to breed in a polygynous breeding system (Banks 2004). Bandicoot populations are typically variable, having evolved to exploit highly unpredictable conditions. Juvenile mortality in bandicoots is typically high, regardless of annual conditions, while adult mortality is relatively low, with 10 percent mortality every 10 months. Causes of mortality include predation by cats, dogs, native predators (birds of prey), and starvation (lack of resources), although the most common source of death is from collisions with vehicles. Predation by red foxes (*Vulpes vulpes*) is sporadic but devastating, with two recordings of their presence on the headland in the past seven years, killing four radio-collared animals in one instance and 15 adult animals in another year.

The simulation indicated that under current conditions, the population had a good chance of survival (table 2). The prevention of predation was predicted to have a positive effect on the population, indicating the need for a rapid response to fox arrival on the headland.

Table 2. Management scenarios explored for bandicoots at North Head. See Banks (2004) for more details.

			Probability of Survival	
Scenario	Carrying Capacity	Adult Mortality (%)	20 Years	50 Years
Basic model	120	10	0.90	?
Remove predation	120	9	0.97	0.94
Increase fatalities	120	16	0.68	0.20
Increase habitat and fatalities	200	16	0.85	0.35
Decrease habitat and increase fatalities	75	16	0.69	0.28

If the proposed development went ahead it was anticipated that fatalities on roads might increase, and this increase was predicted to have a dramatic impact on the probability of the population surviving. The likelihood of extinction after 50 years was 0.8 under this scenario. As a potential means of offsetting this increase in fatalities, the possibility of increasing the amount of habitat was examined (i.e., increasing the carrying capacity from 120 to 200 individuals). The modeling indicated that even with this adjustment the population would still be at risk of extinction. On this basis the proposed development was suspended.

Swamp wallabies at Muogamarra Nature Reserve (NSW, Australia) – Ben-Ami (2005)

Muogamarra Nature Reserve is a 2,274-ha peri-urban reserve located 50 km north of Sydney. A population of swamp wallabies (*Wallabia bicolor*) exists within the reserve but is isolated as the reserve is bounded by Berowra Creek, the Hawkesbury River, the six-lane F3 Freeway, and the townships of Berowra and Cowan. Although swamp wallabies have an extensive range, running from Cape York to southeastern Australia, an estimate of their numbers is purely guess-work. In addition, the genus *Wallabia* is distinct from all other wallabies and represents a monophyletic clade. The swamp wallaby population in Muogamarra Nature Reserve ranges from 300 to 800 individuals. The public are prohibited from entering the reserve, and it is, therefore, reasonably pristine.

Threats to the swamp wallabies within the reserve include wildfire, road-kill, and predation. Detailed fire records for the past 25 years show that two large-scale fires occurred within the last 10 years, although there were none in the previous 15 years (NSW NPWS 2000). Radio-tracking of mature individuals during fire events in the reserve indicated that all wallabies survived load-reduction burns by management and that where the fuel load was decreased in this way all wallabies survived the subsequent wildfire (N. Garvey, University of New South Wales, unpublished data). As there are no roads within the park, only along its border, road-based fatalities are not high, although estimates indicate that roughly five percent of the population is killed on the F3 Freeway and Pacific Highway each year. Predation by domestic dogs, entering the park from townships, appears to be a larger problem, with 10 percent of juveniles and 5 percent of adults taken annually (Ben-Ami 2005). The swamp wallaby is the preferred dietary wildlife item of free-roaming domestic dogs and a component of the red fox diet in the reserve.

As the population was currently predicted to be in decline, a range of management strategies was explored to investigate how the population could be prevented from this decline (Ben-Ami 2005). If predation was to be removed from the system, the annual mortality of young (< one year old) and adult females would decrease by about half from the current best estimates of 25 and 20 percent, respectively (table 3). Under this scenario, the population is projected to experience a positive growth trend of 14 percent per year. If only one major fire were to occur every 50 years, rather than two, no other management actions would be necessary. Under this scenario, over the next 50 and 100 years, the population would only be limited by the carrying capacity of the reserve, and the risk of extinction would be minimal. This possibility is unlikely to occur given that in the last 10 years two major wildfires occurred in the area. As such, prescribed-burn management action is critical. This action increases the chance of swamp wallabies surviving wildfires, and even a slight increase in swamp wallaby survival of large-scale wildfires, from 85 to 90 percent, can ensure the population's survival. The elimination of road-kill along the Pacific Highway and the F3 Freeway adjacent to Muogamarra would also decrease annual mortality and, therefore, greatly increase the probability of survival. However, even if road-kill was completely eliminated from the system, the risk of population extinction would not be completely removed. From this it is apparent that while the prevention of road-fatalities in this system is important, on its own it would not stabilize the population.

Table 3. Management scenarios explored for swamp wallabies within Muogamarra Nature Reserve. See Ben-Ami (2005) for more details.

Scenario	Female Mortality		Probability of Survival	
	Juvenile	Adult	50 Years	100 Years
Basic model	25	20	0.88	0.29
Prevention of second wildlife in 50 years	25	20	1	1
Predator control	15	15	1	1
Eliminate road-kill	20	15	0.99	0.87

Swamp wallabies at the Royal National Park (NSW, Australia) – Ramp and Ben-Ami (In Press)
A population of swamp wallabies also exists to the south of Sydney in the Royal National Park, the second oldest national park in the world behind Yellowstone. The park covers 16,000 ha and has a wide diversity of vegetation communities, including heathland, woodland, eucalypt forest, rainforest, and wetland. The park contains 90 km of single-lane paved roads with various speed zones of 50, 60, and 80 kmh^{-1}, although recommended speeds are often 25 kmh-1 on bends. Traffic volume comprises mostly local residents of the two townships within the parks boundary, visitors and tourists, and NSW National Parks and Wildlife Service staff. Again, as is common in peri-urban reserves, the park is effectively isolated. On its western and southern limits the park is bounded by a major highway, partially fenced train tracks, and contiguous urban communities. The Pacific Ocean and a series of bays and inlets mark the eastern and northern boundaries of the park. Population assessments using fecal pellet counts and known defecation rates estimated the population in the Royal National Park to be 402 in 1999, 328 in 2000, and 381 in 2001 (Moriarty 2004). As pellet-based population surveys tend to be inaccurate as pellet degradation can lead to an underestimation of population size (Johnson and Jarman 1987), we set the initial population size at an optimistic 1,000 individuals.

Threats to the swamp wallabies within the reserve include wildfire, road-kill, and predation. Fires occur regularly in the park, but wallaby survivorship is thought to be high as these fires are of low intensity. There are few if any dogs within the park, although there are red foxes and these may predate on juvenile swamp wallabies (Banks 2004; Higginbottom 2000). There is currently no published information on how predation affects breeding success but it is highly likely that it does so. Road-based fatalities are thought to be the primary cause of mortality within the park, killing up to 15 percent of the population annually (Morrissey 2003).

Given the estimated levels of the threats identified, the population was predicted to be in a slow decline. A range of management strategies was explored to investigate how the population could be prevented from this decline (Ramp and Ben-Ami In Press). The high survival rate associated with wildfires and the negligible impact of increased carrying capacity on the model suggest that wildfire would not, on its own, be an effective management strategy (table 4).

Table 4. Management scenarios explored for swamp wallabies within Muogamarra Nature Reserve. See Ramp and Ben-Ami (In Press) for more details.

Scenario	Female Mortality			Reproduction	Population after 100 years
	Pouch Young	Juvenile	Adult		
Basic model	25	30	20	0.70	100 ± 129
Decrease road-kill by 20%	23	27	18	0.70	876 ± 143
Decrease road-kill by 40%	21	24	16	0.70	973 ± 49
Decrease road-kill by 60%	19	21	14	0.70	989 ± 24
Decrease foxes by 20%	24	29	20	0.71	385 ± 209
Decrease foxes by 60%	22	27	20	0.73	831 ± 187

Management of the red fox population was shown to be beneficial; however, the growth rate of the swamp wallaby population changed from negative to positive only after 60 to 80 percent of fox-related fatalities was prevented. On the other hand, reducing fatalities of female swamp wallabies on roads by only 20 percent had a dramatic impact on the viability of the population, and any reduction greater than this resulted in the population reaching carrying capacity and becoming stable. Road management, as a means of reducing fatalities and increasing reproduction, is clearly the most beneficial approach to reversing the current trend of population decline. In addition, managers have a tangible goal of fatality reduction on roads to achieve, although on-going monitoring should be encouraged to investigate the success of the program. The only remaining factor park managers need to consider is just how they will achieve this reduction.

Conclusion

Vehicles on roads caused fatalities of wildlife in all four reserves and presented a direct threat to the persistence of the populations investigated. In the Royal National Park where the population of swamp wallabies is in decline, roads were the primary threat, yet in the other systems roads were not the major contributor to decline. However, in the case of North Head, if the proposed development was to proceed, the likely increase in road-kill was predicted to be the primary cause of decline. In the Muogamarra Nature Reserve, predation by free-roaming domestic dogs and wildfires were the primary disturbances, yet these disturbances are difficult and expensive to manage. Easier to manage disturbances, such as road mortality in conjunction with the restriction of free-roaming domestic dogs, would also ensure the persistence of the population, yet these factors are not addressed by park managers. At Iluka, the small koala population was identified as requiring increased immigration and fertility, yet before this could be successfully addressed, road-kill and predation made the population virtually extinct. In part, this outcome reveals a collective inability to address local threats, such as road deaths, clearing of koala habitat, and a high frequency of fires (Lunney *et al.* 2002).

The take-home message is that conservation strategies that seek to address the impact of roads must include an assessment of other threats to wildlife and must be situation specific.

Management of peri-urban and urban reserves in Australia is focused on maintaining biodiversity, cultural heritage, and ensuring public access. Contrary to the objectives of conservation management plans, roads are normally listed as an asset to be developed further to support fire management programs and public access of the peri-urban parks. Fire management is a well recognized threat in the Australian landscape whose management, unfortunately, requires the mobilization of heavy equipment. Nonetheless, as evidenced by the case summaries and the stated objectives of management plans for national parks and reserves, a road management program should accompany roads that intrude on such conservation areas, and these plans should include models to estimate the effectiveness of various conservation strategies that could be employed to ensure the viability of wildlife populations. Little effort has so far been made to utilize the improvement in population modeling over the last 10 years, and there is great opportunity to develop robust frameworks for managing our wildlife and transportation networks sustainably.

Biographical Sketch: Dror Ben-Ami received his B.A. in biology from the University of California-Santa Cruz in 1997, then his master's qualifying at the University of New South Wales in 1998, and he was recently awarded his doctorate in animal ecology at the University of New South Wales in 2005. He has been working with the Road Ecology Research Group since 2004 as a research associate. Daniel Ramp received his B.S. (with honors) from the University of Melbourne in 1994, and his doctorate in botany/zoology at the University of Melbourne in 2001. He has worked at the University of New South Wales since 2001, and in 2003 he established the Road Ecology Research Group with Dr. David Croft.

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Taking the High Road: Treetop Bridges for Arboreal Animals (Formerly Titled, Walking At Height)

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Abstract

The major impact of habitat fragmentation results from the barrier effect caused by the construction and use of linear infrastructure of transportation systems. Habitat fragmentation can be described as the splitting of natural habitats and ecosystems into smaller and more isolated patches. Habitat fragmentation is recognized as one of the most important global threats to the conservation of biological diversity.

Fauna passages are constructed to minimize the negative effects of habitat fragmentation. However, there are only some vague ideas about measures for tree-living mammals (excluding bats). Some anecdotal stories, collected by this author from the international network and from discussion with interested people, helped to develop some thoughts for the design and construction of tree-bridges. There is some information about measures for squirrels, dormice, monkeys, possums, and pine marten. These species, for which such measures could be fruitful, are sometimes very common and well known by the public: e.g., squirrels; and sometimes rare and only known by specialists and biologists: e.g., several obscure possums.

This presentation offered some current examples and results of tree-bridges and sought input from the broader audience on ideas for additional measures.

Biographical Sketch: Hans Bekker is engineer of the Agricultural University of Wageningen and is working at the Road and Hydraulic Engineering Institute (DWW), an inside advisory unit of the Ministry of Transport, Public Works and Water Management. He works as program leader mainly with wildlife, roads, and traffic and functions as a liaison between civil engineers and ecologists. He was chair of the European project COST 341: Habitat Fragmentation due to Transport Infrastructure. He is program leader for the Dutch Long Term De-fragmentation Program. He is member of the Steering Committee of the International Conferences on Ecology & Transport (ICOET), as representative of the Infra Eco Network Europe (IENE).

Chapter 8

Herpetofauna

Amphibian Road Kills: A Global Perspective

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Abstract: Transportation infrastructure is a major factor determining land use forms. As global changes in this factor are the most important for biodiversity, roads fundamentally influence wildlife. The effect of roads on wildlife has been categorized in several ways resulting in six to ten categories with road kill as an obvious and important component, and amphibians are greatly affected by this factor. As this animal group has been documented to decline from multiple threats worldwide, the study and mitigation of their deaths on roads has become an important conservation priority. It was also detected as a single cause of decline, and data have accumulated on related population fluctuations, isolation, decline, and extinction in several countries. Genetics studies greatly improve our insight into these processes, e.g., by repeatedly proving significantly low heterozigocy in populations of several species living near roads.

Amphibian road kills have been long documented and described due to their spectacular nature, but the overall effect of transportation infrastructure on amphibians was often underestimated due to contrasting research results. The speed of transport and the duration and timing of the surveys in which information was collected turned out to be decisive factors, causing differences of 5.5-16 times the number of road-killed amphibians recorded, mainly in connection with the low visibility and retention time of amphibians on roads. In light of such amphibian-related differences, the often cited national road kill estimates may well be considerably higher in practice, as well.

Amphibian road mortality studies have been conducted almost exclusively in developed countries, mostly in Europe and North America, and under temperate zone conditions. In general, all terrestrial and semi-aquatic amphibian species can suffer from road kills where they have populations near roads. However, different amphibian species are threatened to a different extent by traffic because of their specific life history characteristics. Besides amphibian-specific factors (amphibian movement types, length and direction of movement, velocity, temporal movement pattern, behavioural changes on roads), the spatio-temporal pattern of amphibian road kill is also influenced by habitat and transportation characteristics (especially aquatic habitats and vegation, road density, traffic intensity, vehicle speed, position and structure of roads, and awareness of drivers, respectively) and weather conditions (precipitation, temperature, wind). The effect of these factors must be understood before the need for mitigation can be evaluated and measures designed and built.

Many mitigation measures have been built since the first amphibian tunnels were created in 1969 near Zürich, Switzerland, and a high diversity of technical solutions successfully reduced amphibian road kills under different conditions. New research results have shown that amphibian tunnels can also be permeable for reptiles, such as snakes and small mammals. However, the lack of maintenance and construction deficiencies are common problems, which lower the efficiency of these measures worldwide.

Road kills also have socio-ecological importance. Successful road-kill related projects have the potential to improve the understanding of decision-makers regarding road-related problems, also leading to their support of more complex conservation projects, including, for example, habitat restoration or compensatory developments near roads. Using the media to educate the general public about conservation efforts to reduce road kill, such as setting up frog fences in the USA and toad saving campaigns in Europe, clearly helps to realise this aim by influencing support provided by various authorities.

Introduction

Effect of roads on wildlife

Transportation infrastructure is a major factor determining land use forms. As global changes in this factor are the most important for biodiversity (Sala et al. 2001), roads fundamentally influence wildlife. The effect of roads on wildlife is categorized in several ways according to the background, approach, and aim of the investigators. Trombulak and Frissel (2000), for example, put road effects into seven categories (increased mortality from road construction, increased mortality from collision with vehicles, modification of animal behavior, alteration of the physical environment, alteration of the chemical environment, spread of exotic species, increased alteration, and use of habitats by humans); and Jackson (2000), into ten (direct loss of habitat, degradation of habitat quality, habitat fragmentation, road avoidance, increased human exploitation, road mortality leading to loss of populations, disruption of social structure, reduced access to vital habitats, population fragmentation and isolation, disruption of processes that maintain regional populations). Andrews (1990) divided them into six (habitat loss and modification with accompanying effects on populations, intrusion of the edge effect into the core of natural areas, subdivision and isolation of populations by roads acting as a barrier, source of disturbance to wildlife, increased road-kills, increased human access with undesirable impacts on undisturbed areas); Seiler (2001, 2003), into five (habitat loss, disturbance, corridor, mortality, barrier); Scoccianti (2001) regarding animals, into eight (loss of habitats, increasing harm to the habitat and fragmentation of the territory, increased "edge effect," restricted movement of individuals in the territory, growing genetic isolation of the populations residing on each side of the road, higher mortality rate, with consequent numerical impoverishment of the populations living on each side of the road, increased human access to natural habitats, greater likelihood of invasion by alien species, with consequent risks of increased predation and competition); and Rudolph (2000), focusing on amphibians and reptiles, into six categories (habitat loss, habitat degradation, habitat fragmentation, increased mortality due to direct vehicular mortality, increased mortality due to increased vulnerability to harvest, alteration of behavior). As demonstrated by the lists above, the effect of roads on wildlife has been categorized in several ways, but road kill is an obvious and important component, and amphibians are an animal group that is greatly affected by this factor.

Conservation status of amphibians

Amphibians, which are threatened more than most other animal groups (Abramovitz 1996, IUCN, Conservation International and NatureServe 2004), suffer from multiple threats leading to a worldwide decline documented in all continents (Blaustein and Wake 1990; Griffiths and Beebee 1992; Houlahan et al. 2000). Some of the factors in this process, such as habitat destruction or pollution, are long known and studied; others have been recognized only relatively recently. Potential threats were grouped into several categories by different authors. For example, Collins and Storfer (2003) distinguished six (alien species, over-exploitation, land use change, global change including UV-radiation and climate change, contaminants, emerging infectious diseases), while Waldman and Tocher (1998) listed nine (UV-B radiation, climate change, acid rain, pesticides and fertilizers, habitat disappearance or destruction, fragmentation, demographical causes, genetic causes, diseases) groups. In most cases, however, the combination of several factors leads to the decline of a species (see, e.g., Hatch and Blaustein 2000), and different species react differently (see, e.g., Hamer et al. 2004).

Besides a wide-scale decline, several amphibian species became extinct at the end of the 20th century, such as *Bufo periglenes* in South America (Crump et al. 1992, Pounds and Crump, 1994), *Rheobatrachus silus* and *R. vitellinus* in Australia (Tyler 1991, Griffiths and Beebee 1992). This event is an even greater cause for concern as this animal group is less known than other vertebrates, which is well demonstrated by the unprecedented ratio of new species (even new families) described in the last 20 years. The number of known amphibian species changed by nearly 20 percent from 4,003 to 4,780 between 1985 and 1995 (Hanken 1999); it became higher than that of mammals by the millenium (Glaw and Köhler 1998) reaching 5,743 by 2004 (IUCN, Conservation International and NatureServe 2004). New species were not only found in less studied continents, but also in Europe and North America, where a new *Batrachoceps* species was discovered 50 km from San Francisco (Hanken 1999). As a result, there is a fair chance, that some amphibian species become extinct even before they are described.

Effect of roads on amphibians

The effect of roads and, to a lesser extent, rail traffic on amphibians has been long known due to its spectacular nature. What is more, amphibians, because they are predominantly surface water-bound organisms, are among the most affected taxa by this factor. Besides the overall loss and alteration of habitats, creation of edges and their consequences, which all animal groups suffer, they are also greatly influenced by pollution, such as lead accumulation in tadpoles developing near roads (Birdsall et al. 1986), road kill, and the related barrier effect. Amphibian road mortality was first described by Savage (1935), who reported 49 *Rana temporaria* road kill near London. Besides common species, which often encounter transportation infrastructure, rare taxa, such as *Ambystoma macrodactylum croceum* in California, are also threatened by roads (Robinson 1986). However, the overall effect of transportation infrastructure on amphibians was often underestimated even as late as the 1980s in spite of, e.g., several earlier studies demonstrating high mortality rates on roads (van Gelder 1973; Kuhn 1987).

Aim of work

Because amphibians have been documented to decline from multiple threats world-wide and transportation infrastructure plays a role in this process, the study and mitigation of amphibian road kills has also become an important conservation priority. The aim of this study is to summarize the available knowledge on amphibian road kills at a global scale.

Amphibian Road Kill

Significance of amphibian road kill

Though the phenomenon was recognized as early as the 1930s (Savage 1935), evidence of the ecological consequences of amphibian road kill accumulated only at the end of the 20th century (for an overview, see table 1). Road mortality was detected as a single cause of decline in the Austrian Alps (Landmann et al. 1999), and data accumulated on road kills and related population fluctuations, isolation, unequal sex ratio, decline, and extinction (e.g., Bressi 1999, Cooke 1995, Fahrig et al. 1995, Reh 1989, Ryser 1988, Sjögren-Gulve 1994, Vos and Chardon 1998, Vos et al. 2001). The length of paved road within 1 km was found to be negatively associated with salamander diversity and also with the presence of *Ambystoma tigrinum tigrinum* (Porej et al. 2004), and the chorus index of frog and toad relative density was also negatively correlated with traffic intensity, i.e., the frog and toad density decreased with increasing traffic intensity (Fahrig et al. 1995).

Table 1. Effect of road kills on amphibians (for more information, see the text above)

Effect	Country	References
determination of distribution areas	Netherlands	Vos et al. 2001
extremely unequal sex ratio	Hungary	Csapó et al. 1989
genetical isolation, low heterozigocy	United Kingdom France Germany Netherlands	Hitchings and Beebee 1997 Lesbarrés et al. 2003 Reh 1989 Vos et al. 2001
low density in the vicinity of sections with high traffic	Canada Switzerland Netherlands	Fahrig et al. 1995 Ryser 1988 Vos et al. 2001
single cause of decline	Austria	Landmann et al. 1999
local extinction	Italy United Kingdom Sweden Switzerland	Bressi 1999 Cooke 1995 Sjögren-Gulve 1994 Holzgang et al. 2000

Genetic studies greatly improved our insight into these processes. Lesbarrés et al. (2003) studied small (less than 40 adult frogs or 20 egg clutches) *Rana dalmatina* populations along the A11 highway in France and at control sites. Heterozygosity was significantly lower in populations near the highway, indicating the negative influence of roads by road kills during breeding migration and juvenile dispersal. Similarly, Vos and Chardon (1998) detected negative correlation between *Rana arvalis* populations and roads within 250 meters. Furthermore, the density of roads within 750 m of the breeding sites was also negatively associated with the probability that the pond would be occupied. What is more, in the Netherlands the genetic structure of *Rana arvalis* populations correlated better with the position of roads and railways than with geographical distances (Vos et al. 2001). As a consequence of these findings, today traffic mortality is also listed as a significant factor causing amphibian decline (Seburn and Seburn 2000).

In contrast to natural predation, traffic mortality is non-compensatory, and the kill rate is independent of density. This implies that traffic will kill a constant proportion of a population and, therefore, affect rare species most significantly. In general, species that occur in small, isolated populations, and those which require large, extensive areas for their home ranges, or have long migratory movements, are especially sensitive to road mortality (Seiler 2003). Moreover, road kills also have a sociological significance as they can be used for education purposes, e.g., on amphibian decline, more easily than more sophisticated and sometimes even contradictory processes.

Importance of methodology: relative frequency of amphibian road kill and its relation to survey speed and timing
The method of collecting information on road kills seems to be easy and obvious. However, though both long-term and (if coincided with mass amphibian migration or dispersal) short-term studies show the relative importance of amphibian road kill among vertebrates, a lot of contradictory results have been published due to differences in sampling protocols, especially in the duration and timing of the surveys, period of the day in which information was collected, and speed of driving/cycling/walking.

To analyze these differences at a global level, ten studies from Canada, Czech Republic, Hungary, Poland, Slovenia, UK, and the USA (figure 1.), with different sampling protocols were selected for comparison (Ashley and Robinson 1996, Bartosewicz 1997, Clevenger et al. 2003, Denac 2003, Fenyves 1989, Holisová and Obrtel 1986, Kline and Swan 1998, Lodé 2000, Slater, 2002, Wolk 1978). Figure 2 shows the relative frequency of vertebrates among road-killed animals. As demonstrated by figure 2, the relative frequency of amphibians varied between 4.9 and 92.1 percent in the individual studies. The comparative analysis of the sampling protocols emphasized the determining power of driving/cycling/walking speed in this respect. The five studies plotted on the left side of the graph detecting considerably more amphibians were made by walking/cycling or motorcycling while the other five by driving a car. Besides the comparison of different studies, this difference was also noted in the same survey. In Wales Slater (2002) recorded 5.5 times more road killed animals surveying on foot than driving by car even if it was relatively slow, less than 40 km per hour.

Figure 1. Distribution of road kill survey localities compared in the present study (• = locality).

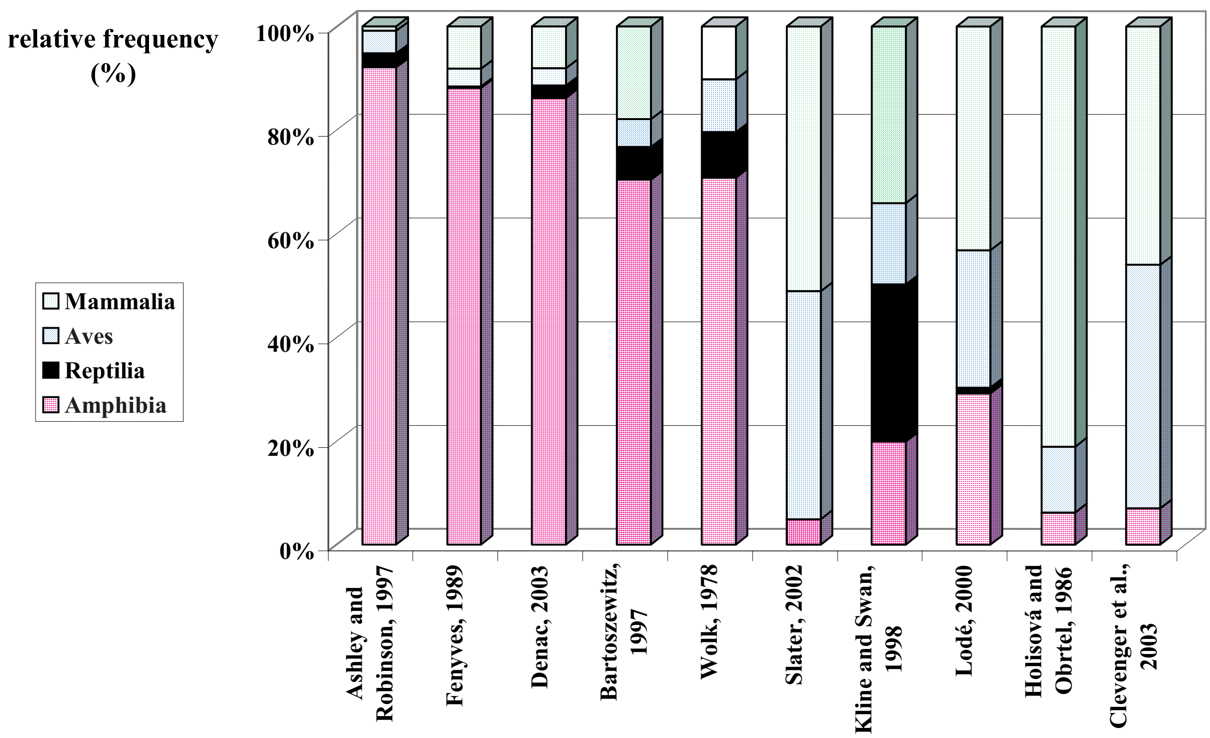

Figure 2. Relative frequency of vertebrate road kill in ten European and North American studies.

In other studies, walking surveys also recorded taxa, which were otherwise overlooked, such as *Triturus* in France, which turned out to be commonly noted on roads in the Rhone-Alpes region only during more detailed walking surveys (Grossi et al. 2001) or *Notophthalmus viridescens* efts, which were found every 1.4 m along a stretch of a Virginia road (Mitchell 2000). Difficulties in the detectability of newts due to their size and shape and the consequent underestimation of newt migration was also noted by Denac (2003) and Evans (1989).

Besides speed, timing within the year and the part of the day selected to collect samples are also key elements in determining road kill results. Slater (2002) recorded a 4.8 percent amphibian road kill in a year long survey in Wales when driving in the morning. However, an observation within the same study recorded 178 *Bufo bufo* (50%) corpses removed from the road surface from a short section near Llandrindod Wells Lake on the same circuit within an hour after dawn on a single morning during migration, proving that the actual relative frequency of amphibian road kills is much higher. During a regular, 10 a.m. survey no evidence of road kill would have been found there. The fact that this single event included ten times more amphibians than the annual total amphibian mortality recorded over a year for a 68 km circuit driven by less than 40 km per hour twice a week, because the remains of very degraded amphibian corpses are visible only on close inspection, show the difficulty of such estimations.

Similar evidence exist in other studies in America as well as in Europe. Kline and Swan (1998) found that only 15 of at least 63 *Scaphiopus couchi* corpses (< 23.8%) remained on the road surface until the time of regular morning surveys between 8:30 a.m. and 12:00 noon, while Hels and Buchwald (2001) calculated a 7- to 67-percent retention rate for members of a six species amphibian community. Besides scavengers, people occasionally also remove amphibians from the road for their legs (Ashley and Robinson 1996).

The underestimation of amphibian road kill originates both from low retention time on roads as compared with other vertebrate classes and from small size, especially for newts and juveniles. Short retention time partly originates from the lack of hair, feathers and scales (Hels and Buchwald 2001). Taking into consideration all factors Slater (2002) estimated a 12-16 times greater vertebrate kill rate on roads than what could be found by a single daily census. This figure is nearly identical with that was suggested for bird road kill in Sweden by Svensson (1998).

In the past twenty years various national estimates have been made for road casualties. Lalo (1987) estimated that one million vertebrates are killed on U.S. roads every day, while Caletrio et al. (1996) calculated an annual 10 million vertebrate road kill rate for Spain. Ehmann and Cogger (1985) estimated an annual amphibian and reptile mortality of five and a half million individuals for Australia. In light of the primarily amphibian-related data described above, these often-cited figures may well be considerably higher in practice.

A determining network characteristic: global road density

As the distribution of road kill surveys in figure 1 suggests, amphibian road kill studies are mostly limited to developed countries, first of all to Europe and North America. However, roads occupy an increasing area in most countries, which urges further studies in this field. There are striking differences, however, in the extent to which individual countries and continents are affected by the transportation network due to its density and the traffic intensity on them as there are three orders of magnitude of difference in road density between different countries in the world (fig. 1).The quality and width of roads also greatly differ among individual countries, and not only according to their economical development. The density of motorways and highways alone is 0.47 km/km^2 in Belgium, which is at least twice as dense as the total road density of many African, South American, and Asian countries, but the primary and secondary road network of the Netherlands, for example, is also nearly 12 times denser than the Swedish network (Farral et al. 2003). Smaller countries and some islands usually have a denser road network than large, mainland states. The ratio of paved sections to the total paved and unpaved road network also differs. Usually it is over 50 percent in Europe and under that ratio in Africa, South- and Central-America, and Asia, which is also an important factor for determining road kill through affecting driving speed.

Characterization of amphibian road kills

In general, road traffic poses a severe threat to amphibians due to their slow capacity of movement; their inability to notice the danger from cars in time and to make successful attempts to avoid them; their tendency to become immobilized in moments of danger, which causes them to remain on the road longer; limited dispersal rate; and thus, ability to recolonize areas, and complex life cycle of many species, which involves periodic migrations between different habitats (Scoccianti 2001). As amphibian road mortality studies were made nearly exclusively under temperate zone conditions, the results presented here (e.g., seasonality) primarily refer to those conditions.

Species composition: In general, all terrestrial and semi-aquatic amphibian species can suffer from road kills where they have populations near roads. However, some species are more common victims. According to a national survey in the Czech Republic, although 14 species were recorded killed on roads, 82 percent of the populations affected by road kills were of either *Bufo bufo* or *Rana temporaria* (Mikátová and Mojmír, 2002), two abundant species with long breeding migration routes (for a comparison of average migration radius of seven European species, see figure 4.) and large size, which makes it easier for humans to detect the corpses. Similar species-related differences exist not only at the population, but also at the individual level. *Bufo bufo* and *Triturus helveticus* represented 56.7 perecent and 28.4 percent of road-killed amphibians, respectively, in a 33-week survey along the A83 motorway in France while *Rana dalmatina* and *Alytes obstetricans* corpses were only recorded in low numbers (Lodé 2000).

The species composition of road kills, however, also reflects the local species pool, resulting in different species compositions and relative frequency in different regions. This phenomenon was also statistically proved using G test to check the similarity (homogenity) of amphibian road kill data collected over seven years from five protected regions in Hungary. The distribution of the sampling localities can be seen in figure 5, where the color change from green to dark brown symbolizes an elevation change of nearly 1,000 m. As expected, the species composition of road kill was significantly different from the hilly or lowland areas in the Körös - Maros National Park, which is a lowland area in the southeastern part of the country.

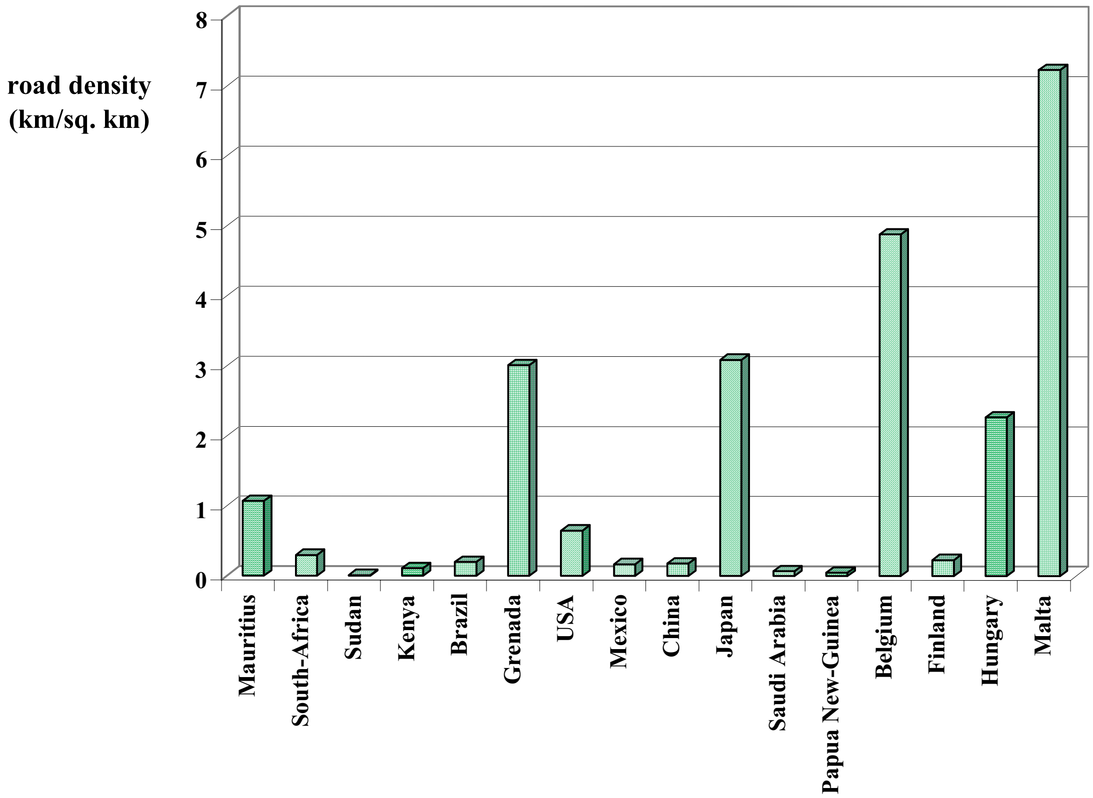

Figure 3. Density of national road networks. (Source: IRF World Road Statistics 2003)

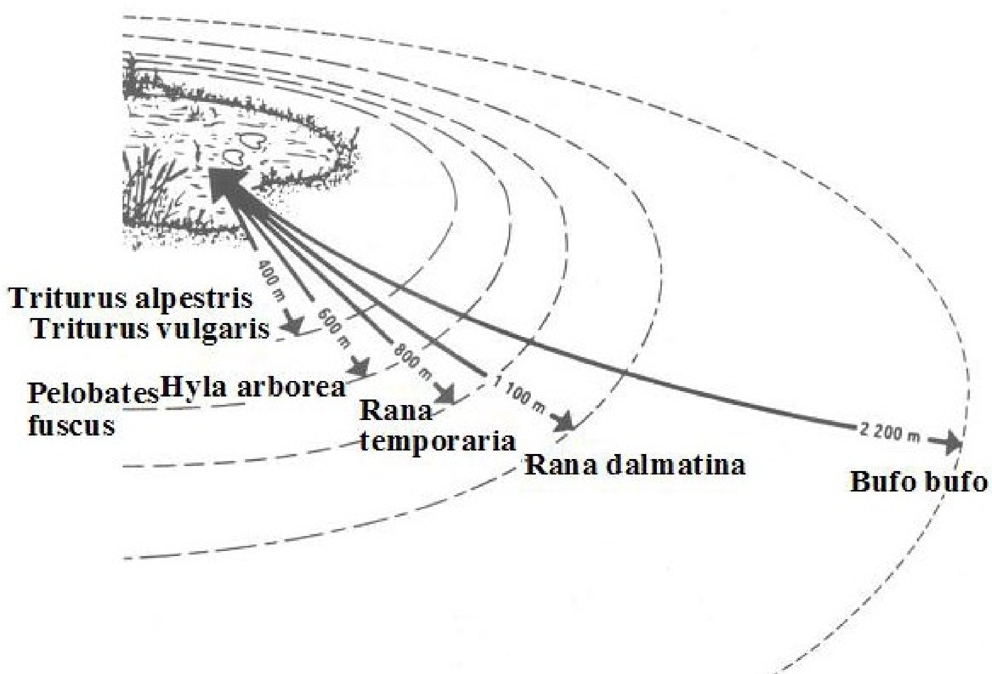

Figure 4. Migration radius of seven European amphibian species (after Blab 1986).

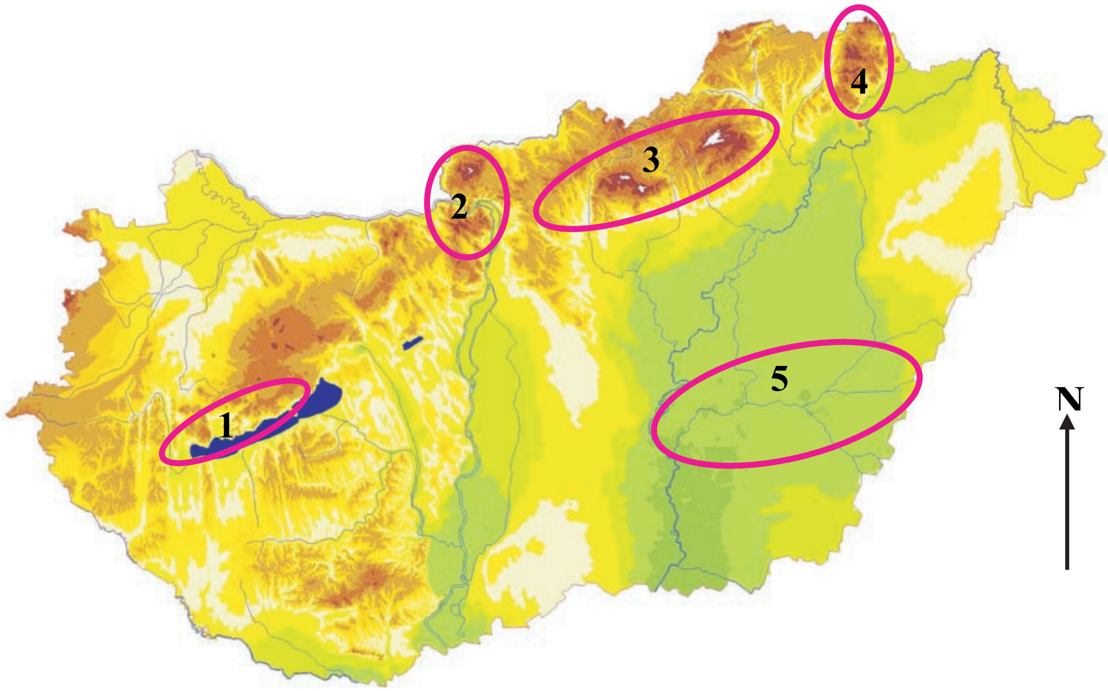

Figure 5. Localities of the national amphibian road kill surveys.
(1= Balaton Uplands National Park, 2= Danube - Ipoly National Park, 3= Bükk National Park - Mátra Landscape Protection Area - Kelet-Cserhát Landscape Protection Area, 4= Zemplén Landscape Protection Area, 5= Körös - Maros National Park)

Usually more than one amphibian population is present at the same breeding site, and the migration periods of the populations partially overlap. As a result, usually individuals of different species are affected by roads, and they also often cross roads at the same section. For example, Aresco (2003), Frank et al. (1991), and Kelemen (2000, 2001) recorded ten; Grossi et al. (2001), up to nine; Kárpáti (1988), nine; and Denac (2003), at least eight species at the road sections studied. Often, there is also a spatially different migration pattern of the individual species, and they cross the road at slightly different spots within the the same section (Grossi et al. 2001; Proess 2003).

Seasonality and annual changes

Under temperate zone conditions the highest peaks are usually recorded during spring (breeding migration to, where overwintering sites overlap with summer habitats, and also from the breeding sites). This pattern has been shown by several authors, e.g., Rettig (1996), who found 73.4 percent of all amphibian road casualties in March during a whole year survey. Juvenile dispersal, however, if recorded, can produce even higher peaks during summer (see, e.g., Ashley and Robinson 1996). Where the habitat is more homogenous, e.g., when roads cross wetlands, amphibian mortality remains high throughout the year. In either case, if tadpoles metamorphose successfully, juvenile dispersal occurs in summer. In autumn, there is also a longer migration period with smaller peaks than in spring. In other climate zones the actual weather pattern, e.g., the time of monsoons, summer rains in deserts, etc., determines the activity periods of amphibians and, thus, the presence of amphibians on roads (Kline and Swan 1998).

There are major fluctuations in the number of amphibians crossing the road each year, which can reach an order of magnitude difference between years (Marsh 2001). To achieve reliable counts and accurately pinpoint the main crossing points, where mitigation measures should be built, and still produce results within a reliable amount of time, the detailed monitoring of amphibian road kill for at least three years was suggested by Grossi et al. (2001).

Sex-related differences

Male and female amphibians spend different periods of time in different habitats, and there can also be marked differences in the migration radius as well as the period of migration of the two sexes. Regosin et al. (2003) found that a higher ratio of *Rana sylvatica* males winter near (65 m) their breeding ponds than farther from the pond, which also means that females of this species (at least at the site studied) had a longer migration radius. Kuhn (1994) noted that a large number of females die at the breeding sites, which lowers the number of amphibians migrating out of the breeding area, and consequently a lower number crossing the road. Similar to individual number changes, the sex ratio of migrating amphibians can also change. Such a shift was described by Griffiths et al. (1986): from 6.5:1 to 2.1:1 males to females in four years *with Bufo bufo.* Other species (*Triturus vulgaris, Triturus helveticus, Rana temporaria*) migrating at the same site in Wales, however, did not show a similar phenomenon.

Site of road kills

The proximity of natural and artificial water bodies increases the probability of road kills. Scoccianti (2001) found 80 percent of main amphibian crossing sites near artificial water bodies. Road kills often happen along sections with contrasting habitats including wetlands on either side of the road (Csapó et al. 1989). Another crucial habitat type is forests, where the majory of amphibians might cross as opposed to open areas, as with *Notophthalmus viridescens* (Mitchell 2000). Because of construction considerations, roads are often situated along the edge of geographic features that provide different habitats for amphibians, e.g., as winter hibernation sites, breeding sites, or summer habitats. As a result, a seasonal migration pattern is likely to occur in such sections that run, for example, between foothills of mountains and floodplain, or along large lakes and reservoirs (Rybacki 1995). In other cases, roads cut the same habitat, e.g., wetlands into smaller fragments (Dodd et al. 2004) causing road-kill problems to be present as long as the animals are active (Puky 2003).

Factors determining amphibian road kills

The spatio-temporal pattern of amphibian road kill is influenced by various factors. They can be grouped into major units as amphibian-specific factors, habitat and transportation characteristics, and weather (table 2). Due to the length of this paper, the overview of only three less frequently discussed factors (temporal movement pattern, habitat characteristics, awareness of drivers) are given here, but the effect of all these factors must be understood before the need for mitigation can be evaluated and measures be designed and built.

Table 2. Factors determining amphibian road kill

Major unit	Individual factor
amphibian specific factors	amphibian movement types length and direction of movement velocity temporal movement pattern behavioural changes on roads
main habitat characteristics	vegation available aquatic habitats
transportation characteristics	road density traffic intensity vehicle speed position and structure of roads awareness of drivers
weather conditions	precipitation temperature wind annual changes of weather conditions

Temporal movement pattern

In temperate zone conditions most amphibians move across roads during the night (e.g., Ashley and Robinson 1996). In general, they migrate from dusk on, but the exact timing and daily peaks vary between species of the same community (Hels and Buchwald 2001). During the peak of migration amphibians also move during the day. Under cooler climates, however, this phenomenon can become regular, as it was described for *Rana pipiens* by Linck (2000). At Baker Park Reserve, Minnesota, this species starts spring migration in mid-morning, after basking while the night air temperature is below freezing. The autumn migration at that locality, however, occurs during the night as well. Species which move diurnally are at greater risk than nocturnal species due to the greater traffic by day (Hels and Buchwald 2001).

Habitat characteristics

The effects of two factors are important to stress here. Amphibian movement is often associated with water, e.g., streams as demonstrated by Beshkov and Jameson (1980) on *Bombina variagata*. On the other hand, Ashley and Robinson (1996) found that *Rana pipiens* road kill was significantly associated with roadside vegetation. In some studies both factors were revealed as important. Mitchell (2000), for example, found that road-killed *Notophthalmus viridescens* efts were distributed more or less equally on the road stretch next to a wetland and a wooded road section, further indicating the importance of both habitat characteristics.

Awareness of drivers

There are several experiments with contrasting results on the effect of informing drivers through road signs and the media and asking them to slow down. Flashing road constructions signs operated during peak (diurnal) migration hours received positive reactions by drivers in Minnesota (Linck 2000). However, road signs in Wales at migratory amphibian crossings encouraged some drivers to deliberately kill toads with their cars (Slater 1994), Although referring to marsupials and not amphibians, the speed of vehicles was not reduced by use of signs in Australia (Coulson 1982).

Mitigation Measures: Summarizing History, Design, and Problems

Amphibian mortality can be reduced by several ways. Avoidance is the best solution if an important breeding site should be protected. Compensatory measures, such as creating new aquatic habitats, are becoming more common, and in the construction phase the translocation of amphibians was also used in several cases, such as at the Wilmslow and Handforth Bypass of the A34 road in Cheshire, England. After construction, the temporary closing of road sections is the best solution; however, it is rarely a realistic option, similar to the removal or translocation of the road itself. However, mitigation measures are the most widely used solutions to lower the effect of transportation infrastructure on amphibians. Frog rescues have been organized and temporary protective measures introduced by many national park authorities, non-governmental organizations, and private people in Europe and North America (see, for example, Ballasina 1989, Kárpáti 1988, Langton 1989a, Puky et al. 1990, Schád et al. 1999, Wisniewski 2001). Amphibians may use wildlife bridges if adequate fencing is provided, but in most cases amphibian tunnels and fences are set up to protect anurans, newts, and salamanders.

The first amphibian tunnel was built in 1969 near Zürich in Switzerland (Ryser and Grossenbacher 1989). In North America an amphibian tunnel was first constructed in 1987 near Amherst, Massachusetts (Jackson and Tyning 1989), while in the Oceanian region one was constructed in 1995 near Auckland, New Zealand (Close 1995). In the past 40 years, tunnels of different design and fences of different material were successfully used to help amphibians cross roads (for an overview on its development in Central-Europe, see Puky 2003).

Besides the success of many different designs and the improvement of tunnel parameters, such as material and size over the years (see, e.g., Langton 1989b, Puky 2003, Ryser and Grossenbacher 1989), the limitations of these constructions also became obvious. In Hungary, for example, less than half of the amphibian mitigation measures work properly (figure 6), which is an unacceptably low percentage. In general, most problems originate from lack of maintenance and construction deficiencies (see figs. 7 and 8.). To avoid such problems, several guidelines exist, which can be used in the planning and construction phase as well as during the operation of roads and railroads (Iuell et al. 2003; for amphibian-specific recommendations, see Puky 2003).

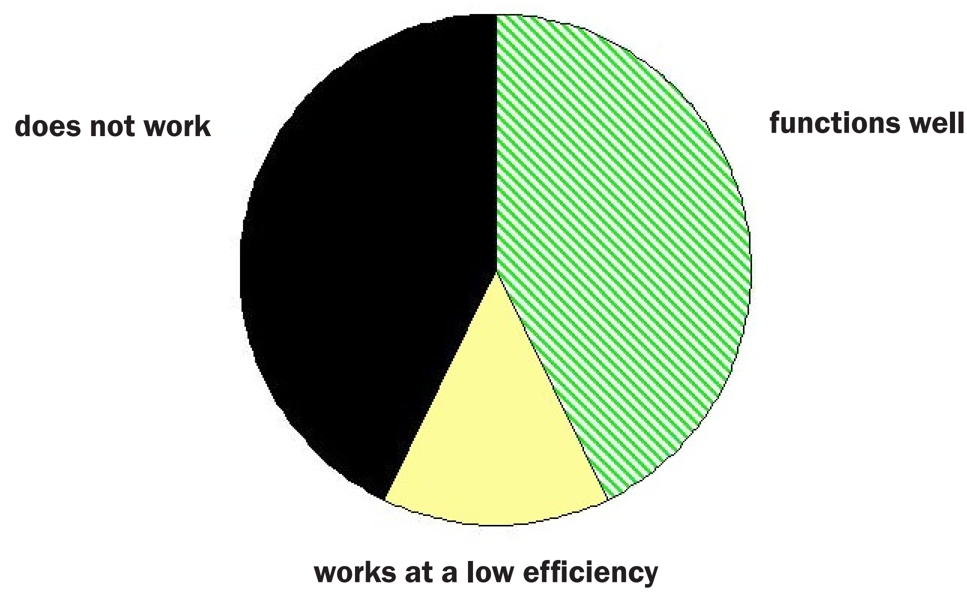

Figure 6. Efficiency of amphibian mitigation measures in Hungary (modified after Puky and Vogel 2004).

In the light of data collected at the tunnel systems at Fertöboz and Mosonszentmiklós in 2004 (for more detailed description, see Puky 2003), the functioning of amphibian tunnels is also important for other fauna elements of the local ecosystems, namely reptiles and small mammals, as they also cross under roads using these passages (Puky et al. 2005).

Socio-Ecological Importance of Road Kills

Importance of road kills for non-road oriented studies

Road kills can also provide valuable information for non-road related projects, too. They can serve as an important data source in mapping projects, especially when time and personnel are limited, to obtain a rapid overview of a large (e.g. 10 km x 10 km) sampling unit (Puky 2001). There is also the possibility of using them in molecular analyses similarly to mammals (Doyon et al. 2003) or other research projects with a similar need of samples, which would be especially important when conservation regulations make it difficult to get licences for such studies.

Figure 7. Main causes of misfunctioning amphibian mitigation measures I.: lack of maintenance (Henley-on-Thames, England).

Figure 8. Main causes of misfunctioning amphibian mitigation measures II.: construction problems (tunnel entrance over the ground), besides the fence is lacking (near Auckland, New Zealand). (Photo courtesy: Dr. Phil J. Bishop)

A main challenge and opportunity: education

Successful road-kill-related projects have the potential to improve the understanding of road-related problems, leading to the launching of more complex conservation projects, including, for example, habitat restoration or compensatory developments near roads. As stressed by many, there is still a lot to do in this respect world wide. Even if regulations have been made in many countries, authorities are often negligent with regard to amphibian conservation and conservation in general along roads (see Caletrio et al. 1996 remarks for Spain). Influencing that group, however, is far from being the only task at which road-related education activities should aim. If mitigation measures are built at the local road level, it is important to inform local people as well as the general public on the aim, benefits, and functioning of the mitigation measures in order to build up social support. Convincing local people and NGOs about supporting their local wildlife tunnel, for example, may even reduce the construction cost of permanent mitigation measures, as happened in Lab Hollow, New York State (pers. comm. Kurt Weiskotten, NYSDOT), and it also protects against vandalism in the region, which also clearly improves the efficiency of toad tunnels. Using the media to inform the general public on conservation efforts on roads to reduce road kill, such as the setting up of frog fences in the USA (Hoffman 2003) and toad saving campaigns in Europe, is also important. Educating these groups effectively, however, requires different strategies as summarised in table 3.

Table 3. Important target-specific aspects of road-related environmental education

Target group	Important information and communication forms in road-related education
Children	personal experience (in the field or with live animals) and involvement interesting stories (e.g. on the life of amphibians) realising their own abilities, and that they can have a positive influence
General public	general overview (also on e.g. protected species) interesting stories (e.g. on the life of amphibians) important relationships
Local people	general overview (also on e.g. protected species) values of local habitats why and how the project is done how they can benefit and get involved and help (contact addresses)
Decision-makers	concise text easily understandable message list of actions

The support of well-known (and positive) personalities, such as Dr. Jane Goodall, may also be a key element of a long-term education strategy. Her general support and talk in front of a large audience (fig. 9), increased, for example, the recognition of the Toad Action Group (DAPTF Hungary) by ministry officials and helped gain more attention to road-related environmental projects. In another example, as figure 10 demonstrates, a minister, children, and frogs can participate in such project activities with the hope of bringing a brighter future for road-crossing amphibians. Besides informing and educating many motorists, news articles and televison/radio programs reporting on road-related environmental education activities clearly help to get support from different authorities, when they realize that such conservation efforts are not only a legal obligation, but also an important objective for the communities in which they live and especially for the children around them. Partly due to such developments, positive changes can also be recognized in the approach of decision-makers, such as road builders, towards wildlife mitigation measures. At the beginning of the 1990s debates in Hungary often dealt with the necessity of such constructions and if they should be built at all. By the 2000s, it has shifted toward discussions on the number and dimensions of tunnels, how many, and what size should be made to protect amphibians – which is, even if there remains much left to do, still a great step forward.

Figure 9. Dr. Jane Goodall gives a talk in Hungary organized by the Toad Action Group, an international award winning NGO founded in 1986. (Photo courtesy of Norbert Erdei)

Figure 10. The Hungarian Minister for the Environment and Water Management participates in a frog saving project in March 2005. (Photo courtesy of Szabolcs Jónás, Toad Action Group)

<u>Final Remarks</u>

The importance of amphibian road kills was recognised at the end of the 20th century. Its relative frequency greatly depends on the speed and timing of the survey. The comparison of earlier studies indicates that the number of road-killed amphibians is often considerably higher than was previously estimated. Mitigation measures can be an effective way of lowering amphibian road kills, but they often fail to work due to construction problems or lack of maintenance. As figure 11 demonstrates, the ratio of amphibian studies among road studies is lower than what the conservation status of the group and the importance of this factor would need. Also, more studies in new geographic areas as well as the monitoring of existing mitigation measures are needed. In the future, a new, comprehensive strategy needs to be applied using the available knowledge and experience to make new, effective mitigation measures and increase the efficiency of the existing ones both on old and new roads. Education has an important role in this process. As a result, new projects should be at least as much based on conservation-minded planning, building, and maintenance as on using more financial resources.

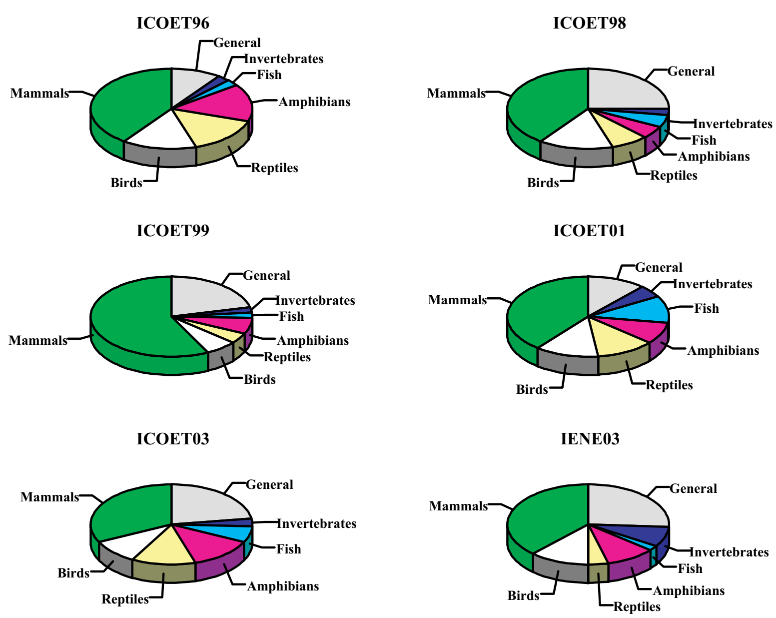

Figure 11. Relative frequency of papers dealing with different animal groups presented at road ecology conferences between 1996 and 2003.

Acknowledgements: This article and the related presentation is the result of more than a decade of work. During that period I received a lot of professional and personal support from many individuals and organizations. I express my heartful thanks to all of them.

Biographical Sketch: Dr. Miklós Puky is a research fellow at the Hungarian Danube Research Station of the Institute of Ecology and Botany of the Hungarian Academy of Sciences and the chair of the IUCN SSC Declining Amphibian Populations Task Force Hungary. Most of his work is dedicated to different conservation and environmental education programs, and he also teaches conservation ecology at the University Eötvös, Budapest. Dr. Puky began amphibian road-kill research and conservation in 1986, which was a first attempt in the Central-European region. For organizing and leading international programs he was presented several conservation and education prizes, such as Pro Natura, For the Environment, and the Henry Ford European Conservation Award, and he was also a winner of the Ten Outstanding Young People competition.

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Dissimilarities in Behavioral Responses of Snakes to Roads and Vehicles Have Implications for Differential Impacts Across Species

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Abstract: Roads can act as a barrier to overland movement of animals by causing habitat fragmentation, disrupting landscape permeability, and having an impact on survivorship patterns and behavior. We conducted field experiments to determine how southeastern U.S. snake species with different behaviors and ecologies responded to roads. We attributed interspecific differences in how individual snakes responded to ecological and behavioral differences among the species tested. The probability that a snake would avoid entering the road rather than crossing it varied significantly among species. Smaller species showed high road avoidance behavior. We also observed significant differences in crossing speeds among species. Most nonvenomous species crossed more rapidly than venomous ones. Nonetheless, all species minimized road-crossing time by traveling at perpendicular angles. We also conducted field tests to determine how individual snakes respond to passing vehicles. We observed that most individuals of the three species tested became immobile when a vehicle passed, a non-adaptive behavior that would prolong road-crossing time of an individual and further exacerbate a species' vulnerability when crossing roads. It is essential that the differential responses of snakes and other animals to roads be identified if the direct impacts of road mortality are to be incorporated into future mitigation plans that minimize road impacts in efforts to design more effective transportation systems.

Introduction

In the United States, the road network extends approximately 6.4 million kilometers, comprising one percent of the nation's land (Forman & Alexander 1998). Roads even penetrate the nation's protected lands, with 10 percent of them occurring in national forests (Youth 1999). Although roads comprise only one percent of the land surface area in the United States, the ecological impact has been estimated to extend to 15 to 20 percent of the country's land (Forman & Alexander 1998). Development, traditionally defined in terms of structural buildings, has expanded legally to include roads (i.e., Transportation Equity Act for the 21st Century [TEA-21], 1998) due to their potential to have enormous overall impacts. Roads, despite their relative narrowness, are increasingly being recognized by biologists as having the potential to alter numerous ecosystem balances. Streams are polluted, altering water quality and faunal communities (Welsh and Ollivier 1998); animals attempt to cross the road and are hit by vehicles (e.g., Lodé 2000); and some species behaviorally avoid the road (e.g., Forman and Deblinger 2000), which potentially fragments their habitat, reducing their range, restricting gene flow, and threatening population viability. Road effects are not a static impact that only results in an immediate loss of habitat in an area; they enable human access and are a precursor to future development (Riitters and Wickham 2003)

To understand ecological impacts, we must understand not only resource-limiting aspects of habitat loss but also behavioral reactions of wildlife to such loss that determine how readily wildlife acquires necessary resources amidst landscape alteration. The degree to which the road poses a barrier to movement defines whether the bisected habitat is continuous (animals cross successfully in significant enough numbers that resources on both side of the road are still available and gene flow is sustainable) or functionally fragmented (mortality rates or behavioral avoidance is high enough that populations are isolated). If the barrier effect of the road continually prohibits immigration and emigration, this isolation will eventually affect fundamental population and community dynamics. For prudent conservation measures to be realized, a balance must be achieved between the construction of roads for domestic and commercial purposes and the persistence of intact habitats and wildlife populations. This balance can be formulated effectively only with science-based designs that are favorable to movement patterns of both humans and wildlife.

Direct effects are defined here as those that can be attributed to the road itself. The most obvious direct effects are immediate habitat loss (physical land area that the road covers) and on-road mortality. The threat of being killed on a road can be of even greater consequence if populations recover more readily from a one-time reduction in spatial resources than to the continual removal of individuals from a population. Approximately one million vertebrates die per day on U.S. roads (Lalo 1998) from the 190 million vehicles that travel the roads daily (FHWA 2001). Animals attempt to cross roads in an effort to access resources on the other side or to disperse permanently (i.e., emigrate) to escape unfavorable circumstances. The level of crossing success is dependent on the extent of human use of the road. A standard U.S. highway experiences traffic volumes of approximately 20,000 cars each day at a given location, averaging a car or truck every four seconds (Higgins 2000). In areas of lower traffic density, larger time spans between vehicles may allow greater permeability of the road to crossing animals. A developing problem is that an increasing number of roads are experiencing increasing traffic densities, decreasing these crucial windows of time (e.g., Smith and Dodd 2003). Whether an animal successfully crosses within these windows depends on their movement biology and crossing behaviors, such as the length of time required to cross the road.

Indirect effects are defined here as secondary effects that occur off road. The indirect effects of roads are more numerous and detrimental to wildlife than direct effects (Forman and Alexander 1998), although they have received less attention because most are difficult to observe and quantify. The situation is further complicated because impacts differ with species, locality, and road condition. For example, road age, substrate, and width, in addition to vehicular speeds, densities, and daily or seasonal traffic patterns (Andrews et al. 2006) add to the complexity of assessing environmental impacts of roads. The purpose of this research is to focus on factors influencing road fragmentation and investigate behavioral responses as an indicator of road permeability.

Roads can act as barriers not only when rates of mortality exceed sustainable levels such that inadequate numbers of individuals are exchanged, but also when selective (i.e., genetic or behavioral) avoidance occurs. The barrier effect of roads has tremendous implications as the pressure of isolation can reduce genetic diversity via the creation of subpopulations and also result in increased mating competition among fewer individuals. The ultimate threat of local extirpation becomes a concern if inbreeding depression results in more individuals of reduced fitness, lowering viability for the population as a whole. This indirect effect of isolation spurred by road avoidance can ultimately have bottom-up effects by altering the structure of an entire food chain. The intensity of fragmentation effects varies with each organismal group as shown by Hargis et al. (1999), wherein American marten abundance decreased in edge habitats but small mammal densities increased. Therefore, road impacts on population dynamics should be examined at the level of a particular animal group before generalizing across phylogenetic boundaries.

Snakes, the focus of this research, are an ideal group to investigate the generality of road impacts, both direct and indirect, due to (1) road mortality that has been documented for over half a century (e.g., Klauber 1939, Fitch 1949, Campbell 1953, Pough 1966, Whitecar 1973, Dodd et al. 1989, Bernardino and Dalrymple 1996, Smith and Dodd 2003) and (2) the large breadth of ecological niches represented among species. To adequately mitigate anthropogenic disturbance of wildlife patterns resulting from road development, we must understand the basics of how different groups are affected in regard to daily activities, life cycles, and migratory patterns.

Crossing speeds and angles influence the length of time required for an animal to cross the road, and, therefore, affect the animal's vulnerability to vehicular-induced mortality. For instance, snakes that cross the road at a wide angle or at a slower pace prolong the amount of time spent on the road and in the direct path of traffic. The road can become impermeable when road mortality reaches rates such that genetic interchange is reduced or halted, dividing the local population into isolated subpopulations. The threshold at which the number of snakes being killed on the road is so significant that the number crossing successfully is insufficient to maintain viable populations and would vary with species and location. While the numbers of snakes killed on roads can be appallingly high, mortality measures alone do not reveal how snake populations in surrounding habitats are truly affected.

An array of snake behaviors and physiological traits may influence a snake's use or avoidance of the road and its probability of crossing successfully, in addition to extrinsic variables (road and environmental conditions; Andrews and Gibbons 2006). Snake species demonstrate drastically different ecological strategies, ranging from fossorial and clandestine behaviors to wide-ranging habitat uses. Snakes are more vulnerable to predation when dispersing or migrating to acquire the necessary resources and have evolved adaptations to minimize the chances of being preyed upon when traveling overland (e.g., Shine and Lambeck 1985). Such strategies include crypsis (e.g., green snakes), venom (e.g., rattlesnakes), or speed (e.g., racers and coachwhips). However, species unequipped to avoid predation are less likely to cross open spaces (e.g., ringneck snakes, Fitch 1999). Some species may be more susceptible to road impacts due to ecological demands, such as home range size, that determine the degree of dispersal necessary to satisfy the critical needs of mating, foraging, and securing hibernacula (Bonnet et al. 1999). Consistencies would be expected among organisms having similar instinctive behaviors or comparable physical constraints, so that interspecific groupings would be recognizable. Consequently, snakes should exhibit varying levels of mortality and crossing rates among species that result in interspecific differences in road impacts that are reflective of natural behavioral and ecological regimes characteristic of particular species. In addition, snakes crossing the road are predicted to experience differential probabilities of mortality due to the instinctive behavior and physical ability of some species to move faster across an open space than others.

Exploring road impacts from a behavioral perspective allows determination of degrees of inhibition to and readiness of movement in the road environment, permitting a better understanding of species sensitivities. For instance, species that do cross the road are more susceptible to direct mortality. However, interspecific variation exists within that response, with species differing in the amount of time necessary to cross the road, due to speed, angle, and/or reactions to passing vehicles. Snake species that do not readily cross the road could be more directly vulnerable to barrier effects and habitat fragmentation.

We designed a two-part study to address interspecific variation in responses to the main threats presented by roads for snakes: the road itself and vehicles traveling on the road. The research objective for the road study per se was to investigate interspecific variation in how snakes behaviorally respond to the road. Based on established ecological behaviors, we hypothesized:

1. Some snake species will have a higher rate of road avoidance than others due to innate ecological inhibitions to cross open spaces.
2. Those species that cross the road readily will exhibit interspecific variation in crossing speed that reflects the variation present in movement speeds across natural substrates.
3. Snakes will cross the road at a perpendicular angle, minimizing the length of the crossing trajectory and, therefore, reducing the amount of time spent crossing the road, which would be perceived by a snake as the risk of crossing an open habitat.

The research objective for the vehicle study was to determine if snakes respond to a passing vehicle, and if this response varies across species. We hypothesized that snakes would react to the vehicle as they would an approaching predator. We predicted that species that rely on crypsis would become immobile and that species that rely on the ability to flee would exhibit flight responses.

Materials and Methods

Study site

The study was conducted on the U.S. Department of Energy's (DOE) 750-km^2 Savannah River Site (SRS) located in west-central South Carolina, USA (in parts of Aiken, Barnwell, and Allendale counties). The area is protected as a National Environmental Research Park (NERP) (Shearer and Frazer 1997) and is closed to the general public. The Wackenhut Corporation maintains security on the SRS and controls access and use of all roads. The SRS is noted for a diversity of upper coastal plain habitat types, including Carolina bay wetlands, pine and hardwood forests, cypress swamps, and sandhills, and harbors 35 native species of snakes (Gibbons and Semlitsch 1991). The field tests were conducted on a two-lane asphalt highway (1.9 km; 6 m wide) that was closed to traffic. The surrounding habitat was second-growth mixed hardwood-pine forest. The closed road allowed us to conduct testing in a situation in which behavioral responses were not disturbed by outside distractions. In addition, the vehicle tests could be carried out without regard for other traffic, and the safety of all test specimens could be assured.

Study specimens

Snakes used in the study were obtained on the SRS primarily by personnel from the Savannah River Ecology Lab (SREL). A variety of capture methods was used including aquatic minnow traps and hoop nets, drift fences with pitfall traps and terrestrial funnel traps, coverboards, standard road collecting, opportunistic captures, and time-constrained searches. After capture, snakes were held individually in snake sacks in the laboratory until testing. None of the snakes were handled or otherwise disturbed until after testing. Following testing, standard body size measurements and sex were determined. Before being released at the original capture site, all snakes were marked for future identification by cauterization (Clarke 1971) and recaptured snakes were not used in future tests. Snakes were then released at original point of capture.

Testing procedures

We tested each individual twice, from opposite sides of the road, to control for any directional component that might influence crossing behavior. An individual snake was used for a road test one time during a day in order to minimize stress on individuals. Tests in which an individual did not move after release or became defensive (vibrating tail, striking) were removed from the final analyses. Daily testing times for a particular species were based on the natural activity patterns of the species that have been reported in the general literature (Ernst and Ernst 2003) and local long-term road capture records (Gibbons and Semlitsch 1991). We tested species that are primarily nocturnal or crepuscular at dawn or at dusk. We tested typically diurnal species in the morning during summer and in the afternoon in spring and fall. We did not use specimens in the tests if they had been collected near the testing site because we assumed that the individuals would already be familiar with the area and possibly even the road itself. We also excluded specimens that appeared to be in poor health (emaciated, injured) or that were clearly gravid.

Release procedures

We constructed three release sites 12 m apart on each side of the road (figure 1; see schematic in Andrews and Gibbons 2005) at the study site. Thus, all six sites were positioned in flat, evenly vegetated shoulders with equivalent roadside habitat where similar habitat types were on adjacent and opposite sides. The use of multiple release sites minimized any potential for snakes to detect pheromone trails or other scents of previously tested snakes. We erected hardware-cloth fences (~0.5 m high and 10 m long) along the tree line at each of the six release sites to reduce the possibility that snakes would escape following the test. Observers were concealed from the test animals by a transportable blind consisting of a PVC pipe (1.6 m x 2.0 m) frame covered with camouflage fabric. The blind was placed immediately behind the hardware-cloth fence on the release side for a particular test.

Figure 1. Side shot of a release site showing fence, release pole and bucket, blind, and researcher prior to trial initiation. Two additional pairs of release sites are not shown.

We used upside-down black plastic planting pots for the release bucket in three sizes appropriate for small, medium, and large snakes. We drilled holes in the bottom of each bucket to attach string for lifting the bucket. The string was tied to a 5.1-m bamboo pole, and the bucket was placed upside-down. Thus, the observer could stand behind the blind and lift the bucket to release the snake but remain concealed during the test. To allow the snake to sample both on-road and off-road substrates before test initiation, we positioned the release bucket on the road's edge so that half was on the asphalt and half was on the vegetated roadside. A Basil 3500 cage-washing machine was used to wash each bucket between tests to eliminate the scent of previously tested snakes.

To release the snake under the bucket, we untied the snake sack and placed it under the bucket, removing it by holding a corner and sliding it out from under the bucket (tongs were used for venomous species). This procedure left the snake beneath the bucket and prevented exposure to the surrounding area prior to the test. We allowed the snake one minute to acclimate before test initiation by lifting the bucket. Defensive and search behaviors, along with their time of occurrence were recorded throughout each test in order to assess if a snake was disturbed (e.g., tail vibration, kinking, striking) and whether typical search behaviors (e.g., tongue flicking, head raising, and lateral head bobbing) were used for exploring the road environment.

Environmental variables

We recorded a suite of conditions for each test including temperatures at the release point (road, ground, and air), barometric pressure, humidity, and rainfall during the previous 24 hours, along with ranked measurements of cloud cover and wind strength. To avoid testing in temperatures outside of those of documented movement tendencies for snakes in the region (Gibbons and Semlitsch 1991; Gibbons, unpubl. data), we set a road temperature range of 15 C – 55 C (depending on and appropriate for the season). We conducted tests at times when the sun's orientation resulted in no light/shade gradient on the paired release sites opposite each other on the road, which allowed for maximum consistency of temperatures across the road-zone area.

We did not conduct tests during or immediately after rainfall. While effects of the environmental variables were analyzed, the purpose of collecting these data was to maximize standardization rather than a targeted attempt to examine environmental factors affecting road-crossing behaviors.

Road tests

Response variables of an individual were cross, avoid, or deter. Deterrence is defined here as an avoidance response in which the snake did enter the road but did not cross it and ultimately retreated, returning to the release side of the road. This testing strategy allowed us to determine if some snake species might attempt to cross the road but ultimately avoid it, in contrast to those that did not enter the road. The test was terminated when the snake reached the fence on the opposite side of the road from the release point (cross) or on the release side of the road (avoid/deter). In either case, the snake was recaptured and returned to the laboratory. For individual snakes that crossed the road, the entry and exit times and total distance were recorded for road crossing speed calculations. Additionally, the angle of the crossing trajectory relative to the road (90° = perpendicular to the lane direction) was recorded using a protractor.

We conducted a pilot study in 2002 with 27 species of snakes (n=225 individuals; Andrews 2004a) for the purpose of identifying target species that exhibited a range of life-history characteristics and behavioral responses to roads. After the initial testing period, we selected nine species [cottonmouth (*Agkistrodon piscivorus*), black racer (*Coluber constrictor*), canebrake rattlesnake (*Crotalus horridus*), ringneck snake (*Diadophis punctatus*), corn snake (*Elaphe guttata*), rat snake (*Elaphe obsoleta*), eastern hognose (*Heterodon platirhinos*), southern banded watersnake (*Nerodia fasciata*), southeastern crowned snake (*Tantilla coronata*)] for testing during the core season (March—November 2003) These included species that could be categorized as aquatic or terrestrial and venomous or non-venomous, and that covered a range of average adult body sizes (table 1). Data from the pilot study were not used in the core analysis, with the exception of crossing speeds and angles.

Table 1. Species of snakes selected for road tests in 2003. The black racer, canebrake rattlesnake, and rat snake were also used in the vehicle tests. Each species is categorized as (A) aquatic or (T) terrestrial, (V) venomous or (N) non-venomous, or (L) large or (S) small in average body form.

	Name	Habitat	Venom	Size
	Cottonmouth	A	V	L
	Black racer	T	N	L
	Canebrake rattlesnake	T	V	L
	Ringneck snake	T	N	S
	Corn snake	T	N	L
	Rat snake	T	N	L
	Eastern hognose	T	N	S
	Banded watersnake	A	N	L
	Southeastern crowned snake	T	N	S

We examined the influence of different variables by using a general model that incorporated all potential covariates, and category models in which variables were either classified as experimentally controlled (release site number, side of the road of release, time held in captivity, and whether the snake was initially caught on a road), physical (sex, SVL, and mass), or environmental (date, time, temperatures of road, ground and air, humidity, barometric pressure, 24-hour rainfall, wind, and cloud cover). We used stepwise regression (PROC LOGISTIC, SAS Institute, Inc., Cary, NC, 1999) to analyze for model fit and developed full models for all snakes with "species" included as a variable, and species-specific models were developed separately for each species. The use of multiple models allowed us to describe effects of covariates in greater detail for each species. Though individuals were tested twice, repeated measures designs could not be applied to the data set; therefore, models were run including all tests and only the first test of an individual, and odds ratios were calculated to investigate potential biases of carryover effects from the first test on the outcome of the second (Agresti 1996). Response probabilities were analyzed per species using Chi-square tests (PROC FREQ, SAS Institute, Inc., Cary, NC, 1999). Variable influences on crossing speeds and angles were also analyzed using stepwise regression (PROC REG, SAS Institute, Inc., Cary, NC, 1999). Interspecific differences in crossing speeds and angles were investigated using the Kruskal-Wallis test (StatSoft, Inc. Tulsa, OK, USA, 1998) after the removal of outliers (PROC UNIVARIATE, SAS Institute, Inc., Cary, NC, 1999).

Vehicle tests
We conducted the vehicle tests from early March through early November 2003. A 2002 Chevrolet Silverado 1500 pick-up truck was used for all vehicle tests to control for the event that observed behaviors were in part dependent on vehicle characteristics (e.g., size, mass). We conducted the tests on only three species (rat snakes, black racers, and canebrake rattlesnakes) that represented three distinct defensive behaviors (crypsis, speed, and venom, respectively). The same release sites and methods from the road tests were applied with the vehicle experiment. With the exception of humidity, barometric pressure, and amount of rainfall during the previous 24 hours, all other environmental variables we measured were the same as for the road tests.

The vehicle was positioned 0.3 km down the road from the release point. After the snake was contained, the observer lifted the bucket from behind the blind. The snake was not forced into the road and, therefore, had the same directional options as in the road tests (i.e., cross, avoid, deter). When the snake's movement became consistent, the observer signaled the driver by radio to begin driving. A speed of 35 mph was maintained as the vehicle approached and passed the snake. As the vehicle approached, the observer notified the driver of the snake's location in the road in order to minimize the distance between the passing vehicle and the snake but without jeopardizing the safety of the animal. As the snake was not always in the same physical location relative to the road in every test, distance between the snake and the vehicle could not be strictly standardized, but only minimized, and was estimated to the nearest 0.25 m. No study specimens were injured or killed during this study.

We recorded the timing of the snake's response relative to the vehicle in terms of whether it reacted before, after, or at the moment that the vehicle passed. We also recorded if the snake exhibited no reaction, i.e., not altering speed or direction with the passing vehicle; however, we rarely observed this behavior (n=7). After the vehicle passed, we recorded any secondary response of the snake in regard to whether it continued to crawl if it had not stopped. If the snake had become immobile we recorded whether it resumed movement or continued to remain immobile. Search behaviors were recorded as in the road tests along with defense responses characteristic of the target species; rat snakes often kink as a crypsis mechanism and black racers "bow," raising the upper half of their body. Snakes were recaptured within one minute of the vehicle passing to prevent escape. Therefore, the secondary response is a short-term observation and does not represent the maximum amount of time a snake may remain immobilized.

We used stepwise regression (PROC LOGISTIC, SAS Institute, Inc., Cary, NC, 1999) to determine if there were any covariate effects on the responses of snakes to the passing vehicle by examining both general and category models and on a grouped and individual species basis as described above in the "Road Tests" section. We again calculated odds ratios to determine the degree of consistency between the responses of an individual's first and second test (Agresti 1996). We used Chi-square analysis (PROC FREQ, SAS Institute, Inc., Cary, NC, 1999) to examine response probabilities of each species.

Results

Road tests
Multiple analyses were run after applying exclusion criteria (n=38) to determine the consistencies in models using all tests (n= 355), and using only the first test of an individual (n=185). Due to difficulties incorporating the within-subject effects into the model itself, we used only the first test in the final analysis, although the results were similar when all tests were used. The odds ratio was marginally random (θ=1.09) but demonstrated that an individual had a greater tendency to repeat the response of the first test in the second (if θ=1, there is no correlation between the response exhibited in the first test with that in the second). In addition, when all tests were included, response was observed (p<0.02) based on which side of the road the release point was on, but no significant relationship was observed when only first tests were used.

The effect of species on road avoidance frequencies was highly significant in all models (p<0.0001); however, in the category analyses, no control or environmental variables were found to be significant. Among the measures of individual characteristics, SVL was found to be significant (p<0.05), where smaller snakes had a greater tendency to avoid the road. Single-species regressions did not yield significance for any of the variables with the exception of SVL ($p<0.05$) for canebrake rattlesnakes, in which larger specimens had a greater tendency to avoid the road. Black racers demonstrated a marginally greater avoidance tendency when tested on the west side of the road ($p=0.05$). However, if racers are removed from the sample before analysis, no effect of side of the road was observed in any of the generalized or category models. Chi-square analyses conducted on a single-species basis yielded response probabilities that deviated significantly from expected (50:50) for six of the nine species with only black racers avoiding the road less frequently than expected (figure 2). Most snakes that exhibited avoidance did not attempt to cross the road, but two species (cottonmouths and southern watersnakes) entered the road and then deterred almost 50 percent of the time; ringneck snakes deterred in 63 percent of all avoidance occurrences.

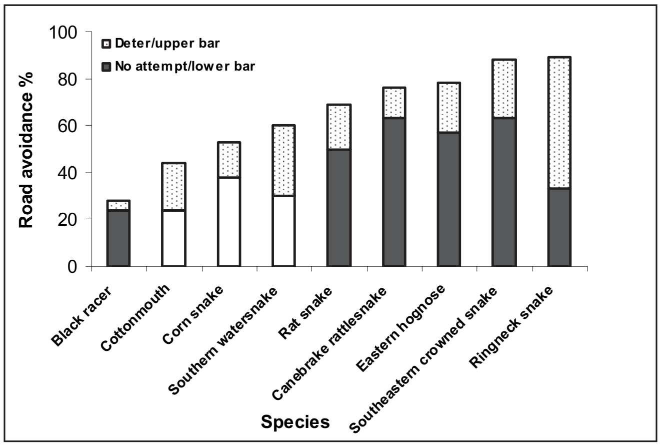

Figure 2. Road avoidance rates for nine species of southeastern snakes (adapted from Andrews and Gibbons 2005). Gray bars represent species that significantly deviated from expected ($p<0.05$). Lower bars represent individuals that retreated to the woods without entering the road (i.e., no attempt); Upper bars represent individuals that attempted but did not cross the entire road (i.e., deter). Species had a highly significant effect on crossing probability ($p<0.0001$). Sample sizes, in order by species, are black racer 54, cottonmouth 25, corn snake 13, southern watersnake 20, rat snake 26, canebrake rattlesnake 16, eastern hognose 14, southeastern crowned snake 8, ringneck snake 9.

Model results did not vary for crossing speed and angle analysis whether all tests were included or only the first tests were used. The effect of species was highly significant for crossing speed (Kruskal-Wallis test, $p<0.0001$, figure 3); five outliers were removed (black racers, $n=4$; canebrake rattlesnakes, $n=1$). SVL, mass, and road temperature significantly influenced crossing speed (SVL and mass, $p<0.01$; road temperature, $p<0.0001$). SVL and mass parameter estimates demonstrated that longer and lighter snakes move faster than did short and heavy snakes. Speed was positively correlated with road temperature across species. No species deviated significantly from a perpendicular (90°) crossing trajectory, and no species differed significantly in crossing angles ($p=0.06$) when six outliers were removed (black racer, $n=1$; corn snake, $n=1$; eastern hognose, $n=4$). Single-species regression analyses showed an effect of mass ($p<0.05$) on eastern hognose, cottonmouth, and southern watersnake. Road temperature had a significant effect specifically on cottonmouth ($p<0.01$).

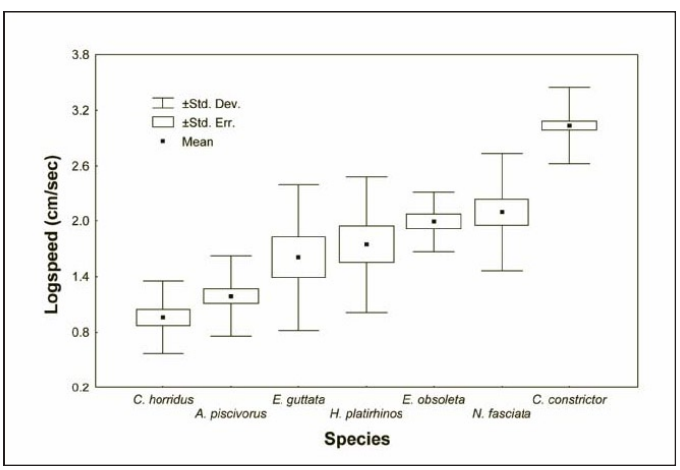

Figure 3. Crossing speeds for each of nine target species of snakes that had >10 crossing occurrences (adapted from Andrews and Gibbons 2005). Species had a highly significant ($p<0.0001$) effect on crossing speed. Sample sizes for species are canebrake rattlesnake 20, cottonmouth 29, corn snake 13, eastern hognose 14, rat snake 17, southern watersnake 19, black racer 73.

Vehicle tests

We conducted 218 trials with 113 individual snakes and found no differences between model results when all tests were used, after applying exclusion criteria (n=42), and only the first test of an individual (n=84) was used. The responses of individuals did not vary between their first and second test (θ=4.37). All models and analyses showed a high significance both at the species level (p<0.0001) and on a single-species basis (black racer, p<0.0001; canebrake rattlesnake, p=0.00; rat snake, p<0.0001). All canebrake rattlesnakes exhibited an immobilization response (n=30) and were subsequently removed from covariate analyses. Seven tests in which we observed no response to the vehicle (black racer, n=6; rat snake, n=1) are included in the presentation of the data (figure 4). However, these variations in behavior had no overall significance on the prevalence of the immobilization response for these species. None of the measured environmental, physical, or control variables had a statistically significant effect on response (p>0.05).

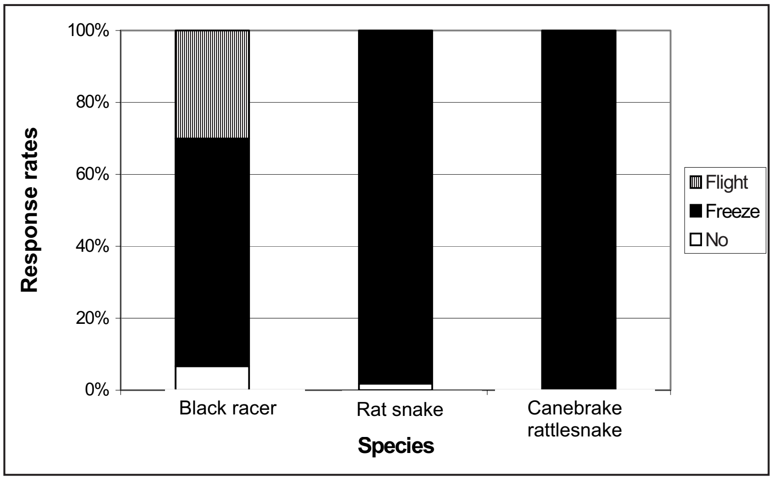

Figure 4. Vehicle response rates for three species of southeastern snakes (adapted from Andrews 2004b). All species were significant in deviating from unity. Interspecific differences were found to be highly significant (p<0.0001). Sample sizes in order by species, are black racer 90, rat snake 55, canebrake rattlesnake 30.

The snake's position relative to the road and the vehicle showed no effect on response to the vehicle. However, both the timing of the individual's reaction in relation to the vehicle passing and its secondary reaction after the vehicle had passed were significant for species (p<0.05). Black racer and rat snake were more likely to immobilize as the vehicle passed. Canebrake rattlesnakes immobilized 50 percent of the time (n=15 of 30; figure 5) before the vehicle reached the snake on the road. Few snakes (n=5 of 144, 3%) immobilized after the vehicle passed them. Sixty-two percent (n=89 of 144) immobilized when the vehicle passed, and 35 percent immobilized before the vehicle passed (n=50 of 144). Once the vehicle had passed, more than half of the snakes commenced moving again (n=42 of 76, 55%; figure 6), but 28 of 76 (36%) remained immobilized on the road afterwards. Both rat snakes and canebrake rattlesnakes restarted movement 65-70 percent of the time after the vehicle had passed. The highest percentage of a continued immobilization reaction occurred with black racers (n=11 of 28, 52%).

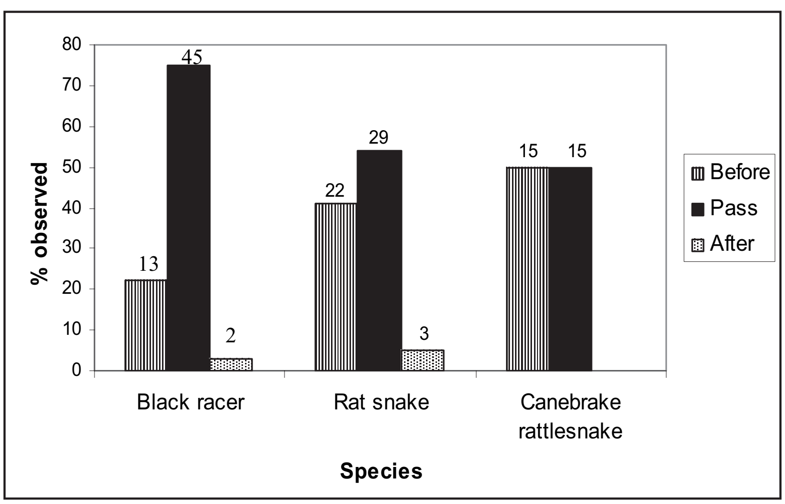

Figure 5. Timing of responses as related to a passing vehicle (adapted from Andrews 2004b). "Before" represents the proportion of responses exhibited before the vehicle passed. "Pass" represents responses exhibited at the vehicle pass. "After" represents the proportion of observed responses that occurred after the vehicle passed. Time of the reaction in relation to the vehicle passing was significant at the species level (p<0.05). Sample sizes are listed above the bars.

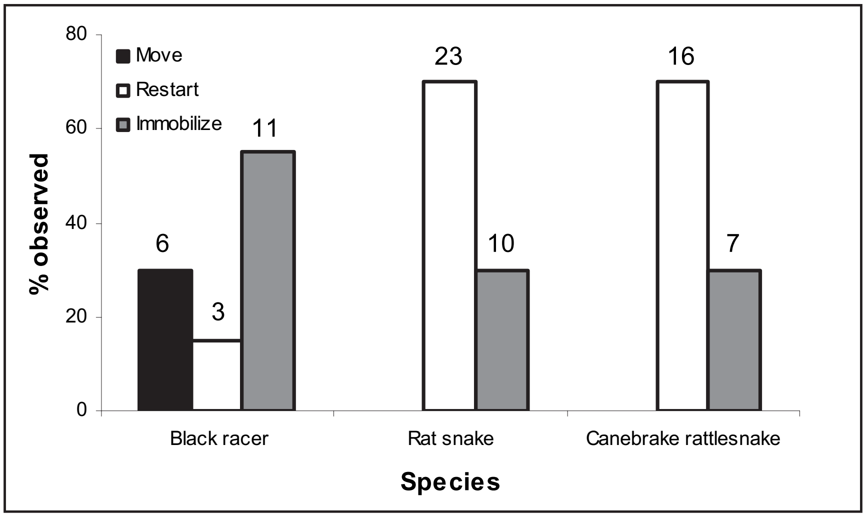

Figure 6. Secondary responses observed after the vehicle passed (adapted from Andrews 2004b). "Move" indicates that the snake fled in response to the vehicle and continued to flee after the vehicle passed. "Restart" indicates that the snake became completely immobile in response to the passing vehicle but restarted movement after the pass. "Immobilize" indicates that the snake became immobile in response to the passing vehicle and continued to freeze after the vehicle had passed. Species had a significant effect on the probability of a particular response after the vehicle passed (p<0.05). Sample sizes are listed above the bars.

Discussion

Road tests

Our findings supported our three hypotheses: species varied in road-crossing rates and speeds, but did not significantly vary in crossing angle. Body length comparisons conducted across species showed that smaller snake species had a greater tendency to avoid rather than cross the road. This avoidance generalization was also observed in the pilot study; data from the pilot study that were not used in analysis showed 100-percemt avoidance levels of both ringneck snakes (n=6) and southeastern crowned snakes (n=10). This finding is consistent with the observation that smaller snakes are more likely to have avian predators and are at greater risk of predation when in more exposed terrains (Fitch 1999; Gibbons and Dorcas 2005). Additionally, smaller snakes, which move shorter distances (e.g., ringneck snakes average 1-3 m/day, Fitch 1999), are less likely to encounter a road.

Ringneck snakes and southeastern crowned snakes, the smallest species in length and the ones with the highest avoidance rates, are heavily fossorial, spending predominantly more time under litter and other debris. These snakes minimize time spent in the open (e.g., ringneck snakes, Fitch 1999) and, therefore, are less likely to encounter or cross roads. We are not proposing that small snakes do not cross roads, but that road environments are not conducive to overland movement by these species. Despite the avoidance rates observed in this study, both the ringneck snake (Fitch 1999) and the southeastern crowned snake (Messenger 2004) have been observed to cross roads. In both cases, the surveyed roads bisected areas with high densities of these species. In areas with these densities, encountering the road is unavoidable for some individuals, and crossing is likely to occur in some instances.

Clear patterns did not emerge for avoidance rates across species in terms of other ecological groupings (i.e., aquatic/terrestrial, venomous/non-venomous). However, the ecological groups were not evenly represented (e.g., 2 aquatics, 6 terrestrials), so a thorough comparison could not be made. Even with comparable group sizes, it is possible that trends would not have been detectable on the group level, as ecological needs and patterns vary greatly within each group across species. Also, as road placement within a habitat is likely the key factor determining crossing probabilities, road-crossing rates cannot be generalized at this level.

Three species that showed >70-percent road avoidance (canebrake rattlesnakes, rat snakes, and eastern hognose snakes) are frequently found on the road, such that road cruising is one of the more productive techniques used to find them throughout much of their ranges. However, the observed level of avoidance in this study suggests that not all individuals that encounter roads actually cross them. Road crossings are also a consequence of home range dynamics. If snakes readily encounter the road via dispersal mechanisms, frequent road observations could be made even if only 20-30 percent of individuals cross. Thus, even the species that are more equipped to deal with the predatory threats of open spaces via body size or venom could still respond to the road as an environment to avoid.

A species-level effect of the side of the road on which the test was initiated was observed for black racers. Snakes in this study were collected from many different locations on the SRS and still exhibited species-specific tendencies; therefore, spatial displacement is not a concern in interpretation of this result. This effect suggests the potential importance of habitat cues in movement patterns in regards to directional decisions by snakes. As the study was conducted in an open outdoor environment, use of the road site by other animals could not be controlled. Therefore, trace scents from prey and predators (including other snakes) could also have influenced crossing patterns. This factor cannot be conclusively addressed from this particular study but warrants future investigation into the sensitivity of snakes to detect prior use of an area by other animals, even when the snake is placed in unfamiliar territory. Black racers also showed a significant tendency to cross the road at a higher than expected frequency. However, search behaviors were exhibited in these tests prior to crossing, demonstrating that the racers acclimated before making a directional selection. These data do not necessarily suggest that racers prefer to cross the road, or are choosing the road over the nearby forest habitat. Although it cannot be ascertained why racers showed an above-expected crossing rate, it can be concluded that the species will readily cross the road, a conclusion supported by existing road capture data of more than 1,500 racers from the SRS (Andrews and Gibbons, 2006).

Whether a snake was initially caught on the road had no significant effect on response rates although this factor was not directly tested in this study. Here again, an altered reaction to the road due to cumulative exposure could influence crossing, or avoidance, patterns at the inter- or intra-specific level. As was seen with these results, older (i.e., larger) canebrake rattlesnakes had a greater tendency to avoid the road than did younger (<1000 mm SVL) ones. Canebrake rattlesnakes, an example of a wide-ranging snake species, are inhabitants of an increasing number of areas penetrated by roads, thereby increasing the chance that an individual snake has encountered a road. Eastern diamondback rattlesnakes (*Crotalus adamanteus*) have been observed to truncate their home ranges along roads (Bruce Means, pers. comm.), and timber rattlesnakes (= canebrake rattlesnakes) have also been observed to travel parallel to country roads (e.g., Fitch 1999).

There was a strong species effect on crossing speeds, which is explainable by natural differences in body size and movement styles across species (Gibbons and Dorcas 2005). In addition to the physical implications of these species being slower due to higher length to mass ratios, venomous snakes are equipped to use venom, not flight, as their ultimate defense mechanism (Gibbons and Dorcas 2005). Therefore, these snakes are at less risk of predation than are nonvenomous species while crossing open spaces. The barrier effect can also arise with species that cross slowly (e.g., canebrake rattlesnakes), resulting in high levels of mortality, after which population stability could suffer from the pronounced loss of individuals. Fitch (1999) described the road crossing behavior of timber (= canebrake) rattlesnakes as crossing "so slowly, movement was likely to be unnoticed." This behavior is again demonstrated in these data, not only for canebrakes, but also for our other venomous target species, the cottonmouth. The correlation between body mass and speed was negative. Long, slender snakes cross the road more quickly as observed with black racers. The three species (cottonmouths, eastern hognose snakes, and southern watersnake) for which a mass effect was shown are all stout-bodied species as adults when in physically optimal conditions (Gibbons and Dorcas 2005). Collectively, snakes moved faster at warmer road temperatures, and a specific effect was seen with cottonmouths. This general response of increased speed at warmer temperatures has been documented (e.g., Blouin-Demers et al. 2003, Heckrotte 1967). The true role of temperature in road-crossing behaviors cannot be concluded from this study as snakes were tested within constrained temperature conditions. However, as road temperature showed significance despite controlled efforts, it is likely that this factor is of considerable influence in road crossing patterns. Particular crossing frequencies have been documented to be correlated not only with season, but also during certain times of day (e.g., Klauber 1939), likely due to natural temperature fluctuations within a day (e.g., Gibbons and Semlitsch 1991).

No species deviated appreciably from a perpendicular (90º) crossing angle, and crossing angles did not vary significantly among species. This observation suggests that snakes, regardless of whether they view the road as a threat, spend no more time crossing than necessary. We observed search behaviors such as tongue flicking and head lifting in individuals at the beginning of the test, snakes were not observed to search extensively while crossing. After snakes had done initial searching and made a directional decision, they typically proceeded with consistent movement. Snakes took the shortest route possible, their inter-specific crossing speed rate notwithstanding.

In summary, highly significant levels of species-specific variation are apparent in (1) how readily a species will cross the road and (2) crossing speeds when a crossing attempt occurs. Although this study was not designed to test for importance of variables both intrinsic and extrinsic to the snake, physical features of the individual snake or species itself, certain habitat cues, and road temperatures (as a consequence of time of day or season) can potentially influence both avoidance rates and crossing speeds.

Vehicle tests

The frequency of immobilization responses was higher than initially hypothesized. Canebrake rattlesnakes, which rely on crypsis as a primary defense, did immobilize in response to the passing vehicle. Black racers had a higher immobilization response than expected, but we have also observed this behavior in close encounters in the field. Conditions in which no response was observed could not be statistically pursued due to the low sample with which this lack of exhibition was observed (n=7). In five of the seven tests (6 black racers and 1 rat snake), the snake was either on the road shoulder or the distance between the snake and the vehicle was 4 m or greater, suggesting that possibly if snakes can sense if they are a "safe" distance from the vehicle, they do not enact defensive behaviors. Therefore, distance between the snake and the vehicle, and the relative positions would likely have an effect on response. These data are unable to test this effect due to the lack of variance in these data for the distance between the vehicle and the snake. Studies inquiring into responses of snakes to specific distances from the vehicle are needed to determine if this factor is of significant influence.

The majority of snakes immobilized as the vehicle passed, as opposed to before or after the pass. Additionally, the majority of snakes restarted movement after the vehicle passed, suggesting that although a passing vehicle temporarily interrupts road crossing, it is a momentary reaction. However, canebrake rattlesnakes often remained immobilized for up to a minute, posing a significant extension of crossing time for species exhibiting persistent immobilization. Persistence of immobilization needs to be quantified to assess actual crossing time and mortality probabilities accurately.

Although snakes verifiably use the road for thermoregulation in some locations and under particular environmental conditions (e.g., Sullivan 1981), it is possible that immobilization behavior lends support to the belief that snakes commonly use the road for thermoregulatory purposes. Thermoregulation likely occurs at times of the day in which the road is not heavily traveled by vehicles or in regions, such as the West, where the landscape is vast and animals are more accustomed to open spaces, and in areas of reduced traffic densities.

In conclusion, vehicle responses mimic predator responses in natural habitat. The immobilization response appears to be momentary for most species. However, snakes encounter more than a single vehicle in reality; this response could significantly prolong crossing time if immobilization behaviors are repeated. It follows that the time it takes to cross the road is positively correlated with traffic density for species that immobilize in response to passing vehicles. This in-road behavior needs to be considered as a factor increasing the threat of mortality with a group that already is not adept at crossing roads due to secretive natures or applied defensive behaviors and presumed vulnerability to natural predators in open spaces.

General Conclusions

In the developing field of "road ecology" (Forman et al. 2003) an increasing number of land managers, research ecologists, environmental chemists, and hydrologists have begun to recognize the irreparable alteration to the landscape that can be caused by the nation's transportation infrastructure. To develop more environmentally sound transportation systems in the future and allow for efficient mitigation practices, we must first understand the biological impacts that result from these alterations. The research reported here was designed to identify sensitive species and the potential diversity in type and degree of road impacts across snake species.

Although a range of species behaviors is observed across snakes as a group, these data make it apparent that snakes do not deem the road area a favorable environment. It is notable to management designs that road impacts cannot be generalized even within an animal group. Perhaps some are maintaining viable populations amidst road development, but perhaps others will go locally extinct without implementation of measures minimizing road impact. The difference between the two categories needs to be apparent so that resources and future research can be prioritized for the sensitive species.

As this study was designed to investigate behavioral effects at an inter-specific level, research into intra-specific comparisons also needs to be conducted with the identified sensitive species (Andrews and Gibbons 2006). The seasonality of road mortality has been documented both across and within seasons (e.g., Case 1978, Sherbrooke 2002), but a greater understanding of the conditions of road avoidance needs to be achieved in order to document a representative section of road impacts on wildlife. Ultimately, population- and community-level assessments must occur to determine how roads are affecting ecological processes at landscape scales. The degree of permeability of the road determines whether the conduits that wildlife relies on for dispersal and survival remain open.

The most exciting phrase to hear in science, the one that heralds new discoveries, is not 'Eureka!' (I found it!) but 'That's funny ...' -Isaac Asimov (1920 - 1992)

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Factors Influencing the Road Mortality of Snakes on the Upper Snake River Plain, Idaho

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Abstract: This study documents the magnitude of road mortality on snake species that occur in sagebrush steppe habitat, provides insight into how susceptibility to this mortality differs among species as well as by sex and age class of individuals, and examines how different landscape variables influence road-kill aggregations using a logistic regression model. I collected data by road cruising a 183-km road loop on the upper Snake River Plain in southeastern Idaho from May through October of 2003. I conducted 56 total routes, traveling 10,248 km and encountering a total of 253 snakes (0.025 snakes/km) over the six-month survey period; 93 percent of these animals were found dead on the road surface (DOR). The majority of observations belonged to two species, with gophersnakes (*Pituophis catenifer*) comprising 75 percent of all road records, and western rattlesnakes (*Crotalus oreganus*) comprising 18 percent of all road records. Monitoring data from three of the largest snake hibernacula on the site indicate that rattlesnakes are the most abundant snake species, comprising 50 percent of all captures at trapping arrays since 1994. This suggests that gophersnakes may be more susceptible to road mortality due to higher vagility, or that our monitoring efforts do not effectively estimate their populations; this question remains to be explored. Overall, I documented more traffic casualties of adults than any other age class, the majority of which were males (64%). Road mortality varied seasonally by age and sex classes for both gophersnakes and rattlesnakes. More adult male gophersnakes were discovered DOR in May and June, while the death of adult females did not exhibit a trend. I documented a significant pulse of subadult mortality during the month of September. The seasonal trends in mortality of rattlesnakes differed from gophersnakes, but were not significant. This indicates that individuals may be more susceptible to road mortality during specific movements, such as mating or migration. The logistic regression indicated that increased cover of grass along roadsides, basalt piles, and mean distance to den were positively associated with gophersnake occurrence on roads. As most grasses on the site are invasive, this result implies that habitat change due to invasive species may be increasing susceptibility of gophersnakes to mortality.

Introduction

An expansive network of roads stretches across our landscape affecting ecosystem processes in myriad ways (Forman et al. 2003). Roads transform existing vegetation into a compacted earthen surface with altered thermal and moisture characteristics and create a replacement zone of intense human activity. Therefore, roads facilitate future development of an area, increasing use of surrounding habitats by humans and the hunting, collection, and observation of wildlife (Andrews 1990; White and Ernst 2003). Road characteristics are variables that potentially affect wildlife both directly and indirectly. Several road aspects of apparent influence include age, access, substrate, and size. Finally, road placement within the context of the surrounding landscape can also influence road-kill locations, rates, and species presence.

Wildlife behavior and ecology influences the probability of wildlife being affected by roads. Animal movement across the landscape includes home range activities (e.g., foraging, thermoregulation, and territorial behavior), dispersal, mating, escape behavior, and migration. Habitat use may vary seasonally, and the frequency and type of movement differs by life stage, sex and species. Vagile species are more likely to encounter roads as a result of greater movement distance and frequency (Bonnet et al. 1999; Carr and Fahrig 2001). Sometime during the last three decades, roads with vehicles overtook hunting as the leading direct human cause of vertebrate mortality on land (Forman and Alexander 1998). Vehicles on roads kill over one million vertebrates each day in the United States (Lalo 1987). Roads can affect demography and gene flow by disrupting dispersal through mortality of breeding adults. The immediate threat to animals (i.e., being killed by traffic) can result in the effective isolation of populations (Lodé 2000). Ultimately, isolation can strongly influence long-term persistence of populations through inbreeding depression, which increases susceptibility to extinctions (Sjögren 1994, Vos and Chardon 1998). The survival of populations in fragmented habitats depends on the interaction between the spatial pattern of roads and the movement characteristics of the organisms (Carr and Fahrig 2001).

Many snake species possess life history characteristics that increase their vulnerability to roads (reviewed in Jochimsen et al. 2004). Briefly, characteristics include: the tendency to thermoregulate on road surfaces (Klauber 1939), activity patterns that coincide with traffic flow (Seigel 1986), relatively slow locomotion, long life spans, low reproductive rates and low adult mortality (Rosen and Lowe 1994; Rudolph et al. 1999), and habitat requirements that vary seasonally. For example, northern temperate snakes migrate seasonally to locate specific resources (Gregory et al. 1987; King and Duvall 1990), such as refuge, mates, prey, and egg-laying habitat (for oviparous species). These resources tend to be located in distinct habitats that are patchily distributed across the landscape. Many large-bodied snake species make a loop-like migration from a communal hibernaculum (overwintering den site) to summer foraging habitats (King and Duvall 1990). Seasonal movements are defined by three distinct phases: (1) egress, or rapid movement away from the hibernacula, (2) stationary, or periods of short-distance movements associated with foraging, gestation, or ecdysis, and (3) ingress, or long-distance movements toward the hibernacula, as described by Cobb (1994). Their populations, therefore, depend on the maintenance of "landscape linkages" between these habitats. When roads fragment patches of summer and winter habitat, traffic and associated highway mortality affect snake populations.

Understanding how mortality differentially affects individuals could provide further insight into the effects that roads have on snake populations. For example, the loss of a gravid (pregnant) adult female can have greater implications than the loss of a juvenile male. This study quantifies the relative susceptibility of different age/sex classes and species across seasons to road mortality to provide a basis for recommendations to mitigate the adverse effects of roads. For example, closing specific road sections during selected seasons could allow for migratory movements that are predictable (Seigel 1986, Podloucky 1989). In addition to protecting the snakes themselves, the importance of snakes as trophic components of terrestrial ecosystems (Rosen and Lowe 1994, Siegel et al. 2002) emphasizes the need for mitigation efforts to maintain ecosystem health. It is uncertain how roads are linked to the widespread decline of amphibian and reptile populations (Gibbons et al. 2000, Stuart et al. 2004), but unlike many potential factors, the prospect of mitigating and, even more ideally, preventing the adverse effects that can be attributed to roads seems more attainable. However, the correct placement of mitigation efforts is critical for their success (Jackson 1999).

Research objectives

This study was designed to address three objectives: (1) quantify the road mortality of snakes on the upper Snake River Plain; (2) measure any variation of mortality with respect to species, season, sex, and age; (3) use logistic regression to evaluate the importance of habitat and landscape factors associated with road-kill locations. These correlations could then be used to identify areas that may represent high risks for snake road mortality and candidates for mitigation.

Methods

Study area

I conducted surveys along a 183-kilometer route that lies on the western edge of the upper Snake River Plain located in southeastern Idaho, USA (figure 1). This route is loop shaped and composed of six road sections with differing levels of traffic volume: US Highway 26 (45-km), US Highway 20/26 Junction (25-km), State Highway 22/33 (running N/S, 26-km), State Highway 22/33 (running E/W, 21-km), Franklin/Lincoln Boulevard (restricted access, 39-km), and US Highway 20 (27-km). Annual average daily traffic (AADT) estimates obtained from Idaho Transportation Department are reported as 1200, 2200, 610, 730, 300, and 1700 vehicles per day, respectively. In addition, I observed pulses of high traffic volumes during early morning and evening commuting hours on weekdays. All roadways are two lanes (approximately 10 m in width) and paved.

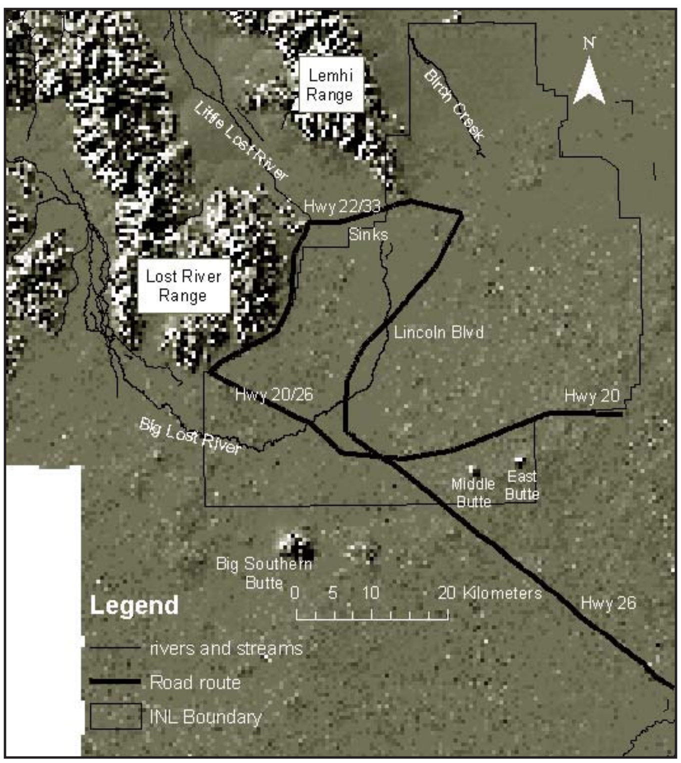

Figure 1. Shaded relief map of the Idaho National Laboratory (INL), showing the 183-km survey route (thick black line) with landscape features labeled. The inset shows the location of the INL in Idaho, USA.

The majority of the route lies within the Idaho National Laboratory (INL) (the boundary of which is designated by a thin border in fig.1), a Department of Energy facility established in 1949. Its establishment created one of the largest contiguous reserves (2,315 km) of sagebrush steppe ecosystem in the world. Sagebrush steppe describes the extensive vegetation type of the Intermountain West in the United States, which is dry habitat characterized by sagebrush, shrubs, and grasses (Anderson et al. 1996). Over the past 130 years, human disturbance, grazing, and increased fire frequency have radically altered this ecosystem. Fortunately, public access onto the INL is restricted, and approximately 40 percent of the total area has been closed to grazing since the 1950s. The value of this site for ecological research has been recognized since 1975, with on-going studies monitoring both plant and animal communities. However, grazing, agriculture, and low levels of urbanization occur along the periphery of the INL, which is managed by the Bureau of Land Management (BLM) and private owners.

Natural vegetation of the INL is predominantly a sagebrush-grass community consisting of shrub overstory with a perennial grass and forb understory. Anderson and Inouye (2001) estimated the total plant cover at 38 percent in 1995, with shrubs contributing 52 percent, perennial grasses 15 percent, and forbs 7.5 percent of that total. Habitat adjacent to roadsides comprises grasses, the degree of which varies across the study area. Many disturbed areas on the site (including roadsides) were intentionally seeded with crested wheat grass (*Agropyron* spp.), a non-native species that is resistant to native plant colonization. In addition, cheatgrass (*Bromus tectorum*), a common invasive in this ecosystem, is present.

The landscape of the study area reflects a history of volcanic activity. Mean elevation across the INL is about 1,500 m with the lowest values in the north-central portion of the site, and highest atop East Butte. Adjacent to the western and northwestern boundaries of the site are the Lost River and Lemhi Mountain ranges. The landscape is interspersed with buttes and craters with lava outcrops and tubes concentrated across the southern portion of the site. These features possess certain structural and thermal attributes characteristic of snake hibernacula (overwintering sites) (Doering 2005).

The Environmental Surveillance, Education and Research Program (ESER) manages and coordinates research concerning wildlife and habitat on and near the INL. Since 1975, students and faculty from Idaho State University have conducted research on the herpetofauna communities that occur on the INL. Visual searches have documented species occurrence (Linder and Sehman 1977, Cooper and Peterson 1996); the thermal ecology and activity patterns of reptiles have been investigated (Guyer and Linder 1985a, b; Cobb 1994); and research examining predator prey interactions and the response of snakes to habitat change is currently underway (Jenkins unpublished data). Furthermore, the ISU Herpetology Laboratory continues to monitor the three largest known hibernacula on a yearly basis since 1994; several thousand snakes have been marked, and population estimates are available (ESER Annual Environmental Reports 1994 – 2004: www.stoller-eser.com/Publications.htm).

Study species
Herpetofauna surveys document the occurrence of six snake species on the INL. The majority of these species belong to the Colubridae family including: racer (*Coluber constrictor*), nightsnake (*Hypsiglena torquata*), striped whipsnake (*Maticophis taeniatus*), gophersnake (*Pituophis catenifer*), and terrestrial gartersnake (*Thamnophis elegans*). *Crotalus oreganus* (western rattlesnake) is the lone representative of the Viperidae family. All species are known to overwinter communally at hibernacula distributed across the site. Racers and striped whipsnakes are diurnally active species that possess excellent vision, long tails, and are known for their speed (Nussbaum et al. 1983). Night snakes are small in body size, rear-fanged, and generally nocturnal or crepuscular; they tend to be associated with rocky outcrops (Nussbaum et al. 1983). Gophersnakes are large, active foragers that kill prey via constriction (Nussbaum et al. 1983) and are very adept burrowers (Ernst and Ernst 2003). Gartersnakes tend to be found in the vicinity of water, are associated with vegetation, and are viviparous (females give birth to live young) (Ernst and Ernst 2003). Finally, western rattlesnakes are sit-and-wait predators, medium-sized, and viviparous (Ernst and Ernst 2003). Many of these species migrate seasonally between hibernacula and summer foraging ranges that may be separated by greater than 2 km (Ernst and Ernst 2003).

Data collection: systematic routes
I quantified the road mortality of snakes along a 183-kilometer route by driving slowly in a vehicle (48 kmph), and recording all snakes observed on the road surface. In 2003, I drove a minimum of five days/week during the egress of snakes from hibernacula (May-June 2003) and up to three days/week from July through early October to monitor over the ingress period. I rotated the start time of each survey to account for the variation of snake activity across the seasons, as well as the direction I traveled around the route (clockwise or counterclockwise). Morning surveys were initiated prior to 1000, evening surveys after 1700 – 2000, afternoon surveys between 1200 and 1400. I conducted the initial survey (Survey #1) in the morning, the following survey (Survey #2) during the evening, and finally drove the next survey (Survey #3) in the afternoon, and continued this cycle through the end of this study. I did this to ensure that survey times were not biased to coincide with peak hours of snake activity. I attempted to conduct an equal number of surveys for each time period across all months. The duration of each survey ranged from four to eight hours dependent on traffic volume and number of snakes observed. In 2004, I reduced sampling efforts and conducted an additional 12 surveys between June 5 and October 3.

Data collection: description of snake characteristics
During each survey, I recorded variables for each snake that I encountered. I recorded whether the snake was alive on road (AOR) or dead on road (DOR), reported the observation time, and GPS coordinates (UTM, Zone 12, NAD 27 Datum) for the location using a hand-held GPS receiver (GeoExplorer II, Trimble Navigation Ltd. Sunnyvale, CA, USA). I also recorded the distance (m) to the next mile marker and the road segment on which the animal was observed. I measured both total length and snout-vent-length (SVL) of each snake. In some cases, only a portion of the carcass remained and I recorded the length of that portion. I used SVL measurements to estimate the age class for each individual based on published data of sexual maturation and SVL relationship for each species (Parker and Brown 1980, Diller and Wallace

1996, C. Jenkins unpublished data). Finally, I recorded the sex of each individual. I then marked carcasses with two spots, one close to the snout and the other to the vent, using a biodegradable spray paint and left all carcasses on the road, which allowed for easy visual identification during subsequent surveys.

Data analysis

I compared the mean number of snakes observed per survey to detect differences across the months among adult males, adult females, and juveniles for both gophersnakes and western rattlesnakes. Statistical analyses are restricted to the survey year of 2003 due to the intensity of effort. Analyses based on day number or survey week could not be conducted because the data were highly non-normal in this form. The distribution for snake mortality observed per survey across months departed significantly from a normal distribution, and attempts to log transform the data did not improve normality, so I used the non-parametric Friedman tests to detect differences. When significant, I then conducted a Wilcoxon Signed Ranks Test for *post hoc* comparisons. I used sequential Bonferroni corrections when making multiple comparisons so as not to inflate the alpha level.

Data collection: generation of "non-crossing points"

I created a shapefile of the survey route using ArcMap (version 9; Environmental Science Research Institute, Redlands, CA) GIS (Geographic Information System) by selecting and exporting specific road sections from the Area of Concern (AOC) roads data maintained at Idaho State University's GIS Training and Research Center website (http://giscenter.isu.edu). The AOC refers to land areas that surround Yellowstone and Grand Teton National Parks in Idaho, northwestern Wyoming, and southwestern Montana. I used Tool 5 of SANET: A Toolbox for Spatial Analysis on a Network (Version 1.2; Okabe et al. 2003) to generate a shapefile of random points along the entire route. This tool places points randomly on a road network based on a Poisson point distribution. I then generated a shapefile of x, y coordinate data for all snake crossings (snakes discovered both AOR and DOR) that I added to the ArcMAP project. This allowed me to visually compare the two shapefiles. I identified a random point as "non-crossing" if its position on the route was at least 30 meters from the snake crossing localities (to account for GPS error) and exported the coordinates.

Data collection: description of habitat and landscape characteristics

I measured site-specific attributes of the surrounding habitat for each snake observation and for the equal number of non-crossing points generated by SANET. First, I classified the road shoulder slope into one of six categories in a similar manner to Clevenger et al. (2003): (1) road surface raised compared to surrounding landscape; (2) no slope; (3) road surface sunken relative to surrounding landscape; (4) one side flat, one sunken; (5) one side flat, one side raised; and (6) one side sunken, one raised. I then measured the distance from the pavement edge to the closest vegetative cover, and to the nearest shrub for both sides of the road. I then walked 10 m straight out from the pavement edge into the adjacent habitat to estimate percent cover and major type (classified as shrub, grass, or forb) and percent shrub cover within a 157 m^2 area of the roadside. I measured these values for both road sides for each location. Based on these field measurements, I calculated additional categories for use in the logistic regression analysis, such as mean and minimum distance from the road edge to vegetation and shrub, and mean and minimum percent vegetation cover and shrub cover. I also created six different categories to describe the major cover type spanning both sides of the road: (1) shrub, shrub; (2) grass, grass; (3) forbs, forbs; (4) shrub, grass; (5) shrub, forbs; and (6) grass, forbs. Finally, I searched for mammal burrows and recorded this variable binomially based on burrow density on both roadsides within the 157 m^2 area (0 for < 5 burrows; 1 ≥ 5 burrows), and noted the presence of basalt outcrops within 100 m of each location by recording a "1" if present and a "0" if absent.

Data collection: GIS variables associated with locations

I used a GIS database to measure supplementary landscape variables that I would be unable to estimate accurately in the field. I used the AOC vegetation coverage assembled by Idaho GAP Analysis Project in 2001 available on the ISU GIS Training and Research website to measure vegetative composition at three spatial scales. I first generated coverages of the snake crossing and non-crossing point shapefiles and created a buffer centered on each location to calculate the percentage of each vegetation type within three different circular areas based on 50, 100, and 500 meter radii. I accomplished this with use of an AML (Arc Macro Language) written by Bob Klaver (USGS EROS Data Center). The AOC coverage classifies vegetation into 72 different cover types. However, the majority of my areas encompassed only seven different categories, four of which (silversage, blacksage, low sage, and big sage) I consolidated into sagebrush; the remaining three classes included grassland, agricultural, and urban areas.

In addition, I measured variables related to hibernacula and thermoregulation, both of which are physiological needs for snakes. I calculated the distance from each crossing and non-crossing location to all known snake hibernacula (Doering 2005) within 10 km using ArcInfo. Using the output files, I calculated the minimum distance of each point to den habitat and the mean distance to all hibernacula within 10 km. I also calculated an index of solar radiation for each crossing and non-crossing point. I used an AML (Jeff Evans, USDA Forest Service, Rocky Mountain Research Station, Moscow, Idaho) that computes a radiation index (continuous variable between 0-1) based on aspect (Roberts and Cooper 1989). A landscape oriented in a north-northeast direction (typically the coolest and wettest orientation) receives an index of 0, while south-southwesterly slopes receive a 1, with other aspects intermediate to these extremes.

Data analysis: modeling the factors associated with snake crossings

I used logistic regression to model the probability of a snake crossing point as a function of habitat and landscape variables. Specifically, for this study, locations were assigned a 0 for non-crossing points and a 1 for snake crossing points. I used the SAS statistical package version 9.1 for all analyses (SAS Institute Inc., Cary, NC). I used all records of snake occurrence along the survey route, both DOR and AOR, and refer to these points as snake crossing points (n = 251). I ran separate regression models for gophersnakes (n = 187) and western rattlesnakes (n = 46) due to the different ecology of these species. However, I did not include two of the gophersnake records due to GPS error, and did not analyze crossing data for terrestrial gartersnakes or striped whipsnakes due to their low sample sizes (n = 16 and 2, respectively). The western rattlesnake data would not converge during logistic regression analysis, likely a byproduct of low sample size, so the results will focus on gophersnakes.

The original model included 72 explanatory variables, which I reduced to a final set of 12 variables based on biological meaning and multi-collinearity diagnostics (table 1). I tested all the potential explanatory variables for collinearity prior to the analysis, calculating variance inflation factor (VIF) (Belsley et al. 1980) and then calculated Pearson correlation coefficients. When two variables were correlated ($r > 0.7$) I excluded one from the analysis (Menard 2002). Pearson correlation coefficients for mean distance to den and minimum distance to den were 0.626, so close to 0.7 that I included only mean distance to den in the final set of explanatory variables. I classified major cover and slope as indicator variables using category 1 (major cover = shrub, shrub; and slope = raised road surface) of both as a reference class to compare against all other categories. I compared Akaike Information Criterion (AIC) (Akaike 1973) values and classification accuracies to select the "best approximating model" (Burnham and Anderson 1998). To adjust for small sample size, I calculated AICc, which adds a correction factor of to AIC values (Hurvich and Tsai 1989). The significance of explanatory variables and associated coefficients was based on Wald statistics (Hosmer and Lemeshow 1995; Menard 2002). This statistic has a chi-square distribution that tests the null hypothesis that a parameter is 0, in other words, that the corresponding variable has no effect given that the other variables are in the model (Menard 2002).

Table 1. Description of variables collected in the field and generated with a GIS included in the logistic regression analysis

Potential explanatory variables	Measure	Description
Continuous variables		
DSHRUBAVG	cm	Mean distance to sagebrush accounting for both roadsides
MEANDIST	m	Mean distance to all known and predicted snake hibernacula within 10 km
PCOV10AVG	%	Estimated percent habitat cover within a 10 m radius of road edge
PCAG	%	Percent of agricultural cover within a 50, 100, and 500 m buffer radius using GIS
PCGRASS	%	Percent of grass cover within a 50, 100, and 500 m buffer radius using GIS
PCURBAN	%	Percent of urban developed areas within a 50, 100, and 500 m buffer radius using GIS
SOLARRAD	index (0 -1)	Index that measures solar radiation based on aspect of surrounding landscape using GIS
VEGRDAVG	cm	Mean distance to vegetation from the road edge accounting for both roadsides
Categorical variables		
BASALT	P/A	Presence of basalt pile within 100m of location
BURROW	P/A	Presence of 5 or more mammal burrows within 10 m radius of location
MCOV	1 - 6	Dominant roadside vegetation within 10 m accounting for both edges (1 = shrub, shrub;2 = grass, grass; 3 = forbs, forbs, 4 = shrub, grass; 5 = shrub, forbs; 6 = grass, forbs)
SLOPE	1 - 6	Road side topography in respect to roadbed (1 = both sides raised; 2 = no slope; 3 = both sides sunken; 4 = one side flat, one sunken; 5 = one side flat, one side raised; 6 = one side sunken, one raised)

Results and Discussion

Inter-specific variation and demography

I conducted 56 surveys between 15 May and 12 October, 2003, traveled a total of 10,248 km, and observed 253 snakes (0-16 per survey; mean = 4.5) of four species belonging to families Colubridae and Viperidae; however, two species accounted for the majority of records. I observed gophersnakes most often on roads (comprised 74.7% of the records) and western rattlesnakes more frequently than the remaining two species (comprised 18.2% of the records) (figure 2). The relative percentage of observations by species was comparable between 2003 and 2004. Ninety-three percent of the individuals were discovered DOR, yielding a mortality rate of 0.023 snakes/km. I documented more traffic casualties of adults than any other age class, the majority of which were males (64%) (table 2). Daily variability of snake mortality was high with the number of DOR snakes per route ranging from 0-14 (mean = 4.2). The mean number of road-kills per survey was highest during the month of September, despite the survey effort being half that of May and June. I did not observe any individuals during 11 of the 56 surveys, and the number of sampling days without snake observations was highest in late July and early August.

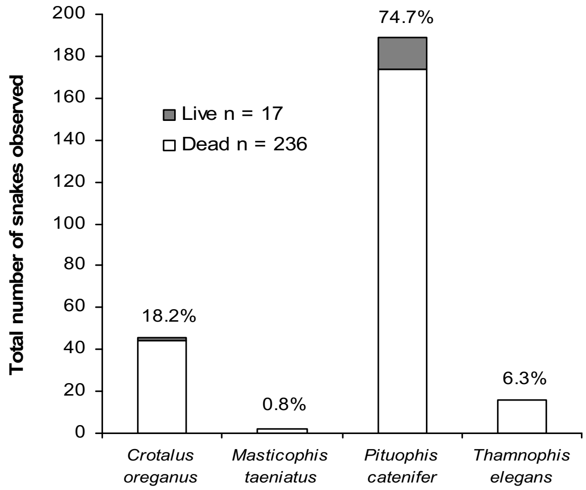

Figure 2. Summary of individuals observed by species during systematic road surveys (n=56) conducted between 15 May and 12 October, 2003 across the Idaho National Laboratory (INL). Values listed above each bar indicate the % of the observations represented by each species.

Table 2. Summary of snake road-kills by species and age class observed during systematic road surveys (n=56) conducted between 15 May and 12 October, 2003 across the Idaho National Laboratory (INL).

Species	Common Name	Age Class		
		Adult	Juvenile	Neonate
Crotalus oreganus	western rattlesnake	32	12	1
Masticophis taeniatus	striped whipsnake	2	0	0
Pituophis catenifer	gophersnake	112	39	36
Thamnophis elegans	terrestrial gartersnake	15	0	1
Totals		161	51	38

When compared to published studies that have measured snake mortality on roads, my results suggest that the magnitude of road mortality along the upper Snake River Plain is intermediate. The mortality rates documented per kilometer of road traveled ranged between 0.005 - 1.854 with an overall mean of 0.188 for 15 rigorous datasets (figure 3). My study has the eighth highest casualty rate (0.023 DOR/km), and is similar to several studies conducted in desert habitats located in regions known for their herpetofauna richness (Mendelson and Jennings 1992, Rosen and Lowe 1994). Three of the four studies with extreme values (Bernardino and Dalrymple 1992, Ashley and Robinson 1996, Smith and Dodd 2003) were conducted along short stretches of highways that bisect wetland habitats and associated movement corridors of snake species. In terms of the percent of individuals discovered DOR during road-cruising surveys, values ranged from 24-93 percent (mean = 69%) with this study ranked as one of the highest (figure 4).

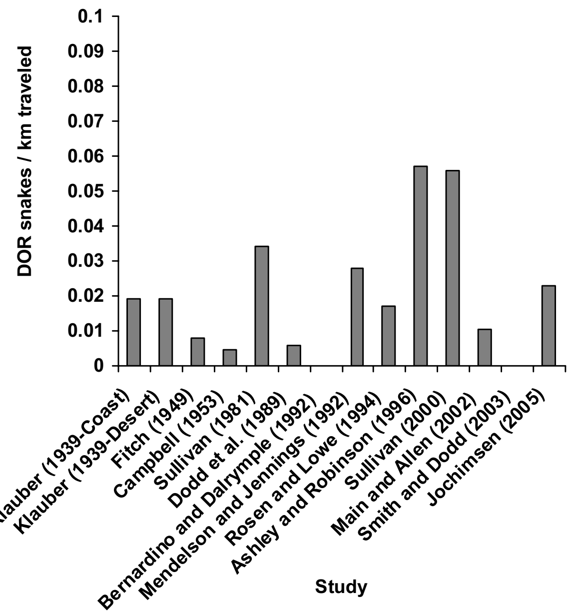

Figure 3. Summary of snake mortality on roads by published studies, including results from this survey conducted between 15 May and 12 October 2003 across the Idaho National Laboratory (INL) located in Idaho, USA. Bernardino and Dalrymple (1992) reported a mortality rate of 0.66, and Smith and Dodd (2003) reported a mortality rate of 1.854.

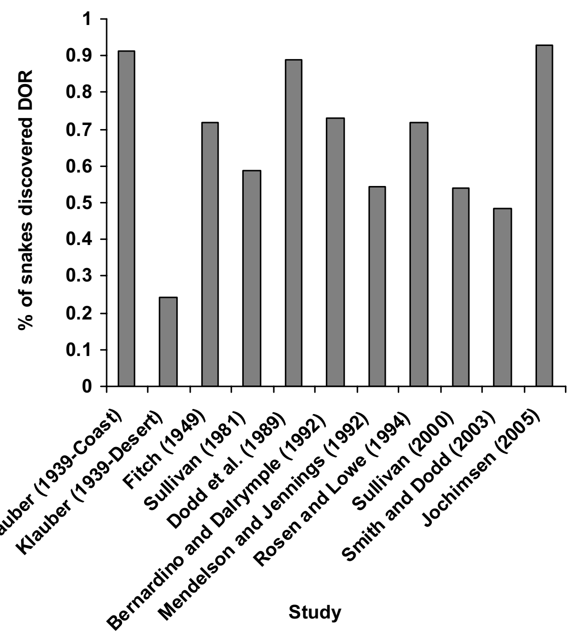

Figure 4. Summary of percent of total snakes observed dead on roads from published studies, including results from this survey conducted between 15 May and 12 October, 2003 across the Idaho National Laboratory (INL) located in Idaho, USA.

The relative abundance of snake species across the INL differed between road surveys and den surveys conducted annually by the ISU Herpetology Laboratory from 1989 to 2003. Over 4,000 individuals have been captured by hand, trap, or along drift fence arrays across the 15-year survey period. These data suggest that western rattlesnakes are the most abundant snake on the site (76% of all captures) with gophersnakes (11% of all captures) and gartersnakes (9% of all captures) comprising the next greatest percentage (C. R. Peterson, unpublished data). These results contrast greatly with my survey data, where gophersnakes comprised the overwhelming majority of road observations gathered over 2003 and 2004 (76%) (figure 5). This could be a consequence of biases associated with the survey methods. We collect snakes at the hibernacula during egress and ingress when rattlesnakes are most obvious and tend to make their presence known by rattling. Gophersnakes may not be as readily encountered due to their subterranean behavior (Grothe 1992, Ernst and Ernst 2003). A radiotelemetry study conducted in southwestern Idaho revealed that individuals surfaced on only 63 percent of the days they were tracked (Grothe 1992). Furthermore, an assessment of hand versus drift fence survey methods reported a higher susceptibility of *Pituophis* to drift fence capture (Diller and Wallace 1996). Road surveys also estimate snake presence along a transect, with road mortality analogous to trap captures along the drift fences. When the proportion of new captures is compared for only drift fence and trap data since 1994 on the INL, western rattlesnakes comprise 53 percent while gophersnakes and terrestrial gartersnakes increase to 22 percent (figure 5). The disproportionate representation of gartersnakes along roads may be tied to their association with water (Koch and Peterson 1995) because this resource is limited across the desert. The majority of individuals that I observed were clustered adjacent to agricultural fields with irrigation. Finally, the small number of striped whipsnake captures (3% of capture data) and road observations (0.5%) suggest small population size on the site, and reflect the difficulty in capturing this species due to its speed and vigilance (Hirth et al. 1969, Enge and Wood 2002).

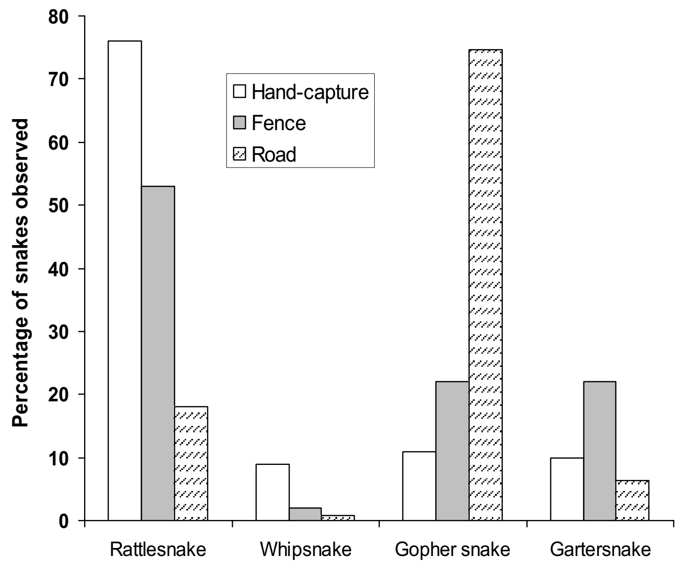

Figure 5. Comparison of snakes captured based on three sample techniques across the Idaho National Laboratory (INL) Idaho, USA

These results raise an interesting question, are gophersnakes more susceptible to road mortality on the eastern Snake River Plain? Diller and Wallace (1996) compared the ecology of *Pituophis* with *Crotalus* in southwestern Idaho, and described them as habitat generalists with a greater propensity for movement. This suggests that individuals would encounter roads more often as a consequence of their vagility, exposing them to an increased risk of road mortality. In further support of this argument, a study designed to compare the overall susceptibility of different snake families to road mortality found that relative to population density, species that use frequent movements experience a higher mortality risk than do sedentary foragers (Bonnet et al. 1999). Finally, when exploring the published road studies, it is evident that these two genera are observed more often than others on roads, with *Pituophis* comprising the majority of observations.

However, there are only a few studies that have investigated habitat use and movement of gophersnakes (Parker and Brown 1980, Diller and Wallace 1996, Rodriguez – Robles 2003), so this question remains to be explored. Specifically, my results suggest that gophersnakes may be overwintering in hibernacula that are not yet documented across the study area, or possibly in small mammal burrows as observed in Indiana (Schroder 1950). Their population densities may be higher than previously calculated based on hibernation site data, especially in the vicinity of roadsides. This species is a relatively large snake, creating a conspicuous target when stretched across the road. I observed motorists purposely swerving to kill snakes on multiple occasions as have others (Enge and Wood 2002). Furthermore, during the repeated surveys, I noted a difference in behavioral response to a passing vehicle between the two species. Gophersnakes tended to remain stretched and freeze for a short time when a vehicle passed, in contrast to western rattlesnakes, which tended to coil if not hit by the first vehicle.

Intraspecific variation of seasonal trends

Seasonal patterns of mortality varied by sex and age class for the two major species observed. Classifying gophersnakes first by age, then by sex for adults only, revealed significant differences, after sequential Bonferonni correction, of observations among the three groups during May (Friedman Test, $X^2 = 10.585$, $P = 0.005$), June (Friedman Test, $X^2 = 14.0$, $P = 0.001$), and September (Friedman Test, $X^2 = 13.04$, $P = 0.001$). These results were attributed to a greater number of adult male casualties than adult females in May (Wilcoxon Signed Ranks Test, P = 0.005, significant after sequential Bonferonni correction) and June (Wilcoxon Signed Ranks Test, $P = 0.002$, significant after sequential Bonferonni correction), and a greater number of adult male casualties than subadults in June (Wilcoxon Signed Ranks Test, $P = 0.005$, significant after sequential Bonferonni correction) (figure 6). The comparison of dead subadult observations to adults in September was significant for males, but only marginally so for comparison with females, after sequential Bonferonni correction (Wilcoxon Signed Ranks Test, $P = 0.018$ for males (Bonferonni corrected $P = 0.025$) and $P = 0.017$ for females (Bonferonni corrected $P = 0.0167$). Seasonal trends of mortality differed numerically for western rattlesnakes compared to gophersnakes, although patterns were not significant. Following the breakdown of individuals by age, the trend for adult males is bimodal across months with peaks in June, July, and September (figure 7). The mean number of subadult road casualties was unimodal peaking in June. The only difference in the monthly mean numbers of road-kills among rattlesnake groups that approached significance occurred in June as compared to the other months (Friedman test, $X^2 = 8.64$, $P = 0.013$, with a sequential Bonferroni correction $P = 0.01$).

The higher numbers of certain age and sex classes with respect to seasons indicates that individuals may be more susceptible to road mortality during specific movements. For gophersnakes, mating generally occurs in the spring, while western rattlesnakes usually mate in summer and early fall (Ernst and Ernst 2003). More adult gophersnake and western rattlesnake males were killed during the spring migration presumably while searching for mates or moving towards foraging grounds, while juveniles were most susceptible during dispersal, following hatching in the fall (gophersnakes) or movements in the spring (western rattlesnakes). These peaks of road mortality follow activity patterns reported for telemetered snakes. A number of studies report that male gophersnakes tend to be active on more days and move more frequently than females (Parker and Brown 1980, Grothe 1992), although on average there is not a significant difference between the maximum distances moved from the hibernacula between the sexes (Parker and Brown 1980). Radiotelemetry studies have demonstrated that males of the closely related prairie rattlesnake move greater distances than females, although they are inactive over a greater number of days (King and Duvall 1990).

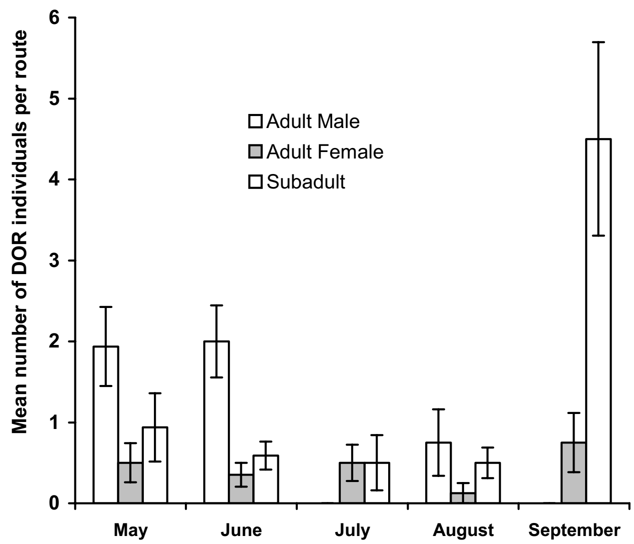

Figure 6. Monthly comparison of mean numbers of adult male, adult female, and subadult road casualties for gophersnakes (*Pituophis catenifer*) observed per survey during 2003 on the INL, with one standard error above and below the mean.

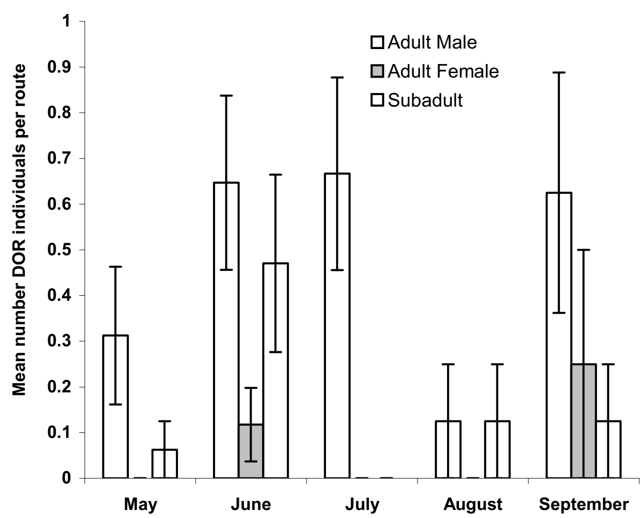

Figure 7. Monthly comparison of mean numbers of adult male, adult female, and subadult road casualties for western rattlesnakes (*Crotalus oreganus*) observed per survey during 2003 on the INL, with one standard error above and below the mean.

Movement patterns also explain why females may be susceptible to road mortality for only a portion of the entire activity period. Female western rattlesnakes were more susceptible to being road killed during both spring and fall migrations; none of these individuals were gravid. Cobb (1994) observed that gravid individuals generally remained within a 1-km distance from the hibernacula, possibly a result of thermoregulatory behavior. Female gophersnakes are reported to undergo egg-laying migrations in late spring or early summer (Parker and Brown 1980) although I did not observe a significant increase in numbers of observed DOR. Both western rattlesnakes and gophersnakes have slightly male-biased sex ratios, based on all captures over the 10-year survey period. These biases could be representative, or simply a byproduct of males being more active than females (Grothe 1992).

Modeling the factors associated with gophersnake crossings

Logistic regression analysis produced eight models that were all supported using an AIC criterion, all of which had a Nagelkerte R^2 greater than 0.9 and classification accuracies between 94-95 percent. These models contained eleven different types of variables. Four variables reflecting roadside habitat and landscape features were included in every supported model (table 3). These included the mean percent cover within a 314-m^2 area around the road, the vegetation type that comprises the majority of this cover, the presence of basalt outcrops or piles within 100 meters from the roadside, and the mean distance between the snake location and hibernacula within 10 km. Specifically, grass as the major cover on both sides of the road (MCOV 2) was positively associated with crossing points and was the most important variable in every model (table 3; figure 8). The second and third most important variables in every model were the mean percent cover within a 314-m^2 area and the presence of basalt, respectively, which were both positively correlated with crossing points (table 3). Finally, while the order of importance varied, mean distance to den, MCOV 4, and MCOV 6 were all positively correlated with crossing points, while MCOV 5 was negatively correlated with crossing points (table 3).

The other variables included in at least one model were presence of >five burrows (1 model, negatively correlated), mean distance to nearest shrub (1 model, negatively correlated), percent agriculture within 100 meters (1 model, negatively correlated), percent agriculture within 500 meters (3 models, negatively correlated), percent urban within 500 meters (2 models, positively correlated), flat slopes (6 models, positively correlated), and solar radiation (7 models, positively associated) (table 3). None of these variables received a high rank in any model. The most important variable was flat slope, which ranked 7^{th} in three models (table 3).

The majority of parameters included in the logistic regression analysis were important predictors of snake crossings. Several characteristics of roadside habitats and features of the surrounding landscape influence snake crossings and, therefore, identify high-risk areas for road mortality. Cover adjacent to roadside areas was the most significant. Habitat composition calculated with GIS did not appear to play an important role in predicting snake presence, except at the greatest distances from road areas. However, there are two weaknesses in using the GAP cover data: (1) the classification accuracy has not been evaluated, and (2) habitat changes have occurred since its creation (e.g., fire). Coverages based on recent remote sensing may improve the accuracy of these data, potentially influencing whether they are maintained in a logistic regression model.

Table 3. Variables included in supported logistic regression models (based on AIC) identifying habitat and landscape features influencing snake crossings on roads on the INL, Idaho, USA. Variables in each model are ranked by importance based on Wald Chi-square value, with the sign in parentheses indicates direction of correlation.

Variables								
BASALT	3(+)	3(+)	3(+)	3(+)	3(+)	3(+)	3(+)	3(+)
BURROW								12 (-)
DSHRUBAVG							9(-)	
MCOV 2-grass,grass	1(+)	1(+)	1(+)	1(+)	1(+)	1(+)	1(+)	1(+)
MCOV 4-shrub,grass	8(+)	6(+)	8(+)	7(+)	7(+)	6(+)	7(+)	8(+)
MCOV 5 -shrub,forb	6(-)	4(-)	6(-)	6(-)	4(-)	4(-)	4(-)	6(-)
MCOV 6 -grass,forb	5(+)	5(+)	5(+)	5(+)	5(+)	5(+)	6(+)	5(+)
MEANDIST	4(+)	7(+)	4(+)	4(+)	6(+)	7(+)	5(+)	4(+)
PCAG100				10 (-)				
PCAG500	9(-)		9(-)					9(-)
PCURB500			11(+)					11(+)
PCOV10AVG	2(+)	2(+)	2(+)	2(+)	2(+)	2(+)	2(+)	2(+)
SLOPE-flat	7(+)		7(+)	8(+)	8(+)		8(+)	7(+)
SOLARRAD	10(+)	8(+)	10(+)	9(+)	9(+)		10(+)	10(+)
Model AIC_c	**102.44**	**103.45**	**103.49**	**104.01**	**104.04**	**104.06**	**104.10**	**104.32**
Model R^2	**0.9313**	**0.9169**	**0.9325**	**0.9297**	**0.9274**	**0.9139**	**0.9296**	**0.9338**
Cross-validation accuracy	**95.2**	**94.7**	**94.9**	**94.4**	**94.9**	**93.9**	**94.7**	**94.7**

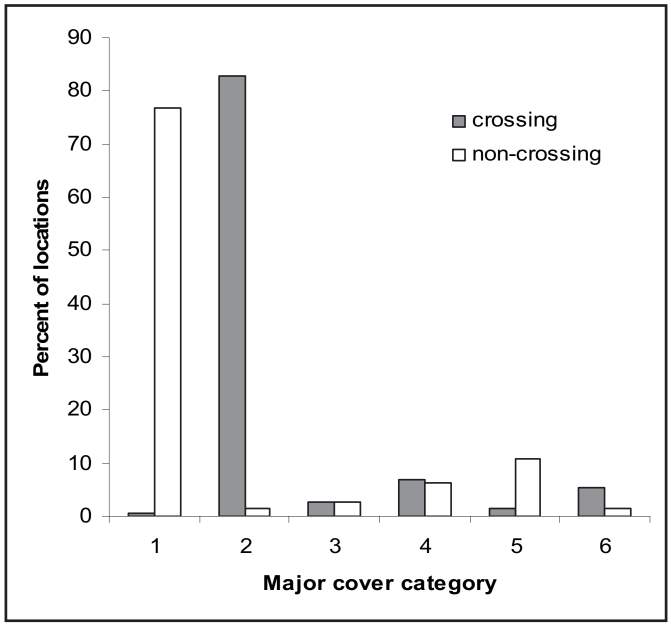

Figure 8. Histogram showing distribution of dominant cover for snake crossing and non-crossing locations across the INL, Idaho USA. Category number describes vegetation composition taking both road sided into account where 1 = shrub, shrub; 2 = grass, grass; 3 = forbs, forbs; 4 = shrub, grass; 5 = shrub, forbs; and 6 = grass, forbs.

Cover type along roadsides is the most important predictor of gophersnake presence on roads. The study area is referred to as a sagebrush steppe ecosystem (Anderson et al. 1996) characterized by sagebrush and perennial grasses. However, the majority of species I recorded along roadsides were invasive grasses that can out-compete sagebrush (cheatgrass and crested wheatgrass). These grass species spread along roadside areas, and are associated with habitat changes. One explanation for the association of gophersnakes with this cover type is that this species occurs more often in grassland habitat. Alternatively, individuals may perceive this habitat as unsuitable and, therefore, move through it quickly, thereby encountering roads at a greater frequency. There are only a few studies that have investigated habitat use and movement of gophersnakes (Fitch 1949, Parker and Brown 1980, Diller and Wallace 1996, Rodriguez – Robles 2003). They describe this species as habitat generalists, suggesting that it is unlikely that this result is due solely to the first explanation. For example, hand and drift fence capture data from southwestern Idaho show a uniform distribution of this species through all habitats (Diller and Wallace 1996, Cossel 2003).

The feeding habits of gophersnakes are varied, and many studies describe this species as an active forager. They are efficient burrowers (Carpenter 1982) that seek out and capture their prey within subterranean retreats or nests (Klauber 1947), or by seizing prey while at rest during evening hours (Rodríguez-Robles 2002). A study summarizing the feeding ecology of gophersnakes based on geographic regions reported that specimens collected from the Great Basin Desert consumed a greater proportion of small mammals compared to those from three other regions (California Province, Arid Deserts, and Great Plains) (Rodríguez-Robles 2002). Several studies report lower abundance of mammal species in cheatgrass and crested wheatgrass habitat (Brandt and Rickard 1994, Gipzen et al. 2001), and one study conducted in the Birds of Prey Area, Idaho (BOPA), found a negative association with ground squirrel burrow densities and cheatgrass (Yensen et al. 1992). Furthermore, capture data of small mammals on the INL suggests that grazing and invasive grasses negatively affect their abundance (C. Jenkins, unpublished data). Because radiotelemetry studies report that individuals spend a considerable proportion of their time underground (47 – 90%) (Grothe 1992, Rodríguez-Robles 2003) both burrow and prey density within a given habitat should influence surface activity. Increased surface activity through unsuitable habitat exposes individuals to highway surfaces.

The presence of basalt piles within 100 m of the roadside influences where snakes cross roads, most likely because of their dependence on these habitat features. When snakes begin their shedding cycle (ecdysis), it is common for them to seek refugia. They may retreat underground for days at a time or congregate in rocky areas (Grothe 1992, Rodríguez-Robles 2003). I have observed shed skins from gophersnakes in basalt piles across the study area. Several studies also report that females may undergo egg-laying migrations and nest communally in these habitats (Parker and Brown 1980, Ernst and Ernst 2003). This association may also be tied to the fact that this species is capable of overwintering in basalt piles. I discovered three new den sites along Hwy 26 that were created by farmers moving basalt rocks to the edge of their field. These areas may serve as temporary refugia or hibernacula.

The number of snake crossings decreased as the mean distance to surrounding hibernacula within 10 kilometers decreased. Surveys conducted in the Intermountain West document that gophersnakes co-occur with other snake species at communal den areas (Hirth et al. 1969, Koch and Peterson 1995). Capture data from the INL and the increased likelihood of occurrence farther from dens suggest that gophersnakes may be overwintering in hibernacula that are not yet documented across the study area, or possibly in small mammal burrows, as observed in Indiana (Schroder 1950). Alternatively, populations within closer vicinity of roadsides may be decimated by traffic mortality (Enge and Wood 2002, Smith and Dodd 2003). Studies suggest that movements of this species are philopatric (Fitch 1958, Rodríguez-Robles 2003), and Parker and Brown (1980) captured individuals within the same general locations across years. Therefore, if there is a genetic component to direction of movement, selection may be acting to remove individuals in a den that consistently cross roads. The closer a den is to a road, the more likely this is to occur. Research should be conducted to further investigate the relationship between roads and hibernacula, as we lack movement data on gophersnakes at this study site.

Roadside topography (slope) was included in the majority of best models (6 of 8) as a factor explaining where snakes cross roads. As a parameter, slope was marginally significant (around $P = 0.11$), but because I specified raised roadbed (slope 1) as the reference class, locations associated with a sunken roadbed were calculated as significant ($P < 0.05$) with a positive relationship with snake presence. Perhaps flat surfaces offer less resistance to movement than do raised surfaces, similar to the logistic regression models presented by Clevenger et al. (2003) that predicted small fauna were less likely to be road-killed on raised sections of roads relative to those that are level.

Although not a major predictor of snake occurrence, solar radiation was included in seven of the eight best models. As ectotherms, snakes require warm areas for thermoregulation and digestion, and are, therefore, attracted to such areas. Gophersnakes may control the amount of solar radiation they are exposed to through behavioral adjustments (Pough et al. 2001). For example, several studies report instances of increased road mortality when snakes are observed basking on road surfaces during cooler temperatures (McClure 1951, Klauber 1939, Sullivan 1981). In addition, one study noted that gophersnakes might preferentially expose the stomach region to sunlight following ingestion of large prey (Ashton 1998), a behavior referred to as regional heterothermy. I have observed this behavior on the INL along roadsides on several occasions.

Conservation Implications

In conclusion, this research has estimated the magnitude of road mortality on snake species in the upper Snake River Plain and provides insight into how roads with vehicles differentially affect snake species and demographic groups within snake species. Understanding these impacts is critical when determining the appropriate conservation strategy for these species and what consequences this might have on a population level. The loss of these individuals affects the population in two ways. Adults are required for successful reproduction, and males actively seek out the females during the mating season. Over time, if road mortality removed more adult males than are replaced, the population could decline if there are too few males to seek out the females or through inbreeding effects. The dispersal of juveniles is critical to gene flow across the landscape, and the roads could, therefore, be isolating certain den populations when road mortality of juveniles is high near these locations. This research augmented the monitoring methods currently employed by the ISU Herpetology Laboratory of the snake populations on the INL, to include road surveys in addition to hand and drift fence surveys at major hibernacula. Additionally, I recommend that research designed to examine the habitat relationships (including effect of invasive grasses) and movements (using radio-telemetry) of gophersnakes is needed on the site. Although this species is widespread across the United States, with their distribution extending from south-western Canada to northern Mexico and east from the Pacific Coast to the Great Plains and Great Lakes regions (Rodríguez-Robles and Jesús-Escobar 2000, Stebbins 2003), the magnitude of road mortality of this genus should not be overlooked because population-level effects are not yet understood. Finally, this research has implications for the mitigation of road effects.

High levels of mortality coincided with seasonal activities specific to different age and sex classes, and there appears to be landscape characteristics that influence where mortality occurs. Methods designed to ameliorate the road mortality of snakes should, therefore, coincide with these activity periods to be effective and should be placed in areas with high proportions of invasive vegetative cover and near basalt piles. However, the question of proper placement of mitigation efforts needs to be studied further based on the data I have collected. It may be difficult to estimate high-risk areas for snake road mortality without measuring parameters at both small and large scales. Although estimates of habitat cover across various spatial scales using a GIS are important, focal studies that measure small-scale attributes should be conducted to effectively identify snake-crossing zones. Further research is needed to investigate the possibility that habitat conversion may be increasing this species' susceptibility to road mortality.

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(officially December, 2005). She has eight years of research experience with reptiles and amphibians, including survey and laboratory work. Main interests include the field of road ecology, specifically regarding herpetofauna, and disease. In the future, she is interested in continuing research on the INL site focusing on the population effects of roads on snakes and mitigation placement.

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Use of Low Fencing with Aluminum Flashing as a Barrier for Turtles

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Abstract: I examined the effects of road mortality on a population of western painted turtles (*Chrysemys picta belli*) in west-central Montana; these turtles make up the majority of road mortalities in a section of highway that bisects the Ninepipes National Wildlife Refuge. The objective of my barrier fencing experiment was to determine whether turtles were able to breach fencing designed to direct turtles towards crossing structures and thereby keep them off the road. I constructed 45.7-cm-high turtle enclosures out of 2- by 5-cm fencing with and without 10- or 15-cm-high flashing attached at the top. Turtles were placed in the enclosures, and behavior was observed for one hour. Of 124 turtles, only four (3.2%) were able to climb to the flashing. No turtles climbed over the flashing within the time allowed. In enclosures without flashing, two (3.8%) were able to breach the fencing. The results of this experiment will help in the design of appropriate barriers to keep turtles off the road and direct them towards crossing structures.

Introduction

In northwestern Montana, U.S. Highway 93 has been slated for capacity and reconstruction improvements along a 90-km (56-mile) section. An approximately 7-km (4.3-mile) portion of this highway bisects a prairie pothole ecosystem that currently supports a variety and abundance of wildlife. One species, the western painted turtle (*Chrysemys picta belli*), comprises the majority of wildlife road mortalities in this area. Through a cooperative agreement involving the Montana Department of Transportation (MDT), the Federal Highway Administration (FHWA), and the Confederated Salish and Kootenai tribes (CSKT), a series of wildlife mitigation measures involving wildlife crossing structures and other design features will be implemented to decrease the amount of road mortality and fragmentation that currently exists (FHWA, MDT, and CSKT 2000).

A variety of barrier and fencing designs have been used in wildlife-highway interaction projects to keep wildlife off roadways and direct them towards wildlife crossing structures. Because barriers and fencing are likely to increase the fragmentation effects of highways, the use of culverts and other crossing structures are important in maintaining connectivity (Yanes et al. 1995, Boarman and Sazaki 1996, Evink 2002). Amphibians and reptiles are potentially less amenable to mitigation using crossing structures and barriers. This is a consequence of the limited movements by many species and the low potential for learning compared with large animals (Rudolf 2000). However, movements through the culverts by at least a few individuals should be sufficient to maintain genetic exchange while at the same time significantly decreasing wildlife road mortality (Barichivich and Dodd 2002). Various turtle species are known to use culverts as crossing structures (Foresman 2004, Pelletier 2005, Walsh 2005).

Rails and curved pipes have been used as barriers for amphibians and reptiles (Frey and Niederstraßer 2000, Bank et al. 2002, Puky and Vogel 2003), as have concrete walls (Barichivich and Dodd 2002), guardrails (Barichivich and Dodd 2002), and fencing (Banks et al. 2002, Evink 2002). Herpetofauna can be directed by drift fences, which have been very effective in directing movements especially during capture sessions (Gibbons 1990, Morreale 1984). Ruby et al. (1994) compared behavioral responses of captive desert tortoises to various barriers and fences. They found tortoises responded differently to the different barrier types. Tortoises were also observed attempting to climb those barriers constructed of wood (Ruby et al. 1994). While anecdotal evidence exists that some turtle species (including painted turtles) are good climbers, no one has examined barrier fencing can be breached.

My objective was to determine if aluminum flashing at the top of a wire fence would be sufficient to stop western painted turtles from climbing over barrier fencing. The particular fencing type in combination with aluminum flashing was used to represent a potentially low-cost alternative for use as barrier and directional fencing at crossing structures.

Methods

The enclosure trials were conducted at various ponds within Mission Valley, Montana (T20N, R20W, Sections 24-26). All trials were conducted during activity periods of turtles (1335 – 1800 Mountain Daylight Time) between July 4 and 11, 2004, and May 26 and 30, 2005.

Eight circular enclosures were built of 2.5x5-cm (1x2-in) welded wire. The enclosures were 61 cm (24 in) in diameter and 45.7 cm (18 in) high with an open top and bottom. On the inside top of each enclosure either 10 cm (4 in) or 15 cm (6 in) of aluminum flashing (#68-010) was attached flush with the top of the enclosure. Four enclosures of each type were made for a total of eight enclosures. Because of the different flashing widths, the distance from the ground to the bottom of the flashing was different for the two types of enclosures. Therefore, the enclosures with 10 cm (4 in) of flashing had 35.6 cm (14 in) of exposed wire, and the enclosures with 15 cm (6 in) of flashing had 30.5 cm (12 in) of exposed wire. For the 2005 trials, the flashing was removed making the enclosures 45.7 cm (18 in) of fencing.

The enclosures were placed at the edge of a pond so that the substrate was always dried mud. Enclosures were placed such that the interior was bare or had little vegetation, and no food, water, or shelter was provided. Trials were conducted with wild-caught, naïve animals that had no known previous experience with enclosures. Each trial began by randomly assigning two turtles to each enclosure and placing the turtles in the center of the enclosure.

A total of 177 turtles were used for the trials. Each trial lasted one hour, during which turtle behavior was noted. Each time a turtle attempted to climb the fencing, the highest level it reached was recorded. A turtle was considered to have reached that level if at least one claw held onto the rung of wire. If a turtle fell onto its back, it was left alone to see if it could right itself. If after one minute the turtle was unable to right itself, it was turned over by the observer.

Trials were run simultaneously in all eight enclosures, and observational data were collected during the entire hour period. Crew members were responsible for observations in two enclosures at a time. Enclosures were placed within 0.5 meter of each other to aid in observations.

Data were analyzed using chi-square analysis to test for differences in distribution of the highest height reached by gender.

Results

Turtles spent a majority of the time walking the perimeter of the enclosures. Only one turtle, an adult, settled down and made no further explorations after one initial attempt at climbing the fence. Some turtles attempted to extend their head and feet through the wire, but none continued to push for periods greater than three minutes. No turtles became stuck in the fencing. The presence of another turtle in the enclosure did not appear to alter behavior. Occasionally, turtles crawled over each other while exploring the enclosure and occasionally stood on the back of another in an attempt to climb. Heights reached while aided by another turtle were not recorded because under natural conditions it is unlikely that turtles will be at the same place along the fence.

Males and females climbed to similar heights in the enclosures with 10 cm (4 in) flashing ($X^2 = 7.527$, $P > 0.05$) and in enclosures with 15 cm (6 in) flashing ($X^2 = 4.944$, $P > 0.05$); therefore, gender was pooled in subsequent analyses.

All (N = 177) turtles reached at least the 10-cm (4-in) level. This could have been obtained by some turtles while keeping one hind foot on the ground. In enclosures with flashing, 82 percent (N = 124) attempted to climb the fencing (climbing was defined as reaching 15 cm [6 in] which meant that at least both front feet were off the ground). No turtles were able to breach the flashing in any enclosure; however, two adult turtles in both the 10-cm (4-in) and 15-cm (6-in) flashing enclosures reached the flashing (3.6% and 3.8%, respectively). All turtles that were able to touch the flashing fell to the ground. All turtles, except one, were able to right themselves within a matter of one minute. In enclosures without flashing, 75 percent (N = 53) of the turtles attempted to climb, and 3.8 percent were able to breach the fencing.

Digging behavior was only observed three times during the trials, and in no instance was the turtle able to breach the fence.

Discussion

Turtles are known to make seasonal movements (Sexton 1959, Gibbons 1990), and given urban development today they are likely to encounter roadways during these movements. Turtles are susceptible to road mortality due to their slow movements; therefore, fencing is an important issue. With the increase in the use of barrier fencing to direct wildlife towards crossing structures, it is important to determine what methods or designs are most effective. One commonly held belief is that turtles are good climbers and, thus, potentially able to breach fencing that is designed to keep them off the roadway.

I found that although turtles were able to climb wire fencing, it is unlikely that many, if any, turtles are able to breach even relatively low fencing if aluminum flashing is attached at the top. Digging behavior may not have been an issue during this experiment; however, longer confinement may have been needed in order for digging behavior to begin. This information can be helpful for agencies, such as transportation departments, in deciding what types of barrier fencing to use.

There are some potential problems associated with fencing. Overall, depending on the fence type, fencing can be expensive to build, maintenance costs can be high, and aesthetics of wire fencing may be an issue. For turtles, if the mesh sizes are too large, hatchlings and juveniles can pass through or get stuck in the openings. Therefore, smaller mesh attached to the bottom of larger mesh fences is necessary (Evink 2002). Fencing should be buried to minimize the chance of turtles breaching the fencing by digging. The type, dimensions, and materials used for barrier fencing should be dictated by the needs of the species of most concern in the project area.

In general, more studies are needed to find the most effective and low cost fencing so that a system of crossing structures and barriers will likely be successfully implemented and maintained. Some specific questions that need to be addressed include whether and how far turtles will follow fencing, and if there are specific conditions that cause turtles to turn away from fencing rather than travel along them.

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Design, Installation, and Monitoring of Safe Crossing Points for Bats on a New Highway Scheme in Wales

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Abstract: The greater horseshoe bat (*Rhinolophus Ferrumequinum*) is strictly protected under European Union (EU) and United Kingdom (UK) legislation. This serves to ensure that the species (as well as its roosting sites and feeding habitat) receives strict protection and that appropriate monitoring of populations will be undertaken.

The Milton-Carew-Sageston area of West Wales (UK) has been shown to be utilized by much of the Welsh population of greater horseshoe bats. Potentially, therefore, anything which significantly affects this area could have an important impact upon the survival of this population.

A proposed road scheme, the A477 Sageston to Redberth Bypass, was to pass through a mosaic of pasture, hedgerows, marshy stream courses, and small woodlands, which constitutes near optimal foraging habitat and dispersal routes for bats. Greater horseshoe bats had been shown to cross the existing road in several locations, and there were known to be nine principal greater horseshoe bat roosts within 2.5 km of the study area.

In order to reduce the likelihood of the bats being killed on the new road, it was necessary to discourage the bats from foraging along the road verge, while simultaneously providing safe and attractive crossing points, at locations where the bats were already known to cross the route of the proposed road. This involved: (i) the maintenance of attractive linear features (lines of trees, hedgerows, etc.) perpendicular to the route to lure the bats away from the road; (ii) a relatively wide verge of poor quality habitat (e.g., amenity grassland, hard standing, etc.) directly adjacent to the carriageway (and for some distance along it) to discourage the bats from foraging along the road; (iii) safe crossing points at culverts underneath the road on the alignment of existing flight lines; and (iv) the omission or alteration of street lighting at crossing points to be retained so that these areas remain in relative darkness.

The exact location of the tunnels, the planting leading to them, and the engineering design of the tunnel approaches were developed by an integrated team of ecologists and engineers.

The measures were installed in 2002, and the road opened to traffic in 2003. The success of the mitigation measures have been monitored through bat activity surveys in 2003 and 2004, and the tunnels are proving to be extremely effective in allowing bats to cross the road safely. No records of bat/vehicle collisions have been recorded.

Information is also provided on other schemes in Wales which have involved the provision of safe crossing points and mitigation for horseshoe bats.

Introduction

This paper relates to a road improvement scheme in Wales, the A477 Sageston to Redberth Bypass, which is a single-carriageway road (two lanes of traffic, one in each direction), covering a distance of over 4 km (around 2.5 miles) bypassing two villages in West Wales, United Kingdom (UK). This road scheme severed the foraging habitat of greater horseshoe bats, and it was, therefore, necessary to design mitigation to avoid the mortality of bats crossing the route and to replace lost habitat. Other issues also influenced the scheme design and construction, such as road safety, traffic flows, community requirements, landscape sensitivity, and heritage.

The greater horseshoe bat (*Rhinolophus ferrumequinum*) is an endangered species and is subject to strict legal protection in the UK. Roads can have a significant negative impact on bats, individually and at population level, through the loss of roosting sites and foraging habitats, the fragmentation of foraging and commuting routes, and through the potential for road mortality. Greater horseshoe bats tend to fly low to the ground, which increases the risk of road casualties. They also avoid excessively-lit areas, increasing the risk of fragmentation of traditional foraging and commuting routes where road lighting is provided. Road schemes must, therefore, be carefully designed and constructed to ensure that foraging habitat and commuting routes for this species are not disrupted.

Legislation

All species of bats are protected in the UK under Section 9 of the Wildlife and Countryside Act (1981). The European Community "Habitats" Directive (enacted in the UK as the Conservation (Natural Habitats, &c) Regulations, 1994) gives further protection to the greater horseshoe bat. This ensures that the species, as well as its roosting sites and feeding habitat, receive strict protection and that appropriate monitoring of populations will be undertaken.

The Ecology of the Greater Horseshoe Bat

The greater horseshoe bat is one of the largest species of bat in the UK, typically 15-30 g, more commonly at the heavier end of this range, with a head and body length up to 71 mm. It has shown a significant decline in the last 100 years, particularly in western and northern Europe. Within the UK, it is now restricted to the south-west of England and south Wales. While the UK population of the species is believed to be increasing, the total number is likely to be of the order of 4-6,000 individuals.

The greater horseshoe bat feeds on insects within deciduous woodland, scrub, permanent pasture, and along water and hedgerows. Greater horseshoe bats have a high frequency call (of approximately 82 KHz), which is quickly attenuated. As a result, even relatively narrow gaps in hedgerows can have a significant impact on their behaviour. Road schemes that sever such commuting routes can, therefore, disrupt the activities of bats and prevent them reaching important foraging areas.

The Value of the Corridor to Greater Horseshoe Bats

The line of the proposed bypass runs through a mosaic of pasture, hedgerows, marshy stream courses, and small woodlands around the villages of Milton and Sageston, which constitutes near optimal foraging and dispersal habitat for bats. Greater horseshoe bats had previously been shown to cross the existing road in several locations at the western end of the scheme (see fig. 1) (Stebbings 1996), and a number of known greater horseshoe and lesser horseshoe (*Rhinolophus hipposideros*) bat roosts were within 4 km of the study area.

The area around the scheme has been shown to be utilized by much of the West Wales population of greater horseshoe bats, and is located between the two most important roosts in the region. A major bat roost at Stackpole (approximately 10 km to the southwest of the scheme) is known to contain approximately 300 greater horseshoe bats, while that at Slebech (12 km (7.5 miles) to the north of the scheme) supports about 150 individuals. Radio-tracking studies have shown that bats routinely disperse between these roosts (often via Carew Castle situated 600 m from the bypass), crossing several major roads in the process. The dispersal of bats around the area varies throughout the year, as bats move to different roosts in order to take advantage of seasonal changes in food availability and to reach hibernation sites. It was, therefore, identified as a risk that bats would cross the route of the new bypass at several different locations over the course of the year.

Carew Castle, which lies to the north of the village of Milton, was designated as a Special Site of Scientific Interest (SSSI), a national designation, in 1995. It is included in Pembrokeshire Bat sites and Bosherton Lakes Special Area of Conservation (SAC), a Europe-wide designation indicating the international value of this roost to this endangered species. The Castle itself is included within the designated sites because of its importance as a transitory roost, especially in the spring and autumn, by greater and lesser horseshoe bats.

Identifying Bat Crossing Points

The points at which bats were most likely to encounter, and cross, the new road were identified, in order to inform mitigation requirements. This was achieved both by assessing the existing bat survey and radio-tracking data, and on the basis of a walk-over survey. The potential significance of the impact of the scheme on greater horseshoe bats was not fully recognized during early scheme development, but during detailed design work by the authors at the start of construction. A total of 12 potential crossing points were identified, as shown in figure 1.

Bats could encounter the route of the new road in a variety of locations, but these points represented the most likely features that horseshoe bats would use. They comprised single discrete features (for example, a lane bounded by hedgerows which was relatively isolated from other potentially valuable features for foraging or commuting bats), or clusters of potential crossing points (for example, a group of hedges intersecting the route). Monitoring these potential crossing points involved pairs of surveyors stationed at appropriate locations. Some remained largely stationery at suitable vantage points; others patrolled short transects in order to “cover” adjacent features. At each location, bats were recorded and identified by using a combination of heterodyne and time- expansion bat detectors. In particular, time-expansion detectors were used to record the sounds of the different species heard, and these recordings were downloaded onto a computer and their sonograms analyzed to confirm field identifications. At all locations, the surveyors focused on detecting horseshoe bats, but as many other bats as possible were recorded incidentally.

Wherever possible, the numbers of bats, the species involved, the directions and height of flight, and their activity (i.e., apparently foraging or commuting) were recorded. In some instances, the bats involved could be seen; on other occasions the surveyors had to rely on echolocation calls alone.

All crossing points were monitored on at least two occasions during the summer at the start of construction in 2001. These visits were undertaken in good weather conditions, when temperatures remained over 10?C, with no rain and very light winds. Monitoring began 30 minutes before dusk and continued until at least three hours after. Each dawn, following the monitoring surveys, and incidentally at other times, the verges of the existing A477, focusing on the most likely crossing points were searched with care for any bat road casualties. The existing road was also examined for bat vehicle strike casualties, particularly at the locations of likely crossing points.

A total of six monitoring visits, each covering two nights, were carried out in 2001 in order to examine in more detail the activity of greater horseshoe bats. In addition, attempts were made to investigate the movements of horseshoe bats to and from the known roost in Carew Castle, to the north of the route.

Greater horseshoe bats were recorded on five of the six visits, in relatively low numbers, and were found to encounter the route in only one section where those hedgerows in close proximity were severed by the bypass. In total, greater horseshoes were observed crossing the proposed route on two occasions, with most records relating to commuting bats which were deterred from continuing across the line of the route by the site clearance work which had already started in advance of construction. It was considered that this represented a significant corridor used by bats which was likely to have been used more heavily prior to the start of work. Other bat species recorded were soprano pipistrelles (*Pipistrellus pipistrellus* and *Pipistrellus pygmaeus*), noctule bat (*Nyctalus noctula*), Natterer's bat (*Myotis nattereri*), and other myotid bats unidentified to species. Although lesser horseshoe bats are known to roost in the area, none was recorded during these initial surveys. Bats crossed under the route at the Milton Culvert, a culverted watercourse at the western end of the route.

Figure 1. The location of potential bat crossing points.

Mitigation Design: Bat Tunnels

Following the baseline surveys, mitigation measures were proposed to provide safe crossing points at the two locations bats had been observed to cross. Although the number of bats crossing at this point was low, it was more economical to install them as part of the main works than to retro-fit later. Since the road was on an embankment at the crossing points, two culverts were set into the embankment, one at each crossing point. A large corrugated steel section elliptical tunnel of 2.2 m diameter was installed at one crossing, and a similar but smaller (1.8 m diameter) tunnel, at the second location (see figure 2). The tunnels were located to be on the alignment of the identified flight path, including one which was not perpendicular to the road. These were installed at a cost of approximately £100,000 ($180,000 USD).

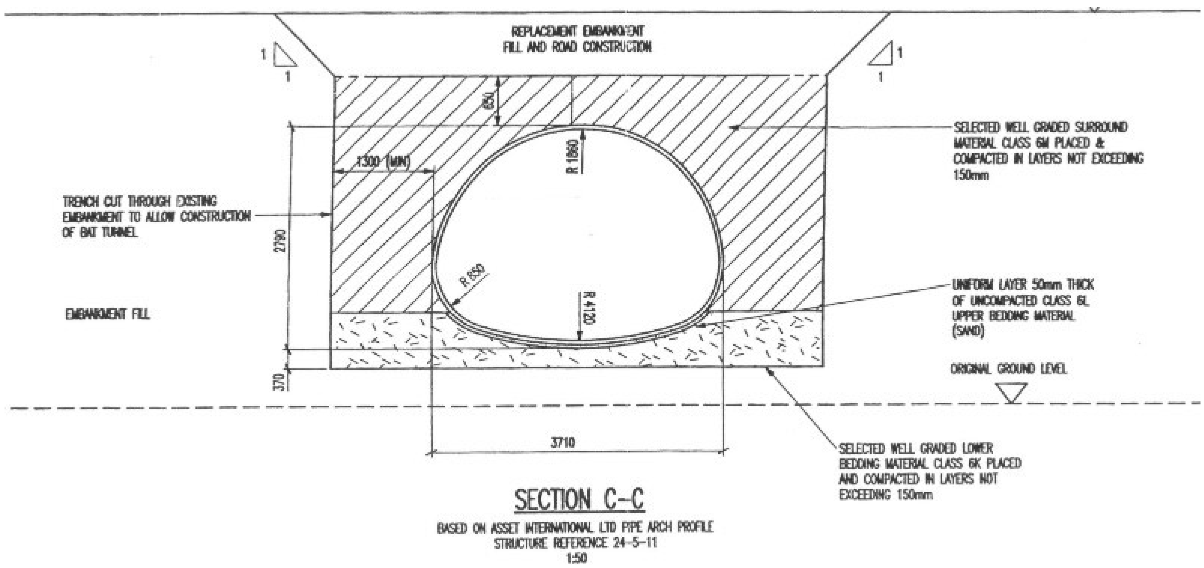

Figure 2. Bat culvert in section.

The culverts were positioned on the lines of severed hedgerows so that they followed the bats desired flight lines as far as possible. Small embayments were made in the embankment earthworks creating a "funnel" shape to maximize the chance of bats encountering the tunnel. Planting was provided around the vertical sides of the funnels, extending towards the severed hedgerows, to increase the funnel effect (see figure 3). The intention of the planting was to guide bats from the severed hedgerow to the culvert mouth, and, thus, planting was not extended up over the top of the culvert as this might encourage bats to fly over the road.

Figure 3. Planting at the bat culvert. These photographs show the planting at an early stage. In the photograph to the left, the culvert is located in the recess.

Container-grown plants were used to replace/restore linear features removed during the works, to guide bats to the culvert mouths.

The plants used were:

1. *Crataegus monogyna* (120-150 cm)
2. *Salix caprea* (80-100 cm)
3. *Salix cinerea* (80-100 cm)
4. *Sambucus nigra* (80 cm)
5. *Ilex aquifolium* (40-60 cm)
6. *Rosa canina* (60-80 cm)
7. *Prunus spinosa* (60 cm)

Monitoring

Bats crossing the road

Further bat activity surveys were undertaken between April and September 2002 and between May and October 2003 (Cresswell Associates 2003, 2004) in order to monitor bats crossing the scheme. The results of these surveys broadly supported the conclusions of the 2001 survey work, that relatively small numbers of greater horseshoe bats encounter the route and that they do so in a small number of key locations. However, greater horseshoes traversed the scheme (either over the road or through culverts) at almost all crossing points where they were recorded.

The frequency at which both horseshoe bat species encountered the scheme at the crossing points adjacent to the bat culverts was low in 2002 and 2003. The 2002 surveys showed reduced levels of activity for this species at these two crossing points, compared to 2001. This could have been a temporary effect due to the additional impact represented by the presence of both the old A477 and the scheme under construction, or a consequence of land-use changes in the wider landscape. However, greater horseshoe activity at these crossing points remained low in 2003 and, although beyond the scope of these surveys, no major changes in land-use patterns have been observed in the vicinity of these crossing points.

Since all the hedgerows and other potential linear features crossing the route had been removed prior to the 2001 surveys, "historical" bat activity could already have been altered substantially, reducing the likelihood that the bats would cross the scheme in 2001.

As far as future mortality associated with bats crossing the new road is concerned, the monitoring in 2002 and 2003 confirmed that greater horseshoe bats appear to be crossing the route relatively infrequently and in small numbers, which suggests that the frequency of road mortality may be expected to be low. However, the bats do appear to encounter the route at hedge-top height and due to the surrounding landform, this would make them vulnerable to traffic using the road. It is conceivable that, as the vegetation close to the new road re-grows and the new plantings mature, the bats may be encouraged back across the route in additional locations. In addition, it is possible that horseshoe bats encountering the new road would be encouraged to forage along its new verges and developing hedgerows, thus subjecting them to enhanced risk from road traffic.

In addition to the installation of culverts, it was also considered appropriate to review planting proposals on each side of the scheme in the area around a crossing point to ensure that bats were deterred from using "unsafe" crossing points. Typical measures included:

1. The maintenance of attractive linear features (lines of trees, hedgerows, etc.) perpendicular to the route to lure bats away from the road.
2. A relatively wide verge of poor quality habitat (e.g., amenity grassland, hard standing, etc.) directly adjacent to the carriageway (and for some distance along it) to discourage the bats from foraging along the road.
3. The omission or amendment of street lighting at "retained" crossing points so that these areas remain in relative darkness, without compromising road safety.

In areas where such landscape planting forms a critical role in "funneling" bats towards a particular structure, their effectiveness will be expected to increase as the plantings mature.

Bat culverts

Bat activity within the two bat culverts was recorded in 2002 and 2003 using automatic monitoring equipment. The equipment consisted of a Pettersson D240X bat detector capturing and downloading ultrasonic calls onto a Sony Professional Walkman tape recorder. As with recordings obtained by surveyors in the field, recordings were downloaded onto a computer and their spectrograms analyzed to and in the identification of species.

Greater horseshoe bats were recorded using the bat culverts in 2002 and 2003. In both years, greater horseshoe bats were recorded using each culvert on only one occasion. One of the bat culverts was also used by a lesser horseshoe bat. These low figures may in part be due to the fact that the frequency at which the species encountered this part of the scheme was greatly reduced, compared to 2001. Furthermore, given the directionality of the bats' echolocation calls, and the technical limitations of the automatic monitoring equipment, it is possible that only bats flying in one direction were recorded, and that these results are, therefore, an underestimate of the use of the culverts by greater horseshoes.

The two bat culverts were well used by myotid and pipistrelle bats, both for commuting and occasionally foraging bats. The culverts were used extensively by these species once the scheme was opened to traffic. Due to the low levels of horseshoe bat activity encountered at these crossing points and the lack of true baseline data, it was not possible to fully assess the success of the bat culverts. However, the suitability of the culverts for greater and lesser horseshoes (as well as other bat species) has been confirmed, and their effectiveness is likely to increase significantly as the planting at the culvert mouths matures. In 2004 a single survey visit recorded greater horseshoe bat passes in one of the culverts, and it appears that their use is increasing.

Milton culvert
Monitoring was also carried out within a stream culvert in Milton village elsewhere on the scheme, which was lengthened to accommodate the increased width of the new bypass. Bats had regularly used the culvert prior to the construction works. In 2002, greater horseshoe bats were recorded using the stream culvert at Milton on all but one visit, confirming the importance of the stream corridor as a commuting route for this species. Typically, two to four greater horseshoe passes were recorded per survey night throughout the year, though again this may only represent bats flying in one direction. Myotid and pipistrelle bats were also recorded using the Milton stream culvert throughout the survey season.

Bat casualties
Following opening of the new scheme to traffic on 29 August 2002, searches were also made along the verges of the new road for bat casualties at likely crossing points. No bat road casualties were recorded on any of the eight visits, either during baseline surveys or once the road had opened.

Although no evidence of bat casualties was found, this should not be interpreted as confirmation that no road casualties occur along the new road, or potentially on the existing road. When hit by a vehicle, the corpse may travel some distance, even remaining attached to the vehicle, before dropping to the ground. Bat bodies are small, particularly when the wings are closed, and in dense or tangled vegetation (such as a hedgerow) they would be inconspicuous. It would be expected that, particularly immediately after opening of the scheme when vegetation along verges was sparse, corpses would be easier to detect; however, they may also be more attractive to nocturnal and diurnal predators (e.g., cats, foxes, birds of prey) in these areas.

The effect of lighting on bat movements
Following installation of lighting at the Milton road junction, close to the culvert used by greater horseshoe bats (shown in figure 4), it was noted during surveys in 2003 that light levels at the mouth of the southern end of the culvert were increased, compared to 2001 and 2002, but not at a regular level across the entrance – one area slightly darker than another. A lighting column on the south side of the A477, located above and to the west of the culvert, spills light behind the lighting column and away from the road. A lighting column to the north of the A477 (east of the culvert) also sheds lights across the road and across the culvert mouth.

Figure 4. The Milton culvert

Levels of greater horseshoe bat activity at the Milton culvert remained high throughout the 2002 survey season. In 2003, however, and subsequent to the road opening in late 2002, the levels of greater horseshoe bat activity at Milton culvert were significantly reduced. The reduced levels of activity were particularly apparent in summer 2003, as no greater horseshoe bats were recorded on three survey visits in June and July. The culvert is most in use during spring, and, therefore, the patterns of use are seasonal as well as related just to light levels. It is considered highly likely that this reduction in activity is a result of the increased light levels at the culvert mouth on the southern side of the scheme (primarily due to the lighting column on the west side of the culvert south of the road), as horseshoe bats are known to avoid well-lit areas. The bats that were observed using the culvert in 2003 appeared to modify their behavior in response to the lighting by hesitating before flying faster and lower between unlit area.

It is not known whether survey results for greater horseshoe bats at Milton culvert in previous years represented regular use by small numbers of bats, infrequent (possibly seasonal) use by larger numbers of bats, or both. It may be that the seasonal importance of Carew Castle nearby, in spring and autumn (as described in previous reports), means that bats using the culvert at these times of year are more likely to do so in order to move between roosting sites, rather than commuting between their roost and foraging areas (as would perhaps be more likely to be the case for bats using the culvert in summer). Consequently, it is difficult to assess any impacts that the reduced use of this culvert in 2003 may have on greater horseshoe bats. Clearly, if lighting at this mouth of this culvert were affecting the bats' movements between seasonal roosting sites, or regular movements between roosts and key foraging areas at critical times of the year, it could have a potentially significant impact, through habitat fragmentation, on the Pembrokeshire greater horseshoe bat population. Conversely, if the lighting were only affecting the foraging behavior of a small number of individual bats, the impact of the lighting in the long-term would be less significant.

The following remedial measures were, therefore, considered to mitigate the impact of the lighting on the bats' use of this crossing point.

1. Realigning the lighting
2. Installing a baffle on the lighting column to minimise the light spill away from the road itself

This would reduce light levels at the edge of mature vegetation close to the scheme, but because of the proximity of the lighting column to the culvert, would probably not be effective in reducing light levels at the culvert mouth itself without also reducing light levels on the road carriageway above.

Consequently, it was also recommended that:

> The area between the headwall of the culvert and the ends of the wingwalls be screened more effectively.

The latter could be achieved by the planting of, for example, willows on each side of the watercourse tied together at the tips to create a "natural" arch extending out from the culvert mouth, or by provision of a screen. Potential screening methods include using standard "garden" type fencing panels or using standard street furniture materials, such as a blank road-sign panel fixed on posts and aligned parallel to the existing fencing running down the wingwall.

At the time of this writing, these measures have been accepted but not yet implemented by the relevant highway authority. Further monitoring will take place in 2006.

Overall, the Sageston-Redberth Bypass gives us an example of how bats can be safely directed under roads using culverts with associated planting and by manipulating lighting and landscape planting. To some extent, the success of the mitigation at Sageston relates to the fact that the scheme is on an embankment at the points bats cross it. There are different issues to resolve where roads are at grade or in cutting. A range of other such situations are described below.

Other Schemes

A487 Llanwnda

The A487 from Llanwnda to south of Llanllyfni Improvement in North Wales is close to a site of European value for lesser horseshoe bats and severs a number of regularly-used commuting routes. Like the A477, it is a single carriageway scheme. There have been records of bat casualties of the common pipistrelle, soprano pipistrelle, brown long-eared (*Plecotus austriacus*), and lesser horseshoe bat (Billington 2001, 2002, 2003). A number of innovative mitigation techniques are being used for Lesser Horseshoe Bats on this scheme with mixed success. Some have proved to be more successful than others, including semi-permanent bollard based lighting to deter bats from crossing the road and divert them to an underbridge; and fencing to guide bats to that location. However, much of the fencing that had been installed to prevent bats from crossing the road, 2 m and 4 m high, with single and double cranks at the top of the fence, has not worked as well as expected. This may relate to the manoeuvrability of lesser horseshoe bats. When they encounter a fence, they fly up over it and immediately twist to return to their original flight path height.

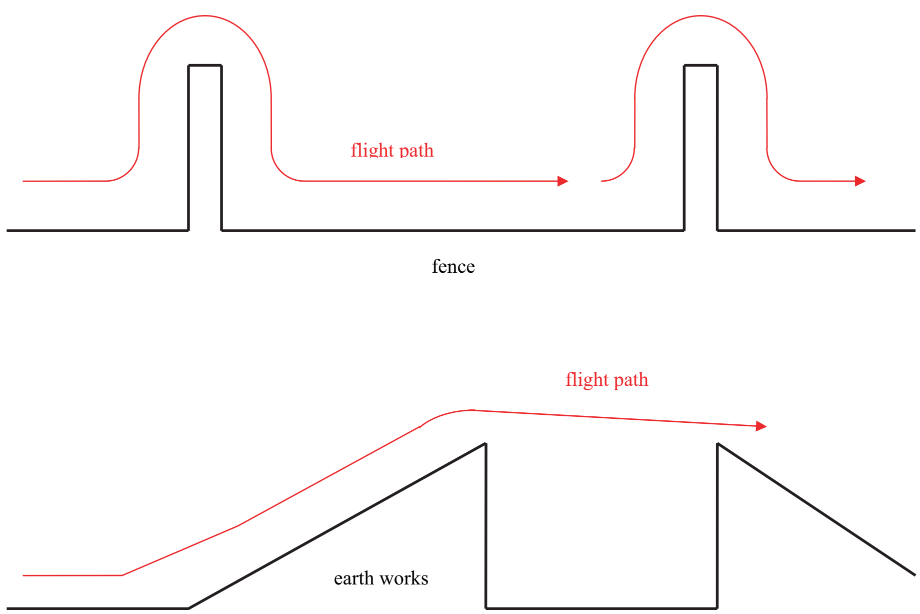

Figure 5. Flight paths of lesser horseshoe bats over obstructions.

In contrast, gently-sloping earthworks (false cuttings) seem to have greater success in extending the bats' higher flight path.

If the potential impact on bats had been better recognized at an earlier stage, more effective means of "lifting" bats up and over the road might have been possible.

Sirhowy Enterprise Way

Mitigation was required for the proposed Sirhowy Enterprise Way in south Wales, as bats were known to use woodland on either side of the new road. Daubenton's (*Myotis daubentonii*), whiskered (*Myotis mystacinus*), and brown long-eared bats were known to forage in the area, and, therefore, it was necessary to design appropriate mitigation for these species. Flight paths crossing existing roads, either at tree canopy level or through bridges, and foraging habitat on and near the proposed route were identified. Based on the findings of these surveys, four high-level crossings comprising netting (approximately 2.5 m wide) tensioned between tree canopies were proposed (see figure 6). This, combined with a reduction in lighting at important locations, provided a commuting route across the road, linking important foraging habitat. To date, only one of these structures has been installed, and its success is yet to be monitored.

Figure 6. Bat crossing at Sirhowy.

Mitigation in addition to crossing points is often required to complement or enhance the crossing structures installed by enhancing one side of the road or another.

A470 Lledr Valley

During surveys to inform mitigation for the improvement of the A470 in Lledr Valley to single carriageway standard, lesser horseshoe bats were recorded foraging on either side of the road, and a bat roost was recorded adjacent to the scheme. Mitigation measures were proposed to provide alternative roosting sites for bats, involving construction of a hibernation chamber and roosting sites within the dry stone retaining walls for the scheme. The hibernation chamber (shown in figure 7) comprised a buried structure with access through a letter-box-sized entrance hole (shown in figure 8). A low level concrete pipe provided access from the outer to the inner chamber, ensuring an unventilated, stable microclimate within the inner chamber. This also ensured that there was no natural light within the inner chamber and provided optimal conditions for hibernating and roosting bats. Rough, untreated wooden boards and battens were fixed to the chamber wall and ceiling in order to provide crevices and roosting sites for bats. The hibernation site is currently being monitored to assess its success.

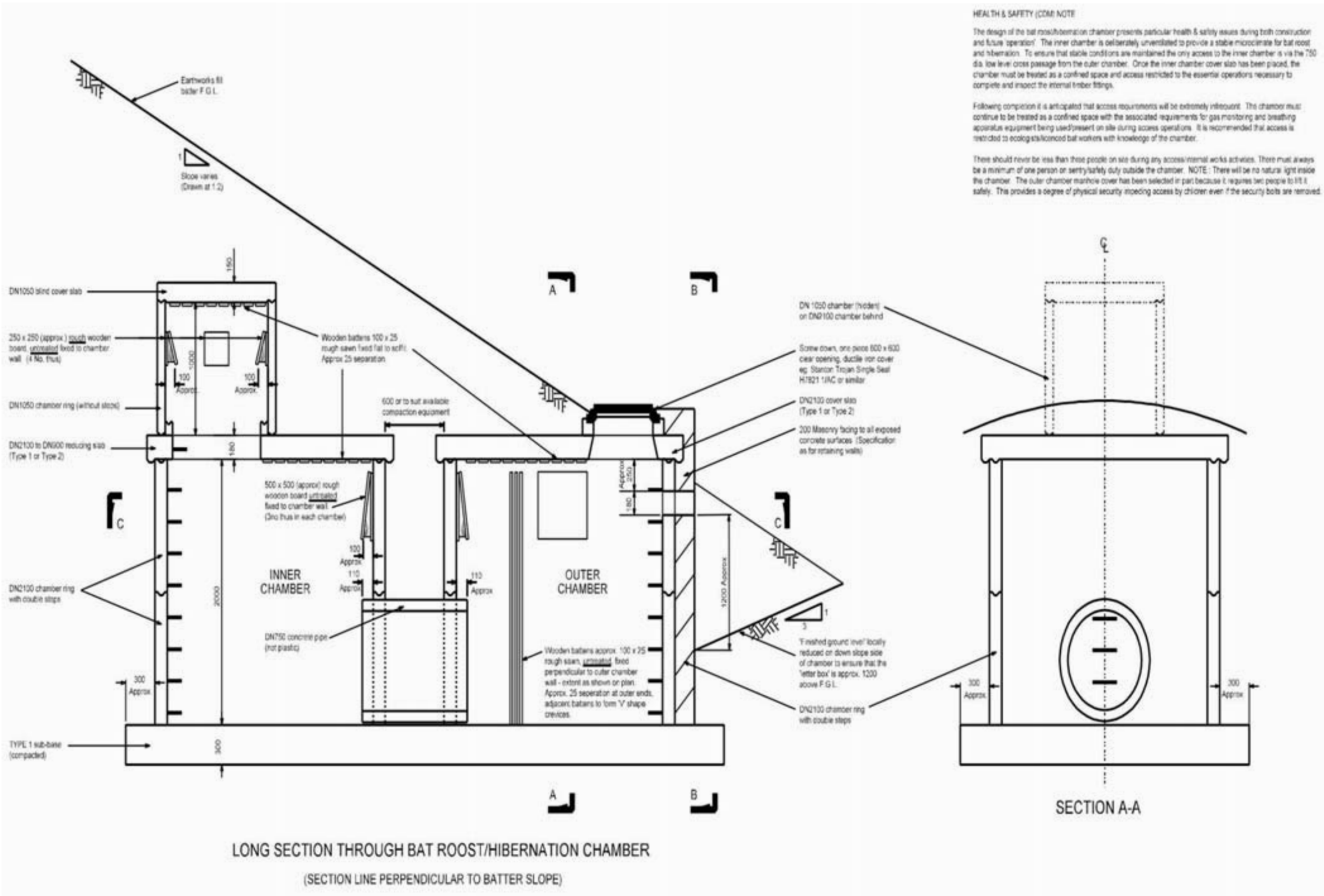

Figure 7. Plan of the bat hibernation chamber at Lledr.

Figure 8. External view of the bat hibernation chamber at Lledr, showing the letter-box-sized entrance to the underground chambers.

A second mitigation measure involved providing bat roosting sites within the dry stone retaining walls for the road. This comprised letter-box-sized entrances (shown in figure 8) leading to small chambers within the road embankment. This not only provided suitable roosting sites for bats, but also provided a refuge for other species, including reptiles.

Figure 9. Entrance to the bat chamber within the retaining walls at Lledr.

Conclusions

The route of the Sageston to Redberth Bypass passes through optimal foraging habitat and commuting routes for the greater horseshoe bat, a species strictly protected by EU and UK legislation.

In order to reduce bat casualties on the new road, it was necessary to prevent bats from foraging on the road verge and provide safe crossing points. This was achieved through a combination of planting, designed to encourage bats away from the road; crossing points at culverts underneath the road; and a change in street lighting at crossing points to be lit, so that these areas were more likely to be used by bats, without compromising road safety. Baseline surveys were carried out in order to identify bat crossing points to inform mitigation requirements.

The road was opened to traffic in 2003, following installation of the mitigation measures in 2002. Following construction, further monitoring was carried out to evaluate the success of the mitigation. These surveys confirmed that greater horseshoe bats were using the retained and additional culverts, as were other species of bats. These measures have reduced the frequency with which bats cross over the scheme, thus reducing the risk of casualties. These surveys highlighted the need for additional mitigation measures at the Milton culvert, which was being used by bats less frequently after the road improvement, apparently due to the change in light levels in this area. Measures have been proposed to re-align the lighting, minimize light spill away from the road, and screen the area being used by bats. Further monitoring is scheduled for 2006 to evaluate the success of these additional measures.

The effectiveness of this mitigation has depended upon:

- Timely identification of the potential impacts allowing mitigation measures to be put in place during construction and avoiding costly retro-fit.
- Locating safe crossing points for bats in the positions most likely to be effective based on comprehensive baseline survey information.
- Modifying the earthworks and planting close to crossing structures to ensure that bats are led towards them.
- Monitoring effectiveness post-construction so that any necessary modifications can be made.

The other experience in Wales described in this paper supports these conclusions, but it is true to say that more needs to be learned about the way individual species of bats cross and use roads, and the effectiveness of mitigation. Work to continue to improve the knowledge of bats and roads interactions continues to take place.

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Paola Reason holds a B.S. degree in zoology and an M.S. in conservation. Her interest in bats began 15 years ago, and she has undertaken a large number of projects in the UK and overseas – one of which has resulted in the funding of an NGO actively working in the Comoro Islands to promote fruit bat conservation. Paola is assistant director at Cresswell Associates and specializes in protected species work primarily relating to bats and the development of best practices.

David Wells holds a B.S. degree in biology and has been involved in bat conservation and research for 15 years. While at university he undertook a research project into the roosting ecology of pipistrelles, the findings of which were reported at the UK national bat conference. David is a senior ecologist at the environmental consultancy, Cresswell Associates, specializing in protected species surveys and mitigation design. Much of his work involves coordinating, and leading, the large survey teams required for monitoring bat activity on road schemes and other developments. This has recently included coordinating fieldwork for a research project into habitat use by lesser horseshoe bats.

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Hannah Walker holds a B.A. degree in biological sciences. She is an assistant ecologist at the environmental consultancy, Cresswell Associates, and has carried out a number of ecological surveys to inform mitigation for developments affecting bats. This has involved bat activity and emergence surveys as well as analysis of the results of these surveys.

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Ecological Impacts of SR 200 on the Ross Prairie Ecosystem

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Abstract: Ross Prairie is a 6,500-ha conservation area in SW Marion County, Florida. It serves as an important regional habitat node connecting the Ocala National Forest to the Withlacoochee and Goethe State Forests. SR 200 is a major two-lane state highway that bisects the reserve. Rapid growth and development have recently necessitated the need to widen the road to four lanes. A comprehensive approach that employed several methods was used to determine the current and potential impacts of SR 200. These methods included road-kill and track surveys, mark-recapture and telemetry studies, and GIS analysis. Each method was used to evaluate road impacts on different taxa. The study was conducted from May 2002 to December 2004. Results of the road-kill surveys included 759 individuals from 57 identifiable species. The majority were anurans followed by meso-mammals. Locations of significant numbers or rare species of road-kills by taxa were identified. A total of 537 sets of whitetail deer, 481 sets of carnivore, and 474 sets of snake tracks were recorded. Hotspots were identified for snake, white-tail deer, and carnivore tracks. A total of 1,777 herpetiles were captured in right-of-way drift fence traps. Southern leopard frogs and Florida gopher frogs were most abundant. Individuals of several species of snakes, frogs, and lizards were recorded crossing the road in the two sandhill crossing sections, and moving to/from the Ross Prairie wetland basin. Of 342 small mammals captured, one cotton mouse was recorded crossing the road; only six small mammals were found as road-kills. The road likely is a significant barrier to small mammal movement. Average home range of 18 gopher tortoises monitored adjacent to the road was 3.14 ha. Only three attempted crossings of SR 200 were recorded, two were successful, and one resulted in death. For gopher tortoise, the road is a semi-permeable barrier. Home range of the 13 eastern indigo snakes monitored averaged 127.6 ha. No road crossings were recorded; they seemed to use the road as a home range boundary. Because of road-kills, there is documented evidence that road crossings are attempted. Only 5 bobcats, 2 coyotes, and 1 gray fox were captured and used in the carnivore telemetry study. Yet observations, track, and scat evidence suggest that a significantly higher number of these animals were present in the Ross Prairie area. Average home range size was 13.67 km2 for bobcats. Most radio-collared felids avoided SR 200 or used the road as a home range boundary, whereas the radio-collared canids commonly crossed major roads. To improve habitat connectivity and eliminate road mortality we recommended installing four box culverts in the upland sandhill areas, bridges at each wetland/upland ecotone, and a series of five culverts within the wetland basin adjoined by a herpetile exclusion wall. Between all these structures we suggested 2-m barrier fencing with herpetile-excluding mesh at the base of the fence.

Introduction

Ross Prairie is a 6,500-ha conservation area comprising three properties managed by three different agencies (Marjorie Harris Carr Cross-Florida Greenway – Office of Greenways and Trails; Ross Prairie State Forest – Division of Forestry; and Halpata Tastanaki Preserve – SW Florida Water Management District) (figure 1). It serves as an important regional habitat node connecting the Ocala National Forest to the Big Bend and Chassahowitzka Wildlife Management Area (figure 2). This diverse ecosystem is a naturally patchy mosaic of many habitat types, including bottomland hardwood swamps, hardwood hammocks, pine flatwoods, oak scrub, wet prairies, and longleaf pine-wiregrass sandhills (figure 3). Wildlife includes many rare and listed species including the eastern indigo snake, gopher tortoise, Florida scrub jay, Florida mouse, and Florida gopher frog.

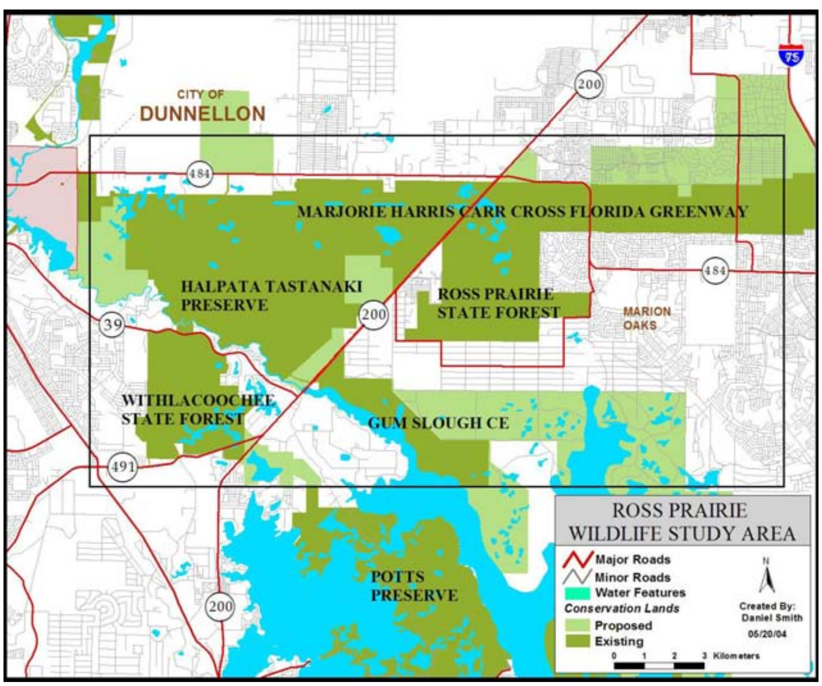

Figure 1. The Ross Prairie Study Area in southwest Marion County, FL.

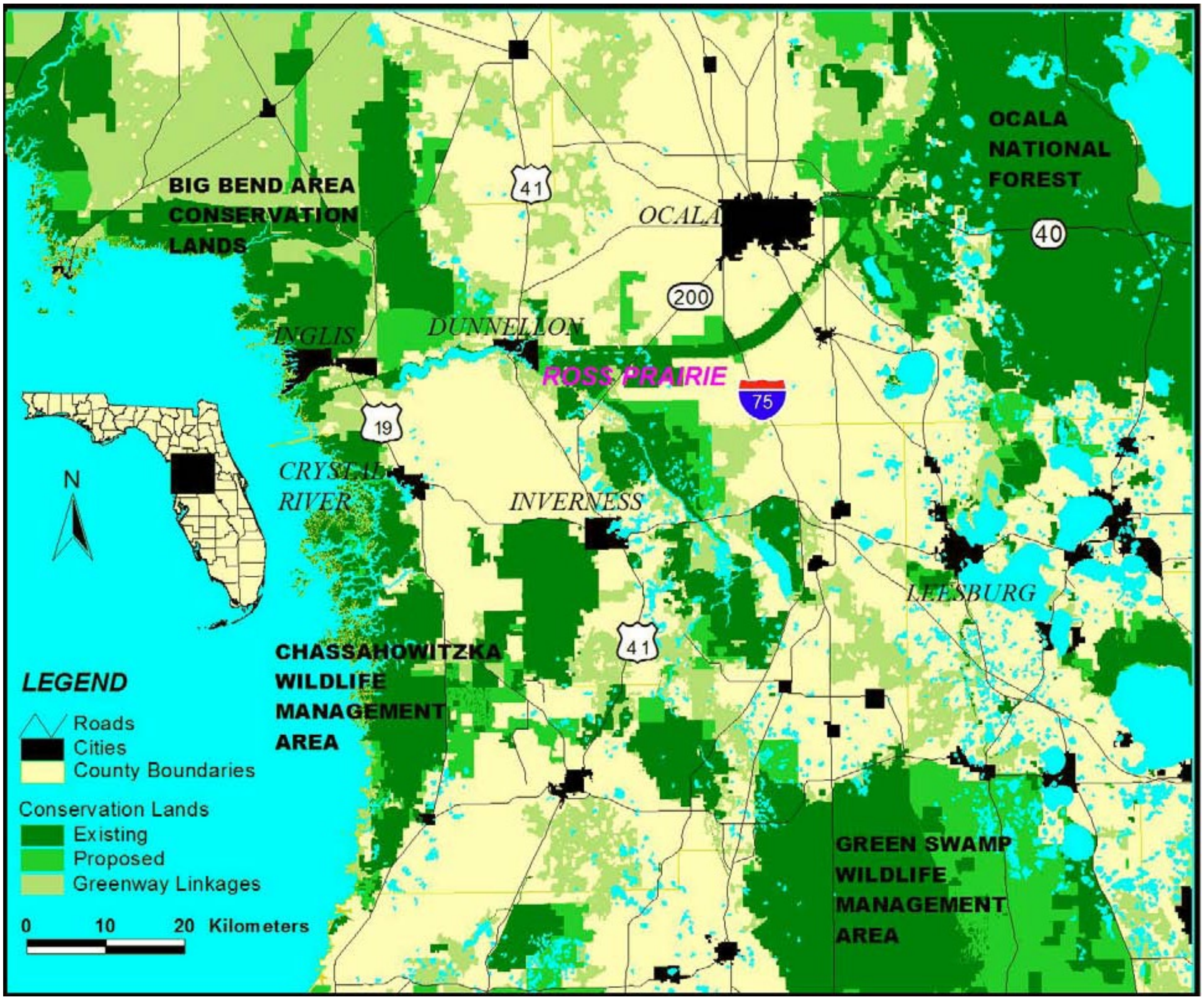

Figure 2. Regional Context of the Ross Prairie Conservation Area.

SR 200 is a major two-lane state highway that bisects the reserve. Average annual daily traffic level is about 11,000 vehicles. Rapid growth and development in Marion County have recently necessitated the need to widen the road to four lanes.

Methods

A comprehensive approach that employed several methods was used to determine the current and potential impacts of SR 200 on wildlife resources in the Ross Prairie conservation area in Marion County, Florida. These methods included road-kill and track surveys, mark-recapture and telemetry studies, and GIS analysis. Each method was used to evaluate road impacts on different taxa. This multi-species approach was used to determine effects of the road on presence and movement behavior for suites of wildlife (e.g., primarily carnivores, selected herpetiles, and small mammals). The study was conducted between May 2002 and May 2004.

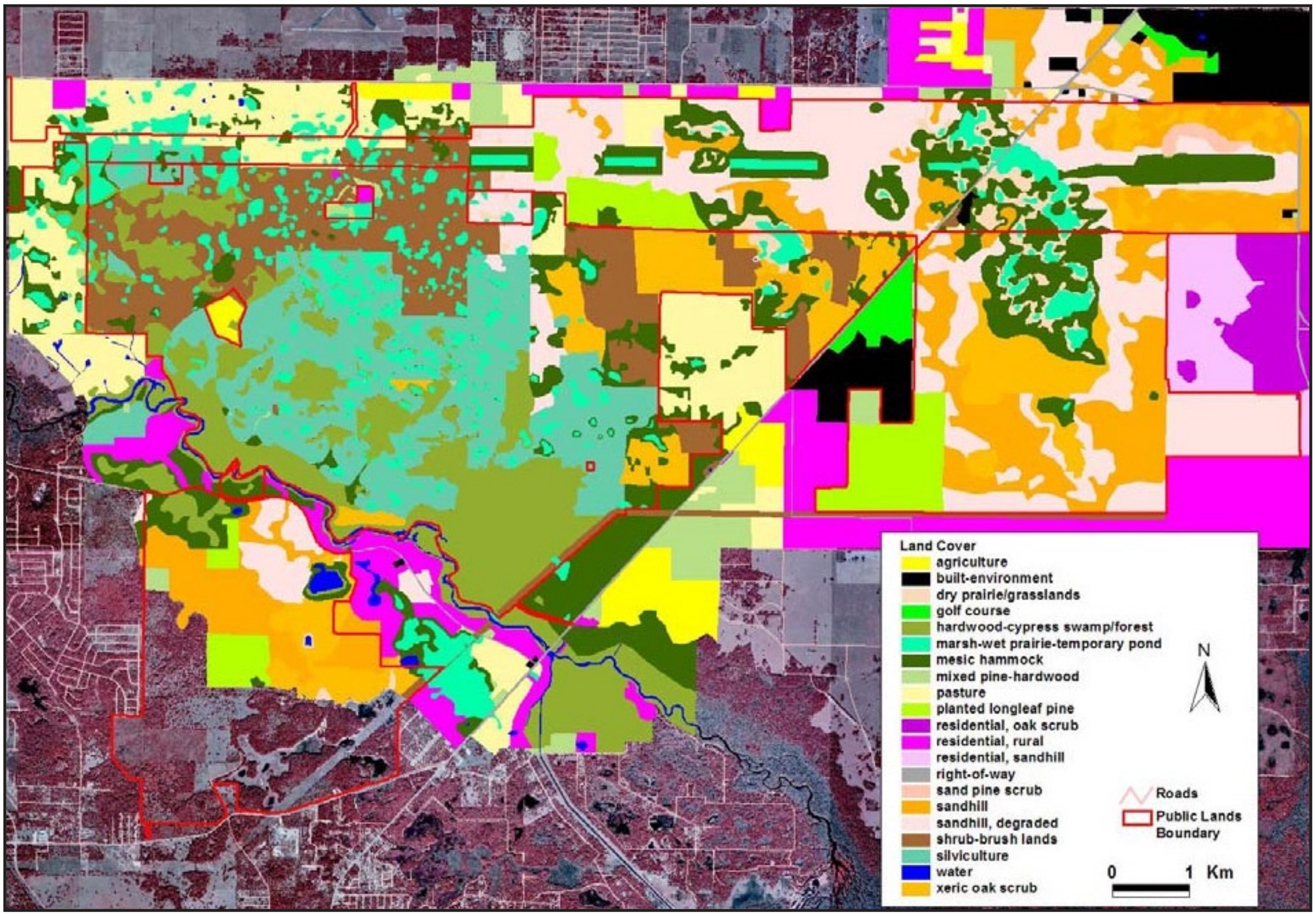

Figure 3. Land Cover (Florida Fish and Wildlife Conservation Commission 2003) of the Ross Prairie Conservation Area.

Successful and unsuccessful wildlife crossing locations were determined by performing road-kill (on all vertebrates) and track (large mammals and herpetiles) surveys. Road-kill surveys were conducted three to five times per week between May 2002 and December 2004. Firebreaks adjacent and parallel to the highway were monitored for animal tracks from September 2002 to April 2004 by dragging a 1-m-wide chain-link harrow behind an ATV. Track paths were checked one to two times weekly for carnivore, ungulate, snake, and turtle tracks. The mark-recapture study was conducted along the road right of way to determine species presence, habitat use, and movement patterns of small mammals and herptiles. Twenty-four drift fence arrays (consisting of 1-m-tall silt fences, each with 4 bucket and 2 funnel traps) were checked five days per week from May 2002 through December 2004. The radio-telemetry work targeted wide ranging species (bobcat, coyote, and eastern indigo snake) and key management-indicator species (gray fox, gopher tortoise, and eastern diamondback rattlesnake). Radio-tagged animals were tracked one to two times per week. Telemetry was conducted between May 2002 and December 2004.

GIS data (landscape and vegetation layers) were used in conjunction with results of telemetry, track, mark-recapture, and road-kill studies to create habitat use and connectivity layers for the area in reference to the overall greenways system and potential effects of SR 200. This information was used to predict movement patterns and behavior of individual species (and faunal groups) to the expansion of SR 200.

Results and Discussion

Road-kill surveys

Results of the road-kill surveys included 759 individual animals from 57 identifiable species. The majority were anurans followed by meso-mammals (figure 4). Proportions by taxa differ from that recorded at Payne's Prairie State Preserve in 1998-99 (Smith and Dodd 1999). In that study significantly greater numbers of alligators, aquatic snakes and turtles were found. Payne's Prairie (near Gainesville, FL) contains much more year-round surface water than Ross Prairie resulting in higher numbers of aquatic-dependents.

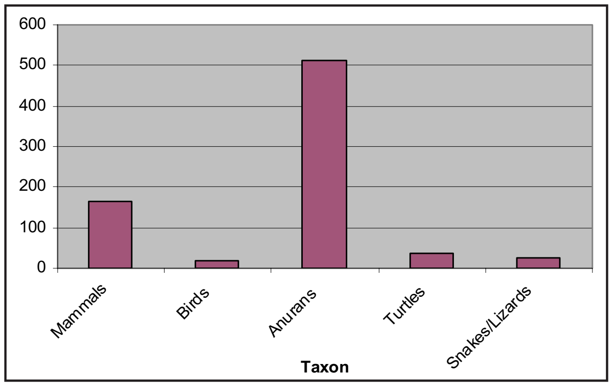

Figure 4. Total Number of Road-kills by Taxon, 200–2004.

Critical locations of significant numbers or rare species of road-kills by taxa were identified. For example, figures 5 and 6 display concentrations of road-killed frogs in the Ross Prairie basin area of the Cross-Florida Greenway (CFG). Variability of road-kills by land cover type was significant for amphibians (X^2=82.01, p<0.0001) and reptiles (X^2=32.74, p=0.0031). Most herpetile road-kills occurred within the wet prairie basin, or in adjacent sandhill or mesic hammock communities.

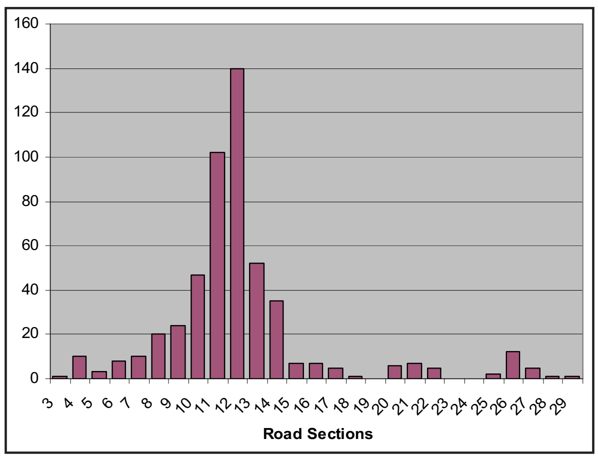

Figure 5. Spatial Distribution of Road-killed Frogs in the CFG Area of SR 200.

Notable focal species killed included: eastern indigo snake (n=5), eastern diamondback (n=1), Florida gopher frog (n=51), bullfrog (n=24), Florida box turtle (n=3), and gopher tortoise (n=9).

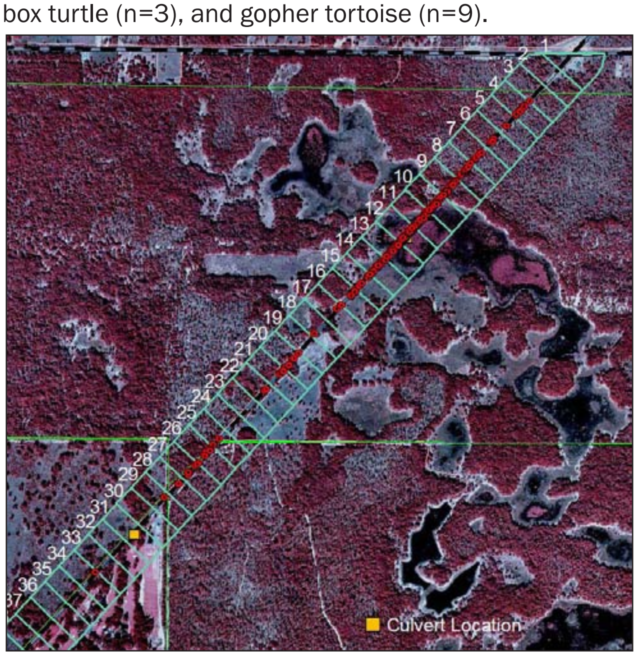

Figure 6. Road Sections Locations of Road-killed Frogs in the CFG Area of SR 200.

Small mammal and avian road-kills were recorded throughout the SR 200 corridor monitored. No relation was found by land cover. Similarly, no patterns were significant for larger mammals, such as gray fox (n=8) or coyote; however, bobcat (n=5) road-kills only occurred within and adjacent to the Ross Prairie basin (figure 7). Several owls (barred, great-horned and screech) preying upon these road-kill were also killed.

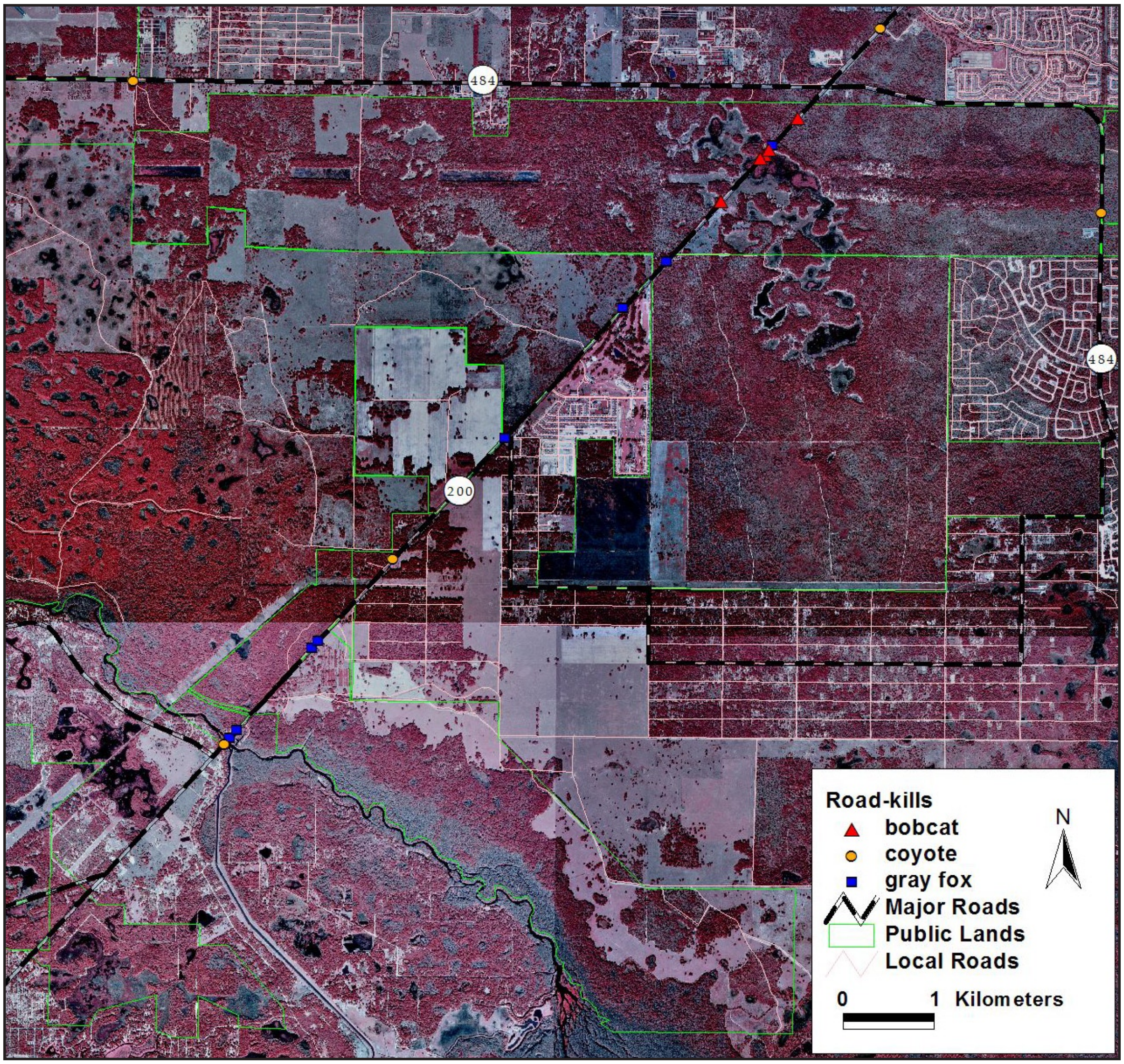

Figure 7. Location of Carnivore Road-kills Documented in the Ross Prairie Conservation Area.

Track surveys

A total of 474 sets of snake, 481 sets of carnivore, and 537 sets of whitetail deer tracks were recorded. Track site hotspots were identified for snakes, white-tail deer, and carnivores. In most instances these correspond to the same locations identified as road-kill hotspots. Figures 8 and 9 display locations of snake tracks in the Ross Prairie basin area of the Cross-Florida Greenway (CFG). The greatest concentration occurred in the sandhill sections north of the Ross Prairie basin.

Coyote tracks were recorded throughout the SR 200 corridor monitored (figure 10). In contrast, gray fox and bobcat tracks were only common within and adjacent to the Ross Prairie basin (figures 11 and 12). Of 21 land cover types, all but 18 sets of carnivore tracks were found adjacent to one of three types: sandhill, mesic hammock, or wet prairie (X^2 = 23.52, p = 0.003). A concentration of white-tail deer tracks were recorded to the south of the Ross Prairie basin (figures 13 and 14).

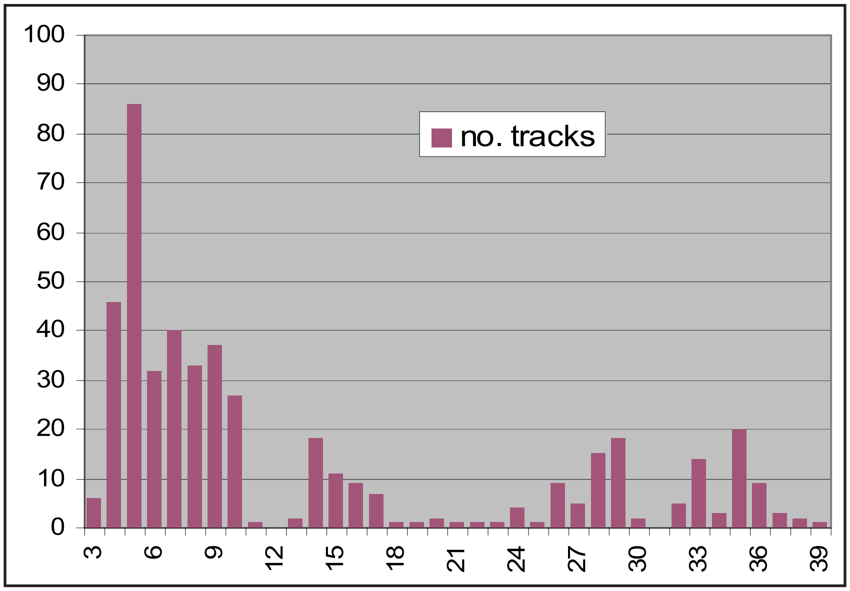

Figure 8. Spatial Distribution of Snake Tracks in the CFG Area of SR 200.

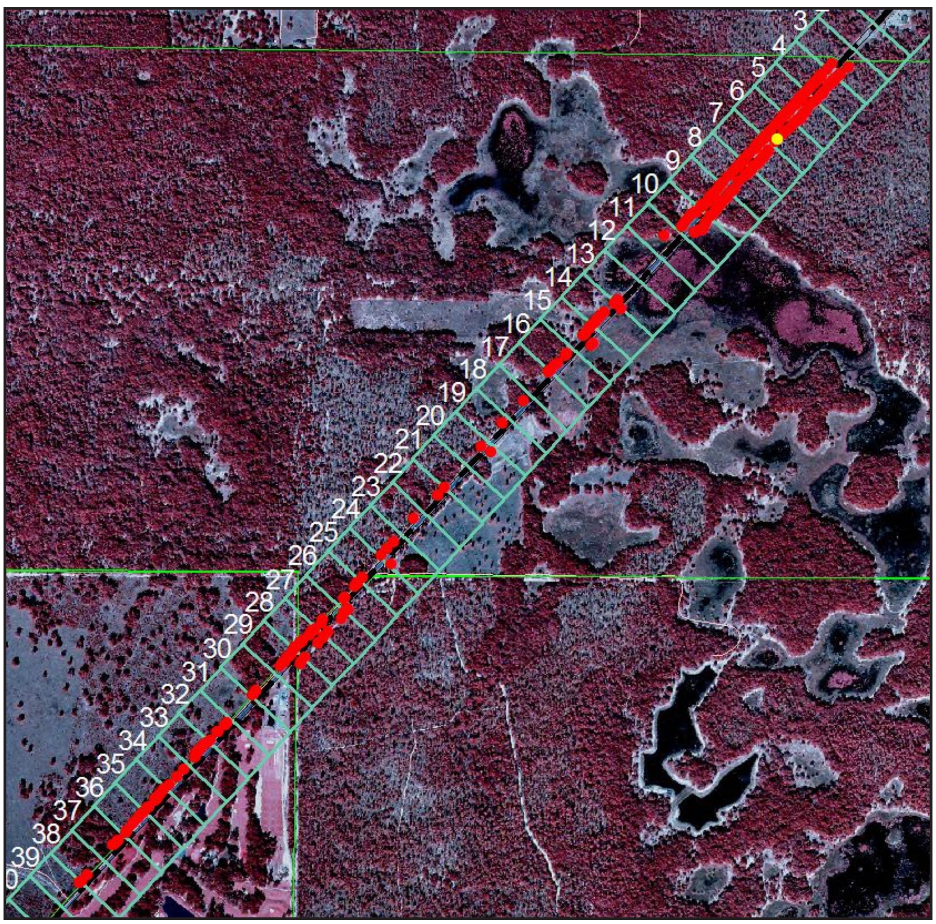

Figure 9. Road Sections Locations of Snake Tracks in the CFG Area of SR 200.

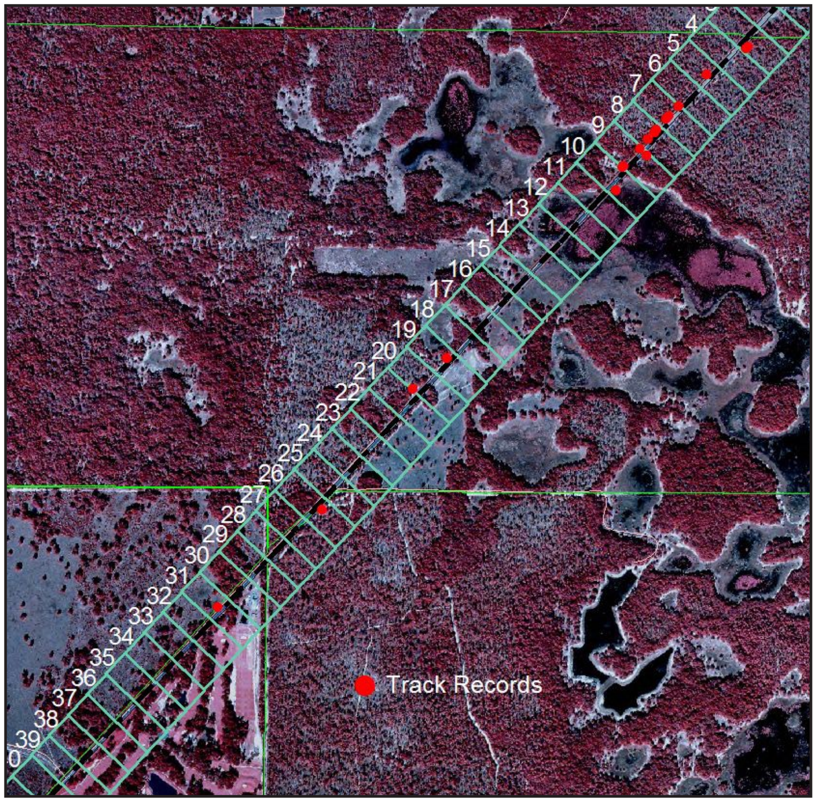

Figure 10. Road Sections Locations of Coyote Tracks in the CFG Area of SR 200.

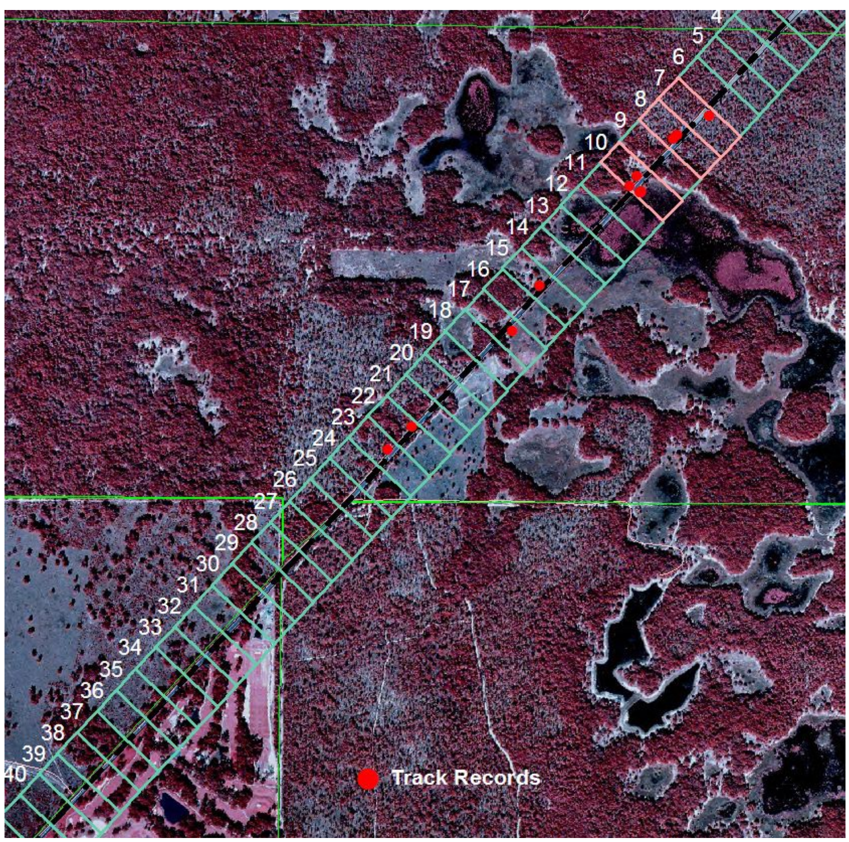

Figure 11. Road Sections Locations of Gray Fox Tracks in the CFG Area of SR 200.

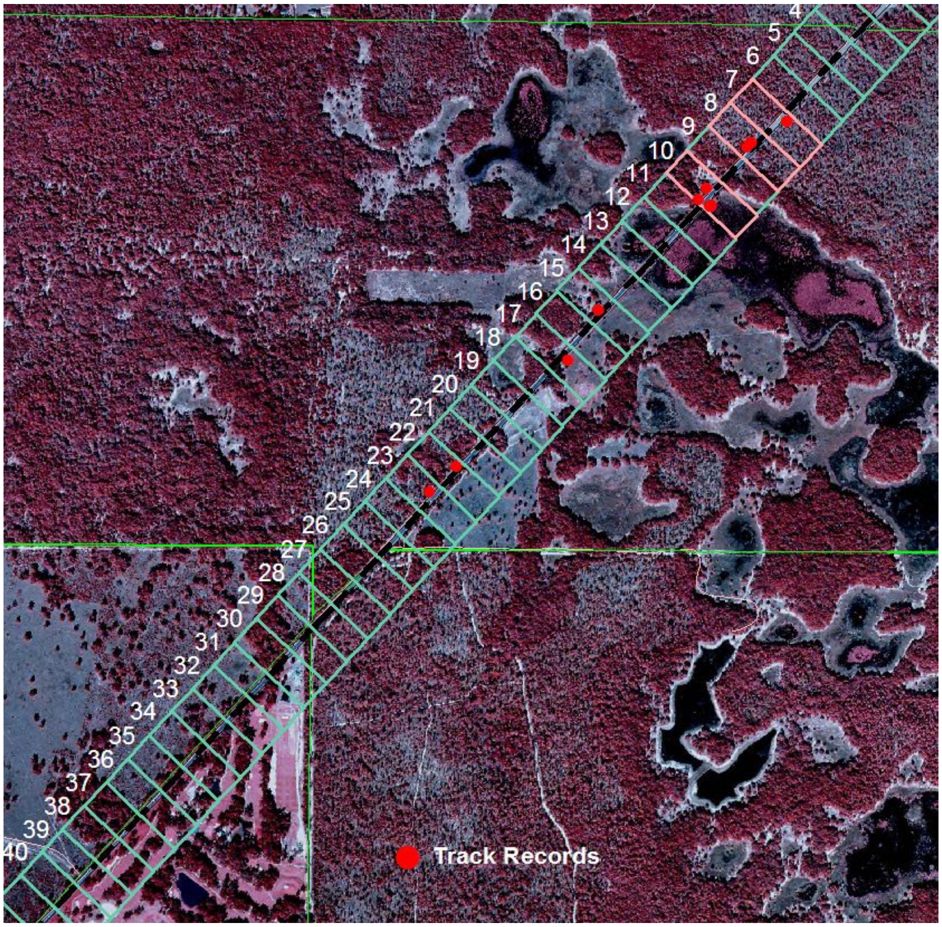

Figure 12. Road Sections Locations of Bobcat Tracks in the CFG Area of SR 200.

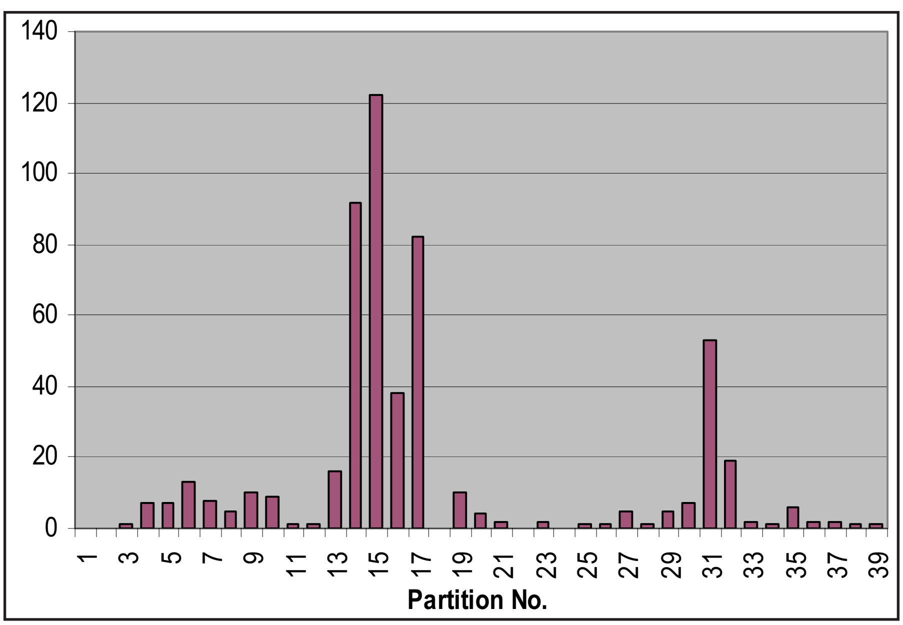

Figure 13. Spatial Distribution of White-tail Deer Tracks in the CFG Area of SR 200.

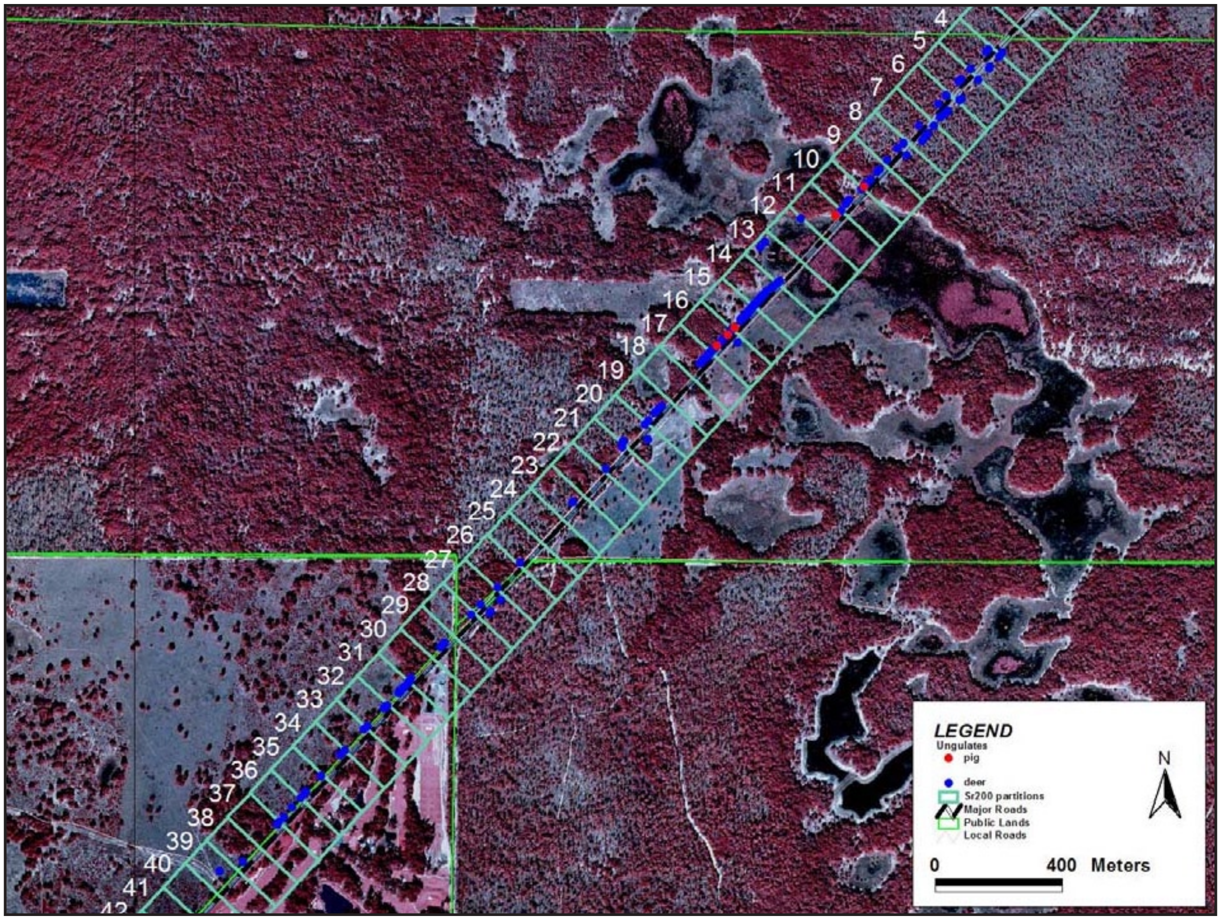

Figure 14. Road Sections Locations of White-tail Deer Tracks in the CFG Area of SR 200.

Mark-recapture surveys

A total of 1,777 individuals from 32 herpetile species were captured in the 24 right-of-way drift fence traps (figure 15) along the 4-km section of SR 200 monitored. Notable rare species captured included the southern hognose snake, gopher tortoise, and Florida gopher frog. Southern leopard frogs and Florida gopher frogs were most abundant. Figure 16 shows the number of gopher frogs captured by trap number (refer to figure 15 for trap location). It was commonly captured in traps adjacent to sandhill habitat areas north of the wetland basin. Also, several crossings were recorded at traps near the basin during breeding season, indicating movement by adults to/from the sandhill areas. These recruitment patterns are similar to that of previous studies in central (Greenberg 2001) and panhandle (Palis 1998) Florida. Greenberg (2001) found that recruitment was influenced by rainfall and pond hydrology as well as competition and predation. Consistent with findings by Means (1989), the current level of road-kills have not threatened the population with extinction, but changes in highway configuration and intensity could effect long-term presence and population size if sufficient measures are not taken to insure successful recruitment and dispersal to/from the wetland basin.

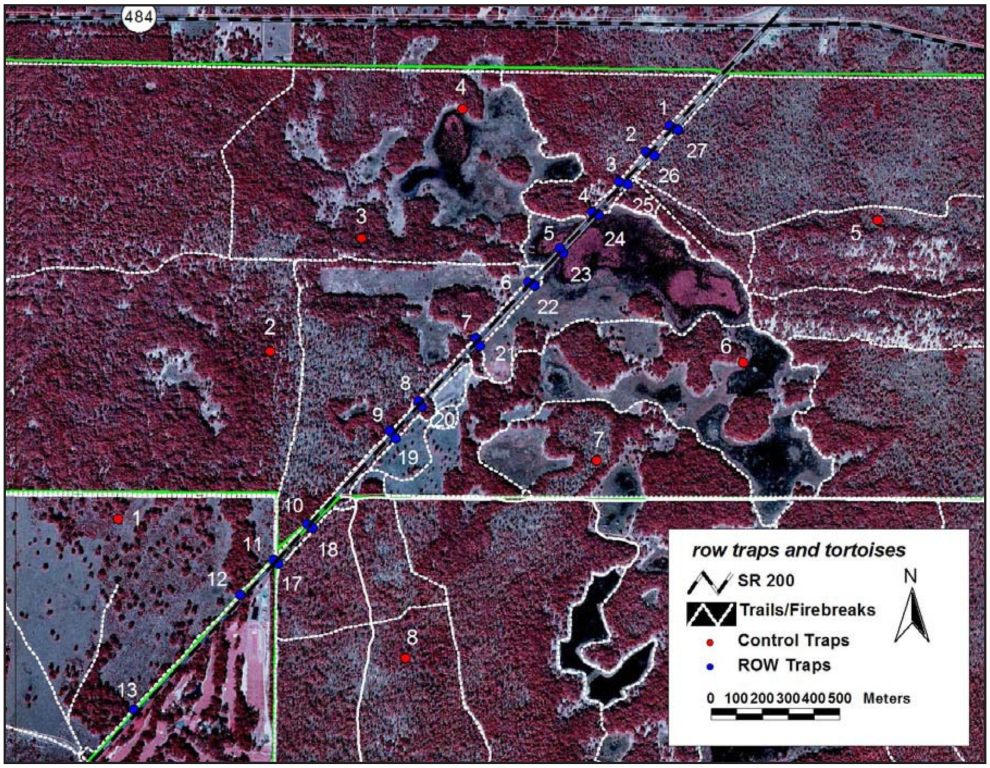

Figure 15. Location of Drift Fence Arrays Used in Mark-recapture Studies. Number of traps by habitat types (n) surveyed - sandhill (8), oak scrub (3), wet prairie (7), and hardwood hammock (6).

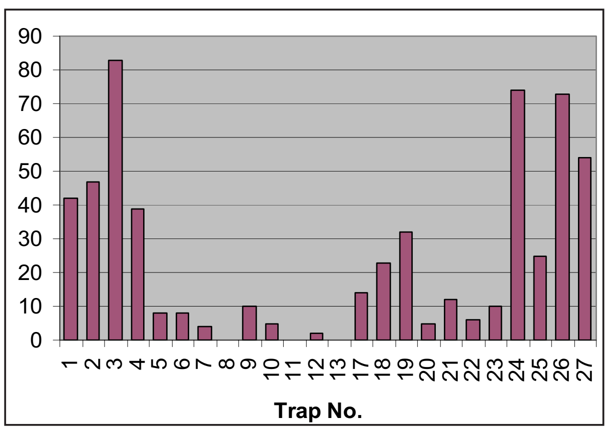

Figure 16. Number of Florida Gopher Frogs Captured/Recaptured by Trap Number.

A total of 157 individuals from 16 herpetile species were recaptured. Of those recaptured, few species (n=14) and individuals (n=44) were recorded crossing the road. Recorded crossing frequency for each species (at least 10 captures) was less than 10 percent. Yet only one species with at least 10 captures, the peninsular crown snake, was not recorded crossing the road. The two sandhill crossings (figure 15 – trap nos. 1 to 4, 17, 18, and 24 to 27) and the wetland basin (figure 15 – trap nos. 5 to 7 and 21 to 23) were important from a population density standpoint as well as for crossing attempts. Individuals of several species of snakes, frogs, and lizards were recorded crossing the road in the two sandhill crossing sections, and moving to/from the Ross Prairie wetland basin.

A total of 342 individuals from 11 small mammal species were captured in drift fence traps. Trap location/land cover type was not statistically significant regarding number of small mammals captured; nevertheless, the highest numbers were found in traps to the south of the wetland basin in grassland areas (figures 15 and 17). The most notable mammals captured were the rare Florida mouse and southeastern pocket gopher. Twenty-four individuals from 7 species were recaptured, yet only one cotton mouse was recorded crossing the road. In addition, only six were found as road-kills. Apparently, the road is a significant barrier to small mammal movement. Several factors influencing this barrier effect are artificial substrate (pavement), road surface and clearance width, right-of-way vegetation management, vehicle traffic, emissions, noise, and vibration (Garland and Bradley 1984, Mader 1984, Wilkins 1982, Kozel and Fleharty 1979, and Oxley et al. 1979).

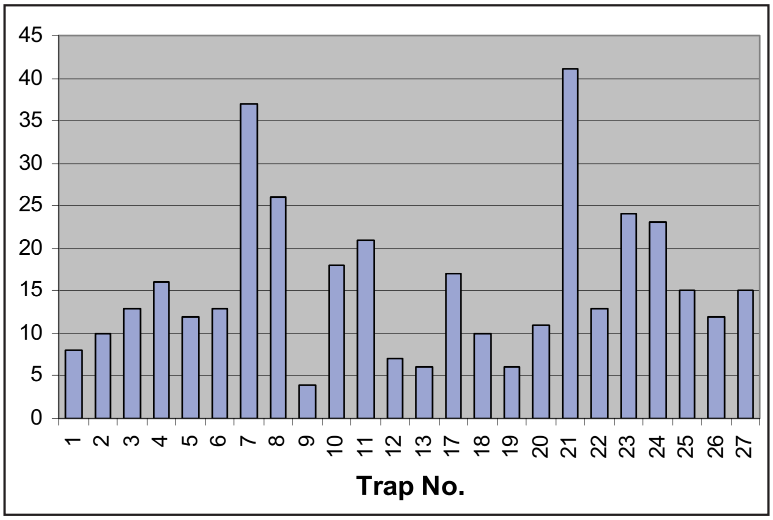

Figure 17. Number of Small Mammals Captured/Recaptured by Trap Number.

Radio-telemetry studies

Fifty gopher tortoises were captured and marked in the entire study area (29 male, 19 female, 2 juvenile). Average home range (95% fixed kernel, minimum 30 points) of the 18 gopher tortoises monitored in burrow colonies adjacent to the road was 3.14 ha (slightly larger than control sites) (figure 18). Home ranges found in this study were higher than those found at Kennedy Space Center (Smith et al. 1997) and Lochloosa Wildlife Management Area (Diemer 1992). Habitat differences may account for the variation in home range size. Our sites were primarily sandhill communities. Kennedy Space Center sites were dominated by scrub habitats and Lochloosa WMA consisted of managed pinelands.

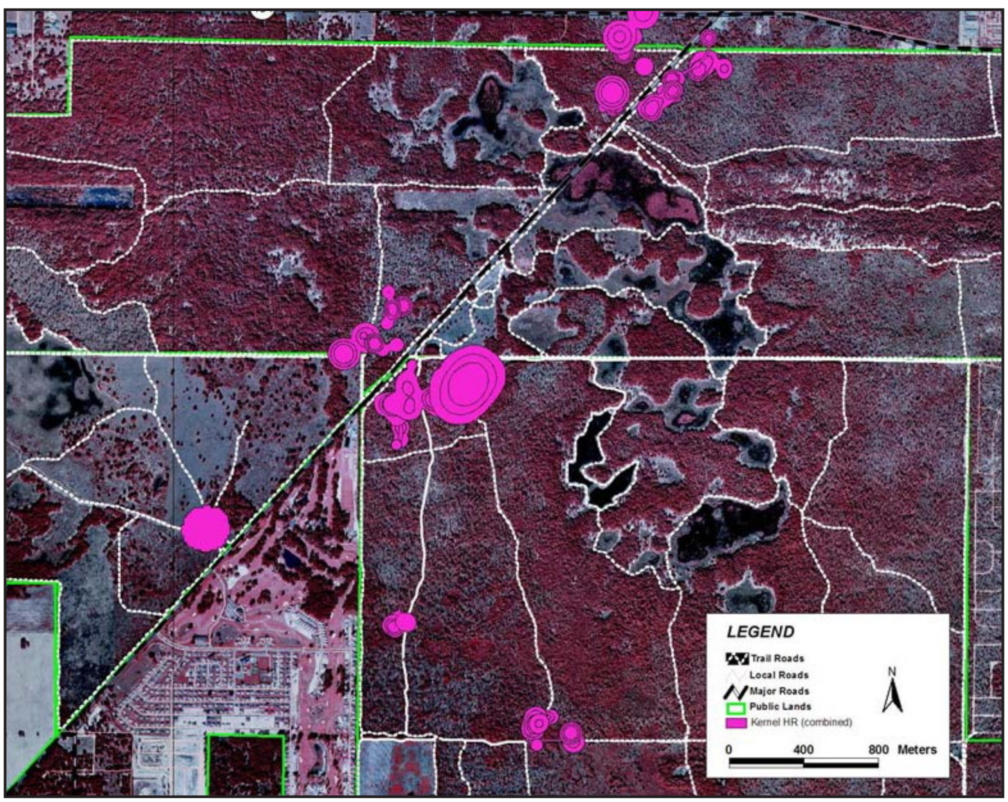

Figure 18. Combined Home Range (50, 75, and 95 % FK contours) for all Gopher Tortoises.

Only three attempted crossings of SR 200 were recorded, two were successful and one resulted in death. Nine unmarked gopher tortoise road-kills were recorded. Tortoises used habitat as close as 10-20 m from the pavement. For gopher tortoise, the road is a semi-permeable barrier. Successful crossings are possible; still their poor mobility increases their risk of collisions with vehicles.

We captured a total of 24 eastern indigo snakes (11 male, 8 female, and 5 of undetermined sex) over the entire study area, observed 2 others, and encountered 5 road-kills. Home range (95% fixed kernel, minimum 30 points) of the 13 eastern indigo snakes monitored averaged 127.6 ha (figure 19). Home range size found here was consistent with that of Breininger et al. (2004) from Brevard County, FL. Considerable overlap of habitat use occurred, except between large adult males. The areas of highest density of eastern indigo snakes coincided with gopher tortoise colonies and sandhill communities (also see Stevenson et al. 2003, and Diemer and Speake 1983). Telemetry data indicated that the road acted as a home range boundary (one signal echo was recorded indicating a possible crossing, but a positional fix could not be obtained). Because of road-kills, there is confirmed evidence that interactions with the road occur and road crossings are attempted.

Five eastern diamondback rattlesnakes were also captured (2 male, 2 female {one adult, one subadult}, and 1 adult of undetermined sex). Two of these were killed (human means) and one transmitter failed. Of note: one unmarked rattlesnake road-kill was also found. The average home range size of the two remaining eastern diamondbacks was 86.5 ha (95% FK contours). None of the tracked eastern diamondbacks was recorded crossing the road; however, two were commonly found in the adjacent right-of-way; as a result the subadult was killed by a utilities worker.

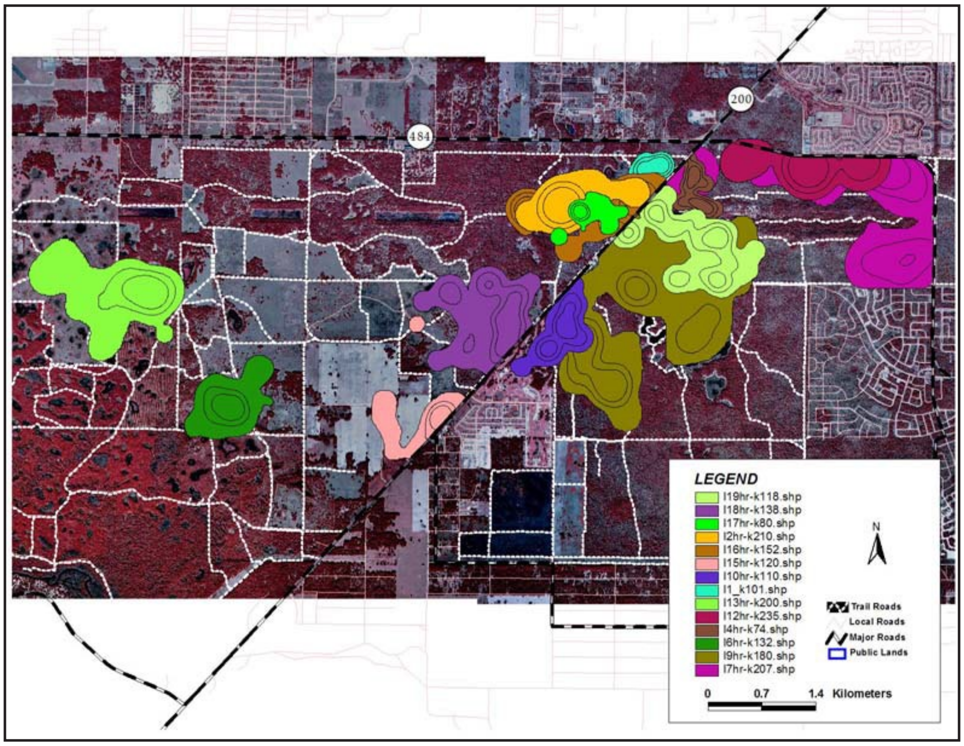

Figure 19. Combined Home Range (50, 75, and 95 % FK contours) for all Indigo Snakes.

Trapping efforts resulted in the capture of 5 bobcats (2 males and 3 females), 3 coyotes (2 females and 1 male), 1 red fox (male), and 1 gray fox (female). Yet observations, track, and scat evidence suggest that a significantly higher number of these animals were present in the Ross Prairie area. Known human-related mortality for those captured was high (50%). Two of the bobcats died after being hit by motor vehicles, and one was shot by a poacher. The gray fox was shot by an adjacent farmer 1.5 months after being collared.

Useful telemetry data was only obtained from 4 bobcats, 2 coyotes, and 1 gray fox (figure 20). Average home range size (FK – 95% contour) was 13.67 km^2 for bobcats (n=3, minimum 40 locations). This is greater than that recorded by Thornton et al. (2004), less than Maehr (1997) or Foster and Humphrey (1992), but similar to that of Tigas et al. (2002). The former three studies were conducted in much larger conservation areas whereas the latter study was similarly conducted in smaller fragmented habitat areas.

Bobcat no. 1 was recorded crossing SR 200 and CR 39, one crossing by an unmarked bobcat was observed, no other successful crossings were recorded. Bobcat no. 1 was a casualty of a vehicle collision on SR 200 near the end of the study. Most radio-collared felids avoided SR 200 or used the road as a home range boundary, whereas the radio-collared canids commonly crossed major roads (SR 200 and CR 484). Tigas et al. (2002) found that bobcats and coyotes adapted to habitat fragmentation and human activity through temporal and spatial avoidance. They also supplemented diet with available human-related foods (fruit, garbage, and pets). Lastly, roads and developed areas were commonly crossed when moving between habitat fragments. Vehicular collision was the principal means of mortality. We found similar behavioral characteristics and movement patterns. Understanding natural history requirements of species being considered (as described above) is essential in the design of functional habitat corridors (Burbrink et al. 1998).

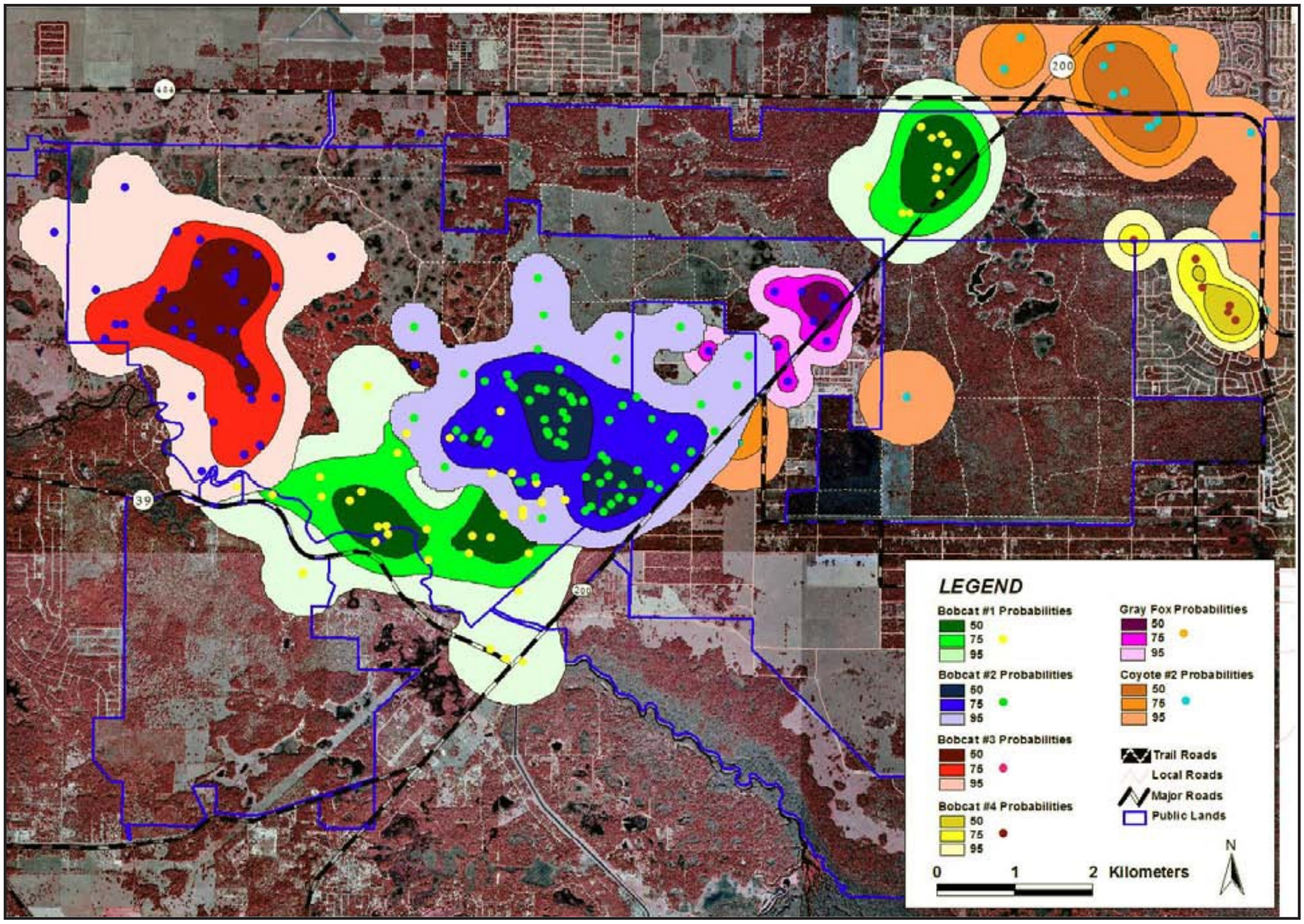

Figure 20. Combined Home Range (50, 75, and 95 % FK contours) for all Carnivores.

Human influence threatens native biological diversity through loss of species from genetic inbreeding, elimination of large uninterrupted habitat, and invasion of alien species (Forman and Alexander 1998, Andrews 1990, and Harris and Gallagher 1989). Connecting corridors must have sufficient width to maintain interior habitat qualities that would enhance use by threatened area-sensitive species (Noss 1983; see also Noss and Cooperider 1994, and Soulé 1991).

Roads, as a barrier to animal movement, are considered one of the six major determinants of functional connectivity (Noss and Cooperider 1994). The use of highway crossing structures at intersections with greenway linkages (habitat corridors) offers a method to reduce transportation-related, wildlife mortality and restore connectivity to the landscape. Recommended designs (as presented below) illustrate the use of wildlife crossings to permeate transport facilities (Noss 1995).

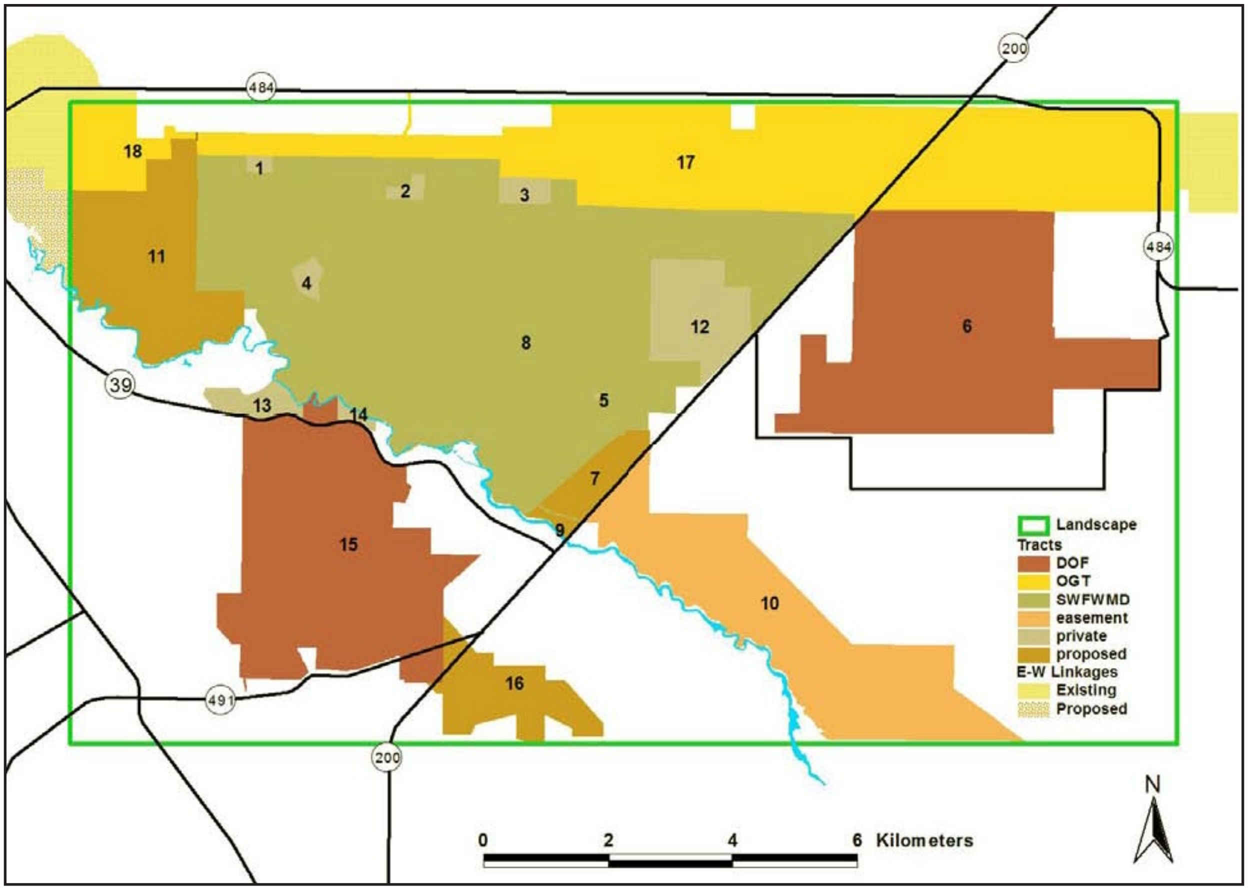

Figure 21. Contextual Analysis: Local Linkages to other Regional Conservation Areas. Ownership Abbreviations: DOF – Division of Forestry, OGT – Office of Greenways and Trails, and SWFWMD – SW Florida Water Management District. Numbers indicate different parcels of land.

Conclusions and Recommendations

Contextual issues

High levels of conversion to urban development are occurring in southwest Marion County; many proposed additions have already been lost (figure 1). Three proposed additions (figure 21 – nos. 7, 11, and 16) are needed to maintain connections to the larger conservation areas to the west, south, and southeast (figure 2). These are critical in minimizing isolation and preserving the area's integrity as a significant habitat node for wide-ranging species. The approximate 0.5-km-wide connection between the Halpata Tastanaki Preserve and the Withlacoochee State Forest tract (figure 1) should be increased to 3 km by establishing habitat buffers on the adjacent vacant parcels (figures 21 – nos. 13 and 14) to create a more functional connection for carnivores.

Based on telemetry and observational data, the size and configuration of the core area (a significant amount of edge habitat and high road density), and the level and sources of mortality, the Ross Prairie core area can only sustain a small number of bobcats, perhaps 8-10 animals. Life expectancy of bobcats and gray foxes in this area is probably below average due to the risks associated with the proximity to human-dominated habitats. In addition, the presence of coyotes may increase mortality levels as a result of inter-specific competition and predation (Fedriani 2000). Considering all these factors, the area generally functions as a sink for these two carnivores, but may provide a functional habitat corridor between larger conservation reserves.

Highway issues

SR 200 is a high-volume transportation corridor that bisects the Ross Prairie conservation area. It inflicts significant direct impacts on wildlife in the immediate area (e.g., Florida gopher frog and Florida mouse) and negatively affects movement of wide-ranging resident and dispersing wildlife (e.g., bobcat and eastern indigo snake). The local gopher tortoise population has been segregated into two disjunct subpopulations. To improve habitat connectivity and eliminate road mortality within the Ross Prairie area, we propose a system of culverts, bridges, and barrier fences that will increase permeability of the road for a diverse assemblage of wildlife in the area.

The Ross Prairie conservation area provides an opportunity to improve upon the design constructed at Payne's Prairie State Preserve (Smith 2003a). At Payne's Prairie, the low elevation of the existing four-lane highway limited the ability of engineers to design and construct a system of structures that function in all environmental conditions. Structures that were installed were smaller than recommended because of low clearance between the pavement and mean high water line of the prairie. Also, recent visits to Payne's Prairie have demonstrated that during high water periods, the structures are completely inundated. This likely prevents most air-breathing animals from using the culverts. To exacerbate the problem, private ownership at the ecotones of the prairie prevented construction of additional culverts/bridges that would have allowed for safe passage of terrestrial species moving along the perimeter of the prairie during high water periods. Ross Prairie does not possess these limitations and, therefore, should give engineers more flexibility in design and implementation. For example, Ross Prairie and the surrounding uplands are in public ownership, and the bed that the pavement is constructed on "appears" to be at higher elevation within the wetland basin.

The following parameters (from Smith 2003a) were considered in making recommendations for improvements to the SR 200 corridor:

- Context Sensitivity—vegetation consistent with surrounding habitat
- Environmental variability—provide for terrestrial passage at semi-aquatic sites during periods of high water levels
- Directional fencing—funnel wildlife through passages and away from road surface
- Berming—reduce effects of traffic noise and lights
- Topography—road should be designed to "fit into" the landscape (e.g., minimize alteration in slope of underpass/overpass approaches)
- Substrate—consistent with adjacent area
- Lighting—reduce tunnel effects by increasing openness value (height*width/length) and providing light penetration in medians of divided highways
- Human presence—reduce human access associated with crossing sites

We recommend installing two box culverts (2-m wide x 1.2-m tall) in each of the two upland sandhill areas, bridges (12.3-m wide x 1.8-2.46-m tall) at each ecotone between the wetland basin and adjacent uplands, and a series of five culverts (1.5-m wide x 1-m tall) within the wetland basin. They should be spaced out along the elevational gradient and will flood and dry at different times as water levels naturally increase and decrease (Adair et al. 2002). Lastly, the equestrian underpass should be located across from the Ross Prairie trailhead to minimize adverse impacts and segregate wildlife and human crossing sites. Recommended dimensions of structures are consistent with structure preferences identified by Smith (2003b), Clevenger et al. (2001), Hewitt et al. (1998), and (Boarman and Sazaki 1996). Culvert amenities should include:

- Lighting grates within the median and on the shoulders (see Krikowski 1989)
- 3-sided design (concrete walls and ceiling with natural soil floor)
- Approaches landscaped with native shrub and ground cover vegetation
- Final elevation within the structure and the adjacent approaches needs to be higher than adjacent areas to prevent pooling of water and buildup of sand and silt within the structure

Between all these structures we suggested a 2-m tall fence to keep larger species off the road. At the base of the fence we recommended installation of a 0.4-m-high mesh-screen (or alternative material) herpetile barrier. The mesh screen should extend below the ground surface to prevent any openings. One-way gates/earthen ramps may be needed to allow escape for wildlife trapped in the fenced enclosure within the right of way (Bank et al. 2002).

Within the wetland basin we recommended a 1.3-m high concrete barrier wall with a 0.4-m mesh-screen fence placed on top. The wall should be placed at the normal water line or higher. Also, the design should be a pre-casted recurved shape (at least 75 degrees) facing outward into the habitat to prevent climbing by snakes and frogs.

Even with these measures, the long-term effects of road expansion may be detrimental and could take decades to determine (Findlay and Bourdages 2000). Following construction we recommend that funding be earmarked to monitor crossing structure performance and population stability of focal species in and around the Ross Prairie basin. More detail regarding this study can be found in the final report of the project (Smith 2005).

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How Far into a Forest Does the Effect of a Road Extend?

Defining Road Edge Effect in Eucalypt Forests of South-Eastern Australia

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Abstract: The concept of the road-effect zone has been developed and researched predominantly in the Northern Hemisphere. This study measures the extent of road impacts into a temperate eucalypt forest ecosystem in south-eastern Australia. The Epsom-Barnadown Road is a two-lane arterial road connecting regional centres in northern Victoria to the City of Greater Bendigo. Passing through the Bendigo Regional Park, the Epsom-Barnadown Road carries more than 1,600 vehicles per day. Transects of 1 km in length cited perpendicular to the road were established to measure road impacts on the flora and fauna of box-ironbark forest. Exotic vegetation was found to extend about 50 m from the road. Traffic noise and light penetration varied according to topography and vegetation cover, but averaged of 350 m and 380 m, respectively, from the road. Mammal surveys indicated there was an increase in species richness once traffic noise reached ambient levels (40 dB) and traffic light penetration ceased. Bird surveys resulted in the identification of four species (9%) that only occurred within 150 m of the road (edge species) and 21 species (58%) that only occurred at distances of 150 m or more from the Epsom-Barnadown Road (interior species). A core habitat area for bird species was identified at about 900 m from the road. It was found that the average width of forest in the Bendigo Regional Park impacted by the Epsom-Barnadown Road was 1800 m, which translates to an area of 1.8 km^2 per kilometre of road.

The Road-Effect Zone

In recent years, Forman and Deblinger (2000), Forman (2000), and Forman et al. (2003) have developed the concept of a road-effect zone. The road-effect zone is defined as the area over which significant ecological effects related to species, soil, and water extend outward from a road into the surrounding landscape (Forman & Deblinger 2000). Over 20 ecological effects of roads have been identified, including alteration to the physical and chemical environment, dispersal of exotic species, noise and pollutants, increased mortality and the alteration to wildlife behaviour (Forman and Deblinger 2000). The road effect zone is usually many times wider than the road surface and associated verge habitat, which is traditionally considered within transportation planning. It is a useful tool to address the ecological effects of roads and to provide a basis for sustainable road management strategies.

The outer boundary or effect distances on either side of the road is usually dictated by a combination of topography, the quality of adjacent vegetation, animal behavior and wind direction (Forman et al. 2003). Wind carries sediments, dust, pollutants, and traffic noise farther distances downwind than upwind. Similarly, sediment and dissolved chemicals carried by water, or noise carried by wind, affect greater distances down slope opposed to upslope. The behavioral attraction to suitable habitat by animals to forage, breed, or live, and by non-native species looking for habitat to invade, all occur for varying distances in one direction more than another (Forman et al. 2003). As a result, the outer boundaries of the road-effect zone are highly asymmetric, convoluted, and generally extend farther down slope and down wind of the road and in areas of higher quality vegetation or habitat (Forman and Alexander 1998, Forman and Deblinger 2000, Forman et al. 2003).

Comprehensive reviews of the ecological effects of roads have been written by Andrews (1990), Bennett (1993), Forman and Alexander (1998), Spellerberg (1998), Trombulak and Frissell (2000), and Forman et al. (2003). Road effects to be considered here are the spread of exotic weeds via roads, habitat fragmentation produced by roads, and road avoidance behavioral traits adapted by some fauna species. Habitat fragmentation relates to the size of the fragment after roads have subdivided habitat into smaller isolated blocks. Removal of forest habitat results in a greater proportion of edge habitat or forest edge. Species can be grouped according to their response to an edge. “Edge” species are those whose abundance increases near habitat edges and are typically habitat generalists. By contrast, “interior” species are those that decrease or are absent from edge habitat, and are habitat specialists, having large home ranges and inhabiting large-sized habitat remnants (Berry 2001). Generalist species are usually able to tolerate disturbed edge habitat, as substantial areas are still available for colonisation. However, for those species restricted to forest interiors, habitat loss due to the construction of a road is several times that of actual forest removal (Andrews 1990, Bennett 1993, Forman et al. 2003).

Roads provide a conduit for the dispersal of exotic species via three mechanisms: providing habitat for exotic species by altering natural conditions, making invasion more likely by stressing or removing native species, and allowing easier movement of wild or human vectors (Trombulak and Frissell 2000). Where weeds replace indigenous vegetation, animals are left without food, breeding sites or shelter from predators (Csurhes and Edwards 1998). In sclerophyll forests of Dartmouth, Australia, Amor and Stevens (1976) recorded the frequency of alien plants and diffuse light both decreased with distance from a road, with an abundant growth of weeds within moisture pockets of water runoff formed in the road shoulder. Morgan (1998) found a similar pattern in south-eastern Australian grassland habitat, and attributed exotic species richness in roadsides to higher nutrient concentrations, such as phosphorous and ammonium, emitted from vehicle exhausts. Vehicle emissions, which extend short distances from a road, fertilized the growth of exotic species, which, in turn, prevented the growth of native vegetation (Morgan 1998).

Road disturbance arises from vehicular noise, headlights, vibrations, and human presence. Species that are sensitive to such disturbance may modify their movement patterns and/or home range to avoid favored habitat near a road

(Trombulak and Frissell 2000, Forman et al. 2003). In both woodland and pastureland adjacent to a road in the Netherlands, 26 of the 43 (60%) grassland bird species encountered showed evidence of reduced abundance and richness near the road, exhibiting avoidance zones up to 3,530 m where the traffic volume was 50,000 vehicles per day (Reijnen et al. 1996). Likewise, on highly trafficked two-lane roads in Boston, MA, USA, supporting 15,000-30,000 vehicles/day, both bird presence and regular bird breeding were reduced to a distance of 700 m away from the road (Forman et al. 2002). Interestingly no distance effect could be determined on adjacent roads supporting 3,000-8,000 vehicles/day in Boston.

In all studies to date, avoidance zones have been shown to widen with an increase in traffic volume. Traffic noise has postulated to be the independent variable causing birds to stop breeding and/or move away from the road. It is believed traffic noise causes both hearing loss and increased stress levels leading to illness, premature death, and population decline (Bowles 1997). A study investigating a disturbance effect zone from vehicle headlights by Jones (2000) reported Tasmanian Devils *Sarcophilus laniarius* becoming dazzled by car headlights when trying to cross a tourist road in Tasmania, Australia. Bright light temporarily destroys an animal's night adaptation vision, and it has been suggested that it can take a half hour for the night vision of fauna to be fully restored once light has been removed (Wilson 1999).

The Box-Ironbark Forest of the Bendigo Regional Park

This study was undertaken in the Bendigo Regional Park, 10 km north-west of the central Victorian city of Bendigo in south-eastern Australia (figure 1). The area is characterized by undulating rises and low hills, comprising Ordovician sandstones and mudstones. The soils are typically shallow, low in nutrients, and have poor water-holding capacity. The vegetation comprises Box-Ironbark eucalypt forest (Muir et al. 1995). The Box-Ironbark ecosystem exists as forests and woodlands between the inland slopes of the Great Dividing Range and the adjacent Riverina Plains of south-east Australia (Environment Conservation Council 1997). The dominant tree species consist of Grey Box *Eucalyptus microcarpa*, Red Ironbark *Eucalyptus tricarpa*, with Yellow Gum *Eucalyptus leucoxylon* growing at lower moister sites, and Red Box *Eucalyptus polyanthemos* on drier upper slopes of the forest. The understorey is dominated by sclerophyllous Acacias *Mimosaceae*, Heaths *Epacridaceae*, and Bush-peas *Fabaceae* (figure 2). Local composition of the forest is dependent on variables of aspect, elevation, and drainage (Campi and Mac Nally 2001).

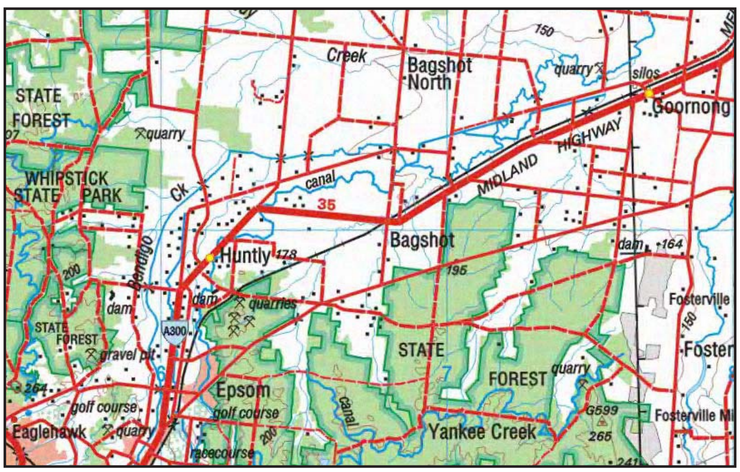

Figure 1. Location of the Epsom-Barnadown Road relative to the Bendigo Regional Park.

Figure 2. The Epsom-Barnadown Road bisecting the box-ironbark eucalypt forests of the Bendigo Regional Park.

Several issues relating to road-edge effect identified in the literature are applicable to box-ironbark forests. For example, fragmentation is one of the most problematic challenges to species conservation in box-ironbark forests. Once existing as three million hectares of large continuous forest and woodland, European settlement and its associated activities of mining, agriculture, and timber harvesting have reduced the ecosystem to a meagre 15 percent of its original extent. Remaining habitat is highly modified and fragmented, and exists as linear remnants along roadsides and streams, or as patches that range from small fragments to large bushland reserves. Furthermore, bushland reserves are internally fragmented by an expanding road network. The structure, width, and present management of this road system is far from uniform, varying from single-lane mining, recreational and forestry roads to multilane paved highways and freeways that carry large volumes of high speed traffic. Yet, as this prevalent network carves its way through almost every corner of the Box-Ironbark ecosystem, the ecological effects of roads, traffic disturbance, and their associated edge effects have not been examined.

The Bendigo Regional Park covers an area of 8,745 ha (Parks Victoria 2002), with the Epsom-Barnadown Road bisecting it from east to west. In October 2003, the traffic volume along this road was determined by the City of Greater Bendigo to average 1,617 vehicles per day, an increase from 1,077 vehicles per day in July 1999 (City of Greater Bendigo 2003). The legal speed limit for this section of road is 100 km/hr. Vehicular speeds were recorded from 10-160 km/hr, and 49 percent of vehicles travelled between 90-100 km/hr. The study was conducted between July and September 2004.

Exotic Vegetation

To measure the extent of exotic vegetation spread into the forest, the flora along three survey lines was determined using the line transect method (Brower et al. 1998). The presence of trees, shrubs, groundcover, herbs, grasses, and weeds, which were found one meter on either side of a 50-m measuring tape, were recorded. Notes were made of the topographical characteristics of the transects (e.g., ridge, gully, etc.). This method was also helpful in identifying major native vegetation zones along the transects.

Transect results indicated the vegetation in the study area was relatively weed free with a few pasture weed species and Large Quaking Grass *Briza maxima* common in the first 50 m, especially where pools of water formed in the road shoulder. Throughout the forest Oxalis *Oxalis pescaprae* and three species of pasture weed including Cape Weed *Arctotheca* were found under patches of Totem Pole *Melaleuca decussate*. These species are considered to be "naturalised weeds" due to their ubiquitous nature within the box-ironbark bioregion, and were not regarded as indicative of road-edge effect. The mean distance for weed penetration from the Epsom-Barnadown Road into the Bendigo Regional Park was about 50 m, creating an effect zone of 0.1 km2 per km of road.

Traffic Noise Penetration

The distance traffic noise extended into the forest was determined along 17 transects running perpendicular to the road marked at 50-m intervals. These transects were strategically placed to encompass gullies, ridge lines, and flat terrain so as to determine the influence of landscape features on noise penetration. A background noise absorber was used to determine the maximum noise each vehicle emitted when it passed the observer. The average noise of 10 cars was recorded each 50-m interval.

Traffic noise could be heard throughout the entire study area. The distance that noise above 40 dB (the ambient level) extended into the forest varied in relation to landscape features (gullies, ridges, flat terrain) 400 m on flat terrain, 325 m down gullies, and 300 m on ridges (figure 3). Past these points, traffic noise remained between 30-40 dB. On average, traffic noise (dB) was recorded slightly higher at each 50-m interval away from the center of the road along gullies compared with flat terrain or ridgelines (figure 3). The mean distance for traffic noise penetration from the Epsom-Barnadown Road into the Bendigo Regional Park was 350 m, creating an effect zone of 0.7 km2 per km of road.

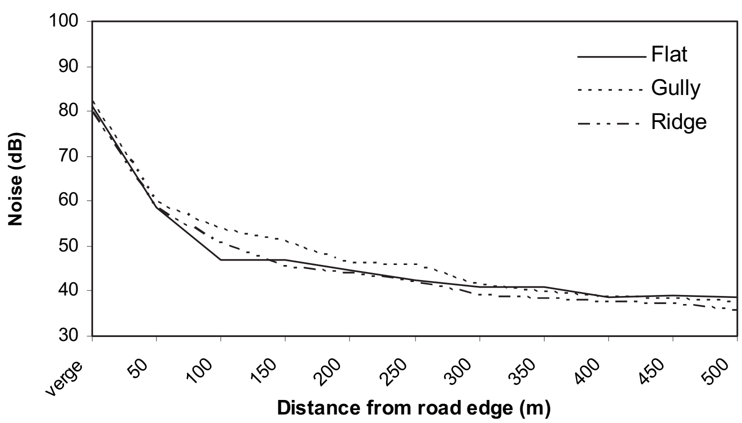

Figure 3. Noise levels in the Bendigo Regional Park at varying distances from the Epsom-Barnadown Road.

It must be noted that traffic noise in the surrounding road network could also be heard within the study area during the peak traffic times of 0800 and 1000, and 1700 and 1900. In the forest block north of the Epsom-Barnadown Road, traffic on the Midland Highway, approximately 2.5 km to the north (figure 1), could be heard between 500 m and 1000 m from the Epsom-Barnadown Road. Where farmland connected the Midland Highway and the Epsom-Barnadown Road, Midland Highway traffic noise could be heard a distance of 100 m into the southern forest block. The Fosterville Road, approximately 2 km south, could also be heard in the southern block at a distance of 1 km away from the Epsom-Barnadown Road.

Traffic Light Penetration

The same 17 transects used to measure traffic noise penetration were also used to determine traffic light penetration. The extent of traffic light illumination into the forest was determined as the distance from the road where traffic lights were no longer visible. The average distance light extended into forest habitat was 360 m for flat terrain, 450 m down gullies, and 260 m across ridges. The mean distance for traffic light penetration from the Epsom-Barnadown Road into the Bendigo Regional Park was 380 m, creating an effect zone of 0.76 km2 per km of road.

It should be noted that 55 percent of the time, dense vegetation defined the outer boundary or effect zone for both traffic noise and light. Randomly placed clumps of Whirrakee Wattle *Acacia williamsonii* and Totem Pole *Melaleuca decussate* reduced noise by 5 dB and screened out vehicle light penetration.

Mammal Surveys

The presence and abundance of arboreal and diurnal mammals was surveyed along three transects in the Bendigo Regional Park using a combination of spotlighting and search surveys. Each transect was traversed six times between 1900 and 2300 hours, and entailed walking each 1,000-m transect checking the ground, bole, branches, and canopy of the trees on a 50-m front ahead of the surveyor (Soderquist and MacNally 2000). Eyeshine from species was detected in the spotlight beam, and the substrate used by the species was recorded. Along each transect, 20 1-m^2 quadrats were searched for presence of fauna. These quadrats were cited every five meters for the first 50 m from the road and then one every 100 m thereafter. Mammal tracks, scats, diggings (eg., Echidna *Tachyglossus aculeatus*), and hair, skull, and bone fragments were sought, and identified with the help of Triggs (2004). Within each 100-m x 50-m cell of the three transects, the bases of three trees were searched for the presence of species. Trees were chosen if they contained hollows or were simply the three largest trees in each cell. Whilst conducting field work, incidental observations involving the occurrence of diurnal fauna were recorded, along with their position in relation to the Epsom-Barnadown Road.

Table 1 details species richness and distribution of mammals in relation to distance from the Epsom-Barnadown Road, synthesized for the three transects. Eighteen hours of spotlighting and incidental observations resulted in a total of 12 individual sightings of four mammal species. Three of the four mammals observed were arboreal: the Sugar Glider *Petaurus breviceps*, Common Ringtail Possum *Pseudocheirus peregrinus*, Common Brushtail Possum *Trichosurus vulpecular,* and the fourth was the introduced Red Fox *Vulpes vulpes* (table 1). Search surveys detected six additional species: the Eastern Grey Kangaroo *Macropus giganteus*, Swamp Wallaby *Wallabia bicolor,* Echidna *Tachyglossus aculeatus*, the introduced European Rabbit *Oryctolagus cuniculus*, the introduced Hare *Lepus capensis*, and an unknown bat species.

Table 1. Mammals present in the Bendigo Regional Park at varying distances from the Epsom – Barnadown Road

		1	5	10	15	20	25	30	35	40	45	50	100 to 200	200 to 300	300 to 400	400 to 500	500 to 600	600 to 700	700 to 800	800 to 900	900 to 1000
Macropus giganteus	Eastern Grey Kangaroo			#			#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Wallabia bicolor	Swamp Wallaby						#	#		#			#		#	#	#	#	#	#	#
Tachyglossus aculeatus	Echidna						#							#	#	#	#	#	#	#	#
Oryctolagus cuniculus	*Rabbit						#							#	#	#	#				#
Pseudocheirus peregrinus	Common Ringtail Possum											#			#					#	#
Trichosurus vulpecula	Common Brushtail Possum												#	#			#	#		#	#
Petaurus breviceps	Sugar Glider															#	#		#		#
Lepus capensis	*Hare															#					#
Vulpes Vulpes	*Fox															#					
Unknown species	Bat															#					
	Total number of species			1			4	2	1	2	1	2	3	4	5	8	6	4	4	4	8

Notes: * indicates introduced species

The data in table 1 suggest a positive relationship between mammal presence and distance from the Epsom-Barnadown Road. Maximum species richness was attained between 400 and 500 m from the Road. Figure 4 presents mammal species richness (with data for the first 100 m cumulated) plotted in relation to noise and light penetration. There was an increase in species richness after traffic light penetration ceased and traffic noise reached ambient levels of 40dB. That the Common Brushtail Possum *Trichosurus vulpecula* and Common Ringtail Possum *Pseudocheirus peregrinus* were found throughout the transects is not surprising, as these species are commonly found in disturbed environments (Menkhorst 1995). The distribution of arboreal mammals is strongly associated with the distribution of tree hollows (Trail 1991), with distance from the road being a lesser factor. The Sugar Glider *Petaurus breviceps* and the unknown bat species may be regarded as interior species that avoid the road traffic zone.

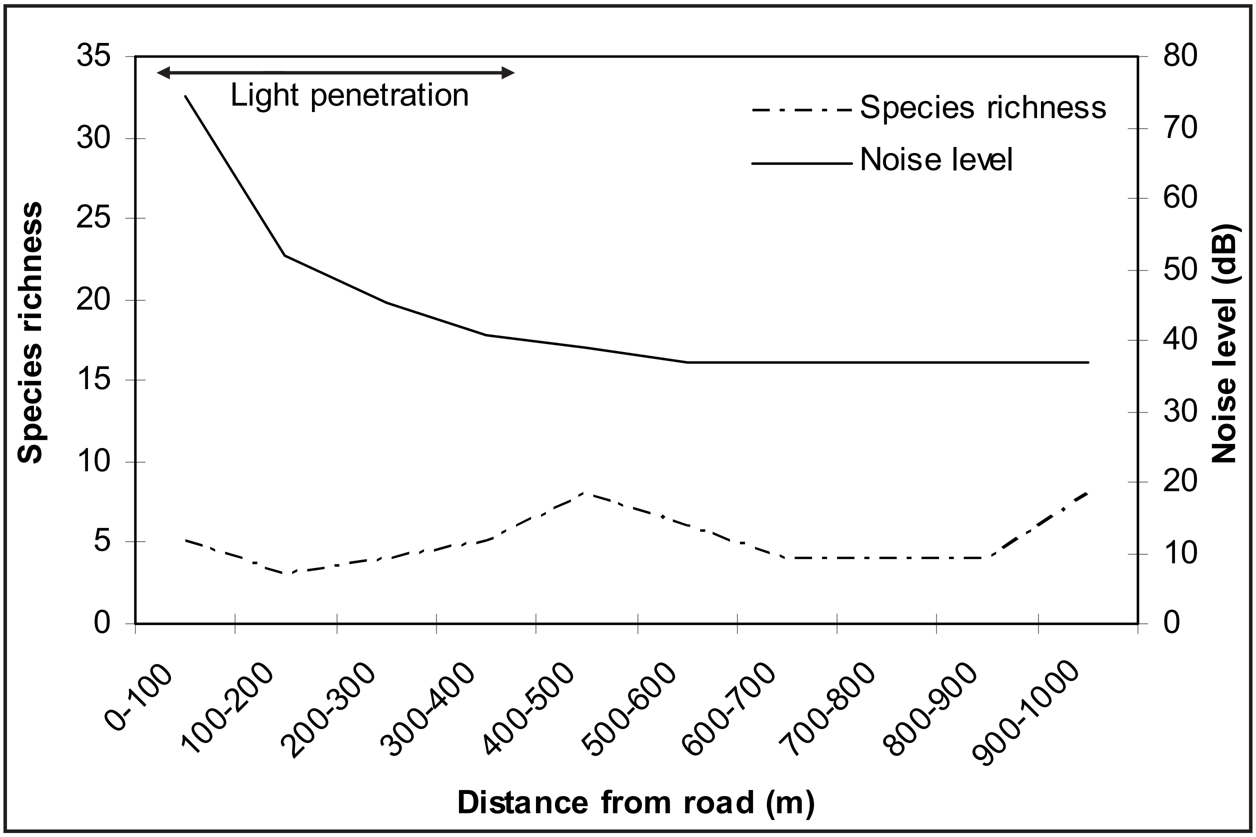

Figure 4. Mammal species richness relative to noise level and light penetration synthesized for three transects in the Bendigo Regional Park

It is noted that two species known to inhabit the research area, the Yellow-footed Antechinus *Antechinus flavipes* and the highly mobile Brush-tailed Phascogale *Phascogale tapoatafa* (Robinson & Rowley 1996) were not recorded in this study. It is possible that such cryptic mammal species may also demonstrate a strong aversion to the road-effect zone, as these species have been found to show a strong preference for large intact forest blocks (Deacon and MacNally 1998).

Bird Surveys

Birds were surveyed along three 1,000-m transects by walking at a pace of 100 m every six minutes and recording species type, relative abundance, and the forest zone used. Only birds seen or heard ahead of the observer and 25 m on either side of the transect line were recorded. Each transect was surveyed six times, equalling a total of 18 person hours of observation. The field guide by Simpson and Day (2000) aided bird identification. Surveys were only conducted during fine weather, between 0800 and 1230, as birds call most frequently in the mornings, and this is when feeding is most obvious (Keast 1984). To avoid bias, the order in which transects were surveyed was randomized. The direction in which the transects were walked was also alternated to avoid the potential problem of continual observer movement pushing birds away from the edge (Luck et al. 1999) or attracting or repulsing different species (Pyke and Recher 1984).

A list of species type and their diversity and abundance synthesized for the three transects is presented in table 2. Species present were typical of those normally inhabiting Box-Ironbark forests. Eighteen hours of surveying resulted in a total of 975 individual sightings of 47 species recorded within the study area. Eleven species were recorded only once.

Table 2. Bird species diversity and abundance in the Bendigo Regional Park at varying distances from the Epsom – Barnadown Road

			0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450	450-500	500-550	550-600	600-650	650-700	700-750	750-800	800-850	850-900	900-950	950-1000
Ocyphaps lophotes	Crested Pigeon	†	1																			
Manorina melanocephala	Noisy Miner		2																			
Corvus coronoides	Australian Raven		3	2							1			1	1		1		1			
Anthochaera carunculate	Red Wattle Bird		12	4	4	2	1	2	7	2	5	4	5	8	4		1		5	3		2
Acanthiza nana	Yellow Thornbill		16	8	14	10	9	1	4	4		4	19				3	3			3	
Gymnorhina tibicen	Australian Magpie	†		1																		
Malurus cyaneus	Superb Fairy-wren			2	8	2	5	17	13	4			4	1	3	4						
Eolophus roseicapillus	Galah			3	2					2	3	1	5	4	3	1	6	1	2	3	3	1
Smicrornis brevirostris	Weebill			7		5	2	3	14			2	10			7		5	2	6		3
Psephotus haematonotus	Red-rumped Parrot			14	5								6									
Corcorax melanorhamphos	White-winged Chough				9						5		10	18			10					
Lichenostomus leucotis	White-eared Honeyeater	§				3	1	4	4	4			1		1	4		3				
Melithreptus brevirostris	Brown-headed Honeyeater	§					1		8	10	6	2			1	2	1	10	4			8
Rhipidura fuliginosa	Grey Fantail	§					1															2
Pardalotus punctatus	Spotted Pardalote	§					1	1							2			1				1
Lichenostomus melanops	Yellow-tufted Honeyeater	§					3	7					2	2	11		7	4	6	6	5	8
Pachycephala pectoralis	Golden Whistler	§						1		2				1		1		1				
Cacomantis flabelliformis	Fan-tailed Cuckoo	§						1	1													
Colluricincla harmonica	Grey Shrike-thrush							2		2			1		1		3		1			
Glossopsitta concinna	Musk Lorikeet							2	12										8			
Zosterops lateralis	Silvereye	§						4					1									
Lichenostomus fuscus	Fuscous Honeyeater							6	12	22	11	8	3				1	4	11	13	6	4
Lichenostomus penicillatus	White-plumed Honeyeater							8	4		10		3		11		8		2	4		15
Melithreptus lunatus	White-naped Honeyeater	§						6	6						5		2					2
Microeca leucophaea	Jacky Winter	§							2	1									2			
Pardalotus striatus	Striated Pardalote								3					1	3	1		2		1		15
Pomatostomus superciliosus	White-browed Babbler	§								10	4			10	6			20	5	2		
Falcunculus frontatus	Crested Shrike-tit	†									1											
Podargus strigoides	Tawny Frogmouth	†									1											
Cormobates leucophaeus	White-throated Treecreeper	§										2	3					2				1
Daphoenositta chrysoptera	Varied Sittella	§										4			3				4			
Ninox connivens	Barking Owl	†											1									
Eopsaltria australis	Eastern Yellow Robin	§											10									
Strepera versicolor	Grey Currawong	†												1								
Phaps chalcoptera	Common Bronzewing	†													1							
Petroica multicolour	Scarlet Robin	†													1							
Platycercus eximius	Eastern Rosella														2	4	1					
Acanthiza reguloides	Buff-rumped Thornbill	†														1						
Oreoica gutturalis	Crested Bellbird	§															1					4
Climacteris picumnus	Brown Treecreeper	§															2	2				1
Coracina novaehollandiae	Black-faced Cuckoo Shrike	§															3					
Artamus cyanopterus	Dusky Woodswallow	§															4		1	2		
Oriolus sagittatus	Olive-backed Oriole	§																1				1
Pachycephala rufiventris	Rufous Whistler	†																	1			
Melithreptus gularis	Black-chinned Honeyeater	§																		4		
Accipiter fasciatus	Brown Goshawk	†																			1	
Lichenostomus chrysops	Yellow-faced Honeyeater	§																			2	5
Total number of individuals			34	41	42	22	24	65	90	63	47	27	84	47	59	25	54	59	55	44	20	73
Total number of species			5	8	6	5	9	15	13	11	10	8	16	10	17	9	16	14	14	10	6	16

Notes: § indicates species classified as interior species; † indicates species sighted only once.

Species abundance was not found to change by either increasing or decreasing with distance from the road. However, for select bird species, the Epsom-Barnadown Road either provided desirable habitat or was a feature to be avoided. Four species were only ever encountered within the first 150 m from the road verge, and only one of those was observed on more than one occasion: the Noisy Miner *Manorina melanocephala* and Red-rumped Parrot *Psephotus haematonotus*. These species are known to tolerate open country habitat (Tzaros 2005). The Noisy Miner has been found to greatly benefit from native forest fragmentation and favors isolated tree patches or fragment edge habitats (Grey et al. 1998).

Species diversity was found to increase away from the road (figure 5). Excluding those species sighted only once (which were too infrequent for meaningful comment), 21 species (58%) were only found at distances of 150 m or more from the Epsom-Barnadown Road. These species have been classified as “interior species” as they demonstrate a distinct avoidance of edge habitat (table 2). Some of these species were observed to avoid vegetation communities next to the road, while inhabiting those same vegetation communities at greater distances away from the road. The average distance avoided by interior species varied according to the species studied and ranged from 150-900 m.

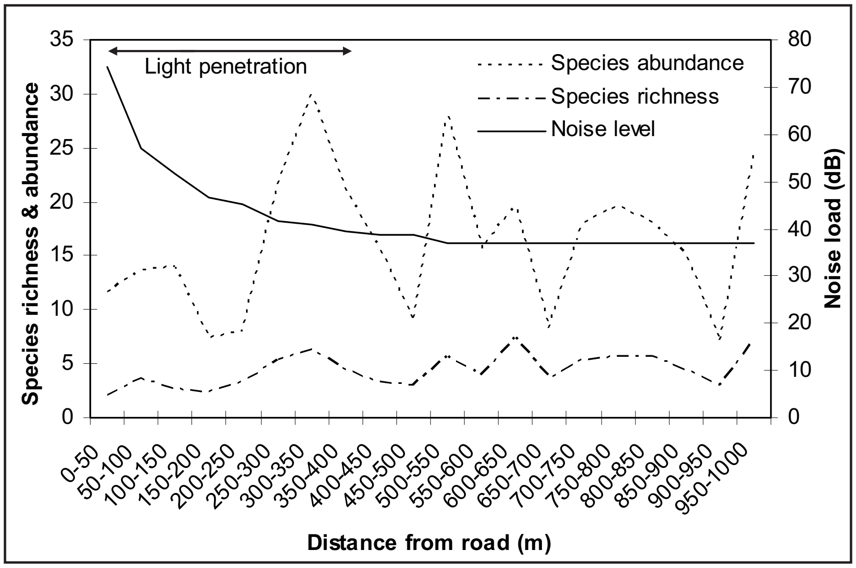

Figure 5. Bird species richness and abundance relative to noise level and light penetration synthesized for three transects in the Bendigo Regional Park

Spatial Patterns of Road Edge Effect

Figure 6 synthesizes the results obtained from this study by mapping the boundaries of the road-effect zone in the Bendigo Regional Park. The area affected by exotic plant invasion associated with the presence of a road is shown to be minimal. The asymmetric nature of traffic noise and light penetration is clearly seen, being dependent primarily on topography and the spatial arrangement of thicket vegetation across the landscape. Specific mammal sightings and zones of habitat are also shown in figure 6. The fact that most mammals were sighted away from the zones of traffic noise and light penetration is evident.

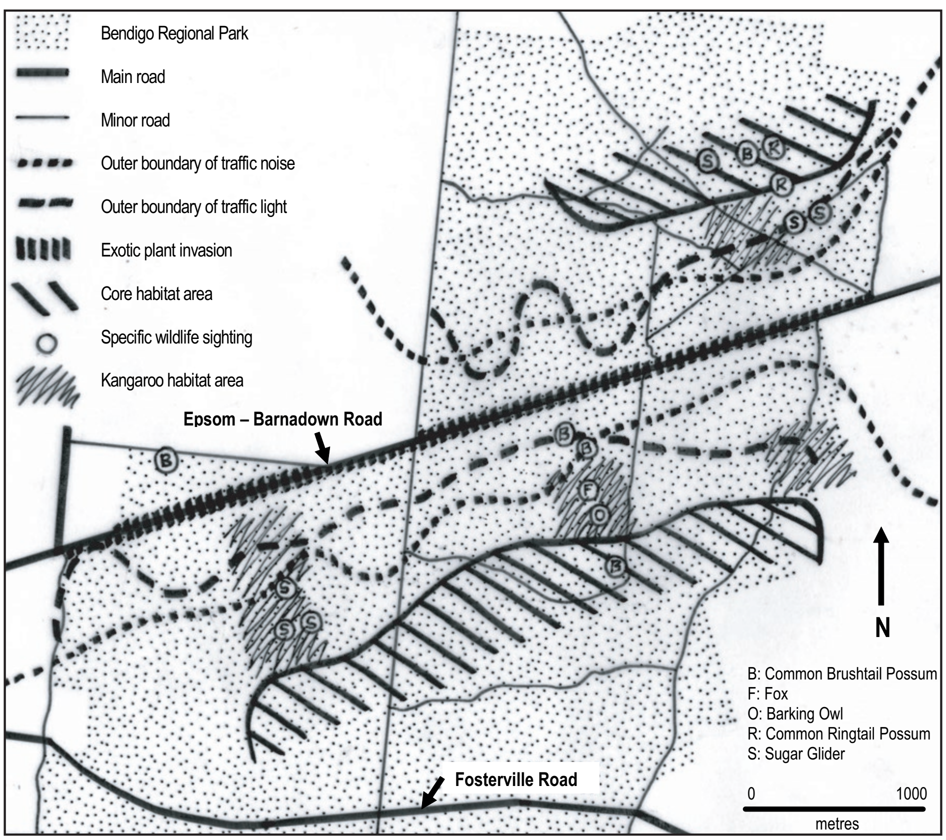

Figure 6. Spatial distribution of parameters contributing to the road effect zone within the Bendigo Regional Park

Also depicted in figure 6 is a zone identified as core habitat area. This zone has been identified as the core area occupied by fauna such as interior bird species. There were 21 species listed in table 2 that demonstrated an aversion to the road-effect zone and were denoted as interior species. The width of the bird aversion zone varied from 150-900 meters. Particularly sensitive species, such as the Crested Bellbird *Oreoica gutturalis*, Dusky Woodswallow *Artamus cyanopterus*, and Brown Treecreeper *Climacteris picumnus*, exhibited a 700-m avoidance zone. Likewise, the avoidance zone for the Olive-Backed Oriole *Oriolus sagittatus* was 750 m, the Black-chinned Honeyeater *Melithreptus gularis* was 850 m, and the Yellow-faced Honeyeater *Lichenostomus chrysops* was 900 m. The maximum distance significant ecological effects extended outward from the Epsom-Barnadown Road coincides with the core habitat area demonstrated in figure 6.

Thus the width of the road-effect zone on Box-Ironbark Forest requiring management for conservation averaged 900 m on either side of the Epsom-Barnadown Road. This amounts to a total width of 1800 m or an area of 1.8 km^2 per kilometre of highway. The implications of this finding have serious ramifications for road management authorities. Traditionally, road engineers have identified the boundary of the road-effect zone as the sum of the road surface and the adjacent road verge. The findings in this study demonstrate the ecological extent of the road-effect zone to be an order of magnitude greater than traditional reckoning.

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How Many Days to Monitor a Wildlife Passage? Species Detection Patterns and the Estimation of the Vertebrate Fauna Using Crossing Structures at a Motorway

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Abstract: The barrier effect imposed by roads and railways on vertebrate populations has aroused both scientific and social concern and has led to the construction of crossing structures for such fauna in new infrastructures. Good practice demands that investment in such mitigation measures should be followed by systematic monitoring of their effectiveness, in order to improve the design of further works. These monitoring schemes need standardized protocols in order to deliver scientifically sound results at an affordable cost. In this context, the present contribution analyzes the suitability of monitoring schemes aimed at determining which vertebrate species use crossing structures in relation to the number of days spent monitoring each crossing structure. The analysis considers data on vertebrates using 22 structures crossing a motorway in northwest Spain, which were monitored for 15-26 consecutive days. Species accumulation curves were fitted by non-linear estimation procedures to the species accumulation pattern detected at each crossing structure in order to estimate the asymptotic number of species using each one of them. Modelling was carried out using 11 functions applied in ecological studies to analyze species accumulation curves in relation to sampling intensity. The results show that species accumulation curves for crossing structures have a rapid increase phase followed by a long tail of slow accumulation. Thus, 25 or more monitoring days may be needed to detect over 80 percent of the species using a crossing structure, but 60 percent of them are detected by day 10, and 70 percent, by day 16. The statistical fit obtained for different function types allows the Clench model to be recommended for evaluating the results obtained in monitoring programs intended to determine the number of species using each crossing structure. This model yielded the highest mean explanatory power (mean r^2=0.905) using only two parameters; it provided neither a systematic overestimate nor an underestimate of richness, and offered a low degree of uncertainty (2.3% non-significant parameters). In short, 10 to 15 days of monitoring may be enough to provide a basic knowledge of the animal species using crossing structures at a particular time, although the monitoring period could be somewhat shorter or longer according to the requirements of particular cases.

Introduction

Scientific and social concern about the barrier effect imposed by roads and railways on vertebrate populations has led to the construction of crossing structures for fauna in new infrastructures. Economic development is accompanied by increases in the kilometerage of motorways and railway lines, and a corresponding decline in the extent of land patches free from such infrastructures (Forman and Alexander, 1998). This process affects fauna in numerous ways (Robinson et al. 1992), but especially by making it difficult or impossible for animals to move freely (Oxley 1974, Mader 1984, Swihart and Slade 1984, Goosem 2001). Hence, crossing structures, such as overpasses, bridges, and culverts, are being increasingly incorporated into road and railway construction to facilitate faunal movement (Saunders et al. 1991, Clergeau 1993, Rodrígez et al. 1996, Kéller and Pfister 1997, Rosell et al. 1997, McGuire and Morrall 2000). Although the number, complexity, and cost of such structures are rising rapidly, studies of their effectiveness have lagged behind their installation.

Good practice requires that investment in mitigation measures should be followed by a systematic monitoring of their effectiveness. Such reviews will not only assist in their management, but will also optimize any future expenditure on improvements (Forman et al. 2003, Iuell et al. 2003). At present, information on the use of crossings by fauna is somewhat fragmentary and derives from intensive scientific research carried out in relatively few places, most of them in North America (see review in Forman et al. 2003). A notable gap in knowledge of the effectiveness of crossings would be filled should routine monitoring schemes by transport agencies become generalized. Ideally, monitoring should evaluate different types of crossing structures and should cover the whole vertebrate community, with a view to discovering to what extent such constructions are used by fauna (Yanes et al. 1995, Ng et al. 2004, Mata et al. 2005). Moreover, monitoring schemes need standardized protocols in order to deliver scientifically sound results at an affordable cost.

One of the key aspects of monitoring protocols for faunal crossing structures is the length of the monitoring period at each structure, which reflects directly on the survey costs and on the utility of the resulting data. So far, a range of different monitoring periods have been employed, most often involving monitoring each structure for 10-20 consecutive days (Rodríguez et al. 1996, Brudin 2003, Mata et al. 2005). Nevertheless, the significance of the duration of such surveys has not previously been evaluated.

In theory, monitoring periods should be the minimum required to obtain the most complete picture possible of the process under study. As a first step, it is necessary to discover which species use the crossings over a particular period, e.g., a season or a year. Such data allow the detection of species which do not use the crossings and, hence, whose populations on either side of the route have become separated. It is also possible to see whether any species found as road-kills shy away from the dedicated crossing structures but cross the carriageway routinely instead. This assessment of crossings, based on the entire vertebrate community, clearly differs from those concerned with particular target species(Singer and Doherty 1985, Foster and Humphrey 1995, Gloyne and Clevenger 2001, Cain et al. 2003), but complements studies of the long-term adaptation of fauna to new infrastructures (Clevenger and Waltho 2005).

The problem of whether our monitoring program is representative of the species using the crossings is a recurrent theme in ecological studies, the relationship between the number of species observed as a function of the sampling effort expended. The problems and usefulness of species accumulation curves have been analyzed repeatedly and have occasionally provoked controversy (Gotelli and Colwell 2001, Gray et al. 2004). The main consideration here is that they may be the only way of estimating a variable that cannot be measured: the species richness that would be detected by an infinitely large sampling. Such an estimate requires a mathematical model, and here another difficulty of species accumulation curves arises: different models tend to produce slightly different results (Flather 1996, Thompson et al. 2003).

The present study has the following objectives: firstly, (1) to analyze the patterns of accumulation of observations of vertebrate species using faunal crossings, to evaluate the representativeness of the data obtained as a function of the sampling period. Also, (2) to establish the capacity for mathematical modelling of the observations obtained by applying functions that permit the modelling of such species accumulation. Finally, (3) to derive recommendations for protocols for monitoring of faunal crossings, relating both to the use of mathematical models and to the duration of the study periods required.

Methods

Data collection

The data on use of faunal crossings by animals were collected during summer 2002 on the Benavente-Puebla de Sanabria sector of the A-52 motorway (Zamora Province, NW Spain, fig. 1). This is a fenced dual carriageway, with average traffic levels of 6,000 vehicles/day. A set of 22 crossing structures between kilometer posts 19.5 and 63.5 were selected for monitoring. They comprised six circular culverts, three wildlife-adapted (box) culverts, four open span underpasses, three wildlife underpasses, four overpasses, and two wildlife overpasses (Mata et al. 2005).

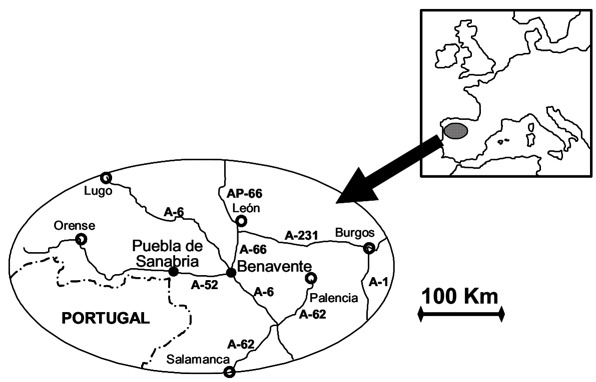

Figure 1. Location of the study area (A-52 between Puebla de Sanabria and Benavente) in relation to main roads in Northwest Spain.

The use of crossing structures by vertebrates was analyzed by daily track monitoring. Records were obtained using marble dust, a scentless material which produces imprint tracks of high quality and persistence given its high density (Yanes et al. 1995). A band 1-m wide and 3- to 10-mm deep of the marble dust was installed halfway across each selected crossing structure (Mata et al. 2005). The animal species using each crossing were identified and recorded daily, although only data from days in which the meteorological conditions allowed correct imprinting were used. Monitoring lasted until a minimum of 15 valid recording days were obtained for each crossing structure, but the dataset includes structures monitored for up to 26 days (fig. 2).

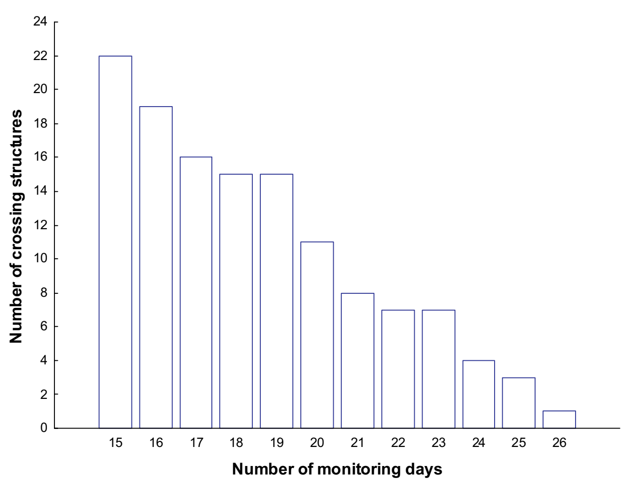

Figure 2. Length of monitoring period of crossing structures used in the present study.

Track identification followed Strachan (1995), Sanz (1996), Bang and Dahlström (1995), and Blanco (1998), and was taken to species level whenever possible. However, apart from those species identified specifically, the following groupings were recorded: anurans (all frogs and toads), lacertids, ophidians (including legless lacertids), small mammals (mice, voles, and shrews), water voles (*Arvicola sapidus* and *A. terrestris*), rats (*Rattus rattus* and *R. norvegicus*), lagomorphs (*Oryctolagus cuniculus* and *Lepus granatensis*), small mustelids (*Mustela nivalis* and *M. erminea*), cats (*Felis catus* and *F. silvestris*), and large canids (*Canis familiaris* and *C. lupus*). For simplicity, the text refers to "species" both for species-proper and for groups producing similar tracks.

Data analysis

The first step of the analysis aimed to test whether the use of each crossing structure by vertebrates was uniform throughout its monitoring period or whether there was any kind of temporal aversion to its use after the marble dust was laid. Hence, an ANCOVA test was carried out with the number of species as a dependent variable, the crossing structure as a fixed factor, and the day as a covariate. Due to the potential non-linear nature of the monitoring day effect, the ANCOVA test was repeated after the log-transformation of the covariate day. A significant covariate with a positive beta parameter value in any of these analyses would mean that fewer animal species used the crossing structure during the initial days following the start of monitoring.

The second level of analysis focused on species accumulation patterns. Thus, the raw data of species using each crossing structure each day were transformed into daily values of accumulated number of species for each structure. These data were then used to fit models of species accumulation curves for each crossing structure. Model fit was carried out through nonlinear estimation methods with Statistica 6.1 (StatSoft, Inc. 2002). The Levenberg-Marquardt estimation method and default settings of the program were set for the analysis. In cases where Statistica was unable to find a solution, a new trial was carried out using the parameters fitted by ModelMaker 3.0 (Walker and Crout 1997) as start values.

In total, 11 species accumulation functions were fitted to the data from each crossing structure. The functions employed represent the spread of those used to a greater or lesser extent in investigations relating ecological problems involving species accumulation to sampling effort (Thompson et al. 2003). Those used include functions with two, three, or four parameters, and there are equations that present one asymptote and others that are infinitely increasing (table 1).

Table 1. Species accumulation functions used in the present study in relation to sampling effort (t =number of monitoring days)

Model name	Mathematical expression	Asymptote
- Two parameters (a, b)		
Clench	$y = (a * t) / (1 + (b*t))$	a / b
Negative exponential	$y = a * (1 – \exp(-b * t))$	a
Exponential	$y = a + (b * \log(t))$	None
Power	$y = a * t^b$	None
B-Logaritmic	$y = \log(1 + (a * b * t)) / b$	None
- Three parameters (a, b, c)		
Asymptote	$y = a – (b * c^t)$	a
Chapman-Richards	$y = a * ((1 – \exp(-b * t))^c)$	a
Rational	$y = (a + b * t) / (1 + c * t)$	b / c
Hill	$y = (a * b * t^c) / (1 + b^c)$	None
- Four parameters (a, b, c, d)		
Beta-P	$y = a * (1 – (1 + (t / c)^d)^{-b})$	a
Weibull	$y = a * (1 – \exp(-(b * (t – c))^d))$	a

After fitting the functions, the asymptotic value of the number of species present at each crossing point could be deduced according to the different models. The number of species predicted to occur after 100 monitoring days was calculated for those functions that did not generate an asymptote (table 1). The choice of 100 days was arbitrary but represented a period thought long enough (longer than a full astronomical season) to derive the maximum expected species number at a crossing point. It is also clearly longer than would be possible during routine monitoring programs.

A number of complementary criteria were used when evaluating the suitability of the different species accumulation functions, relating to goodness of fit, the predictions made, and the type of function used. With respect to data adjustment consideration was given to (1) the number of cases in which the data could not be fitted because the statistical software was unable to find a correct solution, (2) the variance absorbed (r^2) by the adjusted function, (3) the percentage of significant parameters, as a measure of the reliability of the predicted values, and (4) the number of cases in which each function proved to be the most mathematically appropriate. This last analysis was done by comparing the Bayesian Information Criterion values of the different functions (Quinn and Keough 2002).

Two additional criteria were employed in relation to the predictions of the maximum number of species using a crossing. Predictions that were greater than the number of species known to be present in the study area, according to national distribution atlases (Palomo and Gisbert 2002, Pleguezuelos et al. 2002), were rejected as erroneous. The mean number of species predicted by each function was also evaluated with a view to detecting any systematic biases towards over- or under-estimation of species richness (Thompson et al. 2003).

Once the group of functions that best represented species accumulation at the crossings had been identified, the data for each crossing structure were transformed into percentages relating to the predictions of asymptotic (or 100-day) species richness at that crossing. Thus, the observations from the different crossing points were recalibrated to fit a curve showing percentage of observed species as a function of the number of monitoring days. This function is taken as the mean pattern of species accumulation at the wildlife crossing structures, for the purposes of the discussion.

Results

The study detected 20 species, with a daily mean (±SE) of 1.39±0.05 species/crossing structure. The number of species using the crossing structures daily varied significantly between crossings (see ANCOVA test in table 2), ranging from 0.52-2.26 species/day. Nevertheless, the number of species using each crossing did not vary significantly during the study period (table 2), despite a slight increase in this number as the study proceeded (*beta*=0.025±0.017). This same result was revealed by the logarithmic transformation of the day covariate (Covariate ln (day), F=0.929, p=0.346).

Table 2. Results of the ANCOVA used to control for the effects of the “day of monitoring” covariate and the “crossing structure” factor on the variable number of species detected at a crossing structure.

	MS	d.f.	F	p
Day of monitoring	9.799	1	2.248	0.149
Crossing structure	4.360	21	5.626	<0.001
Error	0.775	413		

By the end of the study period, a mean of 5.59±0.34 species per crossing had been detected, with a range of 3-8 species. Although most new species at each crossing were detected during the first 10-12 days of study, some new species continued to appear later (figure 3). Indeed a new species was detected on the last day of study at the only crossing point monitored for 26 days.

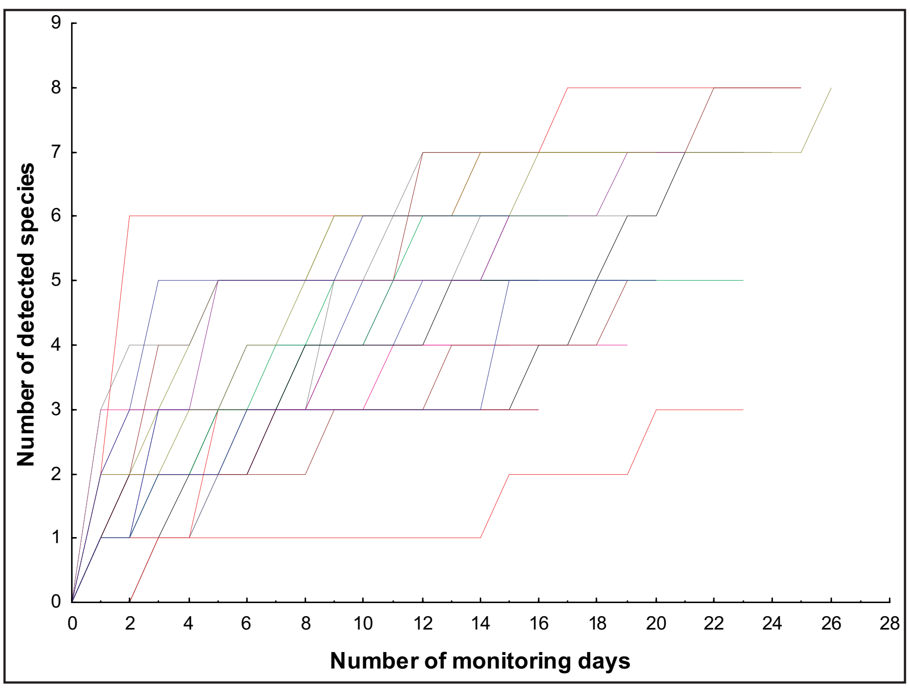

Figure 3. Raw data of species accumulation in crossing structures along the monitoring period. Note that steep lines represent the detection of new species.

The mathematic modelling was generally feasible, and the data fits obtained may be considered good, although the various models differed in performance (table 3). All functions employed produced high explicative values, these being generally higher among models with more parameters (average r^2 of 0.893, 0.908 and 0.930 for two-, three- and four-parameter models, respectively). The fit obtained was highly significant (p<<0.001) in all cases where the statistical program generated a mathematical solution.

Nevertheless, overparametrisation problems arose with some frequency when fitting models with three and, especially, four parameters (table 3). Thus the statistical program did not find an appropriate solution in 41 percent of cases with the Weibull model and in 27 percent with the Beta-P model (the two models using four parameters). Similarly, the three-parameter Chapman-Richards model could not be fitted in two cases (9%). In contrast, a mathematical solution was possible with all two-parameter functions. Overparametrisation is also reflected in that the highest percentages of significant parameters correspond to two-parameter models (four out of five model families with more than 90 percent significative parameters), this feature declining with more complex models.

Table 3. Results of fitting species accumulation functions to data from the A-52 motorway

Model name	no solution	r^2 (mean±SD)	r^2 (min)	unreal prediction	Best fit	% significant parameters	expected richness
- Two parameters)							
Clench	0	0.905±0.054	0.782	2	3	97.7	8.63
Negative exponential	0	0.897±0.065	0.761	2	4	90.9	6.30
Exponential	0	0.860±0.076	0.688	0	0	72.7	8.69
Power	0	0.898±0.054	0.768	0	8	100.0	13.01
B-Logaritmic	0	0.905±0.053	0.799	2	1	90.9	9.57
- Three parameters							
Asymptote	0	0.905±0.058	0.762	3	0	87.9	6.88
Chapman-Richards	2	0.916±0.055	0.768	9	0	56.7	9.50
Rational	0	0.912±0.045	0.829	3	2	59.1	9.55
Hill	0	0.898±0.054	0.768	0	0	77.3	13.01
- Four parameters							
Beta-P	9	0.937±0.042	0.849	4	2	40.4	8.16
Weibull	6	0.924±0.051	0.817	3	2	82.8	7.77

Apart from the problem of a lack of mathematical solutions when fitting certain species accumulation functions, unreal predictions were generated in some instances (table 3). The maximum number of potentially detectable vertebrate species (including taxonomic groups) in the study area was 26, a figure exceeded by eight of the 11 models used. Only the Exponential, Power, and Hill models did not produce this type of error in predictions, although the predictions used for these three models corresponded to the species totals expected at day 100, since they do not have asymptotes (table 1). The models most frequently generating unreal predictions were the Chapman-Richards (9 out of 20 cases) and Beta-P models (4 out of 13 cases).

The models which proved most often appropriate on the basis of mathematical fit (table 3) were the Power (8 cases), the Negative exponential (4), and the Clench (3) models. Considering all the crossing points, two-parameter models were best in 16 cases, three-parameter ones in two cases, and four-parameter models in four cases.

Finally, the different models generate a relatively broad spread of predictions of the numbers of different species using the crossings. The mean numbers predicted (table 3) varied from the 6.30 and 6.88 species generated by the Negative exponential and Asymptote models to the 13.01 species from the Power and Hill models.

On the basis of these results (see Discussion), the fit provided by the Clench function was chosen for further analyses. Once the species accumulation data had been converted to percentages of the asymptotic values, a function was fitted to the data substituting parameter b by the expression $a/100$. This simplification was possible since, by definition, the asymptotic value of the function is 100 percent, and the asymptote of the Clench model is a/b (see table 1).

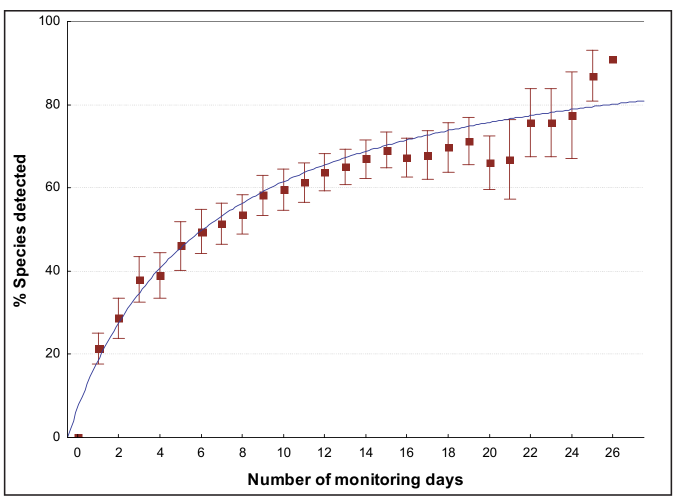

Figure 4. Average pattern of species accumulation in crossing structures in relation to the asymptotic number of species using each one. Points show mean±SE of percentage species detected, and the line represents the Clench model fitted to the whole dataset.

The resulting function (figure 4) is highly significant (F=141.8; 19 d.f.; p<<0.001) and has a value for parameter a±SE of 15.20±0.73. The figure shows that after 25 monitoring days only 20 percent of the species predicted to use a particular crossing would remain to be detected. According to the model, 10 monitoring days are needed to detect 60 percent of the species using a crossing, and 16 days to detect 70 percent of them.

Discussion

This study shows the pattern of vertebrate species accumulation at the crossing structures of a motorway and the procedure for synthesizing such observations mathematically. Furthermore, the results enable recommendations to be made regarding monitoring protocols for such mitigation measures.

The findings show that detecting all the species which use a faunal crossing is a lengthy and uncertain process. In the present study new species were often detected until the final monitoring day, even after 25 days of observation. Undoubtedly more species would have been detected had the study continued for longer. Most studies on faunal use of a broad range of crossing structures have sampled 10-20 days (Rodríguez et al. 1996, Brudin 2003, Mata et al. 2005), although occasionally fewer (Taylor and Goldingay 2003) and sometimes less than a week (Hunt et al. 1987, Yanes et al. 1995, Ng et al. 2004). Longer studies are unusual and tend to concentrate on a small number of species or on particular crossing structures (Reed et al. 1975, Jackson and Tyning 1989, Foster and Humphrey 1995, Mathiasen and Madsen 2000), or have formed part of extensive investigations into roads and fauna (Clevenger and Waltho 2000, Clevenger et al. 2001).

In any event, the representability of the sampling period must be borne in mind when analyzing and discussing the data obtained. Most studies do not evaluate the potential effects of sampling period duration or sidestep the problem by grouping all the data into one large sample (Clevenger et al. 2001, Ng et al. 2004). In the former case, short sampling periods may underestimate the usage of faunal crossings and may complicate inter-sample comparisons as a result of the random variation between small samples. This problem is more significant if, in addition, the sampling period differs between samples (Rodríguez et al. 1996). Grouping data from different sampling projects avoids these concerns, given that the total sampling period is then quite long, but such a procedure prevents the analysis of the seasonal use of faunal crossings.

Thus, a proper choice of study period permits the optimizing of the amount of work done in relation to the value of the results obtained. The ideal situation is to adjust the study period for each faunal crossing so that the results are directly representative of the animals using the crossing during the season sampled. This permits between-season comparisons (Rodríguez et al. 1996, Mata et al. unpublished data) and the evaluation of long-term changes in the use of the crossings (Clevenger and Whalto 2005).

Mathematical approximations, by means of species accumulation models, may play an outstanding part in deciding how long monitoring periods should be. On the one hand, models extend variables beyond the sample limits (Gotelli and Colwell 2001, Wainwright and Mulligan 2004), in this case to estimate the number of species missed due to the brevity of the sampling period. Although such approximations do not allow the missing species to be known, they do permit the reliability of the data obtained to be evaluated. In addition, the models allow generalizations to be made from sample series which show some degree of variability (Quinn and Keough 2002). Nevertheless, the application of mathematical models to natural processes requires caution to avoid generating mathematically-sound predictions which are unreal from a biological viewpoint (Peters 1991). This applies here in the cases of models which predicted the use of crossing structures by more species than are actually present in the area.

The results support using the Clench species accumulation model to analyze observations of vertebrates using road crossings. The simplicity of the species accumulation pattern detected and the use of short datasets make it unnecessary and even counter-productive to use models based on more than two parameters, which are frequently adequate for large data sets (Flather 1996, Thompson et al. 2003). This aside, two-parameter models enable the use of general purpose statistical software (e.g., Statistica, SPSS) in future applications; whereas, solving more complex models often demands the use of specific modelling programs. Among the two-parameter functions, the Clench model achieved the highest value of r^2 and the second highest percentage of significant parameters. In addition, it has the advantage of having an asymptote, a feature shared only with the Negative exponential model among the two-parameter functions. This characteristic avoids the need to use an arbitrary sampling period (100 days in this study) to estimate the number of species potentially using a faunal crossing. Finally, the Clench model gives intermediate estimates within the range generated by all the models, distinct from the over- and under-predictions of the Power and Negative exponential models, respectively (see also Thompson et al. 2003).

Applied implications

The results obtained generate recommendations applicable to monitoring programs at faunal crossing structures, although certain considerations must be taken into account. Firstly, the results were obtained from data collected in one area in a single season. Similar studies elsewhere are desirable to confirm the general validity of the conclusions. There could be seasonal differences in the usage patterns of faunal crossings, although these seem to be fairly uniform throughout the year, at least in Mediterranean landscapes (Rodríguez et al. 1996, Mata et al. unpublished data). In addition, differences may arise associated with the faunal richness of the areas surrounding the crossing structures, in a manner analogous to those encountered in applications of species accumulation curves to other sampling problems (Flather 1996, Gray et al. 2004). Finally, it is necessary to emphasise that the suggestions made are aimed at routine monitoring programs intended to evaluate the use of crossing points by vertebrates. In comparison with these, studies aimed at specific species have radically different characteristics (Singer and Doherty 1985, Foster and Humphrey 1995, Gloyne and Clevenger 2001, Cain et al. 2003).

The present study draws two basic conclusions in relation to the establishment of monitoring protocols for faunal crossing points. Firstly, the species accumulation curves obtained should be examined to evaluate the extent to which the monitoring program has detected the majority of the species using the crossings, to see whether the study period needs extending. The Clench model is indicated for this purpose. Moreover, the use of models may allow comparisons of data derived from sampling periods of different lengths (Flather 1996, Gotelli and Colwell 2001).

Secondly, the results of the present study indicate that study periods at crossing structures should comprise 10-15 days in order to detect most species. Nevertheless, this period may be extended or curtailed depending on various factors. It may be worth shortening the study period to 7-8 days per structure, for example, where there are a large number of crossings to monitor and if the costs of putting on and removing the monitoring systems are small. More than 50 percent of species will have been detected by then, and the rate of appearance of new ones will decline so that it may then be advantageous to switch to another crossing. By this means, at least in theory, the rarest species should eventually be detected at one structure or another, providing a more complete picture of the use of the crossings by fauna. On the other hand, study periods should be longer where there are few crossings structures, such as large ecoducts, to monitor. With these figures as a guide, the suggestion is to employ standardized study periods for all the structures monitored, with only exceptional variation: e.g., extending the period at ecoducts.

In conclusion, our results support the feasibility of establishing compulsory monitoring programs for the measures adopted to remedy the barrier effect of new linear infrastructures. On the one hand, the implementation costs are not very great, given the relative brevity of the monitoring period needed to obtain a basic idea of their use by fauna. Also, the monitoring may produce datasets for large areas which can be of great interest provided that data collection follows certain minimum scientific requirements. Hence, the development of protocols that include an adequate sampling period is essential to operating such monitoring programs and for their results to be of maximum utility. The extension of science-based “low intensity - large area” monitoring schemes would complement in-depth research focused on target species or sites.

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Railroad Crossing Structures for Spotted Turtles: Massachusetts Bay Transportation Authority–Greenbush Rail Line Wildlife Crossing Demonstration Project

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Abstract: Loss of access to critical habitats is a key wildlife concern, particularly for species listed for protection by state and federal agencies. Rail corridors pose unique design challenges by virtue of the need to avoid abrupt changes in track curves and grade in the right of way (ROW). Spotted turtles (*Clemmys guttata*) are particularly vulnerable to habitat fragmentation due to their limited mobility and dependence on a diversity of specific foraging, nesting, and aestivation habitats. Spotted turtles also display an apparent reluctance to enter or cross through narrow and confined culverts typically found under road and rail line ROWs. In association with the Greenbush Line Commuter Railroad Restoration Project, the Massachusetts Bay Transportation Authority initiated a demonstration project in spring of 2003 to determine the effectiveness of a proposed railroad crossing structure in an urbanized landscape. Three identical, open-air prototypes were positioned in the ROW of a former railroad bed between adjacent wetlands known to support spotted turtles. Each structure was linked with temporary funneling barriers along the track edges. Structure placement was in accordance with microhabitat survey assessments, radio telemetry data, and direct movement observations. To evaluate the effectiveness of the structures, remote photographic stations were established at each crossing, and radio telemetry was used to track turtle movements. Monitoring was conducted from April 2, 2003, until July 8, 2003. Study results demonstrated spotted turtle crossing patterns and frequency through the ROW during the monitoring period similar to that prior to barrier development. Crossings also were shown to be utilized by 17 other wildlife species, including reptiles, amphibians, birds, and mammals. The demonstration project concluded that location and design of the crossing structures provided an effective means of maintaining habitat connectivity for a variety of wildlife species, as well as spotted turtles. As part of the Conservation and Management Plan developed for the Greenbush Line Project, which is now under construction, 45 wildlife crossing structures are proposed at key locations along the ROW. A post-construction monitoring plan will be conducted to evaluate the use of these structures by wildlife species.

Introduction

The Massachusetts Bay Transportation Authority (MBTA) is currently proposing to reactivate an 18-mile section of the largely discontinued Old Colony Railroad right of way (ROW), which formerly extended from Braintree to Scituate Massachusetts. The rail bed exists for much of the length of the ROW, and in many areas still consists of ballast, rail ties, and rails. Portions of the ROW have become overgrown with vegetation, principally exotic and invasive species common to the surrounding urban and suburban environment. To date, the MBTA and its consultants have conducted a series of wetland mapping and habitat assessments along the full length of the corridor, determined wetland impacts, and proposed wetland mitigation designs. In 2002, additional wetland and wildlife resource surveys were conducted, including a radio telemetry study of spotted turtles (*Clemmys guttata*) (Woodlot 2002a).

Under a variety of Massachusetts environmental regulations, the MBTA is required to outline how natural resources, such as wetlands, natural communities, and wildlife species, will be affected by the completion of the Greenbush Rail Line. In general, the project must demonstrate that measures to avoid, minimize, and mitigate impacts to rare species and their habitats and wetlands have been taken and that a cumulative net benefit will be provided. Perhaps the greatest impact of the proposed ROW development is the potential for the rail line to act as a barrier or filter to smaller species of wildlife, particularly amphibians and reptiles. More specifically, those species that cannot cross over or under the rails will have restricted movement across the ROW. A primary concern was the ability of the spotted turtle to cross the ROW.

Plans to accommodate wildlife crossings through the ROW were presented by the MBTA in the Conservation Management Plan (Plan) (Woodlot 2002b). The Plan details the information and process used by the MBTA to determine the impact of the project on wildlife and natural communities, while developing long-term net benefit mitigation measures for unavoidable impacts. Four types of animal crossing structures (Types A, B, E, and F) were presented in the Plan, along with a form of funneling barrier designed to keep turtles off of the tracks and directed towards crossing openings. Two structures were further designed for single- and double-track scenarios, for a total of six crossing structure types. Crossing locations were based on 2002 spotted turtle radio telemetry data, field investigations along the entire ROW, and the likelihood of wildlife travel corridors to link targeted habitats on opposite sides of the ROW.

The type of crossing structure proposed to be most frequently used, i.e., the Type A design, is largely open to ambient conditions and, therefore, most effective in mimicking the existing natural conditions typically encountered by spotted turtles (e.g., substrate, moisture, temperature, ambient light; figure 1). Tunnel structures were not selected by the MBTA Project Team during the design process as they would likely be avoided by turtles during their seasonal movements to and from various habitats.

Ballast within Type A structures will be cleared to a depth of approximately eight to nine inches in the gaps between three adjacent rail ties (figure 2). These excavations will extend along the full length of the approximately 11-foot ties. The base of the openings will be underlain with a (40 ml) high-density polyethylene (HDPE) material formed to fit tightly between ties to demarcate the limit of excavation. Leaf debris will be placed on top of the HDPE lining to serve as substrate material and to maintain moist natural cover material. Type B structures are similar in design to Type A structures except they extend across double, rather than single, track widths. A total of 45 crossing structures, with corresponding barrier fencing, will be positioned in suitable habitats along the ROW. Type A structures are the dominant type of structure proposed for use along the rail line (33, or 73%), with both A and B structures combined constituting 88 percent of the total number of structures. The purpose of the fencing barrier is to funnel spotted turtles and other wildlife toward the crossing openings, while keeping them from potential collision hazards associated with stations and passing commuter trains.

To further the project compensation effort, the MBTA, at the request of the Massachusetts Natural Heritage and Endangered Species Program (MNHESP), agreed to develop and conduct a demonstration project for three Type A wildlife crossing structures at the proposed Nantasket Junction Station site in Hingham, MA. The objective of the project was to determine what, if any, final design modification might need to be made to the crossings to be installed. Testing of various monitoring means and methods were undertaken in the winter of 2002-2003, followed by the *in situ* placement of temporary crossing and barrier structures in March 2003. The study was subsequently initiated when turtles emerged from their hibernacula in April and continued until early July 2003 when it was determined that all nesting activity had ceased. This document presents the findings of that demonstration project study.

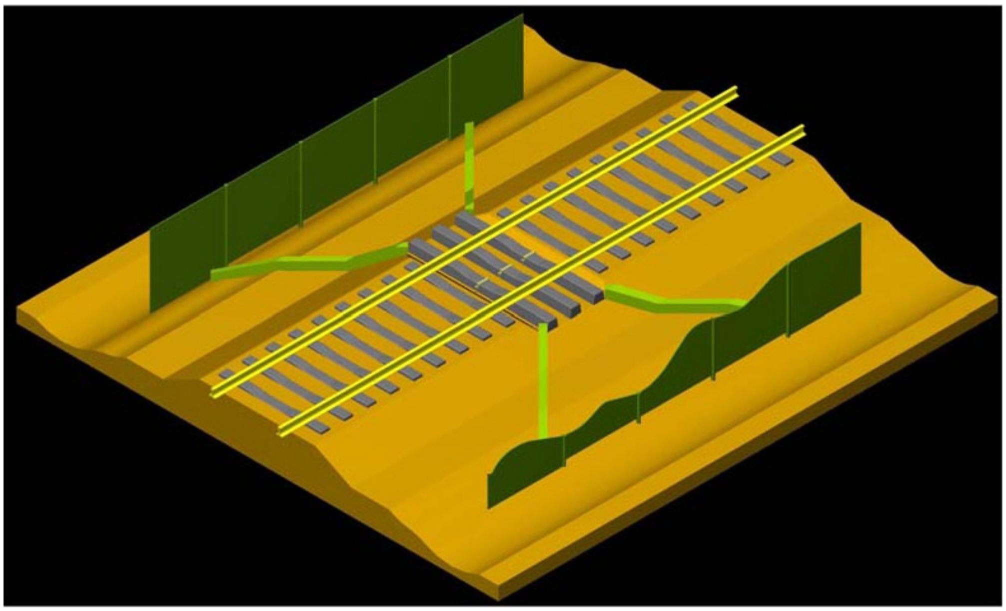

Figure 1. Type A wildlife crossing structure.

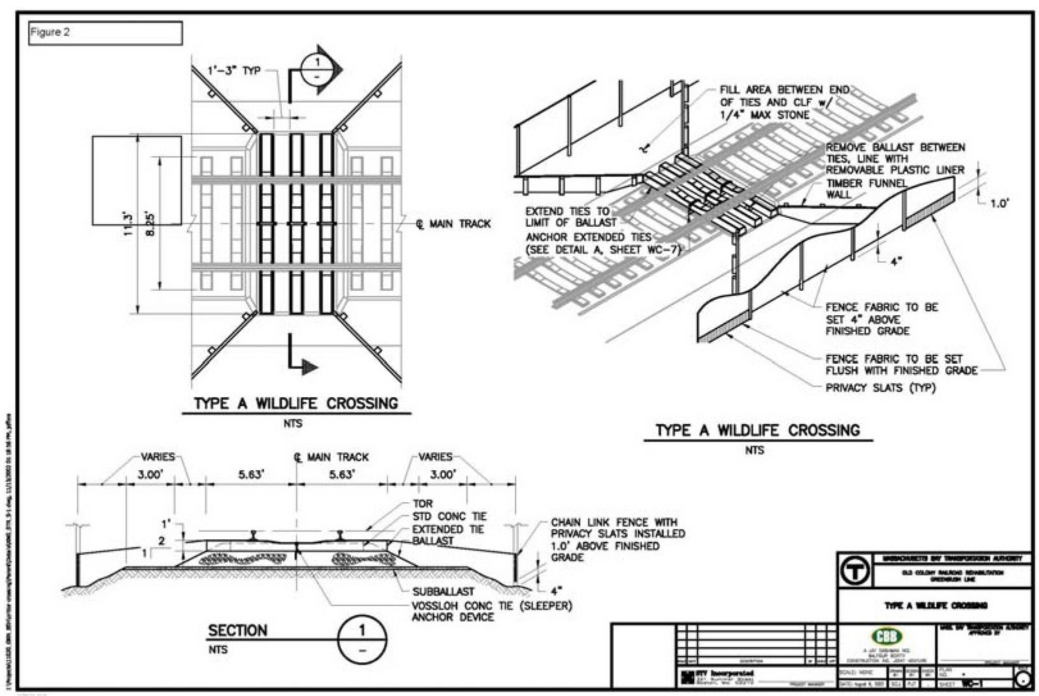

Figure 2. Type A wildlife crossing structure.

Study Area

Study area description

The Demonstration Project was located at the former Hingham Lumber Yard, now the proposed location of the Nantasket Junction Station (figure 3). This area is in a suburban portion of Hingham where active and cumulative development pressures are causing fragmentation of the remaining undeveloped habitats. The study area is situated between Kilby and Summer streets to the east and south, respectively, and contains two extensive scrub-shrub pool habitats separated by the existing ROW (the northern pool and southern pool). Woodlot Alternatives, Inc., submitted applications to certify both the northern and southern pools in 2002 under the Massachusetts Vernal Pool Certification guidelines.

The northern pool is the deeper of the two pools, with maximum depths between three and four feet. Dense button-bush (*Cephalanthus occidentalis*) dominates the entire wetland. The southern pool is forested with numerous shrub hummocks and buttressed root masses, a number of which have been found to be used by turtles for basking in the spring and for hibernacula habitats during the winter months. Additional spotted turtle habitat (i.e., aestivation, staging, and nesting) occurs within upland areas along the eastern wetland boundary of the southern pool near the corner of Route 3A and Kilby Street.

Site selection

An analysis of the 2002 radio telemetry data along the entire corridor length indicated Nantasket Junction Station had the highest number of documented individual ROW crossings by spotted turtles. Each of the turtles was found to utilize a number of upland and wetland seasonal habitats on opposite sides of the ROW. In addition, Nantasket Junction Station was found to support the largest population of spotted turtles with radio transmitters on the corridor and contained a population of both male and female sexes and of varying age class structure (table 1).

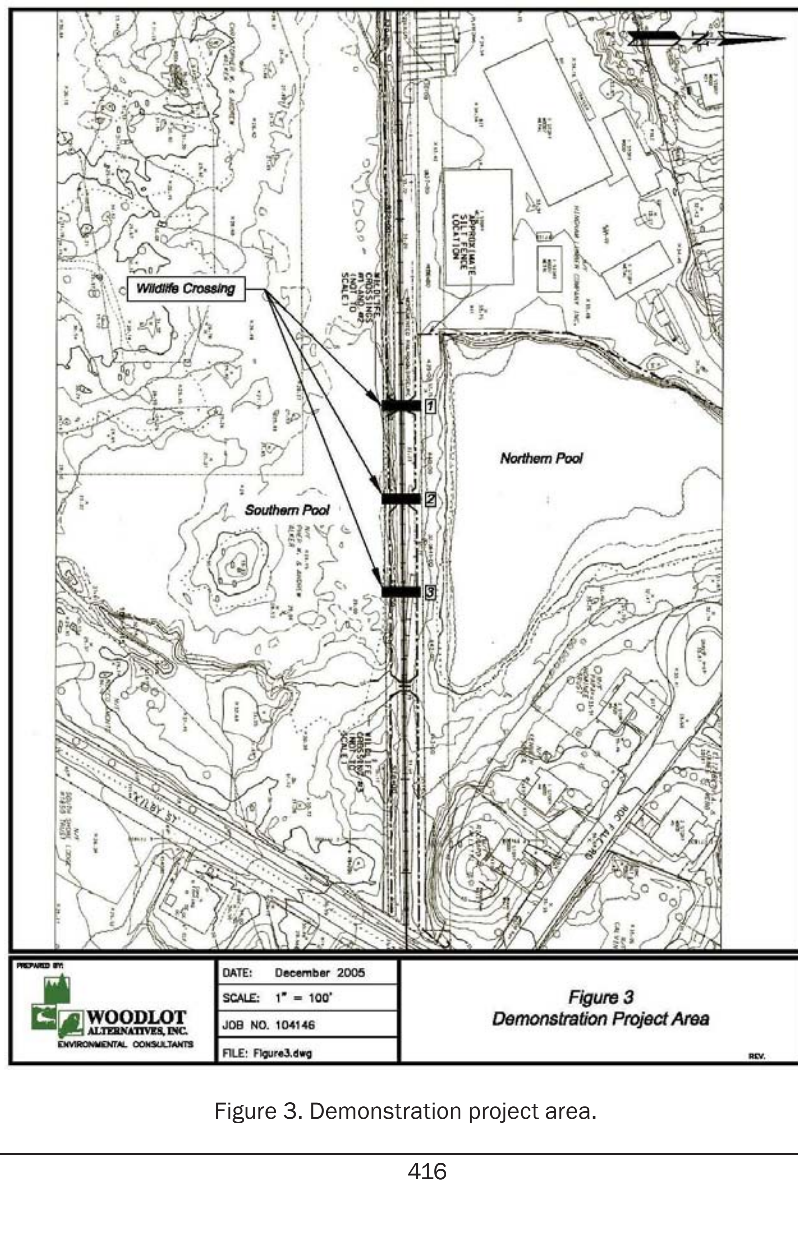

Figure 3. Demonstration project area.

Table 1. Individual spotted turtles with radio-transmitters at Nantasket Junction Station

Notch Code[1]	Sex		Age
103	Female		15+
104	Male		10+
105	Female		15+
108	Female		10+
109	Female		13+
119[2]	Male		8+
TOTALS	**Males: 2**	**Females: 4**	

Notes: 1. Notch codes are based on techniques for individually identifying and marking turtle shell scutes with triangular files described in Milam and Melvin (2001).
2. M119, captured during the Demonstration effort on April 10, 2003, was not monitored in 2002.

Spotted turtle radio telemetry data from the Nantasket Junction Station from April through November 2002 demonstrated spotted turtles were crossing the existing ROW in specific areas to utilize suitable seasonal habitats. Field observations of the existing conditions at the Nantasket Junction Station indicated that several natural gaps near station marker 977+00 were present and that spotted turtles were apparently using these openings as a travel corridor (photo 1).

Photo 1. Observed under rail gaps at Nantasket Station. Woodlot Alternatives, 2003.

Methods

In accordance with MNHESP's request to determine what, if any, final design modification might need to be made to the crossings to be installed, MBTA project team members worked collaboratively during the winter of 2003 to develop and design the demonstration project. The overall study objective was to evaluate the viability and effectiveness of the Type A crossing structure as a conduit for cross ROW movements by spotted turtles and other small wildlife species. The evaluation also included an assessment of the barrier fencing design and fence lengths as a funneling structure and barrier. All surveys were designed to be conducted with the use of remote sensory equipment at the individual crossing locations and backed by radio telemetry surveys. Prior to the design phase, MNHESP was consulted on site selection, remote sensory techniques, and duration of the demonstration project.

Installation of the crossing structures and barrier fencing

Three crossing structures were installed within the project area, one each at station markers 974+00, 975+00, and 977+00. Temporary silt fabric fencing was utilized as a form of barrier fencing and extended on both sides of the ROW between Summer and Kilby streets (photo 2). Temporary silt fabric fencing extended along the entire southern boundary of the ROW between Summer and Kilby streets. Along the northern boundary of the ROW, temporary silt fabric fencing extended from Kilby Street to the western boundary of the northern vernal pool (Station 973+25). The temporary fencing then continued in a northerly direction for approximately 150 feet along the parking lot edge. All structures were installed with snow cover and under frozen ground conditions to ensure that potential early season movements by turtles emerging from the hibernacula would be avoided during installation. This also allowed an opportunity for any resultant soil disturbances to settle.

Photo 2. Silt fencing as surrogate barrier fence in the project area. Woodlot Alternatives, 2003.

To ensure the proper identification of individual openings, each crossing structure was assigned a number, with individual structures numbered in increasing order beginning at station marker 974+00 and moving east along the tracks (figure 3). Each individual opening was designated with an identifying letter ("A" for south facing openings and "B" for north facing openings).

Selection of remote sensory equipment
Various methods (e.g., thread bobbins, scanners, and *in situ* traps) for evaluating the use of the crossing structures were initially tested. Ultimately, most of the options were abandoned for a variety of technical and logistical reasons, particularly due to the limitations of monitoring spotted turtle in the environment, i.e., slowing movements, cold-blooded, and low overall height (< 4 inches). Cutler and Swann (1999) reviewed the application of remote photography systems in 107 studies from the field of wildlife ecology and found their use to be common for studies involving nest predation, feeding ecology, nesting behavior, and species presence/activity patterns. Remote photography was found to be particularly useful in evaluating long-term and secretive 24-hour activity that can be otherwise impractical and disruptive with the use of human observers. The use of remote photography additionally prevented user bias, as time-specific and dated photographs were made available for analysis.

Infrared Photography System. Infrared motion detection equipment similar to that used with automatic garage door openers was tested with small turtle shells and deemed to be a reliable and effective trigger for detecting spotted turtle movements. Equipment was set up at ground level and the sensitivity of the infrared beam set high enough to be triggered by the slow movement and small size and height of the target species (photo 3). An infrared motion detection beam and reflector system was securely housed in a waterproof container and electronically wired into a modified DeerCam® (photo 4). Two 12-volt marine batteries were left on site to power the remote photography systems.

Photo 3. Modified Deercam® and infrared-triggered remote photography system prior to installation. Woodlot Alternatives, 2003.

Photo 4. Infrared beam and reflector (flush with ground) triggers remote camera (foreground on post) when interrupted. Similar setups were positioned at each end of three crossing structures. Woodlot Alternatives, 2003.

Field Monitoring. Late winter and early spring field conditions were regularly monitored to determine an appropriate start time for the field monitoring to begin. After a series of late season snow delays, field-monitoring activities were initiated April 2, 2003, immediately upon the determination of suitable conditions for spotted turtles to be moving from their hibernacula. The project area was initially visited two to three days a week to monitor each remote photograph system and to reload film as necessary (primarily during the month of April). The project site was subsequently visited on a regular five-day per week basis as spotted turtles began to move farther distances from hibernacula, and as ambient conditions began to regularly hit 70° F (late April). Daily monitoring continued until July 8, 2003, as the spotted turtle nesting season concluded.

Blowing leaves and debris around the structures were initially found to trigger and rapidly expose rolls of film at each camera location. Frequently, a single leave would become briefly snagged within the path of the light beam and cause a quick series of exposures to consume the available film. Limitations of this nature were also observed in studies conducted by Rice et al. (1995) and Buler and Hamilton (2000). Regular efforts were made to remove leaves on or immediately near the infrared beam to minimize the rapid exposure of film.

Radio Telemetry Surveys. Similar to the 2002 effort, spotted turtle movements were also monitored in 2003 with radio telemetry equipment. Radio tracking of spotted turtles involved locating turtles several times a week with a radio receiver to document and map habitat use in proximity to the ROW.

Results

Crossing efforts and general movement patterns by spotted turtles across the ROW and throughout the demonstration area in 2003 were essentially identical to those observed in 2002; movements between the pool habitats on either side of the ROW showed no discernable difference. Use of each of the three crossing structures was documented. Overall frequency of crossings over the ROW was found to be the same in both years, with an additional increase due to the capture and release of one additional, radio-tagged turtles in the demonstration area during the course of the study.

Nine crossings were recorded for six spotted turtles that had functional radio transmitters affixed to their carapace in 2003. Of these nine crossings, five were recorded by the infrared photography system. As already noted, early season crossings were not photo documented due to the loss of film caused by the high level of blowing leaves and debris around the crossing structure openings. However, 2002 and 2003 radio telemetry data provided evidence of regular, seasonal inter-pool travel patterns for each turtle in the demonstration area.

A total of seven crossings were recorded for four of the same spotted turtles equipped with functional radio transmitters in 2002. Female 109 (F109) did not cross the ROW prior to May 14, 2002. However, the transmitter failed in late May of 2002; therefore, no crossings after that date could be documented. One additional male turtle (M119) was captured in 2003 and fitted with a radio transmitter and released. This turtle recorded one crossing in 2003.

The infrared-triggered cameras also recorded eight passages through the crossing structures by snapping turtles (*Chelydra serpentina*) and one by a painted turtle (*Chrysemys picta*), denoting a total of 17 crossing that occurred in 2003 among the three turtle species observed at the demonstration project site.

It is important to note that cold temperatures and several late season snowstorms delayed spotted turtle hibernacula emergence and movement in 2003. This was in stark contrast to the early spring conditions of 2002. Initial observations of spotted turtles in 2003 were on average 23 days later than in 2002 (table 2) at each of the spotted turtle monitoring locations within the corridor in Hingham and Cohasset. Within the demonstration project site, four spotted turtles were also observed crossing through the structures up to 23 days later in 2003 than in 2002 (table 2).

Table 2. Comparison of initial observation dates of radio-tagged spotted turtles at various sites in Hingham and Cohasset, MA (2002-2003)

Town	**Site Location**	**2002 Average Date of First Observation**	**2003 Average Date of First Observation**
Hingham	Foundry Pond	March 21	April 29
	Hingham Lumber Yard	March 29	April 10
Cohasset	Castle	March 28	April 15
AVERAGE FOR ALL TURTLES		**March 26**	**April 18**

The timing and total number of spotted turtle ROW crossings from 2002 and 2003 were not significantly different. For many of the turtles, differences is crossing times can be directly attributed to seasonal variation in ambient conditions (table 3). Female 103 (F103) crossed the ROW during similar time periods in 2002 and 2003. Female 108 (F108) and Male 104 (M104) each crossed the ROW two to three weeks later in 2003 than in 2002; however, seasonal variation is a plausible explanation for these differences. Female 105 (F105) was encountered along the temporary barrier fencing on May 20, 2003, traveling towards crossing structure #3 (station marker 977+00) in an attempt to travel to the northern vernal pool. The six to seven week timing difference in crossing dates for F105 between 2002 and 2003 could possibly be due to seasonal variation, but an additional factor may include balking or a temporary inability to locate a crossing structure. However, in both 2002 and 2003, F105 was documented to have crossed the ROW within a two- to three-day window in late June/early July. F109 recorded one crossing in 2003 that was similar to dates of crossings of F105, M104, and F103 this year. M119 was a new capture in 2003, and it is hypothesized that M119 exhibits similar seasonal movement patterns as other turtles being monitored.

Another observation involved the effect of "privacy fencing" along the ROW edge. Segments of temporary silt fabric barrier fencing were originally located directly in front of each crossing at the edge of the ROW, as part of the demonstration project. These segments of fencing provided a field representation of conditions expected to occur with the establishment of "privacy fencing" along certain portions of the ROW. Each of the fence segments was positioned to allow a five-inch gap between the fence bottom and the ground. Several crossings of spotted turtles were recorded with the fencing in place. After a further review of the proposed fencing plans for the entire route, it was noted that all known proposed crossing locations were in areas that would not require the use of privacy fencing. As a result, the apron fencing was removed after several weeks. This also helped alleviate potential balking concerns for other wildlife species. In any event, the crossings were found to allow crossings to occur with the fencing in place.

Table 3. 2002 – 2003 Radio Telemetry Crossing Dates (April 2002-July 2003)

Spotted Turtle Notch Code	**Date of Documented Crossings in 2002**	**Date of Documented Crossings in 2003**
F103	April 25 and May 15	April 18 – May 7, and June 25 – 30
M104	April 8	May 1
F105	April 4, June 9, and June 25	May 20, June 27 – 30, and July 3 – 8
F108	April 9	April 21
F109	Transmitter failure in early May	May 18 – June 10
M119	Not captured in 2002	June 25 – July 3
TOTAL DOCUMENTED ROW CROSSINGS	7	9

Note: Notch codes based as described in Milam and Melvin (2001). "F" depicts female; "M" depicts male.

Times of entry and exit from the crossing structures generally occurred during the mid-day to late afternoon. Time-specific photographs occurred between 1200 and 1600 hours on May 20, June 9 and 30, and July 1, 2003 (table 4), with the exception of one crossing at 0733 hours on June 28. All of the spotted turtle crossings took between two and four minutes for the individual to completely pass through the crossing structure.

Table 4. Photographic Spotted Turtle Crossing Data from Nantasket Junction Station

Crossing Structure No.	Date	Entry Time	Exit Time	Direction of Movement
3	May 20	12:56	?	North
3	June 9	15:52	15:56	North
2	June 28	?	07:33	South
1	June 30	15:05	15:08	North
2	July 1	12:13	12:15	North

Note: Eight additional instances of snapping turtles traveling north and south through the crossing structures at Stations 1, 2, and 3. One painted turtle was also documented traveling north using Station 1. Average time within the crossing structure among all three turtle species was similar to that of spotted turtles.

Other wildlife also used the crossings. Between April 2 and June 30, 2003, 11 mammal species, 4 reptile species, 1 amphibian, and 2 bird species were documented using the crossing structures (table 5). Species ranging in size from green frogs (*Rana clamitans*) and mice (*Peromyscus* spp.) to coyotes (*Canis latrans*) were documented, suggesting that a wide variety of species was able to use the crossings. Waterfowl species used crossing structures when moving with young between the northern and southern pools (photo 5).

Photo 5. Brood of mallards (*Anas platyrhynchos*) traveling from the north pool to the south pool; May 14, 2003, at 16:07. Woodlot Alternatives, Inc. 2003.

Table 5. Species photographed using crossing structures between April 2 and June 30, 2003

Common Name	Species	Crossing Structures Used
Spotted Turtle	*Clemmys guttata*	1, 2, 3
Eastern Painted Turtle	*Chrysemys picta picta*	1
Snapping Turtle	*Chelydra serpentina*	1, 2, 3
Eastern Garter Snake	*Thamnophis sirtalis sirtalis*	3
Green Frog	*Rana clamitans melanota*	1, 2, 3
Coyote	*Canis latrans*	2, 3
Grey Fox	*Urocyon cinereoargenteus*	1, 3
Muskrat	*Ondatra zibethica*	2, 3
Longtail Weasel	*Mustela frenata*	1, 3
Eastern Cottontail	*Sylvilagus floridanus*	1, 2, 3
Raccoon	*Procyon lotor*	1, 2, 3
Skunk	*Mephitis mephitis*	1, 2, 3
Opossum	*Didelphis marsupialis*	1, 2, 3
Mouse	*Peromyscus* spp.	1, 2, 3
Eastern Gray Squirrel	*Sciurus* carolinensis	1, 2, 3
Eastern Chipmunk	*Tamias striatus*	1, 2, 3
Wood Duck	*Aix sponsa*	3
Mallard	*Anas platyrhynchos*	1, 2, 3
Northern Flicker	*Colaptes auratus*	N/A
Blue Jay	*Cyanocitta cristata*	N/A
Catbird	*Dumetella carolinensis*	N/A
American Robin	*Turdus migratorius*	N/A
Common Grackle	*Quiscalus quiscula*	N/A
House Sparrow	*Passer domesticus*	N/A
Northern Saw-whet Owl	*Aegolius acadicus*	N/A

Conclusions

Field observations made during the 2003 monitoring effort at the Nantasket Junction Station demonstration project site support evidence that the crossing structure location and design provide an effective means for maintaining habitat connectivity for a variety of wildlife species. Crossing structures and funneling barrier fences were successful in allowing movements by spotted turtles through the ROW. Radio telemetry methodology documented the ability of spotted turtles in the study area to locate, travel to, and utilize the designed gaps under existing rail ties in order to travel between adjacent vernal pool habitats. No changes to seasonal spotted turtle behavior patterns were observed during the course of the 98-day active photo-monitoring period. The current Type A design did not appear to significantly influence balking behavior along the barrier fencing or near the crossing structures.

The demonstration project indicated the viability and effectiveness of the combined crossing and funneling barrier design as a means of maintaining cross-corridor connectivity. No major modifications or design refinements of the crossing structures were made. The demonstrated success shown by the lack of change in the number of spotted turtle crossings through the ROW and the lack of discernable change in their general behavior within the adjacent habitats provides a justification for the expanded use of the crossing structures to other locations previously selected by the MBTA project team along the project corridor. We anticipate that the expanded use of this same system would work as well in other corridor areas.

Biographical Sketches: Steve Pelletier is a certified wildlife biologist, professional wetland scientist, and certified and licensed professional forester with over 20 years of professional experience. A co-founder and principal of Woodlot Alternatives, Inc., he specializes in a variety of landscape and site-level habitat analyses, including avian risk assessments related to windpower development, forest ecology and management, wetland assessments, and impact mitigation. He offers particular expertise in rare species impact evaluations and for developing impact avoidance and mitigation measures for a variety of projects ranging from transportation and energy development.

Lars Carlson is manager of projects for the Boston office of Jacobs Civil, Inc. His responsibilities include identification and evaluation of ecological resources, preparation of National Environmental Policy Act documents, permitting support, and regulatory compliance oversight for infrastructure projects. Dr. Carlson is a professional wetland scientist and a certified senior ecologist. He has a B.S. in biology from the University of Delaware and a Ph.D. in botany from the University of Massachusetts, Amherst.

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Appendix A

Remote Camera Photos

Photo A1. Spotted turtle at crossing structure 2A; 6/28/03, 07:33.

Photo A-2. Spotted turtle at crossing structure 2B; 7/1/03, 12:14.

Photo A-3. Eastern painted turtle at crossing structure 1A; 6/8/03, 14:43.

Photo A-4. Snapping turtle at crossing structure 2B; 4/29/03, 13:58.

Photo A-5. Garter snake and chipmunk at crossing structure 3A; 7/1/03, 09:33.

Photo A-6. Green frog at crossing structure 1A; 5/19/03, 20:24.

Photo A-7. Coyote at crossing structure
3A; 5/20/03, 21:43.

Photo A-8. Grey fox at crossing structure
1A; 5/9/03, 23:53.

Photo A-9. Longtail weasel at crossing structure
1A; 4/23, 00:35.

Photo A-10. Muskrat at crossing structure
3A; 6/19/03, 00:18.

Spotted Turtle Use of a Culvert Under Relocated Route 44 in Carver, Massachusetts

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Abstract: A new highway alignment for relocated Route 44 in Carver, Massachusetts, resulted in the direct alteration of 2.5 acres and indirect alteration of 3.9 acres of habitat for three statelisted turtle species: the wood turtle (*Clemmys insculpta*), spotted turtle (*Clemmys guttata*), and eastern box turtle (*Terrapene c. carolina*).

As part of the mitigation requirements for impacts to rare species habitat, the Massachusetts Highway Department (MassHighway) conducted a twoyear preconstruction study to determine the habitat preferences and seasonal movements of the statelisted species. The study determined that no wood turtles were present in the study area, that there was a large but declining population of box turtles, and that two highly used spotted turtle habitats would be bisected by the proposed highway entrance ramp. An intermittent stream channel proposed to be piped under the new entrance ramp was identified as a primary travel corridor between the two habitats.

Based on the findings of the preconstruction study, MassHighway identified a simple solution to allow the stream channel to continue to provide a migratory corridor for spotted turtles. To achieve this goal, MassHighway increased the proposed culvert size from a 24inch pipe to a 6foot by 6foot box culvert. In the spring and summer of 2004, postconstruction monitoring was conducted to determine the effectiveness of the culvert as a spotted turtle crossing structure. Nine turtles were fitted with radio transmitters and thread bobbins and followed three times per week in the spring and early summer, and once per week in the late summer to determine culvert effectiveness. Direct evidence (thread trails, visual observation) was documented for seven turtles, and indirect evidence (radio telemetry points on both sides of the culvert, visual observation) was documented for 13 turtles, confirming the use of the culvert as a crossing structure. A future study is recommended to document potential effects of traffic and noise on the spotted turtle population, continued use of the culvert, and potential changes to rare species habitat from the highway construction.

Introduction

In 2002, the Massachusetts Highway Department (MassHighway) began construction of relocated U.S. Route 44 between Carver and Plymouth. Construction of the new highway entrance ramp for Route 44 in Carver resulted in the direct alteration of 2.5 acres of prime rare species habitat and indirect alteration of 3.9 acres of prime rare species habitat. MassHighway conducted extensive mitigation measures to compensate for unavoidable impacts to rare species habitat, including acquisition of 27.8 acres of prime and suitable rare species habitat (a mitigation ratio of 6.4:1) and commitment to complete a twoyear preconstruction study developed by the Natural Heritage and Endangered Species Program (NHESP) to determine the seasonal movements and habitat preferences for wood turtles, spotted turtles, and eastern box turtles.

Field work for the preconstruction study was conducted in 1998 and 1999. Results of the study indicated that wood turtle habitat did not occur in the area, that there was a healthy population of spotted turtles in the emergent wetland adjacent to Route 58 (Wetland 17), and that there was a large but declining population of box turtles. The study also concluded that spotted turtles used a stream channel tributary to the Winnetuxet River and adjacent wetlands to travel to Turtle Pond, a vernal pool located approximately 550 feet east of Wetland 17. The results of the study determined that spotted turtle habitat would be bisected by the new Route 44 entrance ramp.

All environmental clearances and permits were already acquired for the project, and there was no requirement or obligation to further mitigate impacts to the turtle habitat. However, based on the findings of the study, MassHighway identified a simple solution to not only address the direct impacts to habitat, but to provide a critical wildlife passage link that would preserve the greater habitat area and prevent isolation and eventual elimination of 6.5 acres of prime spotted turtle habitat in Wetland 17. To achieve this goal, MassHighway increased the size of the proposed culvert, from a 24inch reinforced concrete pipe to a 6foot by 6foot concrete box culvert, which would not only convey the stream but provide migratory passage for spotted turtles under the highway interchange ramp.

Study Area

The main population of spotted turtles is located in an open emergent marsh, Wetland 17, containing soft rush (*Juncus effusus*), common cattail (*Typha latifolia*), common reed grass (*Phragmites australis*), steeplebush (*Spiraea tomentosa*), and tussock sedge (*Carex stricta*). Two intermittent streams traverse Wetland 17 and converge approximately 100 feet west of the newly constructed Route 44 entrance ramp to form the main tributary to the Winnetuxet River. The main intermittent stream (north channel) is fed by runoff from Route 58 to the west, and flows into the Winnetuxet River approximately 1,300 feet east. A second intermittent stream (south channel) also collects runoff from Route 58. Both channels are approximately three to five feet wide, with depths ranging from 0 to 2.5 feet, depending on the season. The substrate consists of a deep organic layer. The banks are heavily vegetated with overhanging soft rush and tussock sedge.

The new Route 44 entrance ramp constructed between Wetland 17 and the forested wetland east of Wetland 17 conveys the tributary to the Winnetuxet River under the entrance ramp via a 6foot by 6foot concrete box culvert. The 60foot long culvert was constructed below the streambed elevation, providing approximately four to six inches of organic substrate on the culvert bottom. In the vicinity of Wetland 17, the entrance ramp is 10 to 15 feet above the wetland, with 2:1 riprap sideslopes. During construction, the culvert was cut to match the 2:1 sideslopes, which shortened the effective culvert width from approximately 68 feet to 44 feet. Based on a culvert length of 44 feet, the openness ratio (OR: cross-sectional area of the culvert divided by its length) is 0.8. Although the culvert was designed and constructed prior to publication of the Draft Massachusetts River and Stream Crossing Standards: Technical Guidelines (University of Massachusetts-Amherst 2004), the culvert exceeds the recommended openness ratio of 0.75 for new crossing structures. Approximately 200 feet south of the culvert, the ramp is approximately three feet above the replacement wetland elevation. The steep, riprapped sideslopes that support the entrance ramp effectively serve as a barrier to turtles, and turtles are directed to the 6foot by 6foot box culvert if they intend to cross.

South of the main tributary to the Winnetuxet River, the red maple forested wetland ponds in several areas during the spring, and contains many braided, slowmoving channels that outflow from Turtle Pond and drain into the main tributary. A large portion of this wetland is paludal woodland, exhibiting mound and pool topography, with many sphagnum moss mats in the wetter areas. Red maple dominates the tree layer, with black gum (*Nyssa sylvatica*) as a common representative, and white pine (*Pinus strobus*) on hummocks within the wetland. In the lower forest layers, highbush blueberry (*Vaccinium corymbosum*) and northern arrowwood (*Viburnum dentatum*) are common. A dense growth of cinnamon fern (*Osmunda cinnamomea*) covers the forest floor.

Turtle Pond is a vernal pool east of Wetland 17 and south of the tributary to the Winnetuxet River. This abandoned cranberry bog is partially vegetated with shrub vegetation, including highbush blueberry, arrowwood, winterberry holly (*Ilex verticillata*), and cranberry (*Vaccinium macrocarpon*). The pool also contains swamp loosestrife (*Decodon verticillatus*), pondlily (*Nuphar variegatum*), three-way sedge (*Dulichium arundinaceum*), and large mats of sphagnum moss (*Sphagnum* sp.). Depths in the pool range from 2 inches to 2.5 feet.

Methods

Capture and characterization

Turtle capture was conducted daily between April 8 and April 29, 2004. Turtles were handcaptured by visually searching suitable habitat, and trapped using two 10inch diameter minnowstyle traps constructed of hardware cloth with escape hatches, funnel shaped entrances, and sized for spotted turtles. During the weeks of April 20 and 28, two unbaited hoop traps were set in Wetland 17 to capture two radio tagged turtles whose transmitters appeared to be failing (Turtles 30A and 50A).

Captured turtles were aged, sexed, measured, weighed, and notched for individual identification. Each captured turtle was also numbered with a bright orange nontoxic paint pen on its carapace for easier visual observation. Age was determined by counting annuli on each right plastral plate, which is a reasonable estimate of age for many turtle species (Sexton 1959). Turtles were sexed based on eye color, jaw color, vent location, and plastral concavity. Turtles were marked by notching marginal scutes, modified from Cagle (1939). A triangular metal file was used instead of the square file described by Cagle because the triangular file is less intrusive and produced equivalent notches.

Ernst et al. (1994) reported studies that found sexual maturity of spotted turtles was attained by the time they grow to a carapace length of 80 millimeters. We attempted to classify males and females at all ages, but classified spotted turtles with a carapace length of less than 80 millimeters as juveniles.

Monitoring

Thread trailing and radio telemetry were used to monitor the movements of the sample population. Radio telemetry was used to provide “snapshots” of movement, while thread bobbins were used to show actual movement trails. By using these monitoring techniques, effectiveness of the culvert could be determined.

Radiotelemetry

Nine turtles were fitted with radio transmitters (AVM model SM 1H; 164 MHz) between April 8, 2004, and May 19, 2004. Six radiotagged turtles (3 males; 3 females) that were documented to occur on both sides of the culvert during one or both years of the preconstruction study were a priority for the postconstruction study. These turtles were: 6A, 8, 25, 30A, 50A and 60A.

It was theorized that these turtles would attempt to maintain the same home range and movement patterns that they exhibited prior to the highway construction, and that tracking these turtles would yield more useful information on whether and how they crossed than for those turtles that were either known to not cross, or did not have preconstruction data recorded. Three additional turtles (2 females, 1 male) were also fitted with radio transmitters for a total of nine radio tracked turtles. These turtles were: 13, 52 and 550.

Radio transmitters were glued to the right rear side of each turtle’s carapace with a fastsetting, twopart epoxy. Turtles were released at their point of capture within one hour. Spotted turtles were tracked three times a week through June 30, and once a week from July 1 through September 30. Radio transmitters were removed from all but one turtle during the first week of October before the turtles entered dormancy (the signal on one turtle was lost before its transmitter could be removed). Each turtle was tracked to within one foot of its location, and point coordinates were recorded with a handheld Global Positioning System (GPS) unit (Garmin GPS II Plus). Coordinates were transferred to an aerial photo base and used to determine turtle home ranges.

Five females and 4 males were fitted with radio transmitters and tracked for the field season or until the signal was lost. Turtle 6A was initially fitted with a radio transmitter but did not move from its original capture location for 4 weeks of tracking, so her transmitter was removed and placed onto another female (Turtle 52) that had been observed passing through the culvert.

Thread trailing

From the date of capture through June 30, the nine radiotagged turtles were also fitted with thread bobbins to assist in locating travel corridors and provide direct evidence of culvert use. Bobbin attachment was modified from methodology employed by Wilson 1994 with bobbins obtained from Coats North America (formerly Barbour Threads). Bobbins were approximately three grams and contained 200 yards of thread. Bobbins were placed in ¾inch diameter heat-shrinkable tubing (Russell industries, Inc., HUG-34-4PB) then heated so that the tubing encased the thread bobbin. The encased thread bobbin was then epoxied onto the turtle's carapace and edges were smoothed over with caulking to prevent tangling. Bobbins were tied to vegetation and unraveled as turtles moved. Expelled thread was followed each day for three consecutive days to determine individual movement paths. A sketch of the thread trail was drawn, illustrating the movement. Expelled thread was collected daily and removed to minimize the possibility of tangling. Thread bobbins were removed from all turtles during the week of June 30, 2004.

Data and analyses

Based on radio tracking and thread trailing data gathered over the field season, maps of each turtle's home range and movements were generated. Home ranges were determined by the minimum convex polygon method for ArcView 3.x, v. 1.2 (Jenness 2004). Turtles with at least 10 observations over a sixweek period were included in the home range analyses. Because the home range maps contain locationspecific data for a statelisted species, the home range analyses are provided descriptively and not graphically.

Results and Discussion

Spotted turtles were captured from April 8 to July 7, 2004. This section provides the results of the 2004 captures, with comparisons to the 19981999 preconstruction study, as well as a description of the effectiveness of the culvert as a connectivity link between Wetland 17 and Turtle Pond. Home range estimates are also provided for radio tracked individuals, with comparisons to the 19981999 preconstruction study.

Population dynamics

Fifty-six individual spotted turtles were captured during the 2004 study. In 2004, 35 of the 56 turtles (63%) were recaptures, while 21 were new captures (37%). Four turtles captured for the first time in 2004 had been notched by others prior to 1998. As with previous years, most turtles (41 individuals, representing 73%) were captured in April. The majority of the captures (46 turtles; 82%) occurred in Wetland 17, followed by seven captures in Turtle Pond (12%), and three turtles in the red maple forested wetland (6%). As with previous years, most turtles (55 individuals; 98%) were captured by hand. Six turtles were caught in traps in Wetland 17, five of which were 2004 recaptures.

The population of spotted turtles appears to be healthy. To date, 81 spotted turtles have been captured and marked. Forty spotted turtles were captured and marked during the 1998 field season, 20 turtles were captured and marked in the 1999 field season, and 21 during 2004. Of the 81 turtles, 13 were previously captured and marked by others.

In 2004, new captures were skewed towards females (9 individuals) and juveniles (8 individuals), with four male captures (table 1). This ratio is similar to 1999 captures. Over the three field seasons, juveniles comprised greater than onethird of the population (31 individuals; 38%), indicating substantial juvenile recruitment into the population.

Overall, females were captured at slightly greater ratio than males (1.2:1), although in 1998, males outnumbered females by a 1.3:1 ratio. This trend is not similar to what has been reported in the literature, where several studies have documented a male bias in turtle populations when there is an adjacent major roadway such as Route 58 (Aresco 2005, Steen and Gibbs 2004, Gibbs and Shriver 2002). Some researchers theorize that populations contain higher numbers of males because females are physiologically required to seek open, sandy upland areas for nesting, which may involve higher roadcrossing frequency than males, thereby exposing females to greater vulnerability from vehicle mortality.

Table 1. Age and Sex Ratio of Spotted Turtle Captures

Capture Year	Adult Captures		Juvenile Captures*	Total captures
	Male	Female		
1998	14	11	15	40
1999	5	7	8	20
2004	4	9	8	21
Total	23	27	31	81

* Juveniles were classified as those individuals with a carapace length less than 80 millimeters

In the study area, the slight female bias may be caused by nest site selection. Like many chelonians, sex determination in spotted turtles is temperaturedependent. Temperatures at or above 86 degrees Fahrenheit during egg maturation produce all females (Ernst et al. 1994). Roadways can provide seemingly suitable nesting sites as they often have higher soil temperatures, lack canopy cover, and exhibit higher ambient temperatures because of the heat that pavement absorbs and attracts (Aresco 2005). If nesting is occurring adjacent to Route 58, it is likely that more females than males are being produced. Preliminary assessments of juvenile sex, while unreliable because sexual differentiation is not well established in juveniles, indicates that many more females are present in the study area than males. Of the 31 juvenile captures, 23 were female, 4 were male, and 4 were undetermined.

Eight dead spotted turtles were encountered during the three field seasons (five in 1998, two in 1999, and one in 2004). Two adult females (Turtles 43 and 50) and four juveniles were found dead on the Route 58 shoulder (east side), and two dead juveniles were found in Wetland 17. It is likely that the females were either attempting to cross Route 58 to nest in uplands on the west side of the road, or were attempting to nest on the roadway sideslopes. However, the high number of recaptures observed between the postconstruction and preconstruction study appears to indicate that the sexually mature individuals are experiencing relatively low mortality rates.

Based on the slight female bias in the population, and the large number of recaptures observed in 2004, Route 58 does not appear to cause additive mortality. The proportional ratio could mean that the Route 58 and 44 are not a large source of additive mortality. Females may also be nesting in close proximity to Wetland 17 and/or Turtle Pond in areas that do not require roadway crossings.

Home range analysis

In, 2004, radio tracked turtles consisted of five females and four males. Five spotted turtles tracked during both preconstruction seasons (Turtle 5A, 6A, 8, 30A, and 60), and one individual tracked in 1999 (Turtle 25) was radio tracked in 2004. Two turtles captured in 1999 but not previously tracked (Turtles 52 and 550) and one 2004 capture (Turtle 13) were tracked in 2004. Originally, four females and four males were fitted with radio transmitters. After four weeks of tracking, Turtle 6A's signal was weak, and movement appeared to be minimal based on thread bobbin tracking. Her radio transmitter and thread bobbin were removed, and a new transmitter and thread bobbin was fitted to another female (Turtle 52).

Mean home range size for males was 3.1 acres in 2004 and 3.3 acres over the three years (table 2). Female mean home range was slightly smaller (2.6 acres in 2004 and 2.1 acres between years). Male home ranges varied from 1.4 to 4.9 acres in 2004, and female home ranges varied from 1.7 to 3.6 acres. Our data are consistent with Graham's (1995) result of 1.98 acres. His average, however, may be low because only three individuals were tracked. In western Massachusetts, Milam and Melvin (2001) found home ranges varied from 0.5 acres to 85 acres, with a mean home range of 8.9 acres in a study involving 26 individuals. Larger home ranges were attributed to the longer tracking period of study and inclusion of all data points in the analyses. The smaller home ranges observed in this study may be attributed to higher quality habitat in a smaller area.

Table 2: Spotted Turtle Home Range Sizes

Turtle	Male Size (acres)				Turtle	Female Size (acres)			
	1998	1999	2004	Mean		1998	1999	2004	Mean
8	5.2	3.9	3.1	4.1	5A	3.2	0.5	--	1.9
10A	5.4	3.5	--	4.5	6A	--	2.2	--	N/A
30A	1.5	4.2	3.1	2.9	13	--	--	2.7	N/A
60	1.0	2.7	1.4	1.7	25	--	2.0	2.5	2.3
550	--	--	4.9	N/A	50A	3.2	2.5	3.6	3.1
					52	--	--	1.7	N/A
					70A	0.5	1.0	--	0.8
					4002	0.1	1.0	--	0.6
Mean	3.3	3.6	3.1	3.3	**Mean**	1.7	1.5	2.6	2.1

Home ranges for five turtles were analyzed during the pre and postconstruction study. Most turtles showed large yeartoyear variations, with no consistent differences between pre and postconstruction. Turtle home ranges vary year to year, based on numerous factors such as climate and food resources.

Aquatic turtles such as spotted turtles are often found in welldefined populations (Gibbons 1968), and this was also observed for spotted turtles in the study area. Spotted turtles showed a great deal of overlap in their home ranges with other radioed turtles, as well as with other captured turtles. In 2004, six of the nine radioed turtles spent time in both Wetland 17 and Turtle Pond. All turtles, except Turtle 13, spent a portion of their time in Wetland 17. All turtles, except Turtle 6A and Turtle 60, spent a portion of their time in Turtle Pond.

Culvert effectiveness

Past studies have indicated that spotted turtles appear to maintain their corridors and movement patterns between years (Perillo 1997, Klemens 2000). In order to determine if the installation of a 6foot by 6foot culvert was an effective tool to maintain habitat connectivity used by this population of turtles, radio transmitters and thread trailing devices were attached to nine turtles.

Direct Evidence. Direct evidence such as thread trail or visual observation of a turtle moving through the culvert was used to confirm use of the 6foot by 6foot box culvert. Seven of the nine tracked individuals had been followed either in 1998 or in 1999. On average, bobbins were attached for nine weeks, collecting 27 days of movement throughout the late spring, when movement is typically at its highest. Turtle 30A had its bobbin attached for the longest time (11 weeks), while Turtle 52 had its bobbin attached for the shortest time (3 weeks).

Thread trailing was used to show actual movements by the turtles, compared to telemetry, which provided movement "snapshots." The benefit of thread trailing is that it allows researchers to directly observe individuals movement patterns. A list of the turtles and dates of tracking is provided in table 3.

Table 3. Spotted Turtles Tread Trailing Dates

Turtle	Dates: Bobbin Attached	Dates: Bobbin Removed
6A	April 12	May 12
8	April 8	June 8
13	April 15	June 8
25	April 16	June 8
30A	April 6	June 22
50A	April 8	June 4
52	May 19	June 8
60A	April 15	June 4
550	April 16	June 9

Bobbins were only functioning 3 consecutive days per week

Thread trailing provided direct evidence that the culvert was effective as a crossing structure and that the construction of the Route 44 access ramp will not negatively impact the ability of the turtle population to access Wetland 17, Turtle Pond, and other habitats.

Seven individuals (3 male, 3 female, 1 unknown) used the culvert seven times (table 4). A thread trail was observed five times indicating movement; two turtles that were not being tracked were visually observed moving through the culvert, and one unidentified individual (eluded capture) was visually observed moving through the culvert. Four of the nine turtles with bobbins used the culvert. Turtle 30A provided the most direct evidence of use, leaving a thread trail on two occasions. Females appeared to move in relation to nesting (mid-June), while males' movement appeared to correlate to mating (May).

Turtles 7, 54, and 70A were all observed at the culvert entrances multiple times but never observed traveling through or on both sides of the culvert. The culvert may provide additional usefulness other than maintaining connectivity. The culvert has 4 to 6 inches of organic substrate that may be used in thermoregulation as well as the shade it provides. The culvert may also provide foraging opportunities because of the different environment it provides for food resources.

Table 4. Spotted Turtles Culvert Use (Direct Evidence)

Turtle	Sex	Date	Direction	Method of Observation
8	Male	May 6	W17 - Turtle Pond	thread trail
15	Female	June 16	Turtle Pond - W17	visual observation
25	Female	June 17	Turtle Pond - 17	thread trail
30A	Male	May 6	Turtle Pond - W17	thread trail
		June 1	Turtle Pond - W17	thread trail
52	Female	June 16	Turtle Pond - W17	thread trail
5000	Male	April 28	Turtle Pond - 17	visual observation
Unidentified	--	May 18	W17 - Turtle Pond	visual observation

Indirect Evidence. Thirteen individuals were observed on both sides of the culvert during the field season. This determination was made using radio telemetry and from direct observation. It is likely that the turtles used the culvert because other pathways are improbable. The highway entrance ramp is elevated 10 to 15 feet above the wetland with steep, riprap slopes. The bottom three feet to five feet of the ramp sideslopes consist of twofoot to threefoot boulders, which would make it extraordinarily difficult for turtles to climb. Individuals would have to travel several hundred feet to the south with little cover to access a flatter portion of the ramp that could be more easily ascended.

Thirteen individuals (8 male, 5 female) were observed on both sides of the culvert. Seven of the 13 individuals had transmitters. The culvert may have been used a total of 31 times by these 13 individuals (table 5). Overall, between direct and indirect observations, 14 different individuals possibly used the culvert for a total of at least 39 times.

Table 5. Spotted Turtles Culvert Use (Indirect Evidence)

Turtle	Sex	Date	Direction of Movement
1	Male	April 19 / May 13	Wetland 17 – Turtle Pond
8	Male	June 16 / July 14	Turtle Pond – Wetland 17
		August 3 / August 19	Wetland 17 – Turtle Pond
		August 24 / September 31	Turtle Pond – wetland17
15	Female	June 10 / June 16	Wetland 17 – Turtle Pond
18	Female	April 20 / June 10	Wetland 17 – Turtle Pond
25	Female	June 18 / June 22	Turtle Pond – Wetland 17
		August 10 / August 19	Wetland 17 – Turtle Pond
30A	Male	April 29 / May 5	Wetland 17 – Turtle Pond
		May 7 / May 12	Wetland 17 – Turtle Pond
		May 27 / June 1	Turtle Pond – Wetland 17
		June 8 / June 9	Wetland 17 – Turtle Pond
42	Male	April 20 / May 13	Wetland 17 – Turtle Pond
50A	Female	May 14 / May 18	Turtle Pond – Wetland 17
		August 10 / August 19	Wetland 17 – Turtle Pond
52	Female	June 10 / June 16	Wetland 17 – Turtle Pond
		June 18 / June 22	Wetland 17 – Turtle Pond
		June 22 / June 23	Turtle Pond – Wetland 17
		June 30 / July 7	Wetland 17 – Turtle Pond
		July 14 / July 21	Turtle Pond – Wetland 17
		July 21 / July 27	Wetland 17 – Turtle Pond
		August 10 / August 19	Turtle Pond – Wetland 17
60	Male	June 30 / July 7	Wetland 17 – Turtle Pond
		July 7 / July 21	Turtle Pond – Wetland 17
550	Male	June 30 / July 7	Turtle Pond – Wetland 17
		August 10 / August 19	Wetland 17 – Turtle Pond
4400	Male	April 29 / June 9	Wetland 17 – Turtle Pond
		June 9 / July 21	Turtle Pond – Wetland 17
5000	Male	April 19 / April 27	Wetland 17 – Turtle Pond
		April 29 / May 20	Wetland 17 – Turtle Pond
		June 10 / September 31	Turtle Pond – Wetland 17

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Use of Highway Underpasses by Large Mammals and Other Wildlife in Virginia and Factors Influencing Their Effectiveness

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Abstract: The rapid increase in animal-vehicle collisions on U.S. roadways is a growing concern in terms of human safety, property damage and injury costs, and viability of wildlife populations. Wildlife crossing structures are gaining national recognition by transportation agencies as effective measures to reduce animal-vehicle collisions and connect wildlife habitats across transportation corridors. In Virginia, white-tailed deer and black bear pose the highest risk. This one-year study was conducted to monitor various underpass structures in Virginia to determine the structural and location attributes that make a crossing successful in terms of use by large mammals. The underpasses, most of which were not specifically designed as wildlife crossings, consist of box culverts and bridges of varying sizes.

Remote cameras installed at seven underpass sites in Virginia have recorded more than 2,700 wildlife photographs and documented 1,107 white-tailed deer crossings in the most heavily used structures. Underpasses with a minimum height of 12 ft were successful at facilitating deer passage. Such structures were also heavily used by a variety of wildlife species, including coyote, red fox, raccoon, groundhog, and opossum. Structures with drainages that mimic natural waterways can encourage use by a diversity of terrestrial, semi-aquatic, and aquatic species.

This report provides guidance in choosing cost-effective underpass design and location features that are necessary to consider to increase motorist safety and habitat connectivity. The findings also demonstrate that if only a minimal number of deer-vehicle collisions is prevented by an effective underpass, the savings in property damage alone can outweigh the construction costs of the structure.

Introduction

The increasing frequency of animal-vehicle collisions in the United States is taking an enormous toll in terms of wildlife viability and driver safety. For species that commonly attempt to cross roads, the numbers of animals killed can have a devastating effect on their populations. Roads and highways act as barriers for other species, isolating populations and increasing the chance of local extinction. For humans, more than $1.1 billion in vehicle damage is caused in the United States from an estimated 1.5 million traffic accidents involving deer alone (Hedlund et al. 2003). In Virginia, the white-tailed deer (*Odocoileus virginianus*) population has increased 400 percent since 1968, and Virginia's human population has increased 61 percent. As a result of these drastic increases, the number of reported deer-vehicle collisions (DVCs) in the state has increased nearly eight-fold in the last 35 years.

In areas where black bear attempt to cross roads, road-mortality has significantly affected black bear (*Ursus americanus*) populations in the southern Appalachians. As roads are upgraded to accommodate greater traffic volumes, the rate of successful black bear crossings in the Appalachians decreases significantly, and black bears become reluctant to cross roads (Brody and Pelton 1989, Virginia Dept. of Game and Inland Fisheries 2002). This avoidance of roads can isolate wildlife populations, and ultimately reduce biodiversity and genetic variability.

Wildlife crossings, or passages beneath or above a roadway, are a form of mitigation designed to facilitate safe wildlife movement across a transportation corridor. In a literature review of 16 mitigative techniques to reduce DVCs, the only measures consistently found to achieve DVC reductions were the installations of exclusionary fencing and wildlife crossing structures (Knapp et al. 2004). Similarly, the 2003 report issued by the Insurance Institute for Highway Safety regarding methods to reduce DVCs concluded: "Fencing, combined with underpasses and overpasses as appropriate, is the only broadly accepted method that is theoretically sound and proven to be effective" (Hedlund et al. 2003, p. 14).

Because many states have relatively few structures designed to facilitate wildlife passage, monitoring for wildlife use is often limited to underpasses that were designed for other purposes. Structures such as bridges or culverts that were constructed to span streams and rivers, to protect wetlands, or to provide access for farm animals or equipment may function as wildlife crossings. Virginia has multiple structures throughout its roadway system that are likely used by wildlife. The Virginia Department of Transportation (VDOT) has constructed two structures designed for large mammal passage in northern Virginia, and others are currently under construction on Route 17 through the Great Dismal Swamp National Wildlife Refuge. However, VDOT has no information regarding the performance of any of its structures in terms of facilitating animal movement.

The purpose of this study was (1) to determine the effectiveness of VDOT's existing large mammal crossings, (2) to determine the design and location attributes that make a wildlife crossing successful in terms of use by Virginia's large mammals and the associated influence on animal-vehicle collisions, and (3) to analyze the costs of wildlife crossing construction relative to the potential savings in property damage resulting from a reduction in animal-vehicle collisions.

Methods

Underpass study sites

Seven underpass structures were monitored over a 12-month period, from June 1, 2004, to May 31, 2005. These sites were chosen in order to obtain a representative sample of structures beneath Virginia roadways that potentially function as deer and black bear crossings. Five of the structures (Sites 1, 2, 4, 5, and 6) were not constructed for the purpose of wildlife movement, and two structures (Sites 3A and 3B) were installed specifically for animal passage. Because most of the structures were not designed as wildlife crossings, study sites are generally referred to as "underpasses" or "structures" rather than wildlife crossings in this report. Sites 3A and 3B were constructed with a section of grating 45 ft by 10 ft (18 m by 3 m) centered in the ceilings (in the highway median above) to allow in sunlight. Most structures convey water (generally a narrow stream or creek) but also offer ample space for animal movement.

Eleven variables including structural, landscape, and human activity attributes were measured at each site (table 1). The openness factor, a structural variable used as a measurement of ambient light in a structure, was calculated by the equation (width x height)/length. Openness has been found to be a significant factor in determining relative effectiveness of structures in terms of use by deer and other species (Reed et al. 1975). Other attributes, including structure ground covering and frequency of human visits to the structures, were also recorded. The description of the deer habitat suitability indices are described below.

Table 1. Attributes of underpass structures in Virginia monitored from May 2004 through May 2005

Attributes	**Structure**						
	1 Box Culvert	**2 Bridge**	**3A Box Culvert**	**3B Box Culvert**	**4 Triple Box Culvert**	**5 Double Box Culvert**	**6 Bridge**
Structural							
Width, ft (m)	10 (3.0)	32 (9.8)	20 (6.1)	10 (3.0)	6 (1.8)	8 (2.4)	44 (13.4)
Height, ft (m)	12 (3.7)	45 (13.7)	15 (4.6)	6 (1.8)	6 (1.8)	8 (2.4)	15 (4.6)
Length, ft (m)	189 (57.6)	307 (93.6)	192 (58.5)	105 (32.0)	68 (20.7)	260 (79.2)	59 (18.0)
Openness (metric) [a]	0.19	1.43	0.64[b]	0.17[b]	0.16	0.07	3.42
Structure floor	Natural	Natural	Natural	Concrete	Concrete	Concrete	Natural
Fencing, ft (m)	5200 (1,585)	None	40 (12)	40 (12)	None	None	None
Landscape (distance to)							
Forest cover, ft (m)	0	15 (4.6)	12 (3.7)	5 (1.5)	7 (2.1)	0	50 (15.2)
Drainage, ft (m)	320 (97.5)	0	0	0	0	0	0
Human activity							
Human use	3	17	10	5	1	1	2
Traffic intensity[c]	H	H	H	H	M	H	H
Deer habitat suitability index[d]	72.20	74.15	65.68	67.91	72.41	62.56	64.40

[a] Openness was determined by calculating (height x width)/length (Reed et al., 1975).
[b] Because the ceilings of structures 3A and 3B have a grated center section that allows in light, the openness value was calculated using ¾ of the length.
[c] Based on average annual daily traffic of High (10,000-49,999), Medium (1,000-9,999), and Low (0-999).
[d] Based on a scale of 1 to 100. Land use was similar in the immediate surroundings of study sites, reflected by the proximities of the indices.

Underpass monitoring

Data from monitoring animal movements were obtained from Game-Vu (Nature Vision, Inc.) and Stealth Cam® digital scouting cameras. These remote cameras photograph images based on infrared heat and motion sensors. Game-Vu Digital Trail cameras use undetectable infrared illumination at night rather than a flash and were, therefore, installed at sites where human visitation was a concern. Stealth Cam® cameras were used at the other sites because of their slightly longer range at night. Two cameras were installed at each site. For box culvert monitoring, one camera was attached to a tree, to a wooden post, or near the ground at both of the structure entrances. For bridge monitoring, two cameras were attached to trees on either end of the bridge. Because cameras could not capture the entire range beneath the Site 2 bridge, sand beds at each end of the bridge were checked weekly for large mammal tracks to supplement camera monitoring.

Structures were visited once every week during the 12-month period to download photographs from the cameras and to replace batteries. Data recorded from photographs at each site included the date, time, number of photographs of each species, and direction of travel. The number of complete passages through the structure by deer and black bears, the number of turn-around events (approaches to an underpass with incomplete crossings), and the number of hesitancy behaviors by deer (indicated by muzzles lowered to the ground) were determined (Reed et al. 1975, Gordon and Anderson, 2003).

On some occasions, camera battery power depleted one to two days prior to replacement. In order to account for site differences in camera operative days, crossing frequency indices were calculated by dividing the number of crossings by deer and black bears at each site by the respective number of camera operative days.

Development of deer habitat suitability indices
In order to make valid comparisons of underpass use by deer, it was necessary to quantify either deer population or deer habitat suitability in the vicinity of each underpass. Given the spatial and geographic variation among the seven sites, it could not be assumed that deer populations and habitat suitability were uniformly distributed around the sites. Because the size of the deer population immediately surrounding each site was unavailable, deer habitat suitability indices were developed. The higher the index, the higher the relative deer habitat suitability was surrounding the underpasses. These indices were later used in the statistical analyses of underpass use.

A geographic information system (GIS) is a widely used tool for modeling habitat suitability for a variety of applications. Much of the development of deer habitat suitability indices for this study was adapted from the work of Clevenger et al. (2002) and Clevenger and Waltho (2005). They found that a GIS-generated model, using habitat information derived from expert literature to perform pairwise comparisons, most closely approximated an empirical model for identifying black bear habitat. For the development of the deer habitat suitability indices for this study, a similar methodology was applied with the use of ArcGIS® (Environmental Research Institute, Redlands, California) and a pairwise comparison matrix (Saaty 1977).

National land cover data were obtained from the U.S. Geological Survey and imported into ArcGIS®. This dataset included 13 habitat types within the areas surrounding the underpass sites. Because the home range of deer is generally no larger than one mile (Severinghaus and Cheatum 1956), a one-mile buffer was generated around each of the seven underpass sites. The ArcGIS® Spatial Analyst extension was then used to determine the percentage of each habitat type within each one-mile radius.

For the pairwise comparison, each of the 13 habitat types was rated against the other in terms of relative importance of the habitat for white-tailed deer. Ratings were based on a nine-point continuous scale: 9, extremely more important; 7, very strongly more important; 5, strongly more important; 3, moderately more important; 1, equally more important; 1/3, moderately less important; 1/5, strongly less important; 1/7, very strongly less important; and 1/9, extremely less important (Saaty 1977). Information on which to base deer habitat ratings was obtained from four sources of information (Harlow 1984, Newson 1984, Shrauder 1984, Whittington 1984); the latter three were directly relevant to deer in Virginia. Two individuals, including the author, used the information from these sources to complete the pairwise comparison matrix. The completed pairwise comparisons resulted in weights for each habitat type. A consistency ratio was calculated to ensure consistency in rating development. Pairwise comparison matrices with consistency ratios greater than 1.0 were reevaluated (Saaty 1977). The percentage of each habitat type (derived from the GIS analyses) within the one-mile radius of each site was then multiplied by its weight (derived from the pairwise comparison). The weighted values for the site were summed to derive a deer habitat suitability index. This method was repeated with each of the seven underpass sites. Indices are listed in table 1.

Underpass evaluations
The numbers of deer and black bear crossings, turn-arounds, and hesitancy behaviors were compared among all underpass sites. Sites 3A and 3B are located approximately 0.25 mi (400 m) from one another and potentially facilitate the movement of the same animal populations. Because they primarily differ in structural attributes, the use of these structures by all species was compared to help provide valuable information on animal preferences for crossing structures.

Data analyses
Multiple regression analyses were performed to determine the influence of underpass attributes on deer crossing frequency, adjusting for differences in deer habitat suitability between sites. Statistical analyses were performed with the assumption that the crossing frequency was a measure of the quality of the underpass as sensed by wildlife. For all analyses, differences were considered statistically significant when $p < 0.05$.

Criteria for success
In order to evaluate an underpass in terms of its effectiveness in reducing the barrier effect of roads and reducing animal-vehicle collisions, it was necessary to specify the criteria for success. Goals and criteria, adapted from those of Forman et al. (2003), include (1) maintain habitat connectivity (determined by a minimum passage of animals detected), (2) maintain genetic interchange (determined by a passage of adults), and (3) allow for dispersal (determined by passage of juveniles).

Determination of deer-vehicle collisions relative to underpass locations
Using available information obtained from Virginia's Highway Traffic Records Information System and Fairfax County police records, the number and locations of DVCs reported from 1997 through 2001 and 1995 through 2004, respectively, were recorded within several miles of each monitored site used by deer. Because only reported collisions are included in these records, however, a potentially large percentage of the actual collisions that occurred was unavailable for analysis.

Cost analysis

To transportation agencies, cost is often the largest deterrent to constructing wildlife crossings. Because there are currently no regulatory directives or guidelines pertaining to wildlife crossings, the decision by transportation agencies to construct them is often based on the expected return in investment. This may be in the form of ecological benefits and increased driver safety. Ecological benefits include the creation of wildlife corridors, reduced effects of fragmentation (Forman et al. 2003), and reduced road mortality. Driver safety includes a reduction in animal-vehicle collisions and the corresponding reduction in deaths, injuries, and property damage, which translates into savings for taxpayers. With regard to taxpayer savings, one human fatality from a DVC can result in a loss of millions of dollars in damage, hospital costs, and lost wages. Property damage costs alone comprise a substantial taxpayer cost. Since assigning a monetary value to the ecological benefits is difficult, the economic benefits solely in terms of a reduction in property damage were analyzed. Property damage values were derived from the 2003 average cost in property damage from DVCs in Virginia ($2,530).

Construction costs for two effective underpasses in this study, Sites 1 and 3A, were used for the analyses. Annualized costs, or the equivalent uniform annual costs, were calculated for these underpasses for comparison with annual DVC incidents. Annualized costs in these examples are the yearly costs of an underpass as if they were uniform throughout the service life of the structure (estimated at 70 years; Blackwell and Yin 2002). Although these sites do not have fencing designed to funnel animals toward the structures, fencing prices ($125,000 for each structure) were added to the underpass construction costs to represent more realistic examples of wildlife crossing scenarios.

Results

Deer and black bear activity

A total of 2,702 photographs of wildlife were captured at the seven sites over the 12-month period (fig. 1). Six of these photographs were of black bear, and 1,040 were of white-tailed deer.

Figure 1. Black bear approaching entrance of Site 1 (A), deer in Site 1 (B), red fox in Site 3A (C).

Black bears

No black bears crossed through any of the monitored underpasses, although they approached the northern entrance of Site 1 on three occasions. On two occasions, a bear remained facing the culvert entrance for two minutes before turning and leaving the area. On September 20, a bear approached the entrance a second time 38 minutes after the first approach.

Deer

A total of 1,107 deer crossings occurred through four of the seven underpass sites in the 12-month period (x= 277, *N* = 4). Sites 1, 2, and 3A received the heaviest use, and Site 3B the least. There were no crossings or visits by deer in Sites 4, 5, and 6. Although Site 1 received relatively high use by deer, it was associated with the highest number of turn-around events and hesitancy behaviors (fig. 2).

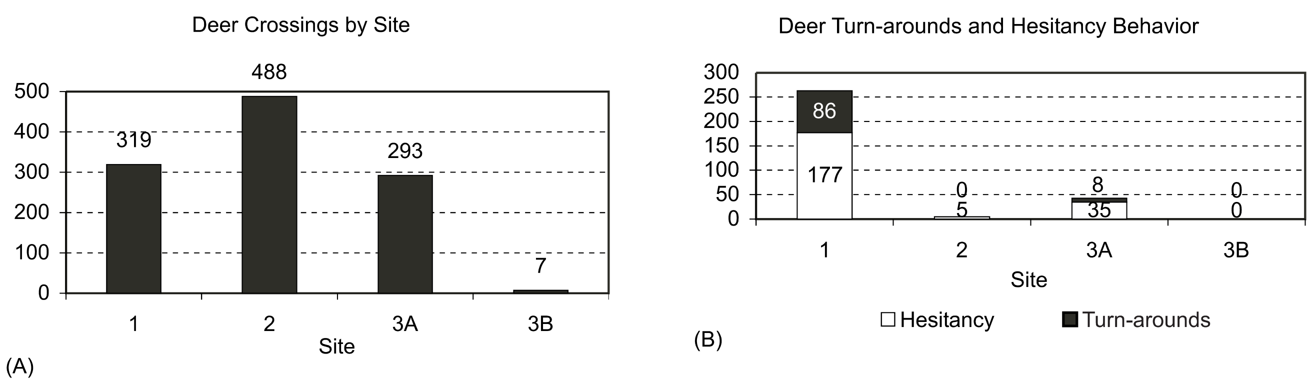


Figure 2. Number of white-tailed deer crossings (A) and number of turn-arounds and hesitancy behaviors (B) for underpasses visited by deer from June 2004 through May 2005.

The crossing frequency index was highest and most consistent at Site 2, with 1.34 crossings per day. Site 1 averaged 1.1 crossings per day, Site 3A averaged 0.91 crossing per day, and Site 3B received relatively little use, at 0.02 crossing per day. The monthly crossing frequency indices at each site were highest in the autumn months, dropped steeply in winter, and rose in late spring. During the period of heaviest activity in the fall, Site 1 received the heaviest use, reaching an average of 4.7 crossings per day in September (fig. 3).

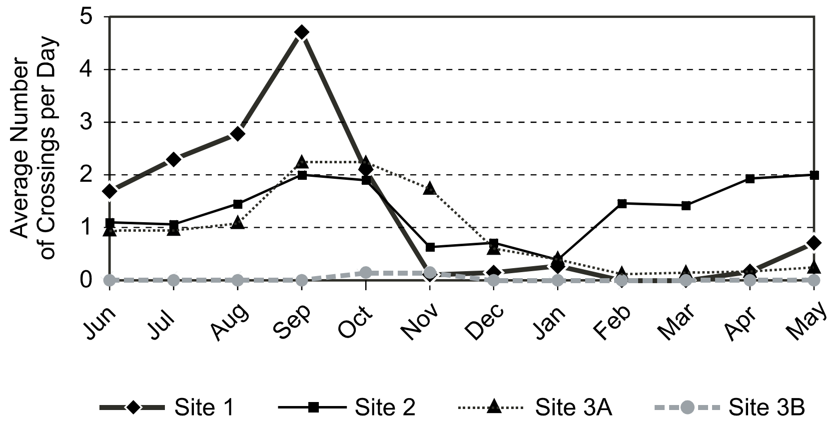


Figure 3. Average number of white-tailed deer crossings per day each month, from June 2004 through May 2005.

Other wildlife activity
Although the focus of this project was large mammal use of underpasses, the number and species of other wildlife were also recorded. Each underpass site was used by a minimum of two species. Other species detected included opossum, squirrel, house cat, bobcat, red fox, coyote, raccoon, groundhog, mice species, amphibian species (southern leopard frog and American toad), black rat snake, at least two bird species (songbird and great blue heron), and fish species. Because amphibian, reptile, mouse, and fish use of the underpasses was observed but not detected by cameras, these species were not included in the analyses. Nocturnal species used the underpasses between dusk and dawn, with daytime use generally limited to deer and groundhog. Cameras at Site 3A photographed a coyote with a small mammal in its mouth (species cannot be determined).

Because of the proximity and similar landscape attributes of Sites 3A and 3B, the sites were useful for comparing use by species. Activity was greater for all species in Site 3A, with 1,177 photographs compared to the 708 photographs at Site 3B (fig. 4).

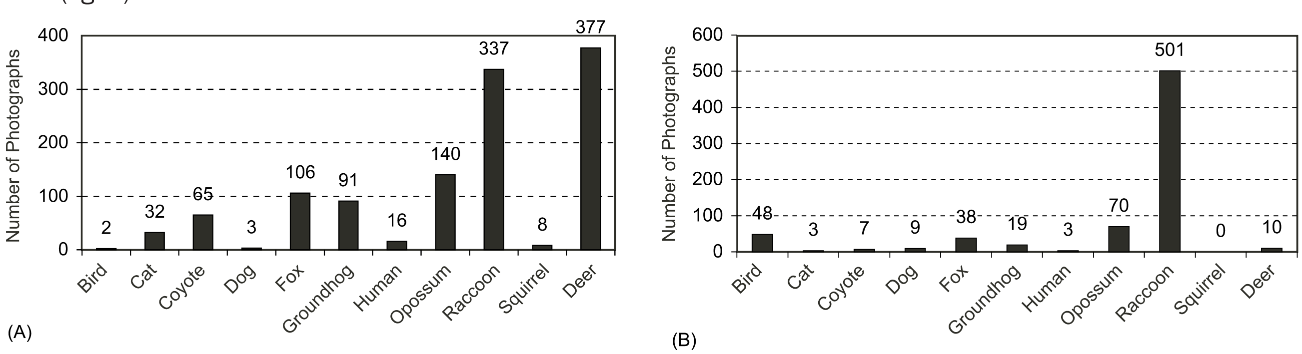


Figure 4. Number of photographs in Site 3A (A) and 3B (B) taken by two cameras at each site.

Underpass evaluations

Data analysis
A large discrepancy in deer crossing frequency was apparent between structures with a height greater than or equal to 12 ft (3.7 m) and those with a height less than 12 ft. To represent this distinction, height values were differentiated into these height groupings. Adjusting for deer habitat suitability at each site, an underpass height greater than 12 ft was significantly correlated to crossing frequency (Beta = 0.78 ± 0.20, P = 0.047). Landscape and human activity variables were not significantly correlated to crossing frequency.

Criteria for success
Underpasses were evaluated according to whether they met the predefined goals (table 2). Because no black bears crossed during the monitoring period, evaluations were based solely on white-tailed deer. In terms of meeting all three underpass goals for deer, Sites 1, 2, and 3A were determined to be effective overall.

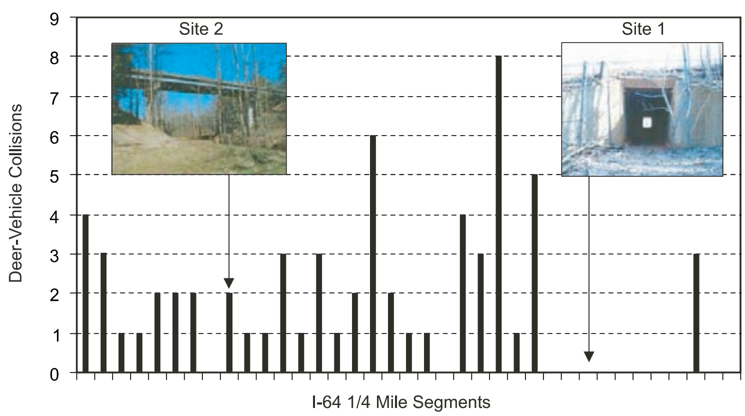
Table 2. Goals and successes (in terms of white-tailed deer use) of seven underpasses monitored from June 2004 through May 2005

Goals	Criteria for Success	Site						
		1	2	3A	3B	4	5	6
1. Maintain habitat connectivity	Minimum passage of deer detected	Yes 319	Yes 488	Yes 293	No[a] 7	No 0	No 0	No 0
2. Maintain genetic interchange	Passage by adults (primarily males in breeding season)	Yes	Yes	Yes	Yes	No	No	No
3. Allow for dispersal	Evidence of juvenile passage	Yes	Yes	Yes	No	No	No	No

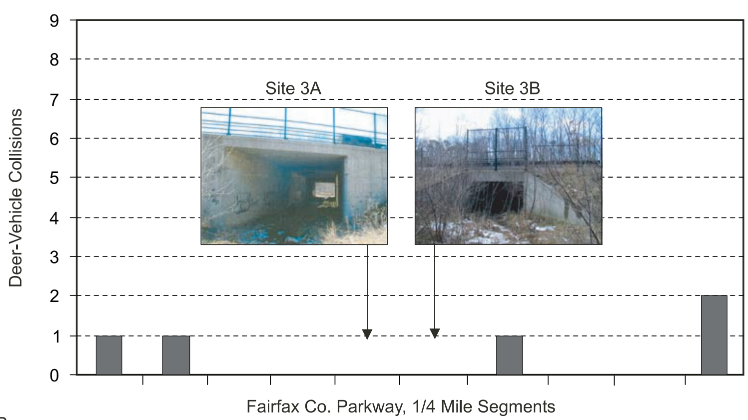
[a]Based on a comparison of the number of crossings at Site 3B relative to that at Sites 1, 2, and 3A, it is unlikely that 7 crossings over a 1-year period adequately met the goal of maintaining habitat connectivity. It is possible that the proximity of 3B to 3A influenced the crossing frequency at 3B.

Deer-vehicle collisions relative to underpass locations

Small sample sizes restricted the statistical analyses of the number of DVCs immediately surrounding the underpasses relative to segments with no underpasses. These data were, therefore, depicted graphically to illustrate the number of DVCs adjacent to underpass locations (fig. 5). For Site 1, there were no reported DVCs 0.75 mi to the west and 1.25 mi to the east of the underpass within a five-year period (1997-2001) for which data were available. At the section east of the underpass, a high ridge prevents deer from entering the highway. Within the 2.5-mile road segment (flanked by two perpendicular roads) under which Sites 3A and 3B lie, there were five DVCs within a 10-year period (1995 through 2004).



A



B

Figure 5. Reported deer-vehicle collisions in relation to location of underpasses used by white-tailed deer. DVC data for I-64 (A) include a 5-year period (1997-2001), and data for the Fairfax County Parkway include a 10-year period (1995-2004).

Cost analysis

The annualized costs were $6,600 for Site 1 and $23,000 for Site 3A (based on total costs of $257,000 and $585,000, respectively). Underpasses at these prices are cost-effective in terms of property damage savings when they prevent a minimum of 2.6 DVCs per year and 9.1 DVCs per year, respectively (fig. 6).

Because the Site 1 and Site 3A underpasses were constructed when the road was constructed, pre-construction DVC data are unavailable. However, considering that the numbers of deer crossings in Site 1 and Site 3A were 319 and 293, respectively, it is probable that more than 2.6 and 9.1 DVCs, respectively, were prevented that year. If this was the case, then the savings in property damage alone outweighed the annualized cost of the underpasses.

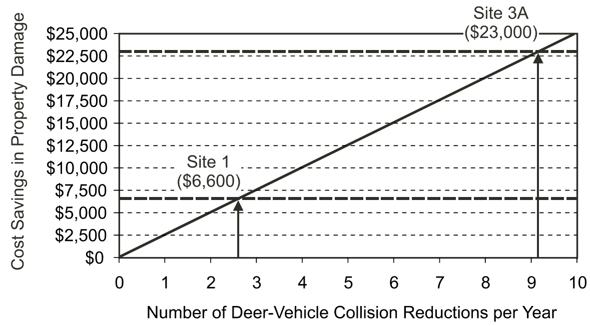


Figure 6. Cost savings in property damage resulting from reduction in deer-vehicle collisions.

Discussion

The results of this research concur with those of studies that have found that properly sized and located structures receive heavy use by wildlife (Foster and Humphrey 1995, Clevenger and Waltho 2005, Mata et al. 2005), thereby reducing the ecological effect of roads and reducing animal-vehicle collisions. For large mammals in Virginia, appropriate structure design is essential for maximizing the benefit from wildlife crossing construction.

Sites 1, 2, and 3A were determined to be effective road-crossing mechanisms for deer. Crossing frequencies were highest during late summer and fall. Crossing use reflected seasonal activity, with deer averaging nearly five crossings per day at Site 1 in the fall months. This corresponds to greater periods of movement associated with mating and feeding activities.

The other sites were ineffective in terms of facilitating deer passage. For most sites, this was a result of the structure's small size and corresponding low openness factor. For the bridge of Site 6, this was not the case. At this site, the structure size was adequate, but the uneven approach and lack of visibility from one end to the other likely discouraged large mammal use. At the western opening of this bridge, a four-foot ledge slightly impeded access to the area beneath the bridge, and the ledge and a rock cliff obstructed views of the habitat on the far side of each entrance. Effective underpasses were easily accessible with level approaches and had clear lines of site to the habitats on the far side.

Black bears approached but did not cross through any of the underpass sites. Because of annual fluctuations in food availability, environmental conditions, and inter- and intra-specific interactions, however, one year of data collection is insufficient to allow the conclusion that the structures are unsuitable for bears (Manen and Pelton 1995).

Attributes of effective underpasses

White-tailed Deer

Underpasses with a minimum height of 12 ft (3.7 m) were significant determinants of deer crossing frequency. The bridge (Site 2) had the highest deer passage rate and lowest number of incidents of hesitancy behavior and turn-arounds. This was expected because of its large size and lack of walls, unlike the Site 1 and 3A box culverts. Although the second highest number of crossings was at Site 1, 19 percent of the approaches to Site 1 were associated with turn-arounds. The high number of crossings at this site was likely influenced by the structure's position in the landscape. The southeastern borders along the underpass openings slope to a high ridge. This ridge functioned as a barrier to deer movement across the highway (as evidenced by no DVCs within 1.25 mi [2,012 m] east of the underpass), and the surrounding hillsides served as a guideway for deer toward the underpass (fig. 7). Although the optimal placement of Site 1 undoubtedly contributed to its high use by deer, the high number of incidents of hesitation and turn-arounds is likely explained by its relatively low openness index (0.19).

Figure 7. Aerial view of topographic features surrounding Site 1.

Conversely, the larger structure (Site 3A) had an openness index of 0.64 and had a low number of hesitancy behavior and turn-arounds (3%). Despite the lower deer habitat suitability rating of Site 3A (65.68) compared to Site 1 (72.20), Site 3A had only 26 fewer crossings than did Site 1 throughout the year. In addition, crossing frequency at Site 3A was more consistent throughout the year than that at Site 1. The size dimensions, presence of a creek, and ceiling grating of Site 3A are, therefore, thought to be more appropriate features for encouraging deer passage than those (or the lack thereof) at Site 1.

Previous studies on deer and other ungulates found that they preferred underpasses at least 23 ft (7 m) wide and 8 ft (2.4 m) high (Carsignol et al. 1993, Foster and Humphrey 1995), which is substantially wider (and likely costlier) than what was necessary to achieve a high crossing frequency in this study. Successful underpasses dimensions for white-tailed deer in this study concur with Smith's (2003) minimum height recommendation of 12 ft (3.7 m), and a minimum width of 10 ft (3 m). The length should be short enough to result in an openness index of at least 0.25 to discourage the high percentage of turn-arounds at Site 1. Lower structures may also be successful if the structure is wide and short (in length) enough to result in a high openness index.

Black bears

Research results on black bear size preferences for underpasses are conflicting. Clevenger and Waltho (2005) found that black bears prefer more constricted crossing structures with low heights and narrow widths. Other research has shown bears to use underpasses with larger, more open dimensions, such as bridges and a culvert 25-ft by 8-ft by 47-ft (7.6-m by 2.4-m by 14.3-m; Land and Lotz 1996). The presence of herbaceous vegetation at structure entrances was found to be important in bear underpass use (Smith 2003), and distance to nearest drainage was found to be positively correlated with black bear use (Clevenger and Waltho 2005). The fact that black bears approached Site 1 on three occasions, remaining at the entrance up to 38 minutes but not crossing through, may indicate that its structural dimensions are unsuitable for black bears. Further studies on black bear wildlife crossing preferences are needed.

Other wildlife

Structures that were effective for deer were also used heavily by other species. With the exceptions of Sites 3A and 3B, cameras were positioned to maximize the likelihood of deer and bear photographs and were, therefore, not optimally placed for capturing photographs of smaller animals. Because of the low camera positioning and the sites' proximity to one another, Sites 3A and 3B were useful for comparing use by small and medium species. Compared to Site 3B, Site 3A received the most use in terms of both number of photographs and number of species using the structure. Other than structure size differences, the only perceptible difference between these sites was the structure floor. Site 3A had an open bottom with a creek passing between two areas of dry land, whereas Site 3B had a concrete bottom that remained dry the majority of the year. In addition to the larger size and natural bottom of Site 3A, the presence of various-sized rocks in the underpass (for cover for small species) also likely influenced underpass use.

For some animals, the habitat within the underpasses appeared to be a center of activity within their home range. Many of the smaller mammals entered the underpass in one entrance, remained for several minutes to hours, and left from the same entrance. Animals, including deer, raccoon, red fox, and a great blue heron, were photographed drinking and/or foraging from the creek in Site 3A on multiple occasions. For medium and large animals, the underpasses generally appeared to be a means to access habitat on either side of the road. The photograph of a coyote with a small mammal in its mouth may suggest that carnivores use underpasses for catching prey. Although the coyote may have been carrying the prey from one side of the road to the other, there is some evidence that crossing structures have been used for hunting (Foster and Humphrey 1995).

Location and placement

Views differ regarding the most effective placement of wildlife crossings and whether structural features or location and landscape features are more important in determining a structure's success. Some studies have attributed success to placement, based on optimal location features or placement along actual travel routes, rather than the dimensions of a structure (Beier and Loe 1992, Foster and Humphrey 1995). Topography and watercourses can affect animal movement across a road. Barnum (2003) found that linear guideways, including ridgelines, drainages, and sharp breaks in cover type, correlate with road-crossing hotspots.

Other research has found structural attributes to be more important determinants of a structure's success for deer (Clevenger and Waltho 2005). In this study, height was the most important determinant of deer crossing frequency, although placement was also important. The hilly topography around Site 1, for example, seemed to serve as a natural guide for deer toward the underpass (fig. 7), and all sites used by deer were surrounded by suitable deer habitat on either side of the structures. Deer have likely altered their movement patterns over the years to cross through structures that meet the minimum size requirements, as it is unlikely that the heavily used underpasses (1,107 deer crossings in 1 year) were coincidentally placed immediately along deer travel routes. Studies suggest that wildlife passage increases as animals learn a structure's location and become accustomed to it over time (Land and Lotz 1996, Walker and Baber 2003).

Savings in property damage

Sites 1 and 3A are cost-effective in terms of property damage savings alone when they prevent a minimum of 2.6 and 9.1 DVCs per year, respectively. Considering the number of deer crossings in Site 1 and Site 3A (319 and 293, respectively), it is probable that those numbers are achieved annually.

Although the bridge of Site 2 received the heaviest use by deer, structures this size are likely not the most cost-effective if constructed primarily to facilitate deer passage. Multiple culverts, designed to serve the dual purpose of drainage, and fencing may provide more passage and reduce more DVCs for the same cost as a large bridge.

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Wildlife Crossings in North America: The State of the Science and Practice

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Abstract: In this paper we present results from a telephone survey as part of a National Cooperative Highway Research Program (NCHRP) project, *Evaluation of the Use and Effectiveness of Wildlife Crossings* (NCHRP 25-27). Specifically, we present a summary of North American efforts to mitigate road effects for wildlife. We stress the need to provide multiple wildlife passages along transportation corridors to begin to accommodate the movement of the full complement of species in an area. We surveyed over 250 transportation professionals in the United States and Canada by telephone to learn more about efforts to make roads more permeable for wildlife. We asked questions about both the practice and science associated with road ecology. Participants employed by agencies, private organizations, and academic institutions answered questions concerning wildlife crossings, planning for wildlife and ecosystems, animal-vehicle collision information, and past, current, and future research activities related to roads and wildlife. As of September 2005, we found that there were at least 460 terrestrial and 300 aquatic crossings in North America. Trends in practice over time since wildlife passages began to be installed in the 1970s appear to show an increased number of target species in mitigation projects, increased numbers of endangered species used as target species for mitigation, increasing involvement of municipal and state agencies, an increase in the number of passages and accompanying structures constructed, and a continent-wide trend of neglect of maintenance of these passages. The trends in the science revealed a tendency for a broadening of the scope of research in terms of the number of species considered, an increase in the length of time monitoring projects were conducted, and an increase in the number of participants in scientific monitoring of mitigation projects and in general road ecology research. There are several projects in North America where multiple crossings have been or will be installed to accommodate a large suite of species and their movement needs. These include Alberta's Trans Canada Highway mitigation efforts, Montana's U.S. Highway 93 mitigation projects, Arizona's projects along U.S. 93 and on State Route 260, Florida's I-75 Alligator Alley project, and Vermont's future Route 78 and US 7-SR 9 projects. These projects may be models for how road construction activities can increase the permeability of the roaded landscape. We also present recommendations to assist in the research, design, placement, monitoring, and maintenance of crossings. We summarize the state of the practice and science of road ecology with respect to wildlife with suggestions to increase permeability of transportation corridors, and to increase communication and cooperation among those who would be involved in the mitigation of roads and other travel corridors.

Introduction

How well are we mitigating the negative effects of roads for wildlife? Progress in the science and practice of road ecology in the past decade has increased dramatically, yet a summary of what has been accomplished and how these efforts are helping to make the roaded landscape more permeable for wildlife is lacking. In this paper we summarize the overall efforts and trends to mitigate roads for wildlife in North America as learned from a continent-wide telephone survey. We also suggest future needs in the practice and science of mitigating roads for wildlife.

Wildlife need to move across the landscape to meet their basic survival needs. Whether looking at phenomena such as long distance caribou migrations, butterfly movements, fish returning to inland waters to spawn, or frogs trying to find the nearest pond to lay eggs, there is a continuous theme of daily and seasonal movements throughout the entire life cycle of all faunal species. With our ever increasing "roading" of natural landscapes, barriers are created that tend to obstruct movements of both aquatic and terrestrial species. The inclusion of effective mitigation measures in our transportation programs and project plans, from the inception of long range plans, to the scheduled maintenance of roads and railways will help restore permeability to the roaded landscape and assist natural movement patterns. In North America, wildlife crossing passages have been installed along roads since 1950. Since that time they have been designed, built, monitored, and studied. While much has been learned, communication of results has been much less successful. One major theme in successful mitigation measures and in current scientific thinking of roads and wildlife is the need for restoring permeability. As biologists study movement needs of different species in a variety of ecosystems, it is increasingly evident that our efforts to help one or two focal species move under and over roads may not adequately compensate for the lack of permeability roads and railways cause for the entire complement of species in an area. Permeability is an essential concept to consider in efforts to accommodate wildlife in transportation corridors.

Permeability

There is general consensus that ecosystems and landscapes must be connected and permeable to support sustainable wildlife populations. The terms "connectivity" and "permeability" often are interchanged, but we argue that it is important to distinguish their meanings. Connectivity most often is used from an anthropogenic viewpoint. For example, when one looks at a map and sees a wildlife passage across that landscape, in the most fundamental sense of the word, the landscape is "connected." Of course, with more passages, the number of connections grows, but is the landscape permeable to species? The term "permeability" is perhaps best defined from an animal perspective and has to do with the allometric positioning of crossing structures based on species movement neighborhoods (Addicott et al. 1987). A "neighborhood" is an area that an animal uses to fulfill its daily needs. Some species migrate and may have a summer "neighborhood" as well as a winter "neighborhood." On a given landscape, a mouse does not use or move across that landscape in the same way as does a moose. The same landscape is viewed in very different ways by each species. The movement neighborhood of any species is defined by its size and vagility. When we define permeability in the context of a species' movement potential, i.e., by allometric scaling, we then have a way of restoring permeability across the landscape. By this definition, a permeable landscape allows free daily movement of a species across its home range (Bissonette, in prep). A permeable roaded landscape is one where the type and placement of wildlife crossings is such that it allows free movement for the complement of species in any given area. If only one crossing was installed over an area, it is likely that only a few species and perhaps only some individuals of a particular local population would be close enough to use the crossing. Connectivity would be maintained to some degree, but the overall permeability of the landscape for all wildlife species and all individuals would be low. Progress towards permeability begins when several different types of mitigation measures, e.g., different types and sizes of crossings, are placed close enough together throughout the course of the transportation corridor so that most species and individuals of populations adjacent to the road are able to use these crossings. A sufficient number of crossings would allow almost free daily movement so that members of most species would be able to find and use crossings within their home ranges. By facilitating daily movement, at least some measure of permeability is achieved. True permeability may not be achievable in practice on the roaded landscape; however, to the extent that barriers can be made less impermeable, then the benefits can be measured in sustainable and less isolated populations.

NCHRP 25-27
Permeability is an important goal of intelligent mitigation and road ecology research. This paper presents the results of a telephone survey that is part of a larger National Cooperative Highway Research Program (NCHRP) project, a three-year research effort titled, "Evaluation of the use and effectiveness of wildlife crossings" (also known as NCHRP 25-27). The objectives of NCHRP 25-27 are to convey the conceptual basis as well as practical management options for the placement of wildlife crossings to transportation professionals, biologists, and others concerned with wildlife and roads. The goal of this research project is to develop effective management guidelines in the form of a decision tool that will lead to effective *landscape connectivity* and the restoration of ecosystem integrity – while at the same time providing recommendations for efficient and effective transportation infrastructure in a cost-effective economic manner.

As part of the project, our research team is conducting several efforts that will assist in the design of the decision tool including: (1) a national telephone survey of state departments of transportation (DOTs) and provincial ministries of transportation (MoTs) to learn about how they mitigate roads for wildlife, (2) the compilation of 27 North American priorities for road ecology science and practice in dealing with roads and wildlife, (3) safety modeling to predict the common factors in animal-vehicle collisions across the continent, (4) the evaluation of past wildlife crossings in their success in reducing animal-vehicle collisions, (5) modeling of how the accuracy of the collection of animal-vehicle collision and animal carcass data influences the results of analyses, (6) evaluation of the indirect effects of roads through small mammal research along highways, and (7) development of allometric scaling equations using species home range and dispersal distance data to help determine the placement and spacing of wildlife crossings. The focus of this paper is to summarize the results of the telephone survey of United States DOTs and Canadian MoTs.

Methods

The telephone survey
A telephone survey was administered to agency personnel and others in all 50 United States, and most Canadian Provinces. The survey consisted of 25 questions centered on three areas of interest: (1) wildlife-road mitigation measure, (2) animal-vehicle collision data, (3) and transportation planning. Interviewees in the U. S. were selected from contact information on individual state project entries on the Federal Highway Administration's "Keep It Simple" website, and through consultation with Federal Highway Administration (FHWA) representatives. Primary as well as secondary and tertiary contacts were made. Canadian respondents were selected through personal contacts of NCHRP 25-27 team members. Once introduced to the survey, the contact was given the opportunity to refer the survey or specific questions to someone more knowledgeable within the agency. A minimum of two people were interviewed within every state to represent both the state DOT and the state (or Federal) wildlife agency. Interviewees not only provided answers to the survey questions, but were also asked to provide reports, articles, and photos of their mitigation measures, and DOT-sponsored research projects that focused on how wildlife move with respect to roads. The survey was conducted from July 2004 through September 2005.

Wildlife passage definition
An important component of this research was in the definition of a crossing passage. For this survey a crossing passage was defined as a new or retrofit passage over or below a roadway that was designed specifically, or in part, to assist in wildlife movement. Culverts and bridges already in place when fencing was installed to lead animals to these pre-existing structures were *not* included unless they had been altered with such methods as weirs for fish passage, shelves for terrestrial wildlife, rip-rap removed for wildlife movement, or other such similar actions. In many cases we had to make an informed decision on inclusion of the passage.

Results

Survey participants
As of 16 September 2005, 255 people had participated in this survey. The number of participants varied from one to 32 per state or province (figure 1 illustrates interviewees within the U.S.). In some states and provinces, it quickly became evident that information was not centrally available within the state DOT or provincial MoT, and biologists/planners within each district or region were called for their knowledge of crossings in their regions. Respondents included engineers, planners, and biologists/ecologists. The different expertise of the respondents provided a broad

range of information not available from any single person. Respondents included representatives from every state DOT, some Canadian MoTs, most state wildlife agencies, the Federal Highway Administration, the U.S. Fish and Wildlife Service, the U.S. Forest Service, the National Park Service, university professors and research personnel, several non-profit natural resource-based organizations, and consulting companies.

Practice - historic crossings

The first documented wildlife crossing in North America can be traced to Florida outside the Ocala National Forest. A pair of box culverts was installed for black bears at the request of a private landowner in 1950 (Evink 1996). This initial action was the beginning of Florida's leadership in wildlife crossings in North America which continues today. The next documented round of wildlife crossings began in 1970, with the second and third crossings installed in Colorado and New York, both for deer. The first overpass in North America was built for deer and elk in 1980 over I-15 near the town of Beaver in southwestern Utah.

Figure 1. Number of survey participants per state, as of August 2005. (Canada not included)

Total crossings

The total number of wildlife crossings in North America can only be estimated: the number depends, among other things, not only on how they are defined, but also on who is asked, and if terrestrial and aquatic crossings are considered separately or together. From our data, we estimate that there are a minimum of 460 wildlife crossings in North America for terrestrial species, and 307 for aquatic species. Crossings are classified by type. In the United States there are at least 253 larger crossings at least two meters high that allow larger animals (e.g., deer, moose, elk, bear) to cross, 149 smaller crossings for other terrestrial wildlife, and more than 307 aquatic crossings for riparian-based species, such as fish. Although our data for Canada are still incomplete, there are a minimum of 56 terrestrial crossings that we have yet to classify. Results as of August 2005 can be seen in figure 2.

Trends in practice

In this study of North American wildlife crossings, a number of trends have become apparent. These trends are based on the information from crossings first established in the 1970s and 1980s throughout North America. These trends include an increase in the number of target species in mitigation projects, increases in the number of endangered species as target species for mitigation, increased involvement of municipal and state agencies, an increase in placement of accompanying structures, and a continent-wide trend of neglect of scheduled maintenance of these structures.

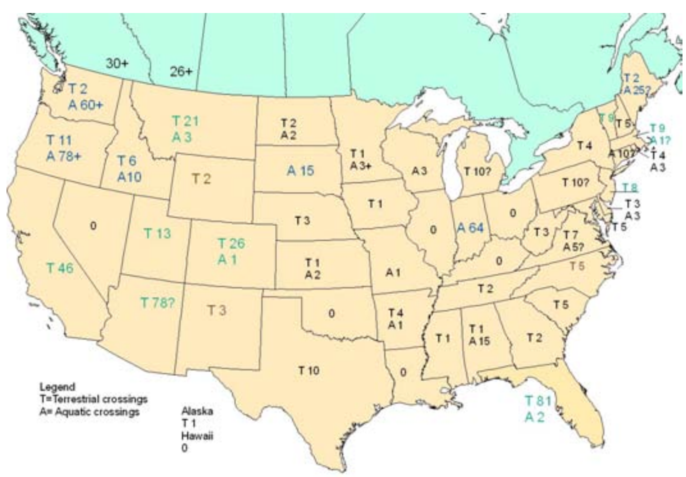

Figure 2. Number of wildlife crossings in each state and province of North America, as of August 2005. Some crossing have not been fully verified and located, and hence some states' numbers are followed by a question mark pending final verification.

Multiple crossings – achieving permeability

There are several projects in North America where a series of crossings has been or will be installed to accommodate a suite of species and their movement needs. A sample of these projects includes the Trans Canada Highway in Banff National Park, Alberta, with 24 crossings in place and eight more planned. These crossings include overpasses, underpasses, and culverts for species ranging from small mammals to grizzly bear and elk (Clevenger and Waltho 2000, Clevenger et al. 2003). In Montana, Highway 93 has 22 crossings of different sizes south of Missoula, and over 50 additional crossings planned from Sula at the Idaho border north to Polson at the south end of Flathead Lake in northern Montana. These crossings are typically intended for multiple species. Several have already been monitored, and they appear to be working for the intended species (Foresman 2001). In Arizona, Highway 93 has four crossings for species ranging from desert tortoises to bighorn sheep, and possibly as many as 50 more planned in the coming 10 years. In Florida the first series of crossings were built in 1992 along Florida's Alligator Alley for the Florida panther and accompanying wildlife species (Florida black bear, bobcat, deer, alligators, wading birds, fox, raccoon, opossum, fish, and others). Thirty eight crossings, from large underpasses to culverts were established over 64 kilometers (Foster and Humphrey 1995), apparently allowing for a higher degree of permeability than has been verified for most established crossings. Vermont has several simultaneous projects under construction across the state that may assist in creating better permeability in the roaded landscape. These include the Route 78 project near the Missisquoi National Wildlife Refuge, the Bennington Bypass on US 7, and work on State Highway 9.

Trends in science

This survey and our concurrent literature search revealed hundreds of relevant papers and reports related to wildlife crossings and roads. The most obvious scientific trends show a tendency for a broadening of the scope of research in the number of species considered, increases in the length of time for monitoring specific crossings, and increased numbers of partners in research projects. Monitoring of wildlife passages began in 1970 with the second underpass for wildlife in North America. This underpass was placed in the Vail Pass area along I-70 in Colorado and was monitored for mule deer use for four years with the most updated electronic technology of the time which included a video surveillance system (Reed et al. 1975). This level of monitoring was rare for passages placed during the following 20 years. Monitoring of passages has steadily increased during the past decade, and has significantly increased for the pre-construction phase of placing mitigation measures. Over the past decade there has been an ever increasing number of studies that considered multiple species near roads, thus broadening the knowledge base as well as mitigation efforts. Research projects today tend to monitor species' use of passages for greater lengths of time than studies conducted during the 1980s and 1990s, with an increase in the length of effort to several years post-construction. Finally, the scientific community is partnering with more entities than in past decades, broadening research to include connectivity analyses conducted by the consensus of natural resource professionals, and inclusion of other professionals in the design and placement of crossings. The increasing sophistication of technologies, such as geographic information systems (GIS), infra-red video cameras, and Global Positioning System (GPS) collars have greatly facilitated all aspects of scientific research of wildlife in relation to roads.

Discussion

Science – general recommendations for crossings

As part of research for the NCHRP 25-27 project, we have begun examining the general recommendations for installing wildlife crossings. Here we list the consistent trends that appear in the literature, conference presentations, and in our telephone interviews. This is what appears to be the consensus about what we know about the science of crossings:

- Bigger is better.
- Cover is important at the ends of passages and for some species inside the passage.
- Ungulates and carnivores appear to prefer different types of passages, for example, ungulates may prefer overpasses while certain carnivores prefer underpasses (see Clevenger's work in Banff).
- Natural light in the middle of tunnels or under-road passages (e.g., as might be provided under a divided lane highway where light is allowed into the underpass in the median) may be helpful for most prey species. Whether carnivores prefer light is unknown.
- Reduction of noise is helpful.
- In general, reduced human use, especially at night, is thought to facilitate passage.
- Pathways or shelves for wildlife to pass through underpasses or culverts with water appear to work for animals as large as deer and moose and for smaller animals, e.g., mice and voles.
- Considerations concerning special conditions for the target species or suites of species are necessary, for example:
    - Deer and perhaps other ungulates require a larger openness ratio than other mammals.
    - Some deer in urban-suburban situations will use pre-existing structures that are far smaller than what their counterparts in more natural landscape will use, for example, a culvert less than 2 meters high or with a 90-degree angle, suggesting that some behavioral plasticity exists in deer response.
    - Amphibians need tunnels that are wet and cool.

- ▫ Small mammals need cover in the form of logs, rocks, and bushes.
- ▫ Pronghorn need open, natural conditions as much as possible.
- ▫ Fish passage through perched culverts decreases significantly in relation to culvert height. Juvenile fish especially need culverts that rise no higher than two body lengths above natural water levels and they prefer low natural volume flows (1cfs) (May these proceedings).
- ▫ Fish can more readily cross culvert bottoms that mimic natural stream bottoms better than concrete or corrugated steel.
- ▫ Fish weirs may be necessary to accomplish low flow rate in existing culverts.

- When exclusion fencing is used, it is essential to include accompanying mitigation, such as jump outs (escape ramps), because large animals often access fenced right of ways.
- Ensure conservation protection for lands and waterways on both sides of the passages.
- Allow for a straight line of site through a passage for animals.
- Involve local biologists in all phases of project.
- Use adaptive management to monitor and improve future designs and maintenance based on monitoring results.
- In order to help restore permeability, provide several different types of crossings, or crossings adapted for suites of species. For example, provide cover, wildlife shelves or paths, small tubes, a culvert within a culvert, and similar modifications.
- Passages and accompanying mitigation elements, e.g., passage floors and holes in fencing need to be continually maintained and repaired in order to help insure their continued use.
- Monitor passage use for at least 3 years after construction: it may take wildlife 2 years or more to adapt, especially if they use the area only for seasonal migration.

Projects to watch

While every state and province in North America may be at a different stage in creating more permeable roads for wildlife, a few existing projects and programs might serve as examples of what can be done to mitigate roads for wildlife. The route that will perhaps be the most mitigated in the United States is U.S. 93, which extends from just northwest of Phoenix, Arizona, through Nevada, into Idaho, and through Montana and into Alberta. This road already has a minimum of four crossings for desert tortoises and ungulates in Arizona, and several crossings for fish and small mammals and 20 large mammal crossings in Montana. This highway will have an estimated 40 additional crossings in Montana, including one overpass, and dozens of crossings in Arizona, for a total of over 125 crossing across its stretch. Perhaps the best known of mitigation measures are those in Banff National Park on the Trans Canada Highway, with two overpasses and 22 underpasses over 45 kilometers, and 8 more planned along the next stage of construction (McGuire these proceedings). An example of a well designed mitigation and research project is the widening and mitigating of State Road 260 in Payson Arizona on the Tonto National Forest. This project was designed, constructed and monitoring in joint collaboration with the Arizona DOT, Arizona Game and Fish, the U.S. Forest Service, and several other collaborators. Seventeen bridges and culverts have been placed along the highway so that elk, mule deer, and other wildlife can cross safely underneath. The biologists working on the project have monitored wildlife use of these passages through the use of GPS collars, video surveillance systems, and road associated mortality data (Dodd and Gagnon these proceedings). Colorado's Mountain Corridor project for I-70 through the Rocky Mountains (Kintsch, these proceedings) with a possible overpass, and Washington's I-90 Snoqualmie Pass project (Wagner these proceedings) will use as many as a dozen new crossings per project. In the east, there are at least nine crossings constructed or under construction in Vermont and at least a half dozen more scheduled for the next five years, many of which will provide opportunities for many species. Florida continues to construct crossings, with 30 more planned for the next 10 years, including an overpass near Orlando.

Summary

Wildlife crossings and road ecology have evolved dramatically in the 55 years since the first crossings were installed in Florida. Wildlife and roads will continue to be an issue for the scientific and transportation communities as well as the general public. In fact, a recent survey of over 1,000 registered voters in the United States found that 89 percent of those surveyed felt that roads and highways were a threat to wildlife (Weigel 2005). The viability and sustainability of wildlife populations will be enhanced by the development of knowledge necessary for installing mitigation measures that create more permeable landscapes, thus allowing free movement by species. To achieve the goal of greater landscape permeability, it will take dedicated work to help insure that consideration of wildlife passages is included early in long-term highway planning, at the project level and in scheduled maintenance operations, as well as support for research that assesses whether passages are meeting stated goals and objectives. Successful mitigation will require effective communication between all stakeholders, including planners, engineers, and administrators. It is important to learn from our successes and failures and build on the current level of awareness among the profession and the public to create a continent-wide system of passages. It is a vision that will take time and needs our collective efforts.

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Wildlife Tunnels and Fauna Bridges in Poland: Past, Present and Future, 1997-2013

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Abstract: In Poland the road and rail network crosses many sensitive areas, such as national parks, landscape parks, wildlife reserves, landscape protection areas and Natura 2000 sites, i.e., the protected area system of the European Union, because of road density, high landscape diversity, and its mosaic pattern. As a consequence of Poland joining the European Union in 2004, many changes have happened and are still happening all over the country, especially in building new roads and railway lines. The harmonization of the Polish legal system with the EU directives required the improvement of environmental legislation making the monitoring before and after the building of such constructions necessary together with the preparation of environmental assessment studies. The animal migration problem has become one of the most important barriers in the decision-making process on where to build new roads and improve others. According to the previous plans, most of the roads that should have become expressways or highways of national or international importance also bring higher traffic and driving speed in those areas. As a consequence, the risk of collisions became higher and many motorists died in fatal accidents. On average, on the 160-km A2 highway running from Nowy Tomyśl to Konin, 40 accidents with mammals were recorded in one month in 2003. The consciousness of the society grew enormously following these events, and it also urged the appropriate governmental institutions, as well as private companies, investors, and non-governmental organizations, to study animals along the roads all over the country, with special attention to their movement. As a first step toward solving this problem, the identification of animal migration routes became an important task. Besides large species that can cause the death of the driver when colliding with a car (such as elk, deer, wild boar), several smaller animals (such as fox, badger, amphibians or reptiles) with vulnerable populations in the surveyed area were also studied, and the building of passages and bridges for wildlife has become not only an obligation but also a necessity both at the constructor as well as at the social level. Since 1997 more than ten overpasses and one underpass were built for large mammals (elk, deer, wolf, wild boar) in Poland. They are located along the E65 international road, Katowice - Kraków and the Przylesie - Nowogowczyce sections of the A4 highway, Poznan - Nowy Tomyśl and Nowy Tomyśl - Konin sections of the A2 highway, Stryszek- Białe Błota section of the no. 10. national road, and Komorniki - Stęszewo section of the no. 5. national road. The decision about the exact location of the game bridges and the game passage was made after detailed interviews with national park officials and foresters, in addition to the results of field work. The monitoring of the effectiveness of these constructions revealed a lot of mistakes and often proved no use of the mitigation measures by the target animals. The main reasons for non-functioning were too-small dimensions, especially width in all of game bridges; lack of screens separating the animals from noise; vibration, light and visual disturbances, no or not enough vegetation on the bridges; lack of guiding structures leading the animals to the passages; and lack of fences along the road. As a consequence of such results, mitigation measures were improved and maintained better. For small mammals, amphibians, and reptiles, nine underpasses were built in 2004 along the Budzisko - Augustów section of the international road called Via Baltica, Jeleniów section of the local road next to the E67 international road, and Chabówka - Rdzawka section of the E 47 expressway. The decision about where to put tunnels was made on the basis of field research (day and night transects, the sound monitoring of amphibians, and amphibian breeding sides investigations) made by national park staff, private companies, and volunteers. The follow-up monitoring of these structures showed that the effectiveness of the tunnels with guiding structures is nearly 100 percent for amphibians and reptiles and 85 percent for small mammals. In the following nine years (2005-2013) several more wildlife passages will be built on Polish roads along the Łódź - Częstochowa section of the A1 highway, Przylesie - Prądy section of the A4 highway, Rosnówek section of the no. 5. national road, Zywiec - Zwardoń section of the S69 international road, Wyszków - Skuszew section of the no. 8. national road, and Poznań - Kórnik section of the no. 11. national road. From among these constructions the most important passages will be along the Zywiec – Zwardoń section of the S69 international road, as they will be aimed to protect wildlife of international importance (bears, lynx, and wolves).

Introduction

Poland (Rzeczpospolita Polska) is a country on the Baltic Sea in the middle of Europe with Warszawa as the capital (Encyklopedia PWN 2005). Its area is 312.685 km^2, and the population is 38.2 million. Poland has borders with Russia (210 km), Lithuania (103km), Belorussia (418 km), Ukraine (535 km), Slovakia (541 km), Czech Republic (790 km), and Germany (467 km). Because of its geographical location Poland is an important country, as its road network connects Western and Eastern Europe as well as Southern Europe with the Baltic countries. Poland is predominantly a lowland country; 91.3 percent of its area is under 300 m with an average height of 173 m above sea level. Its highest point is in the south of the country in the Tatra Mountains (Rysy Mountain – 2,499 m above sea level); its lowest point is in the north (Vistula Delta - 1,8 under sea level). In Poland there are 89 species of mammals (most of them are forest animals like European bisons, roe deer, reed deer, wild boar, wolf, and moose), 220 species of birds, 9 species of reptiles, more than 25,000 insects and around 1,400 spiders.

At the end of 2004 there were 379,500 km of public roads in Poland, 66 percent of which are hard; 34 percent are earth surface roads (Czarniecki 2005). The average road density of hard surface roads was 80.7 km per 100 km^2 at the end of 2004. Highways were 552 km in total (in 2003 their length was 405 km), and one- or two-lane express roads 233 km (in 2003 this figure was 226 km). At the moment, road cover takes three percent of the country. By comparison, the coverage of national parks is one percent.

The environmental effects of the road network (barrier effect, animal mortality) were studied at several sites in the past 20 years (Wolk 1987, Bartoszewicz 1999), but the need to build animal passages developed in last 10 years, in a period when building new, and modernizing existing, roads in order to have a modern road network was decided.

The aim of this paper is to summarize the status of the Polish road network development and mitigation measures and make recommendations for the future.

Road Network Development in Poland

The highway network of Poland

A key to understanding the necessity of building wildlife tunnels and fauna bridges developed with building the road network. Highway building started in the 1980s in Poland. The development of the Polish highways is presented in table 1.

Table 1. Length and construction period of Polish highways through 2002 (Szczepaniak M. 2004)

Code	Highway section	Length (km)	Time of building
A1	Piotrkow Trybunalski- Tuszyn	18	1980s
A2	Wrzesnia- Konin	48	1980s
A4	Zgorzelec- Krzyzowa	2	1992-1993
A4	Krzyzowa- Wroclaw	109	before World War II
A4	Wroclaw- Nogawczyce	126	1997-2001
A4	Chorzow- Krakow	4	2000-2001
A4	Katowice- Krakow	65	1980s
A4	ring road around Krakow	16	1990-1994
A6	ring road around Szczecin	6	1998-1999
	TOTAL	394	

By comparison, Western European countries of similar size to Poland, such as Italy and Germany, had 6,473 and 11,515 km of highways, respectively. Even much smaller countries, such as the Netherlands or Belgium, had a longer highway network, at 2,200 and 1,702 km, respectively (International Road Traffic and Accident Database OECD 2000).

Highway development in Poland

Joining the European Union in 2002 forced Poland not only to improve its transport infrastructure (both roads and railways) faster but also to take environmental needs into consideration. While accessing the EU the Polish government created a special program called Infrastructure-key of development (Infrastrukrura- klucz do rorwoju) in 2002. One of the purposes of this program is road network planning through 2013. A political decision was made to radically speed up road construction: the capacity should increase to reach the ability of 250 km highway (at present it is a maximum of 60 km), 60 km expressway (at present it is a maximum of 20 km), and the rate of modernizing roads should be 500 km per year (at present it is 200 km). As of 2005 the following highway and express way sections have been put in use:

- 122 km of highways (the 103-km Konin - Strykow section of A2, the 19-km Kleszczow - Sosnica section of A4),
- 41 km of expressways (the 11-km Bielsko Biala - Jasiennica, the 7-km Skoczow - Cieszyn section and the 5-km ring road around Skoczow of S1, the 6-km ring road around Jedrzejowo in S7, the 12-km ring road around Torun of S10).

An additional 338 km of highways will begin construction by the end of 2005 (the 91-km Gdansk - Nowe Marzy and the 27-km Swierklany - Gorzyczki section of A1, the 50-km Zgorzelec - Krzyzowa section of A4, while on the Wroclaw - Krzywa section of the same highway 92 km will be modernized: the 8-km Klucz - Kijewo section of A6, the 70-km Olszyna - Golnice section of A18).

An additional 231 km of expressways will begin construction by the end of 2005 (the 11-km Pyrzowice - Podwarpie section and the 5-km ring road around Grodzisk Slaski of S1, the 3-km ring road around Miedzyzdroje, the 10-km ring road around Gorzow Wielkopolski, the 6-km ring road around Miedzyrzecze and the 15-km ring road around Nowa Sol of S3, the 5-km ring road around Szubin of S5, the 16-km Myslenice - Lubien section and the 8-km ring road around Grojec of S7, the 12-km ring road around Olesnica, the 13-km ring road around Wyszkow, the 17-km Radzymin - Wyszkow section and the 11-km Konotopa - Powazkowska section of S8, the 10-km Motaniec - Lipnik section of S10, the 13-km ring road around Gawrwolin of S17, the 51-km Elblag - Grzechotki section of S22, the 25-km Zywiec - Zwardon section of S69). As an additional measure, 180 km of existing country roads will also be modernized in 2005.

Table 2. Highways under construction as of June 2005 (after Szczepaniak 2004)

Code	Section	Total length (km)	Finished (km)	Percentage (%)
A1	Gdansk - Gorzyczki (border)	582	17	3
A2	Swiecko (border) - Kukuryki (border)	610	150	25
A4	Jedrychowice (border) - Korczowa (border)	670	342	51
A6	Kolbaskowo (border) - Szczecin- Kijewo	21	14	67
A8	ring road of Wroclaw	27	0	0
A18	Olszyna (border) - Krzyzowa	70	17	24

The current realization of these impressive plans, however, is still not enough if we take into consideration that most roads need to be renovated. Some roads, for example Via Baltica, expressway 8, connecting Wroclaw, Lodz and Warszawa agglomerations with Lithuania and farther to the Kowno direction and Riga, are still in the planning stage, mostly because of environmental assessment problems and arguments/protests connected to the selection of the new route. Still today, no final decision has been made. One version goes from the border at Budzisko through Suwalki, Augustow, Bialystok and further to Warszawa/ Lody and Krakow crossing many areas of the Natura 2000 network, which should be avoided from an ecological point of view. The other variant gets to the border of Warszawa through Lomza and Ostroleka, which not only avoids Natura 2000 network sites, but it is also more than 20 km shorter. Even if the second variant should be selected, from both an ecological and an economical point of view (as it is cheaper both because it is shorter, the additional cost of building mitigation measures is much smaller, and the other variant needs special constructions like estacades), media-supported ecological protest was needed; otherwise, the worst route would have been chosen, which also crosses the Biebrza valley, a unique, natural riverine ecosystem unprecedented in Europe.

Nowadays, infrastructure development or modernization does not follow the increase of numbers of cars in Poland. In 2004 the number of cars was 6.5 percent higher than in 2003, almost 12 million vehicles, which translates to 314 cars per 1,000 citizens (in 2003 it was 294 cars per 1,000 citizens). In 2004 the number of trucks was 2.3 million, which is a 3.2-percent increase, making 59 lorries per 1,000 citizens.

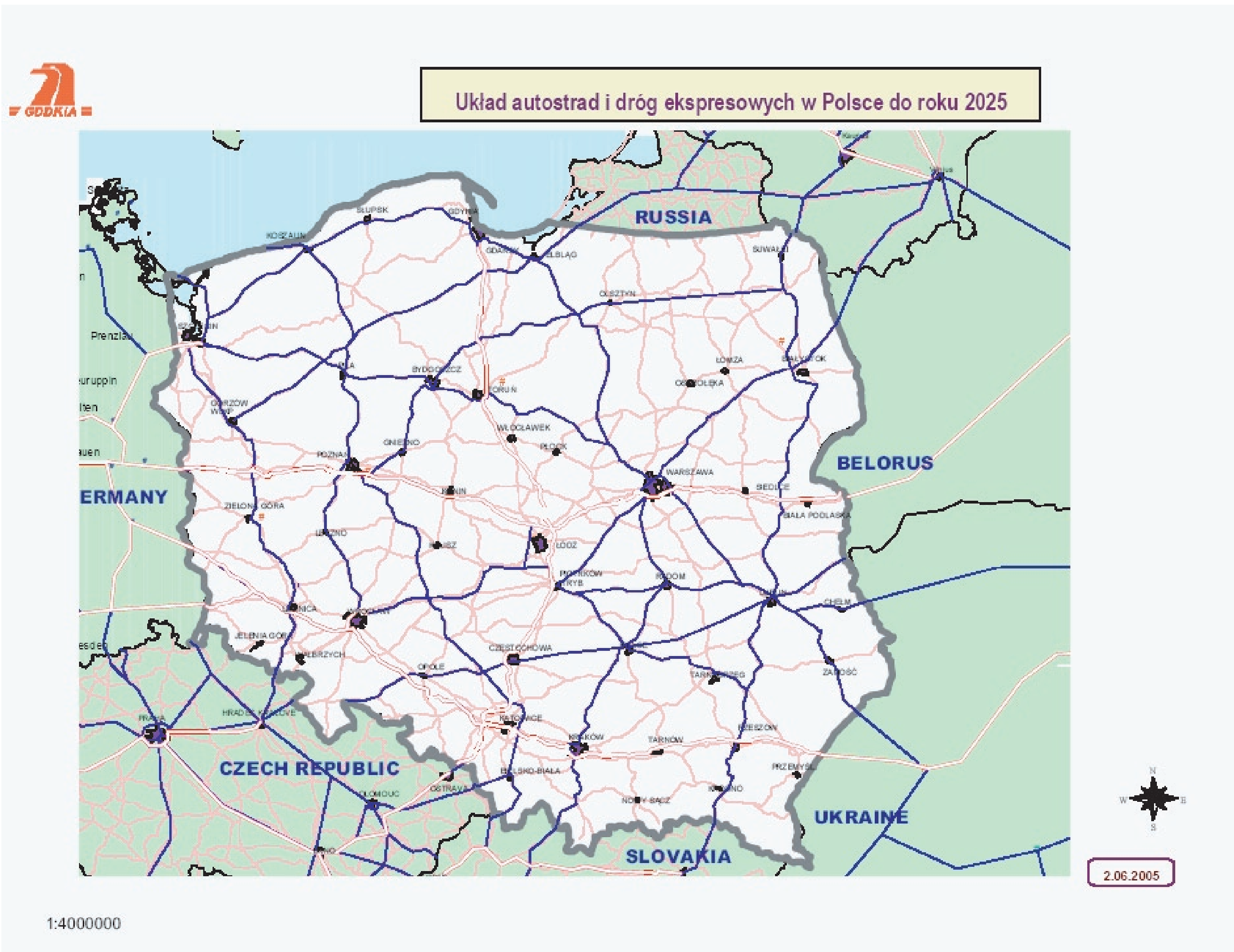

Figure 1. Highway and expressway network of Poland in 2004 (after Szczepaniak 2004).

Future highway network development in Poland

In the next years the following highway lengths are planned to be constructed:

- 170 km in 2006, another 323 km will be under construction
- 735 km between 2007 and 2010 (average of 184 km)
- 508 km between 20011 and 2013 (average of 169 km).

In total, the Polish road network should include 2,085 km of highways by 2013. Figure 2 presents the plans for highway development. Existing roads are marked by black.

Figure 2. Planned highway development in Poland through 2013 (after Ministerstwo Infrastruktury, Generalna Dryrekcja Drog Krajowych i Autostrad, 2005). Different colors represent years of construction planned (black: existing highways; red: 2005; orange: 2006; light brown: 2007; blue: 2008; violet: 2009-2011; green: 2011-2013)

The figures for expressways are the following:

- 156 km in 2006, another 268 km will be under construction
- 1,668 km between 2007 and 2010 (average of 417 km)
- 1,200 km between 20011 and 2013 (average of 400 km
- An additional 3,050 km to be built after 2013

Figure 3 presents the plans for highway development. Existing roads are marked by black.

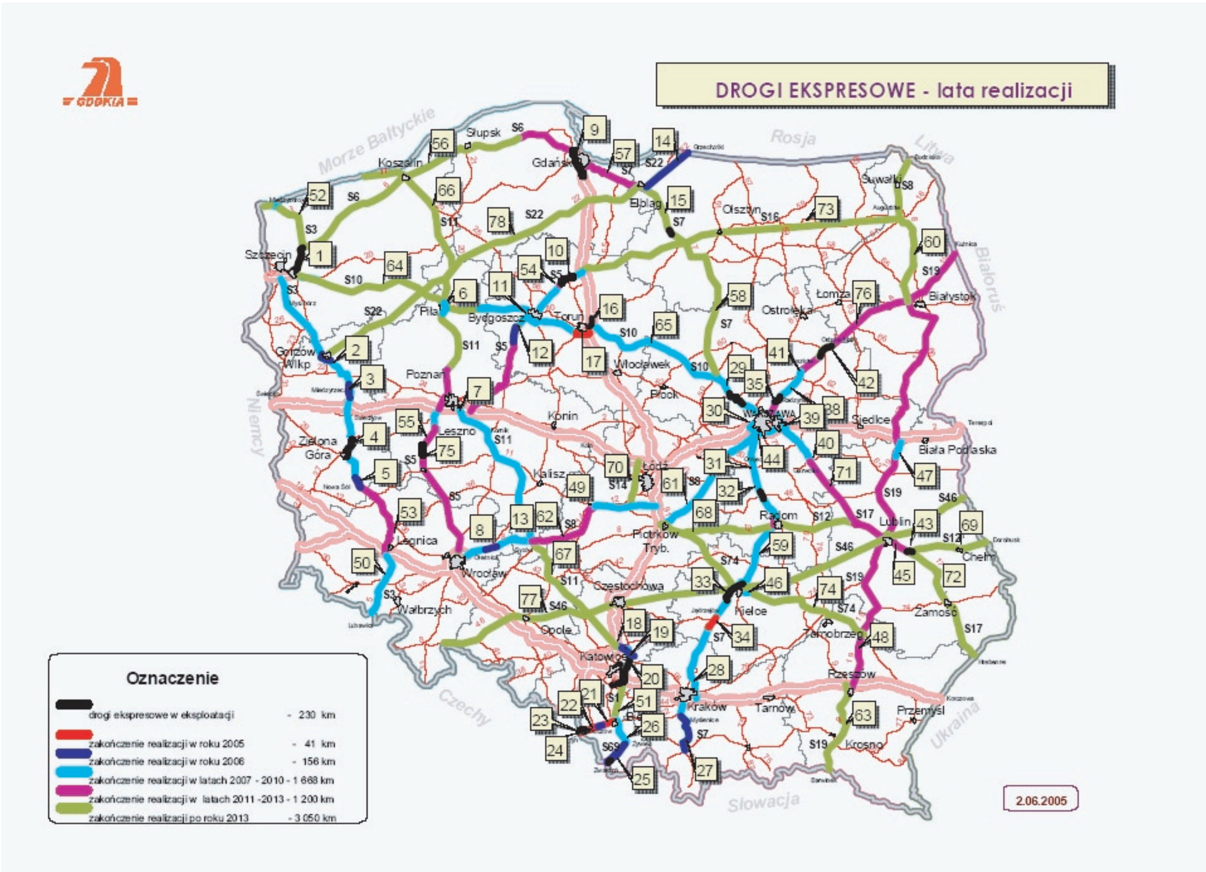

Figure 3. Planned expressway development in Poland through 2013 (after Ministerstwo Infrastruktury, Generalna Dryrekcja drog Krajowych i Autostrad, 2005). Different colors represent years of construction planned (black: existing highways; red: 2005; orange: 2006; light brown: 2007; blue: 2008; violet: 2009-2011; green: 2011-2013)

Ecological Effect of Roads

Background of Polish studies

From an economical point of view infrastructure development has strong positive sides, and the whole country can benefit due to easier access and better transport conditions, which attracts, e.g., large companies to move their regional headquarters into those areas. From an ecological point of view, however, this vision is rather negative. There are several reasons why concern is growing in Poland regarding road-related environmental issues. Legal regulations concerning building mitigation measures for wildlife along the roads are not strong enough; the lack of qualified staff as well as the lack of experience in this field seems to make the situation even worse. Only a very low number of studies were conducted in Poland, which I summarize below.

Animal mortality on roads

According to Jedrzejewski W. (2004) in Austria 34,706 red deer, 428 roe deer, 1,552 foxes, and 36,243 rabbits were killed on the roads in 1997. In Germany these numbers are smaller: 14,906 red deer, 3,901 foxes, and 2,333 rabbits died under car wheels in 2000. In Poland, unlike other countries there are no official national statistics about road accidents with animals. The description of spectacular and fatal accidents is getting into different papers, and local police headquarters have sporadic data, but there is no country-wide overview on this topic. It is known, for example, that on the 160-km A2 highway running from Nowy Tomy?l to Konin, 40 accidents with large mammals were recorded in a month in 2003. Such figures indicate that road kill is quite common due to the lack of protective measures (e.g., fences) and the relatively high density of animals.

What might be considered even more significant from an ecological point of view is that rare species, e.g., lynx or wolves, also die in accidents. Another factor is the importance of local roads in road kills, that Jedrzejewski (2004) proved for a lot of animals, especially for amphibians, reptiles, and small mammals. One reason for this fact is the extent of the road system, but behavioral effects also play a role in the case of mammals. A road with a 6-10,000 cars per day traffic density is less often approached. Another factor is the local decline of populations near these roads, which lowers the probability of road kills on busy roads in comparison to local roads. According to Jedrzejewski (2004), highways with a traffic density higher than 10,000 cars per day are practically complete barriers for animals, and they mostly come on the road when they are in a stress situation, e.g., frightened by hunters or predators.

Some statistics on different animal groups exist for Poland. On amphibians the most detailed investigation during spring migration was made by Baldy (2003) in the Gory Stolowe National Park. Within a 200-m section of road along a lake, several thousand of common frogs and common toads were migrating (figure 4). As a result of the attention of the local national park as well as the media and local people, it became the site of the first permanent amphibian mitigation measure in 2003. Rybacki (1995) worked on amphibian road mortality in the Pieniny National Park, where he, similar to Baldy (2003), also proved a seasonal migration pattern of amphibians, but it varied according to the species.

Less information is available on other animal groups from longer-term data. Wolk (1978) studied road mortality in the Bielowieza forest, while Bartosewicz (1997) worked in the Slonsk Nature Reserve for a year. The ratio of reptile, bird, and mammal species and individual numbers can be seen in figure 5 and figure 6. The ratio of species found on the road was quite similar in both investigations, though relatively more reptiles were found in the more open, and probably warmer, road in Slonsk Nature Reserve. The individual number at that site, however, was more mammal dominated, and the number of birds was lower than in the other investigation.

Habitat fragmentation

More significant than road mortality, but certainly less visible - as there are no visible victims, caused by building new transport infrastructure is habitat fragmentation (Forman 1998, Iuell 2003). It is caused by several mechanisms, such as habitat loss and the barrier effect, and the isolation of particular populations can cause the extinction of all sub-populations.

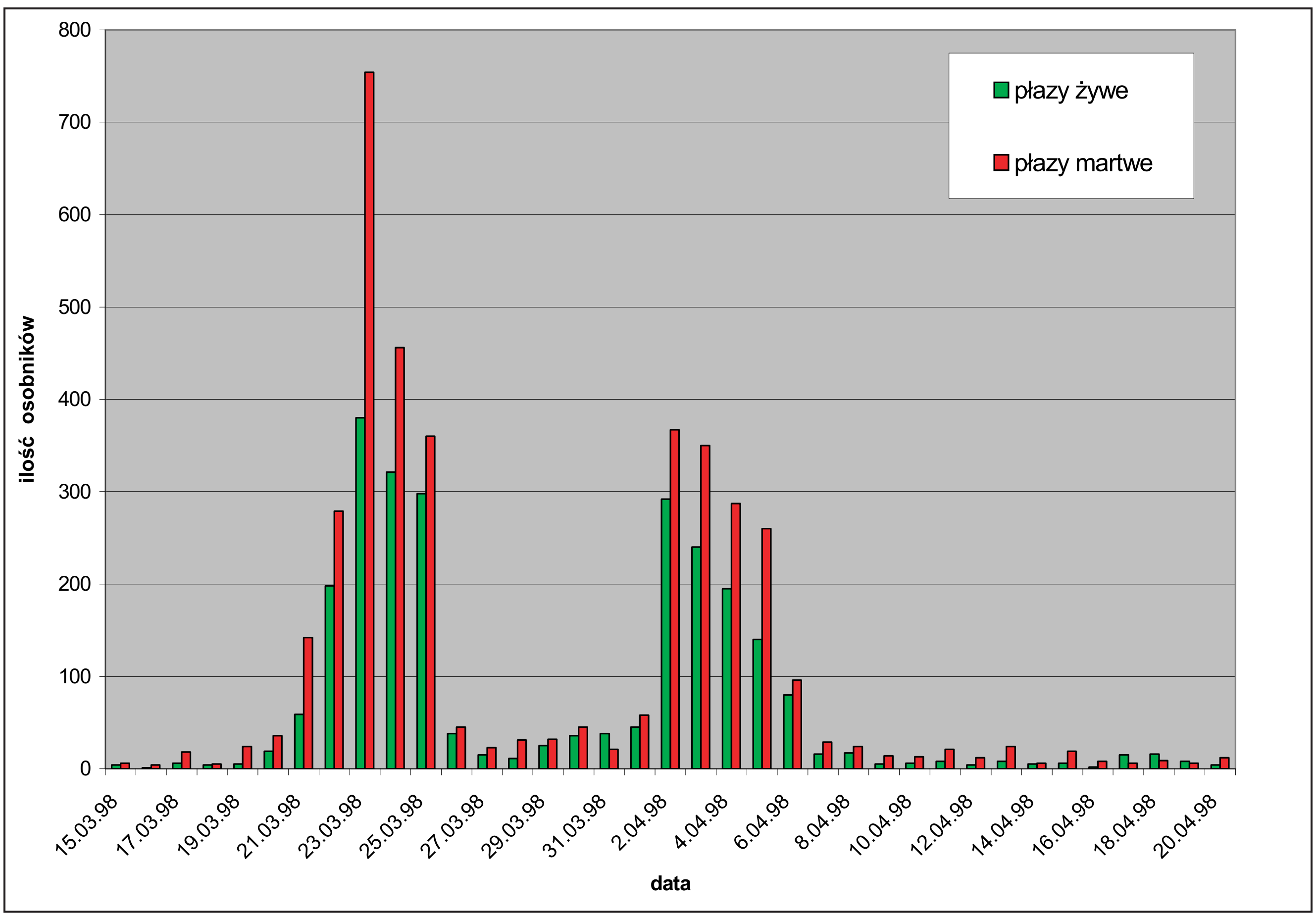

Figure 4. Death rate of amphibians on the road of local importance in Jeleniów near Kudowa Zdroj (after Baldy 2003).

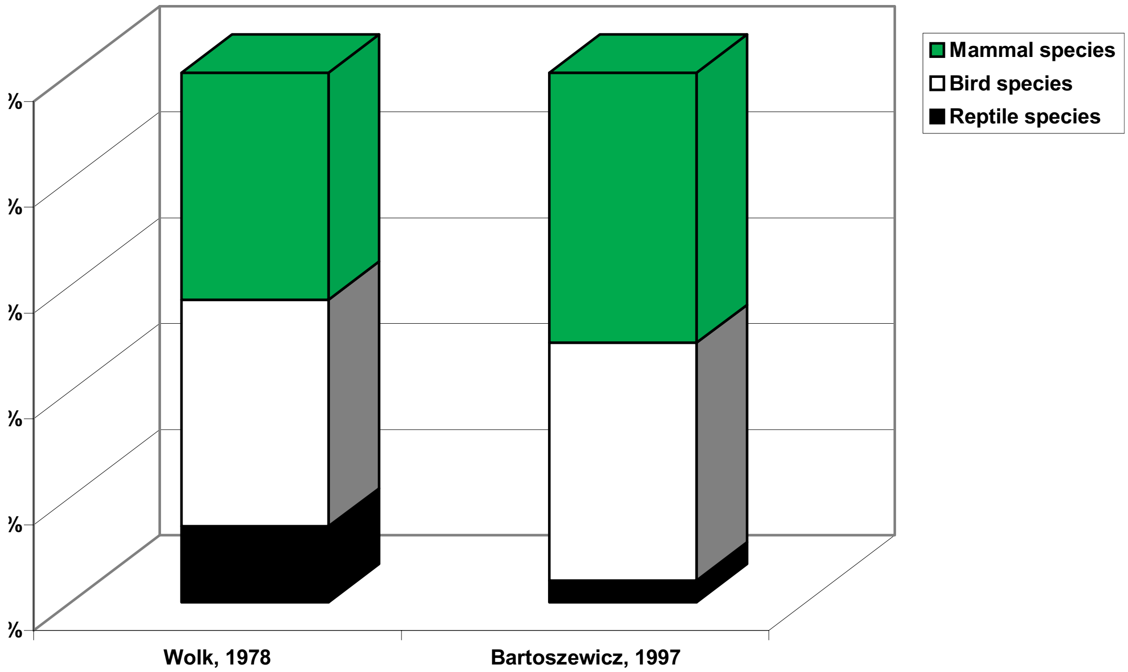

Figure 5. Species number of road-killed reptiles, birds, and mammals in two Polish studies (Bartoszewicz 1997, Wolk 1978).

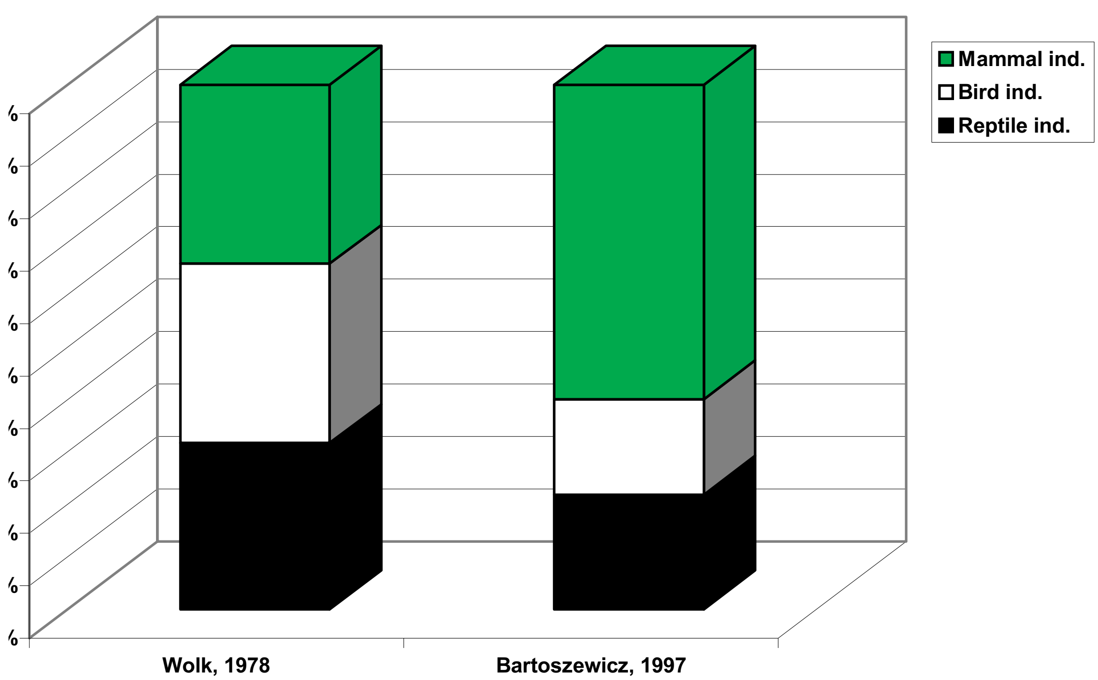

Figure 6. Individual number of road-killed reptiles, birds, and mammals in two Polish studies (Bartoszewicz 1997, Wolk 1978).

The barrier effect can be analyzed at the local or the regional scale. At a local scale it divides natural habitats, for example, an old forest, for two different patches and often causes isolation of both parts and the inability of inidviduals that live in one of the patches to move from one part to the other. Often this permanently separates breeding sites from feeding grounds, which is particularly important for amphibians and some reptiles. For terrestrial species, roads are usually a barrier that makes it impossible to get all habitat patches within their own territories. Wolves, lynx, and bears are very important indicators of negative road impacts. High area demands of those species, for which usually 100 km2 is not enough to keep one territory, are factors that limit the number of areas large enough for those animals. However, highway and expressway system planning nowadays divides large forest complexes in which these animals live for smaller-sized patches in Poland. At a regional scale, roads make animals unable to migrate. As a result of this, healthy, DNA-exchanging populations are scattered and become smaller and isolated sub-populations. In such cases, the extinction of all local populations can happen without the possibility for natural regeneration through immigration. The barrier effect depends on many factors, e.g., the additional facilities along the roads, such as screens, fences, drainage systems, and traffic density (noise, pollution, light disturbance). The analysis of these factors is not the aim of this article, although habitat fragmentation is of growing importance. Because of the lack of financial resources no such studies have been conducted in Poland so far. However, it is important to note those areas, which were recognized by a higher, European Union level, as the most valuable habitats in Poland, as their protection from fragmentation must be safeguarded.

Table 3. List of most important sites in Poland, where habitat fragmentation should be avoided participating in the NATURA 2000 network

Debinskie mokradla
Lachy Valley
Stolowe Mountains

- minors in Zloty Stok
- Karkonosze Mountains
- Church in Konradow
- Skaly Pieninskie
- Devil Valley near Polanica
- Rudawy Janowickie
- Skaly Stoleckie
- Torfowisko pod Zielencem
- Wrzosowisko Przemkowskie
- Sztolnie w Lesniej
- Kamionki
- Forty w Toruniu
- Torfowiska Chelmskie
- Dolina Srodkowego Wiepsza
- Goscieradow
- Jeziora usciwerskie
- Katy
- Krowie Bagno
- Ostoja Poleska
- Roztocze Srodkowe
- Sztolnie w Senderkach
- Torfowisko Sobowice
- Torfowisko Weglanowice Sniatycze
- Zurawce
- Hubale
- Popowka
- Dolina Krasnej
- Ostoja Nidzianska
- Ostoja Przedborska
- Dolina Drwecy
- Gierloz
- Jezioro Druzno
- Jezioro Karas
- Mamerki
- Puszcza Romnicka
- Rzeka Pasleka
- Zalew wislany and Mierzeja Wislana
- Biedrusko
- Dabrowy Obrzyckie
- Dabrowy Krotoszynskie
- Ostoja Nadwarcianska
- Fortyfikacje w Poznaniu
- Jezioro Kubek
- Jezioro Zgierzynieckie
- Kopanki
- Dolina Noteci
- Puszcza Beniszewska
- Rogalinska Dolina Warty
- Sierakow
- Ostoja Wielkopolska
- Pustynia Bledowska
- Diable Skaly
- Kostrza
- Na Policy
- Waly
- Streczow- Scianka
- Tatry
- Torfowiska Orawsko-Nowotarskie
- Lipowka
- Bagno Calowanie
- Baranie Gory
- Dabrowa Radziejowska
- Dabrowy Seroczynskie
- Ostoja Nadbuzanska
- Dolina Wkry
- Dolina Zwolenki
- Legi Czarnej Strugi
- Olszyny Rumockie
- Puszcza Kampinowska
- Sikorz
- Wydmy Lucynowsko- Mostowieckie
- Kantor Stany
- Krogulec
- Forty Nyskie
- Gora Sw. Anny
- Bieszczady
- Ostoja Magurska
- Dolina Biebrzy
- Dolina Gornej Narwi
- Nawianskie Bagna
- Przelomowa Dolina Narwi
- Puszcza Bialowieska
- Ostoja Suwalska
- Ostoja Wigierska
- Jeleniewo
- Bagna Izbickie
- Biale Bloto
- Bialogora
- Dolina Gornej Leby
- Dolina Klodawy
- Dolina Reknicy
- Zachodnie Pojezierze Krzywinskie
- Bobolickie Jeziora Lobeliowe
- Brzeznicka Wegorza
- Dolina Grabowej
- Dolina Iny kolo Recza
- Dolina Krapieli
- Dolina ploni and Jezioro Miedwie
- Dorzecze Parsety
- Janiewskie Bagno
- Jeziora Szczecineckie
- Jezioro Kozie
- Jezioro Wielki Bytyn
- Kemy Rymanskie
- Pojezierze Mysliborskie
- Police- Kanaly
- Ostoja Goleniowska
- Slowinskie Bloto
- Ujscie Odry and Zalew Szczecinski
- Trzebiatowsko- Kolobrzeski Pas Nadmorski
- Wolin and Uznam
- Wzgorza Bukowe
- Dolinki Jurajskie
- Jaroszowiec
- Kalina- Lisieniec
- Kolo Grobli
- Dolina Pradnika
- Pienieny
- Dolina Srodkowej Wietcisy
- Jar Rzeki Raduni
- Jeziorka Chosnickie
- Jezioro Piasek
- Kurze Grzedy
- Mawra- Bagno Biala
- Mechowiska Sulenczynskie
- Mierzeja Sarbska
- Orle
- Pelcznica
- Piasnickie Laki
- Plywajace Wyspy pod Rekowem
- Przymorskie Blota
- Sandr Brdy
- Pobrzerze Slowinskie
- Staniszewskie Bloto
- Studzienickie Torfowiska
- Trzy Mlyny
- Zatoka Pucka i Polwysep Helski
- Twierdza Wisloujscie
- Bor Chrobotkowy
- Hopowo
- Lubnia
- Przywidz
- Wacmierz
- Bytowskie Jeziora Lobeliowe
- Cieszynskie Zrodla Tufowe
- Podziemia Tarnogorsko- Bytomskie
- Szachownica
- Modohora

Measures Used to Minimize the Negative Effect of Roads on Animals

In Poland, most roads were built before people became aware of the environmental problems they pose. Obvious consequences, such as collisions, however, helped people recognize the importance of counter-balancing the negative effects of roads on wildlife. Naturally, the best solution is avoidance, i.e., checking animals' migration routes in a planning stage and avoiding collisions or fragmentation by either planning to build the road in a different area (mostly used in cases where nationally endangered species exist) or building wildlife tunnels and fauna bridges with additional structures, such as fences, guiding structures, and screens.

A perfect road design (Iuell 2003) respects existing landforms, requires the fewest large earthworks, minimalizes the extent of habitat loss, avoids sites of nature conservation interest, and, where possible, protects non-renewable resources and seeks to maintain connectivity through the use of structures that carry the landscape over the infrastructure or permit the landscape to flow under the infrastructure. Naturally, the need to build highways and expressways in Poland preceded that of protecting animals from collisions by fauna bridges or underpasses. Also, the first bridges were more like an experimental design than structures linking divided territories.

Fauna bridges and wildlife passages constructed through 2005

The first Polish fauna bridges were created after building the Wroclaw - Gliwice section of the A4 highway (see fig.7), an important trans-European road linking Ostende in Belgium through Köln and Drezden in Germany, Wroclaw and Krakow in Poland to Kijev in Ukraine, in 2001. When these bridges where built the legal background as well as experience were missing. That is the main reason why they were (and are) not effective wildlife bridges. Five bridges over the highway with a width between 10-12 m for newly built bridges and 9 m for those that were just modified for animal use (people also use them) were created (see fig.7). Five passages under the highway with a width of 6 m and a height from 2.2-4 m depending on local landscape conditions were also created along that highway stretch. On the Nogowczyce - Sosnica highway section, which was designed later, after negotiations and the consequent higher budget, two additonal fauna bridges with a width of 30 m were created. However, follow-up studies showed that only one fauna bridge from the first five was used by animals, although they are present around all structures, and they also did not use one of the new, wide bridges (Gazeta Wyborcza 2003, 2004, 2005). The main reason for this failure was that no data were available about animal migration routes in the area, except survey results made in the building stage on the basis of interviews with forestry workers. Two other very important factors in the failure of the first set of bridges are the narrow design and their common use by people. Also, lack of noise and light screens, guiding structures, and poor quality fences most probably contributed to the problem.

On the A2 highway(see fig.7), which connects Western Europe with Belorussia and Russia crossing central Poland, additional game bridges were put into operation in the Konin - Wrzesnia section in 2004 and 2005. Their monitoring showed that several species, such as reed deer, foxes, and rabbits, used those mitigation measures. This result is considered to be a success and a great step in the progress of building such structures in Poland, especially because the width of these passages is below 33 m. The study also proved that good guiding structures and correctly chosen vegetation planted on both sides of the bridges, joining to the pine forests at both side of the bridges, as well as on the bridges and walls also make animals accept the bridges as crossing points, and they are not afraid to use them. In comparison with the A4 bridges, a lot of development, correct vegetation, guiding structures, noise and light screens were implemented, but still, some elements of these mitigation structures can also be improved upon. Fences in many places do not reach the ground, or it is easy for an animal to dig under them, and then animals can easily get on the road. At those sections, regular collisions with cars was observed, and more than 40 people died in a month in 2004.

Fauna bridges were also built on a former country road that was improved to expressway no. 3. (see fig.7) leading to Swinoujscie port. This road crosses the forested areas of Wolinski National Park. Two fauna bridges and 13 pipe tunnels for small animals were constructed there. The monitoring of the use of the fauna bridges proved high efficiency. At present, they are the best fauna bridges for medium and big mammals in Poland. Besides the proper construction of the mitigation measures, their success is also the result of efficient cooperation of national park staff, designers, and the building company.

The general situation of medium and large mammals using wildlife passages, however, is much worse. Most of the passages are too narrow, and the main target of building them was to provide access to the other side of the road for local people, like local and forestry transport and pedestrians. As a result of human presence that frightens most animals, these passages are not often used by wildlife. On the other hand, the crossing for mammals along streams or rivers improved considerably. In each case, when building or modernizing highways or expressways needed the building or restructuring of a bridge under which water flows, wildlife passages were made according to the needs of mammals (for example, bridges in Sleza Olawa). In most cases, they provide dry passage along the banks to help animals avoid swimming to cross under the road that make possible crossing it by animals that are not swimming.

Wildlife tunnels for amphibians and small mammals constructed through 2005

The protection of migrating amphibians over roads has been the most successful conservation element of the mitigation of road effects in Poland so far. In 1990 a national project called “Amphibians Protection Project” started. A survey was launched in different parts of Poland (mountains, lowlands, seaside) at the same time. Special fences (Wisniewski 2002) were put out along many roads (see fig.8), often even longer than for 300 m, in a way that prevented amphibians from getting on the road in order to protect animals from being killed on the roads. Volunteers (schoolchildren, university students, etc.), national park staff, non-governmental organizations, and private companies started to build temporary measures, including fences and buckets, and amphibians were taken to the other side of the street by volunteers. At the peak of the migration, buckets (see fig.8) with amphibians had to be taken to the other side of the road even 30 times, for example, on a road in Jeleniow (Baldy 2003). However, amphibians research did not finish by only counting amphibians and taking them to the other side of the road. The survey of particular species was also made along the routes of new roads to support decision-making about finding the best alternative. Breeding sides were usually checked by day transects in small groups, and the results were also confirmed by night sound monitoring.

Figure 7. Game bridges and wildlife passages in Poland (*top left*: Multifunction (animals, agriculture) fauna bridge on A4; *top right*: Multifunction (animals forestry) fauna bridge on A4; middle left: Guiding lines of fauna bridge on A2; *middle right*: Fauna ridge on A2; *bottom left*: underpass for Lutra lutra (Kampinos National Park); *bottom right*: Underpass for big and medium mammals on expressway no. 3).

Amphibian road mortality was checked while slowly driving and stopping every 100-500 m and counting dead animals (Bartoszewicz 1997) and also by cycling or walking along the road (Wolk 1978) in different parts of Poland. The aim of such activities was not only to save amphibians, but also to educate people living near those localities where amphibians migrate. Local and country television stations helped spread information and recruit motivated people to save amphibians. In 2003, as a result of successful cooperation of the local national park, NGOs, and private organizations, the first three rectangular concrete tunnels (see fig. 8) were built on a local road in Jeleniow (Baldy 2003). Later, two more were built on the Chrabowka- Rdzawaka section of S7 (Dziennik Polski 2004), and four more, on the international Szypliszki- Budzisko section of S8 (see fig.7). On expressway S3, 15 pipes were improved for small mammal use in 2003, two more on the Bodzecin-Redestowo local road, and also those on the A2 and A4 highways in 2005.

Figure 8. Mitigation measures for amphibians in Poland (*top left*: detail of a temporary mitigation measure at Via Balitica S8. Note that the bucket was dug in farther away from the fence and amphibians can pass it. Also, the pole should have been fixed on the other side of the fence not to disturb amphibian movement. *top right*: Frog King type of amphibian fence; *middle left*: tunnel entrance with guiding structure; *middle right*: concrete amphibian fence element from above built in where a small side road joins the main road; *bottom left*: entrance of an amphibian tunnel at Jeleniow; *bottom right*: concrete fence element at Jeleniow)

Building tunnels for amphibians on local roads is very important because usually these are the roads where amphibians die in large numbers (Jedrzejewski 2004). However, getting financial support for such purpose is much more difficult than building mitigation measures along highways or expressways where it is regulated by law. However, experience shows that tunnels on local roads have been made very carefully, and they also involve many students, local people, and organizations in such projects. The monitoring of toad tunnels (see fig.8) in the Jeleniow section of the local road (Baldy 2002) and those in Via Baltica showed almost 100 percent efficiency. The efficiency of A4 tunnels is currently being monitored. From these three sites, tunnels built on Via Baltica are particularly important because they help *Bombina bombina* (a species from Annex II. of the Habitat Directive of the European Union) to get from their breeding sites to terrestrial areas. The continuous monitoring between 1995 and 2000 (Adrados et al. 2002) showed that it is probably the biggest known metapopulation of this amphibian in Europe.

Wildlife tunnel and fauna bridge construction through 2013

It was quickly recognized in Poland that building wildlife passages is not a “strange idea” of ecologists, but a real need. For an average driver, these passages can ensure his/her own safety and can protect health or even life. As a consequence, the most important factor of why to build passages for wildlife in the country remains lethal collisions with animals (Gazeta Wyborcza 2003, 2004, 2005). As large animals, like moose, still cross roads, it is easy to see that the chances of a motorist surviving a frontal collision with such a large animal are quite small, and measures should be taken to avoid such collisions. Accidents with moose are especially common between Biebrza National Park, Pusza

Augusttowska, and Knyszynska, which resulted in people urging governmental organizations responsible for road safety to build mitigation structures providing migration corridors (if it is not possible to solve the problem in any other way) for moose in the conflict points of S8.

The General Road and Highway Authority (Generalna Dyrekcja Drog Krajowych and Autostrad) quickly realized the advantage of conducting accurate surveys and choosing the best places for these constructions, as the continuous adaptation of incorrect fauna bridges costs three times more than the cost of building one on the right spot in the right way. General Road and Highway Authority (Generalna Dyrekcja Drog Krajowych and Autostrad) fines put on road construction companies pushed road constructors to get highly dedicated to finding the best solutions (Ministerstwo Infrastruktury, Generalna Dryrekcja drog Krajowych i Ministerstwo Infrastruktury, Generalna Dryrekcja drog Krajowych I Autostrad, 2005 Autostrad, 2005). Still, lack of experience and well-qualified staff remain an existing problem. In addition, many years will pass before all constructors change their minds and think of the environment as something not only to use but also to protect. Another key issue is to get the right information in the planning stage. However, it is only possible if the migration corridors are known. Students, researchers, university teachers, national and landscape park staff, and members of non-governmental organizations all can and should participate in such data collection before the final decisions are made.

At the moment, this process seems to be moving more quickly in southern Poland, where members of a nature conservation association, called “Wolf,” are trying to negotiate all parties for the correct location of wildlife bridges for wolves and lynx on the Bielko Biala - Zywiec - Zwardon (border) section of the S68 expressway (Nowak S. 2004). Members of this association made long-term migration surveys and proved that the initial fauna bridge locations that road engineers selected are at the wrong places, and they should be re-situated in other areas. Ecological organizations as well as private companies challenged governmental offices, and the same also happened at other localities. If the present plans will not be changed, international wolf migration corridors will be broken. The participation of ecological organizations, however, involved not only protesting, but also developing proposals to help with designing guiding structures that would be monitored in each stage during construction and afterwards.

In general, wildlife tunnels and fauna bridges must be built for highways and expressways where surveys show that the migration routes of endangered species (according to Polish regulations or EU directives) cross planned or improved highways or expressways, and where moving the road is not advised in the environmental assessment survey. By 2005 such measures will definitely be applied in the following sections:

- Lodz - Czestochowa section of the A1 highway
- Dabie - Emilia and Ciosny section of the A2 highway
- Krakow - Tarnow and Przylesie - Prady section of the A4 highway
- Szubina ring road of the S5 expressway
- Bydgoszcz - Strystek- Biale-Blota section of the S5 expressway
- Radzymin Wyszkow, Wyszkow - Skuszew and Wroclaw - Lodz section of the S8 expressway
- Bielsko Biala - Zywiec - Zwardon section of the S69 expressway
- Rosnowek section of the no. 5. national road
- Poznan - Kurnic section of the no. 11. national road

Future needs

On the basis of the above overview of the Polish mitigation measures over roads, the following areas should be mentioned where further development is urging to protect wildlife effectively:

- More detailed environmental assessments should be carried out that consider more thoroughly the reduction or avoidance of fragmentation.
- Migration corridors should be defined on a local, regional, and national scale.
- Conflict points between road development and wildlife should be identified and mapped.
- Special attention should be given to Natura2000 sites and strictly protected species under European Union or/and Polish regulations.
- National databases including all available data should be built.
- Multi-disciplinary approach should be used to increase efficiency and also to make passages for multiple species.
- Monitoring during all construction stages should be carried out, and the results should be used if changes are necessary.
- The efficiency of mitigation measures are to be monitored.
- The maintenance of all existing and new mitigation measures have to be realized.
- Existing structures should be improved.
- Education programs should be expanded to include a wide range of target groups, e.g., young children.

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Chapter 10

Wildlife-Vehicle Collisions

Prevention and Reduction Strategies

Characteristics of Elk-Vehicle Collisions and Comparison to GPS-Determined Highway Crossing Patterns

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Abstract: We assessed spatial and temporal patterns of elk (*Cervus elaphus nelsoni*) collisions with vehicles from 1994-2004 (n = 456) along a 30-km stretch of highway in central Arizona, currently being reconstructed in five sections with 11 wildlife underpasses, 6 bridges, and associated ungulate-proof fencing. We used Global Positioning System (GPS) telemetry to assess spatial and temporal patterns of elk highway crossings and compare to elk-vehicle collision (EVC) patterns. Annual EVC were related to traffic volume and elk population levels (r^2 = 0.750). EVC occurred in a non-random pattern. Mean before-construction EVC (4.5/year) were lower than EVC on sections under construction (12.4 EVC/year). On the only completed section, EVC did not differ among before-, during-, and after-construction classes, even though mean traffic volume increased 67 percent from before- to after-construction levels, pointing to the benefit of three passage structures and fencing. On one section under construction, EVC increased 2.5x when fencing associated with seven passage structures was incomplete; EVC dropped dramatically once fencing was completed. We accrued 101,506 fixes from 33 elk (25 females, 8 males) fitted with GPS collars May 2002-April 2004. Elk crossed the highway 3,057 times (mean = 92.6/elk) in a non-random pattern. We compared EVC and crossings at five scales; the strongest relationship was at the highway section scale (r^2 = 0.942). Strength of the relationship and management utility were optimized at the 1.0-km scale (r^2 = 0.701). EVC frequency was associated with proximity to riparian-meadow habitats adjacent to the highway at the section (r^2 = 0.962) and 1.0 km (r^2 = 0.596) scales. Though both fall EVC and crossings exceeded expected levels, the proportion of EVC in September-November (49%) exceeded the proportion of crossings and coincided with the breeding season, migration of elk from summer, and high use of riparian-meadow habitats adjacent to the highway. The proportion of EVC and crossings by day did not differ; both reflected avoidance of crossing the highway during periods of highest traffic volume. Though traffic volume was highest from Thursday-Saturday, the proportion of EVC was below expected. A higher proportion of EVC (59%) occurred relative to crossings (33%) in the evening hours (17:00-23:00); 34 percent of EVC occurred within a one-hour departure of sunset, and 55.5 percent within a two-hour departure. EVC data are valuable in developing strategies to maintain permeability and increase highway safety including selecting locations of passage structures.

Introduction

Recognition and understanding of the impact of highways on wildlife populations have increased greatly in the past decade (Forman et al. 2003), to the extent that these impacts have been characterized as some of the most prevalent and widespread forces affecting natural ecosystems in the U.S. (Noss and Cooperrider 1994, Forman and Alexander 1998, Trombulak and Frissell 2000, Farrell et al. 2002). The direct impact of collisions with motor vehicles is a significant source of mortality affecting wildlife populations. An estimated 500,000 (Romin and Bissonette 1996a) to 700,000 (Schwabe and Schuhmann 2002) deer (*Odocoileus* spp.) alone are killed annually on U.S. highways. Wildlife-vehicle collisions (WVC) cause human injuries and deaths, tremendous property damage, and substantial loss of recreational opportunity and revenue associated with sport hunting (Reed et al. 1982, Schwabe and Schuhmann 2002), and disproportionately affect threatened or endangered species (Foster and Humphrey 1996).

Numerous assessments of spatio-temporal patterns of WVC have been conducted, most focusing on deer (Reed and Woodard 1981, Bashore et al. 1985, Romin and Bissonette 1996b, Hubbard 2000). Only recently have WVC assessments specifically addressed elk (*Cervus elaphus*)-vehicle collision (EVC) patterns (Gunson and Clevenger 2003, Biggs et al. 2004). Insights gained from such assessments have been instrumental in developing strategies to reduce WVC (Romin and Bissonette 1996*a*, Farrell et al. 2002), including planning passage structures to reduce at grade crossings and maintain permeability (Clevenger et al. 2002). Consistent tracking of WVC is a valuable tool to assess the impact of highway construction (Romin and Bissonette 1996*b*) and efficacy of passage structures and other measures (e.g., fencing) in reducing WVC (Reed and Woodard 1981, Ward 1982, Clevenger et al. 2001). Though valuable, no study has investigated or validated the relationships between WVC and spatial and temporal crossing patterns exhibited by wildlife involved in WVC. In fact, Barnum (2003) reported that WVC data were not useful in identifying crossing zones, largely due to inaccurate reporting of WVC.

The application of Global Positioning System (GPS) telemetry to wildlife movement studies has become increasingly popular, cost-effective, and reliable (Rodgers et al. 1996). With continuous automated tracking at set time intervals, reduced observer bias (compared to VHF telemetry), and potential to collect large datasets, GPS telemetry has revolutionized wildlife movement assessment. GPS telemetry is increasingly used to address heretofore-difficult questions (e.g., Anderson and Lindzey 2003), and holds tremendous potential to facilitate highway permeability assessment and determine spatial and temporal highway crossing patterns by wildlife (McCoy 2005, Waller and Servheen 2005, Dodd et al. *In review*).

The objective of our study was to investigate spatial and temporal patterns of EVC along a highway currently being reconstructed and incorporating numerous passage structures and associated ungulate-proof fencing to limit crossings at grade and funnel animals toward underpasses. The incidence of EVC here was a key factor used in the planning and prioritization of passage structures along this highway. This highway is being upgraded in phases, allowing us to compare EVC associated with highway under various stages of construction (e.g., before-, during, and after-construction), as well as validate the prioritization of highway sections. We sought to compare spatial and temporal patterns of EVC to elk highway crossings determined by GPS telemetry as a means to validate the management utility of EVC data in developing strategies to reduce collisions and promote permeability. Lastly, we assessed the influence of traffic volume on temporal patterns of EVC and elk highway crossings.

Study Area

We conducted our study along a 30-km stretch of State Route (SR) 260, beginning 15 km east of Payson, and extending to the base of the Mogollon Rim, in central Arizona (fig. 1). The existing two-lane highway is being upgraded to a four-lane divided highway in five phased sections; in places, the footprint width of the reconstructed highway exceeds 0.5 km. When complete, the highway will incorporate 11 wildlife underpasses specifically intended to reduce at-grade elk crossings and EVC, as well as 6 bridges over large canyons and streams (fig. 1).

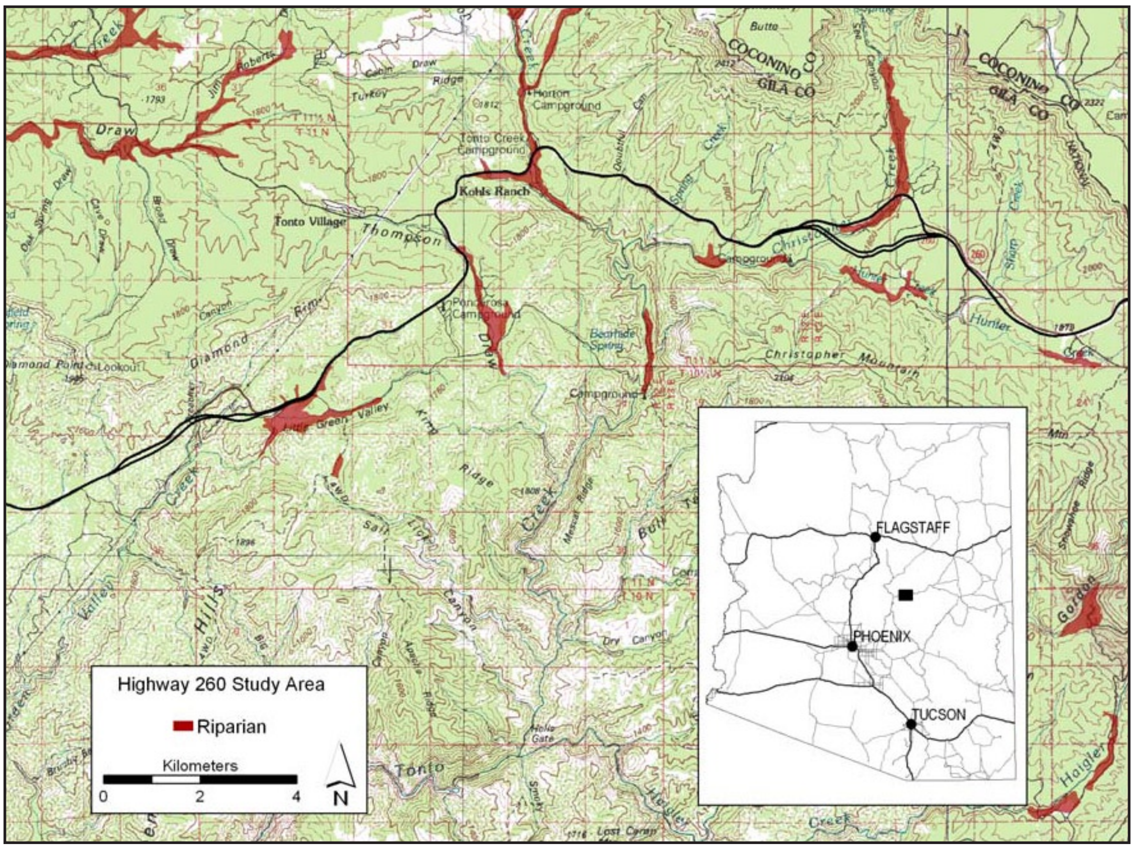

Figure 1. Location of the SR 260 study area, Arizona, USA, including existing and planned wildlife underpasses and bridges on the 5 highway upgrade sections. Riparian/meadow habitats located in proximity to the highway are denoted by shading.

The first section, Preacher Canyon (PC; 4.6 km), was completed and all lanes opened to traffic in November 2001. This section included two-bridged underpasses, in addition to a large bridge; 0.5 km (10%) of the highway was fenced with 2.5-m ungulate-proof fencing associated with the two underpasses. The Christopher Creek Section (CC; 8.2 km) was completed in December 2004, with four wildlife underpasses and three bridges in place since 2003. All lanes were opened to traffic in July 2004 before all fencing associated with underpasses was completed. Here, fencing and alternatives to fencing (e.g., swaths of large rock rip-rap) were implemented along 4.5 km (55%) in association with passage structures. The Kohls Ranch Section (KR; 5.4 km) has been under construction since 2003 and includes one wildlife underpass and two bridges; construction will be completed in late-2005. Construction on the last two sections, Little Green Valley (LGV; 4.0 km) and Doubtful Canyon (DC; 4.5 km), will not be initiated before 2007.

Average annual daily traffic volume (AADT) on this portion of SR 260 doubled in 10 years from 3,124 in 1994 to nearly 6,267 in 2002, and increased to 8,700 (+38%) in 2003 (Source: Arizona Department of Transportation [ADOT] Data Management Section, Phoenix, AZ).

Our study area lies within the ponderosa pine (*Pinus ponderosa*) association of the montane coniferous forest community (Brown 1994*a*). Elevations range from 1,590-2,000 m, and the Mogollon Rim escarpment to the north is the dominant landform, rising precipitously to 2,400 m (fig. 1). Vegetation adjacent to the highway grades from mixed ponderosa, pinyon (*P. edulis*), juniper (*Juniperus* spp.), and live oak (*Quercus* spp.) forest on the lower elevation PC and LGV sections, to forests predominated by ponderosa with interspersed Gambel oak (*Q. gambelii*) at higher elevations to the east. Chaparral (e.g., manzanita; *Arctostaphalus pungens*) with sparse pinyon, live oak, and ponderosa pine is prevalent on the drier south-facing slopes. Numerous riparian and meadow habitats occur at several locations along the highway corridor (fig. 1), with some meadows >150 ha in size. Several perennial streams flow adjacent to portions of the highway, including Little Green Valley (PC), Tonto (KR), Christopher (DC, CC), Hunter (CC), and Sharp (CC) creeks. Climatic conditions for the study area are mild, with a mean maximum monthly temperature (July) for Payson of 32.4oC, and a mean minimum monthly temperature (January) of –6.9oC. Precipitation averages 52.6 cm/year, with a mean of 54.1 cm of snowfall each winter; precipitation has averaged two-thirds of normal since 2002.

Both resident and migratory herds of Rocky Mountain elk (*C. e. nelsoni*) occurred within our study area. Resident elk were common, especially in proximity to meadow and riparian habitats. Elk migrate off the Mogollon Rim with the first snowfall >30 cm, typically in late October (Brown 1990, 1994*b*). Brown (1990) reported that 85 percent of the elk residing within his Mogollon Rim herd unit migrated to an area below but within 10 km of the base of the Mogollon Rim, which encompasses our study area. Elk return to summer range with forage green up at higher elevations (Brown 1990). Whitetail deer (*Odocoileus virginianus cousei*) were frequently seen in our study area, while mule deer (*O. hemionus*) were less common.

Methods

WVC tracking

We used two sources of tracking to assess WVC. Our primary source was a long-term statewide accident database maintained by the ADOT Data Management Section (ADOT database; Phoenix, AZ), including WVC. Most records (86.0%) were logged by the Arizona Department of Public Safety (DPS) Highway Patrol, and reflected dispatcher and accident reports; ADOT maintenance personnel made 11.5 percent of the reports. As such, we considered this database to be a relatively consistent long-term accounting of WVC. Records in this database included the date, time, and location (to the nearest 0.16 km) of the WVC, the wildlife species (genus only in the case of deer) involved, and the reporting agency. Generally, this database did not include sex and age data. For our assessment, we queried the database for WVC that occurred along that portion of SR 260 in our study area (MP 259-280) from 1994-2004. This database was used as our basis to assess long-term trends in WVC and relationships to highway construction.

At the onset of our project in late-2000, we developed and disseminated a WVC tracking form for use by agencies and research project personnel to document all WVC (including roadkills) along SR 260. This database reflected concerted efforts to regularly search for and document WVC along SR 260, especially by project personnel. Of the reports compiled for 2001-2004, 57.6 percent were submitted by DPS, most which were also logged in the ADOT database. Arizona Game and Fish Department (AGFD) personnel accounted for the remainder (42.4%) of the records in our database, of which none were logged into the ADOT database. Our database included the same information as the ADOT database, along with the sex and age of wildlife involved in WVC, species of deer, and road and weather conditions. WVC were recorded to the nearest 0.16 km. We relied on this database to characterize the sex and age of wildlife involved in WVC, as well as to assess the proportion of WVC that were logged in the ADOT database.

From both databases, we calculated the day of week and departure from sunrise or sunset when the WVC occurred where accurate date and times were known. For temporal and spatial analyses involving WVC, we combined all unique records from both databases.

EVC relationships to AADT and elk population estimates

We assessed the relationships of EVC to AADT and elk population estimates for the management units encompassing our study area for 1994-2003. AADT estimates were obtained from the ADOT Data Management Section (Phoenix, AZ), and were calculated based on annual traffic sampling conducted along SR 260 midway though our study area.

Our elk population estimates (pre-hunt) were obtained from the annual elk management summaries (1994-2003) for Game Management Units (GMU) 22 and 23 (AGFD Game Branch, Phoenix, AZ); we combined the estimates as our study area was split equally by the two GMU. Though the entire estimated elk population for the two GMU did not reside in the vicinity of SR 260, we nonetheless used the estimates as an index to relative population levels that fluctuate from year to year based on calf recruitment, hunter success, and drought conditions that affected elk distribution. We also used this population survey data to compare the surveyed bull:cow ratios (expected) for 2001-2004 to the bull:cow ratio of animals involved in EVC (observed) during the same period using X^2 analysis.

We used linear regression (Neter et al. 1996) to assess the association between EVC and AADT and elk population estimates. We assessed the relationship of EVC to AADT and elk population estimates combined by multiple regression, and assessed the relative importance of independent variables by partial regression analysis (Neter et al. 1996).

Comparison of EVC by highway section and construction classes

We tested the hypothesis that our observed SR 260 EVC did not differ from a randomly generated (discrete) distribution using a nonparametric Kolmogorov-Smirnov test, sensitive to both the difference in ranks and shape of the distributions (Statsoft 1994). We compared EVC among highway sections by calculating mean EVC rates (EVC/km/year) that accounted for differential section lengths. We used analysis of variance (ANOVA; Hays 1981) to assess differences in mean EVC rates among sections, with separate analyses for all years and pre-construction years only. For significant ANOVA tests, we assessed pairwise differences in mean EVC rates with Sheffe's post-hoc multiple comparison tests (Hays 1981). We compared mean EVC among highway construction classes (before-, during, and after-construction) using analysis of covariance (ANCOVA; Hays 1981). We controlled for AADT effects (covariate) in our ANCOVA analysis. We used Sheffe's multiple comparison tests to assess pairwise differences in mean EVC among construction classes.

GPS telemetry assessment of elk highway crossings

We captured elk at 10 sites spaced an average of 2.7 km (±0.7 SE) along SR 260. We primarily trapped elk in net-covered Clover traps (Clover 1954) baited with salt and alfalfa hay; all traps were within 300 m of the highway corridor. We also captured elk with a 12.8 x 12.8 m remote-triggered drop net. Animals were physically restrained, blindfolded, ear tagged, and fitted with GPS receiver collars. We timed trapping to target resident elk to maximize year-long acquisition of GPS fixes near the highway.

We used two models of GPS collars (Telonics, Inc., Mesa, Arizona). We used 19 "store-on-board" receiver collars programmed to receive a fix every two hours, and four programmed to acquire fixes every 1.5 hours from 17:00-9:00 hours (12 fixes) and one at 12:00; operational battery life was 22 months. We also deployed five collars with ARGOS satellite uplink capabilities for rapid data return in early adaptive management activities. These collars were programmed to receive fixes every four hours (15-month battery life). All collars had VHF beacons, mortality sensors and programmed release mechanisms to allow recovery.

We employed ArcGIS® Version 8.3 software (ESRI, Redlands, California) to analyze GPS data. We divided the length of SR 260 within our study site into 200 sequentially numbered 0.16-km segments to quantify highway crossings (fig. 2); these segments were referenced to the 0.16-km milepost segments to which WVC were assigned. To infer highway crossings, we drew lines connecting all consecutive GPS fixes (fig. 2). Crossings were identified where lines between fixes crossed the highway (or either set of divided lanes) through a 0.16-km segment (fig. 2). Animal Movement ArcView Extension Version 1.1 software (Hooge and Eichenlaub 1997) was used to assist in elk crossing determination by individual animal and segment, date and time.

To account for the number of individual elk that crossed at each highway segment, as well as evenness in crossing frequency among animals, we calculated Shannon diversity indices (SDI; Shannon and Weaver 1949) for each segment. We used SDI to calculate weighted crossing frequency estimates for each highway segment, multiplying uncorrected crossing frequency x SDI. Weighted crossings thus reflected the crossing frequency, number of crossing elk, and equity in distribution among crossing elk. We assessed the similarity in our observed elk crossing distributions along SR 260 to a randomly generated (discrete) distribution using a Kolmogorov-Smirnov test. We also used this test to compare the elk crossing frequency distributions for uncorrected versus weighted crossing distributions for all highway segments and sections.

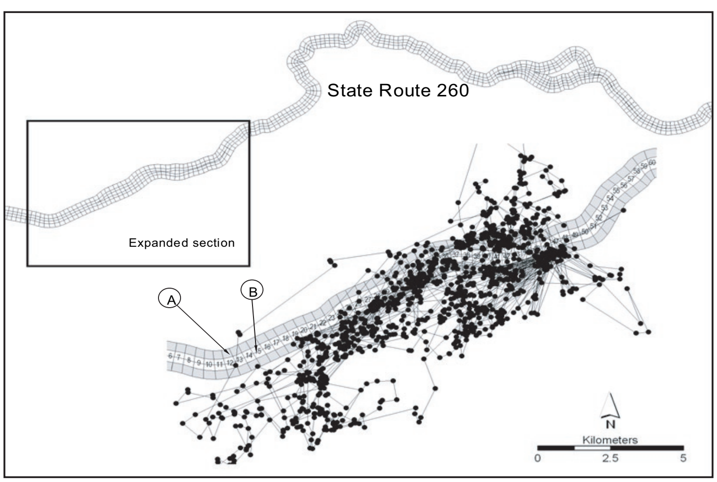

Figure 2. Highway segments (0.16 km) delineated for the SR 260, Arizona, USA, study area, used to compile EVC and highway crossings by elk. The expanded section shows GPS locations and lines between successive fixes to determine approaches within 0.25 km of the highway (shaded band) and crossings. Example A denotes an approach and subsequent highway crossing while B depicts an approach without a crossing.

Comparison of EVC and elk highway crossings
Spatially, we used linear regression to assess the association between the frequency of EVC and elk highway crossings along SR 260, using both uncorrected and weighted elk crossings. To assess the strength of associations at various scales, we compared EVC to crossings at the 0.16-km segment scale, and aggregated the data to 0.5 km, 1.0 km, 1.6 km, and highway section scales for regression analyses. Among scales, we compared correlation coefficients (r) and coefficients of determination (r^2) derived from each regression comparison of EVC to crossings.

Due to the important role that riparian-meadow habitats played in influencing elk highway crossings along SR 260 (Dodd et al. *In review*), we assessed the association between proximity to riparian-meadow habitats and EVC and highway crossings. We used linear regression to measure the association between EVC at the highway section and 1.0-km scales with the number of 0.16-km segments in which riparian/meadow habitat was located within 0.25 km.

We conducted comparisons of EVC and elk crossings by month, day, and time (2-hour intervals), and used X^2 testing to compare observed versus expected temporal values for EVC to those for elk crossings. Also, assuming that the proportion of elk crossings by month, day, and time reflected the expected proportion in which EVC would occur, we compared the proportion of elk crossings (expected) to the actual proportion of collisions that occurred (observed) using X^2 testing. Comparisons by time used only crossings determined from GPS fixes acquired 1.5 or 2 hours apart; we used the interval midpoint as the time for comparisons with WVC. We compared deer-vehicle collisions to EVC relative to month, day, and time, as well as absolute departure from sunrise or sunset. We used mean daily AADT factors for SR 260, obtained from the ADOT Data Management Section to adjust for differential daily AADT (e.g., 7,770 on Sunday versus 10,235 on Friday using the 2003 AADT) when assessing elk and deer collisions with vehicles by day; the product of WVC frequency x daily AADT factors was used to account for the influence of traffic volume.

We defined high EVC and elk crossing (weighted) sections along SR 260 at the 1.0-km scale (total n = 28), using a procedure similar to that described by Malo et al. (2004), predicated on the Poisson distribution. With this procedure, high ECV or crossing thresholds were determined to occur where P = 0.05, using the formula from Agresti (1996:4), where y is the threshold value and u is the mean EVC or crossing level:

$$P_{(y)} = (e^{-u}u^{y})/y!$$

We compared high EVC and crossing sections at or above threshold levels to the location of completed and planned wildlife passage structures along SR 260.

All statistical tests were performed using the program Statistica® (Statsoft, Inc. 1994). Results were considered significant at $P < 0.05$. Mean values were reported with ± SE.

Results

From 1994 to 2004, 395 WVC were recorded in the ADOT database (table 1), for an average of 35.9 WVC/year (±2.5). Of these WVC, 81.5 percent involved elk, and 16.4 percent involved deer species (table 1). Also, three black bears (*Ursus americanus*), one mountain lion (*Puma concolor*), and one javelina (*Tayassu tajacu*) were killed in WVC (table 1).

Between 2001 and 2004, we documented 222 WVC (table 2) compared to 161 in the ADOT database for the same period; elk accounted for 87.4 percent of our WVC (table 3), and deer, 11.6 percent. Of the classified elk, cows were involved in EVC >4x as frequently as bulls, and adult elk accounted for 74.2 percent of the EVC (table 2). Of the classified deer, 70 percent were whitetail versus 30 percent mule deer. In comparing the two WVC databases, 72.5 percent of all WVC were recorded in both databases. A mean of 72.7 percent of our EVC were recorded in the ADOT database (table 3), and ranged from 51.8 percent (2004) to 96.7 percent (2001).

EVC relationships to AADT and elk population estimates
From 1994-2004, WVC increased at a mean rate of 4.7 percent/year, while AADT increased 11.2 percent/year up to 2002, with a 38.8-percent increase in AADT between 2002 and 2003 alone, and 17.8-percent overall (table 1). The elk population estimate for the management units encompassing our study area ranged from 1,488 to 1,716 elk (table 1).

Table 1. Frequency of wildlife-vehicle collisions by species and average annual daily traffic (AADT) volume for SR 260, Arizona, USA, and elk population estimates for management units adjacent to SR 260, for the period 1994-2004

	No. wildlife-vehicle collisions [a]					Elk
Year	Total	Elk	Deer	Other[b]	AADT [c]	Population[d]
1994	29	20	9	0	3,124	1,683
1995	32	25	5	2	3,123	1,678
1996	29	23	6	0	3,652	1,665
1997	31	27	4	0	3,750	1,672
1998	45	33	10	2	3,950	1,660
1999	47	39	7	1	4,930	1,710
2000	21	14	7	0	5,112	1,542
2001	33	29	3	1	4,500	1,716
2002	44	36	8	0	6,267	1,587
2003	40	34	4	2	8,700	1,488
2004	44	42	2	1	N/A	N/A

[a]Source: ADOT Data Management Section, Phoenix, AZ
[b]Black bear, mountain lion, javelina
[c]Source: ADOT Data Management Section, Phoenix, AZ
[d]Source: GMU 22 and 23 annual elk summaries; AGFD Game Branch, Phoenix, AZ

Table 2. Number of total animals killed in wildlife-vehicle collisions along SR 260, Arizona, USA, between 2001-2004, with age and sex of classified animals and proportion of classified animals

	No. of animals killed in wildlife-vehicle collisions										
		Sex (% of total classified) [a]				Age (% of total classified) [a]					
Species	Total	Female		Male		Adult		Yearling		Young	
Elk	194	106	(80.9)	25	(19.1)	98	(74.2)	15	(11.4)	19	(14.4)
Whitetail deer	12	4	(36.3)	7	(63.6)	9	(81.8)	1	(9.1)	1	(9.1)
Mule deer	5	5	(100.0)	-	-	4	(80.0)	-	-	-	-
Deer	8	5	(83.3)	1	(16.7)	5	(100.0)	-	-	-	-
Black bear	1	-	-	1	(100.0)	1	(100.0)	-	-	-	-
Mountain lion	1	-		1	(100.0)	-	-	1	(100.0)	-	-

[a]Unclassified records account for differences between totals and number by sex and age

The association between EVC and AADT accounted for only 20 percent of the variation in EVC (r = 0.449, r^2 = 0.202, P = 0.192, n = 10), while the association between EVC and elk population estimates explained <1% of the variation (r = 0.088, r^2 = 0.007, P = 0.807, n = 10). However, when we incorporated both AADT and elk population estimates into a multiple regression model, the relationship accounted for 75 percent of the variation in EVC (r = 0.866, r^2 = 0.750, P = 0.008, n = 10); partial regression coefficients for AADT (1.43, P = 0.003) and elk population estimates (1.23, P = 0.006) were both significant.

Table 3. Frequency of elk-vehicle collisions (EVC) by SR 260 highway section, Arizona, USA, recorded for the period 2001-2004 by DPS and AFGD, and a comparison of the total EVC to the total EVC in the ADOT database (see table 1) for the same period

	No. of EVC by highway section						Percentage of total
Year	PC	LGV	KR	DC	CC	Total	in ADOT database
2001	10	3	9	1	7	30	96.7
2002	13	0	7	2	18	40	95.2
2003	10	2	7	5	19	43	80.2
2004	14	1	6	4	56	81	51.8
Mean	11.8	1.2	7.3	3.0	25.0	48.5	72.7

Comparison of EVC by highway section and construction classes

The location and frequency of EVC across all SR 260 0.16-km segments were not randomly distributed (Kolmogorov-Smirnov test, d = 0.13, P < 0.005; fig. 3), with EVC ranging from 0 to 3.1/segment/year (mean = 0.15 ±0.02). The mean EVC rate for all SR 260 sections between 1994 and 2004 was 1.1 collisions/km/year (table 4); the PC Section had the highest mean EVC rate of the five sections (1.7/km/year), followed by the CC Section (1.3/km/year). Among sections for all years, we detected significant differences in mean collision rates (ANOVA $F = 11.41$, df = 4, 50, $P < 0.001$; table 2); the mean collision rate for PC Section was higher than that for the LGV and DC sections (both $P < 0.001$), and the CC section rate was higher than the LGV section ($P = 0.009$). Considering only before-construction mean EVC rates, we found that they also differed among sections (ANOVA $F = 11.31$, df = 4, 40, $P < 0.001$). The PC and CC sections had the same mean before-construction EVC rate (0.7 km/year), which were both higher than means for the LGV (0.1/km/year; both $P < 0.001$) and DC (0.2/km/year; PC Section $P = 0.011$, CC Section $P < 0.001$) sections. Also, the mean pre-construction EVC rate for the KR section (0.5/km/year) was higher than that for the LGV section ($P = 0.012$).

In our assessment of EVC by highway construction classes, we found that the mean EVC differed among classes (ANCOVA $F = 19.4$, df = 2, 51, $P < 0.001$; table 5). The mean before-construction EVC (4.5 collisions/year, $n = 45$) was lower than that for sections and years during construction (12.4 collisions, $n = 7$; $P = 0.006$). Mean after-construction EVC (7.0, $n = 3$) did not differ from before- ($P = 0.631$) and during-construction ($P = 0.231$) classes. When we considered the PC section separately, the only section where construction was completed during our study, we found no differences ($P = 0.981$) among mean EVC before (7.7, $n = 6$), during (8.0, $n = 2$), and after construction was completed (7.0 +1.5, $n = 3$). On the CC Section, the mean EVC during construction (19.7/year, $n = 3$) was >2.5x the before-construction mean (7.6/year, $n = 8$), accounting for the differences among construction classes in our ANCOVA (table 5). In our database, the increase in EVC on the CC Section was particularly dramatic, increasing 3x from 19 in 2003 to 56 in 2004 (table 3) when the highway was opened to traffic before ungulate-proof fencing was properly completed.

Table 4. Number of elk-vehicle collisions by SR 260 highway section, Arizona, USA, 1994-2004, and mean collisions/km/year (±SE) for each section.

	No. of elk-vehicle collisi ons by State Route 260 section					
Year	PC	LGV	KR	DC	CC	Total
1994	4	0	4	4	8	20
1995	4	0	3	2	14	23
1996	10	0	3	2	5	20
1997	8	3	10	2	4	27
1998	8	2	8	3	10	31
1999	12	1	6	4	12	35
2000	6	2	2	0	2	12
2001	10	3	9	1	6	29
2002	10	0	7	2	17	36
2003	6	2	7	5	14	34
2004	5	1	5	3	28	42
Mean collisions/year	7.5	1.3	5.8	2.5	10.9	28.1
Section length (km)	4.6	4.0	5.4	4.5	8.2	26.7
Mean collisions/km/year (±SE)	1.7 (0.18)	0.3 (0.09)	1.1 (0.15)	0.5 (0.10)	1.3 (0.27)	1.1 (0.06)

Comparison of EVC and elk highway crossings

GPS collars were affixed to 33 elk (25 females, 8 males) an average of 412.9 days (±39.1; range = 50-684 days). From these elk, we accrued 101,506 GPS fixes, or 70.1-percent fix success (range = 23.1-100.0), with a mean of 3,075.9 fixes/elk (±378.3; range = 344-7,332). Of these fixes, 46,162 (45.5%) occurred <1 km of SR 260. Collared elk crossed SR 260 3,057 times (fig. 4), with a mean of 92.6 crossings/elk (±23.5); individual elk crossings ranged from 1-691. The mean frequency of highway crossings by cows (112.0 ±29.9) was 3.5x greater than that for bulls (32.1 ±12.1). On average, elk crossed the highway 0.22 times/day (±0.04), with cows (0.28 ±0.05) crossing 4.5x more than bulls.

We rejected the null hypothesis that the frequency distribution of crossings occurred randomly (Kolmogorov-Smirnov test, $d = 0.01$, $P < 0.001$); rather, crossings exhibited a strongly clumped pattern (fig. 4). The highest crossing frequency occurred on the PC Section (282.2/km), followed by the CC Section (130.5/km) (table 6). Combined, all other sections exhibited relatively low crossing frequency (<40/km; table 6), though peaks also occurred near meadow-riparian habitats on the KR and DC sections (fig. 4).

Table 5. Dates of construction initiation and completion for SR 260 highway sections, Arizona, USA, and mean number of elk-vehicle collisions (EVC) between 1994-2002 (±SE) by highway construction classes (before, during, and after reconstruction). Letters denote differences among means for the highway construction classes for all highway sections combined and the PC Section separately (ANCOVA).

Highway section	Date construction: Started	Date construction: Complete	Mean EVC (±SE) by construction class and years data (*n*): Before		During		After	
PC	2000	11/2001	7.7 (1.3) A	*n* = 6	8.0 (2.0) A	*n* = 2	7.0 (1.5) A	*n* = 3
LGV	-	-	0.3 (0.1)	*n* = 11	-	-	-	-
KR	2002	2005	5.8 (0.1)	*n* = 9	6.0 (1.0)	*n* =2	-	-
DC	-	-	0.6 (0.1)	*n* = 11	-	-	-	-
CC	2001	1/2005	7.6 (1.5)	*n* = 8	19.7 (4.2)	*n* = 3	-	-
All	N/A	N/A	4.5 (0.5) A		12.4 (3.1) B		7.0 (1.5) A, B	

Table 6. Summary of elk crossings, Shannon Diversity Index, and weighted crossings by highway section along SR 260, Arizona, USA, determined from 33 elk fitted with GPS telemetry collars, May 2002-April 2004

Highway section (km)	No. elk crossings (%)	Crossings/ km	Mean SDI [a]	Weighted no. crossings[b] (%)	Weighted crossings/km
PC (4.6)	1,298 (42.4)	282.2	1.00	1,312 (37.1)	285.2
LGV (4.0)	132 (4.3)	33.0	0.65	193 (5.5)	48.2
KR (5.4)	212 (6.9)	39.2	0.75	237 (6.7)	43.9
DC (4.5)	292 (9.5)	64.9	0.70	332 (9.4)	73.8
CC (8.2)	1,070 (35.0)	130.5	1.07	1,451 (41.0)	177.0
All (29.8)	3,057 (100.0)	102.6	0.71	3,534 (100.0)	118.6

[a]Shannon Diversity Index (Shannon and Weaver 1949)
[b]Weighted crossings = $\sum$ (no. of crossings/segment x SDI)

The number of different elk crossing at each highway segment ranged from 0-8, and averaged 3.3. Our weighted crossing frequencies considering SDI for all segments exhibited significant shifts in crossing patterns compared to those without SDI (fig. 4; Kolmogorov-Smirnov test, d = 0.22, P < 0.001). Most apparent were differences for the CC Section, which had high SDI elevated crossings for many segments, some the highest along the entire study area (fig. 4); weighted crossing frequency for the CC Section was 32 percent over the non-weighted crossings (Kolmogorov-Smirnov test, d = 0.28, P < 0.01). At the PC Section, peak crossings shifted from the western portion, skewed by a single cow that crossed there 691 times, to a large peak in the vicinity of the Little Green Valley meadow complex and two wildlife underpasses (fig. 4), which better reflected the high diversity and frequency of elk crossings there. Even with the dramatic shift in crossing peaks for the PC Section, weighted crossing frequency increased only negligibly (1.1%; table 6), and the crossing patterns did not differ. Weighted and raw crossing distributions for the other three sections also did not differ.

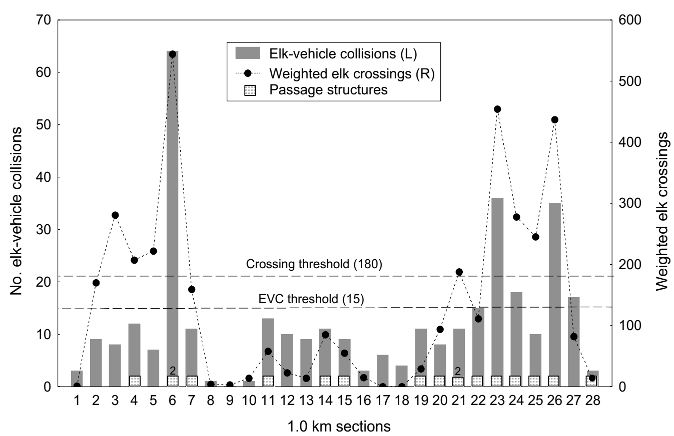

Figure 3. Frequency of EVC reported 1994-2004 and weighted elk crossings determined from 33 elk fitted with GPS telemetry collars from May 2002-April 2004, by 1.0-km sections along SR 260, Arizona, USA. Thresholds for high EVC and crossings are denoted by dashed lines, and passage structures (underpasses and bridges) are denoted within each 1.0-km segment in which they are located.

Spatial relationships between EVC and crossings

The strength of the associations between EVC and elk highway crossings increased as a function of increasing scale (table 7). Our strongest association between EVC and crossings was found at the highway section level for weighted crossings ($r = 0.971$, $r^2 = 0.942$, $n = 5$, $P = 0.006$), while the weakest occurred at the 0.16-km segment scale for uncorrected crossings ($r = 0.396$, $r^2 = 0.156$, $n = 200$, $P < 0.001$). The relationships between EVC and weighted elk crossings accounted for an average of 16.2 percent more variation in EVC compared to uncorrected elk crossings (table 7, fig. 5).

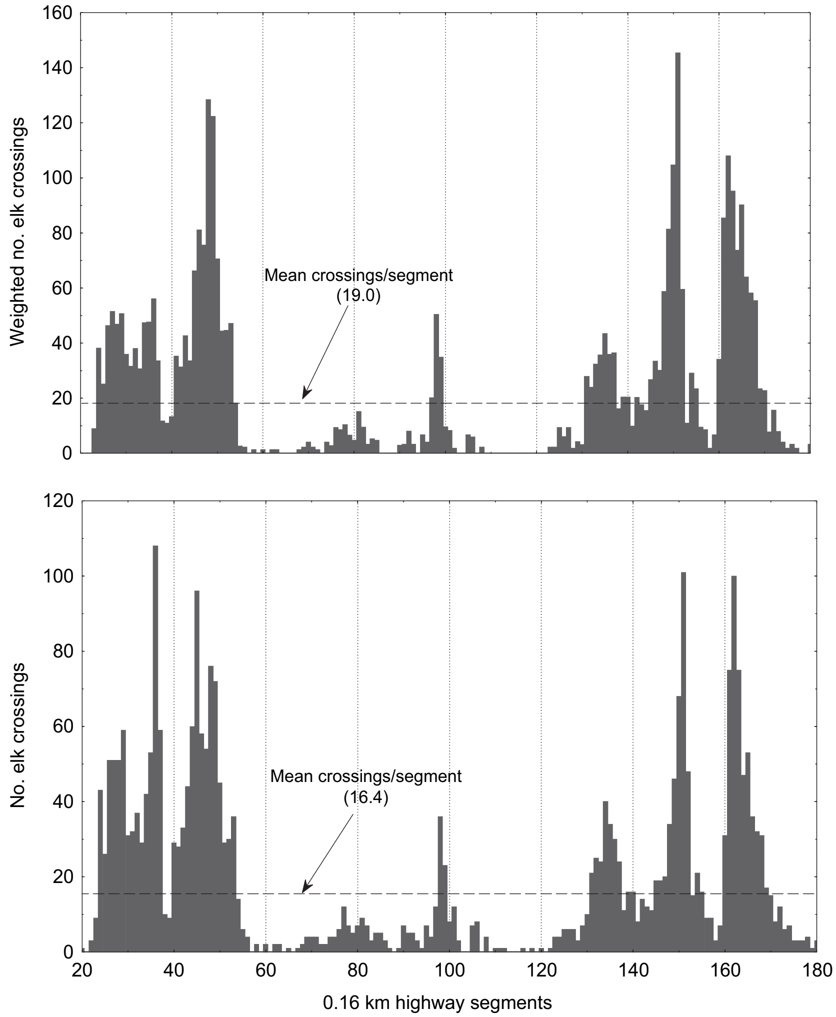

Figure 4. Frequency distribution of elk crossings (bottom) and weighted elk crossings derived from crossings x Shannon diversity index for each segment (top) by 0.16-km segment along SR 260, Arizona, USA, determined from 33 elk equipped with GPS receiver collars, May 2002-April 2004. Highway sections correspond to the following segments: PC (21-50), LGV (51-76), KR (77-111), DC (112-140), and CC (141-200).

Table 7. EVC relationships between highway crossings and weighted crossings by GPS-collared elk at various scales along SR 260, Arizona, USA, including correlation coefficients (r) and coefficients of determination (r^2)

		Elk crossings vs. EVC			Weighted elk crossings[a] vs. EVC		
Scale	n	r	r^2	P	r	r^2	P
0.16 km[b]	208	0.396	0.156	<0.001	0.509	0.259	<0.001
0.50 km	57	0.566	0.320	<0.001	0.700	0.489	<0.001
1.00 km	28	0.688	0.474	<0.001	0.837	0.701	<0.001
1.62 km	18	0.715	0.512	<0.001	0.833	0.693	<0.001
Section[c]	5	0.901	0.812	0.037	0.971	0.942	0.006

[a]Weighted elk crossings = Σ (no. of elk crossings/segment x SDI)
[b]Corresponds to 0.10 mi segments
[c]Average length of each highway section = 6.0 km

The associations between EVC and weighted elk crossings at the 1.62-km and 1.0-km scales were comparable, with both explaining 70 percent of the variation in EVC (table 7, fig. 5). However, the strength of the relationships diminished at scales below 1.0 km; variation explained declined incrementally by >20 percent between each scale below the 1.0-km level (fig. 5).

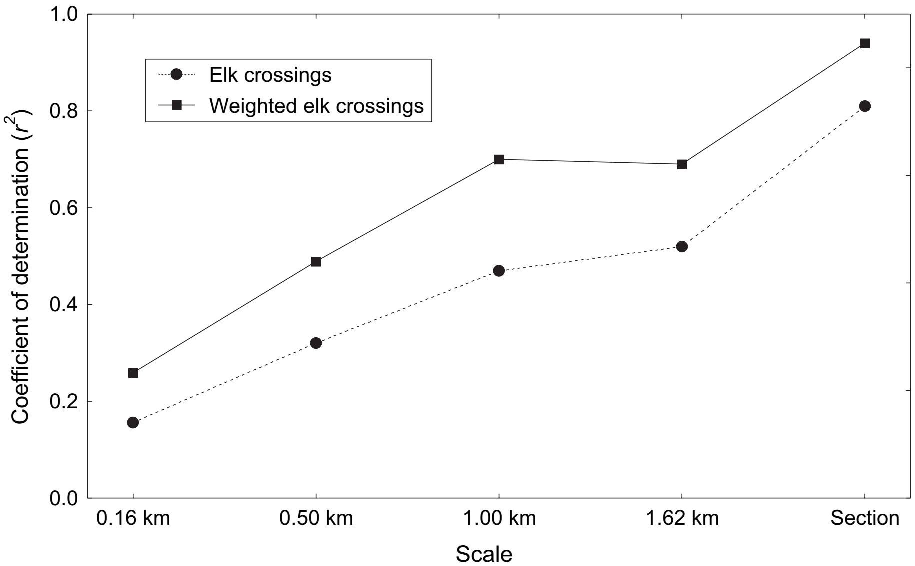

Figure 5. Coefficients of determination (r^2) for linear regression comparisons of EVC to elk crossings and weighted crossings conducted at various scales along SR 260, Arizona, USA. EVC occurred 1994-2004, and elk crossings were determined from 33 elk fitted with GPS telemetry collars between May 2002 and April 2004.

At the highway section scale, the number of 0.16-km segments located within 0.25 km of riparian-meadow habitat was strongly associated with EVC (r = 0.981, r^2 = 0.962, n = 5, P = 0.003). The number of segments located in proximity to riparian-meadow habitat on each section also was related to the frequency of weighted elk crossings (r = 0.898, r^2 = 0.806, n = 5, P < 0.038). At the 1.0 km scale, the number of segments in proximity to riparian-meadow habitat was associated with both the frequency of EVC (r = 0.751, r^2 = 0.564, n = 28, P < 0.001) and weighted elk crossings (r = 0.772, r^2 = 0.596, n = 28, P < 0.001).

Temporal relationships between EVC and crossings

We detected monthly and seasonal differences in the frequency of both EVC and highway crossings. Observed mean monthly EVC for all elk differed from expected (X^2 = 34.0, df = 11, P < 0.001), as did crossing frequencies for all elk (X^2 = 220.8, df = 11, P < 0.001; fig. 6). EVC that occurred during September-November accounted for 49 percent of all collisions (fig. 6); most collisions with cows occurred in November (15%), while October accounted for the highest proportion of bull collisions (28%) and all collisions (20%). While observed monthly EVC (P = 0.251) and crossings (P = 0.691) did not differ from expected for cows, those involving bulls differed from expected (ECV X^2 = 122.0, df = 11, P < 0.001; crossing X^2 = 114.6, df = 11, P < 0.001; fig. 7); cow EVC and crossings were relatively consistent throughout the year. During November-April, only 18 crossings (7% of total) and 3 EVC (12%) involving bulls were recorded, with a subsequent increase from May-October (fig. 7). The proportion of elk crossings by month (as an expected proportion for EVC) differed from the actual observed proportion of EVC (X^2 = 24.8, df = 11, P = 0.010), and differed for both cows and bulls. In contrast to elk, the monthly frequency of recorded deer collisions (n = 70) did not differ from expected, though half the collisions involving deer occurred from November-February.

On an annual basis, the ratio of bull:cow EVC (23.6:100) was less than half the mean bull:cow ratio (51.8:100) from annual surveys (2001-2004) conducted in GMU 22 and 23, and the surveyed ratio (expected) differed from the collision ratio (observed; X^2 = 101.9, df = 3, P < 0.001). However, considering only the period June-October which accounted for 85.7 percent of bull crossings and 84.0 percent of EVC involving bulls, the bull:cow EVC ratio (48.8:100) did not differ from the surveyed population bull:cow ratio (P = 0.808).

Recorded EVC by day differed from expected (X^2 = 22.0, df = 6, P < 0.001), while elk crossings by day (range = 318-384/day) did not differ from expected (P = 0.169) unless we applied daily AADT factors to the expected crossings (X^2 = 34.8, df = 6, P < 0.001). However, the proportion of elk crossings by day (expected) did not differ from the proportion of EVC (P = 0.424), even with daily AADT factors (P = 0.520). The greatest departures in daily EVC above expected levels occurred on Monday (35% above expected) and Friday (19%), and the greatest departure below expected occurred on Wednesday (73% below expected; fig. 8). In applying AADT daily factors to adjust for differential daily AADT, the number of EVC on Monday remained the highest of the week, while Friday dropped 17 percent to below expected levels, and EVC on Sunday increased 12 percent (fig. 8). Observed deer collisions did not differ by day unless AADT daily factors were applied (X^2 = 13.4, df = 6, P = 0.038), which resulted in the same daily trends as EVC.

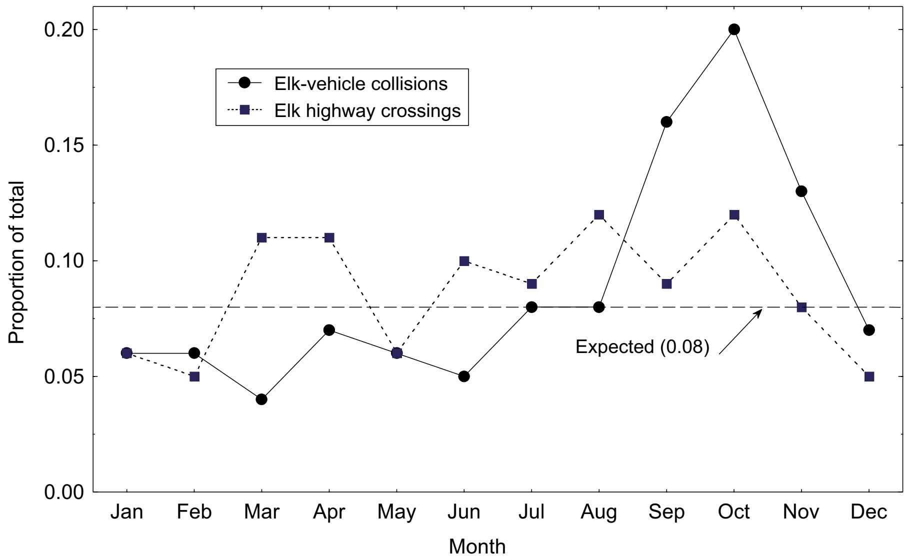

Figure 6. Proportions of EVC (solid line) and elk highway crossings (dashed line) for all elk by month along State Route 260, Arizona, USA. EVC occurred between 1994-2004, and elk crossings were determined from 33 elk fitted with GPS telemetry collars between May 2002 and April 2004. Both observed EVC (?2 = 34.0, df = 11, P < 0.001) and elk crossings (?2 = 220.8, df = 11, P < 0.001) differed from expected values.

Both the observed frequency of EVC and elk highway crossings by two-hour time interval differed from expected (X^2 = 271.0 and 672.2, respectively; both df = 11, P < 0.001). Also, the proportion of elk crossings that occurred in each time interval (expected) differed from the proportion of EVC (X^2 = 39.4, df = 11, P < 0.001). The largest proportion of EVC (31%) occurred between 19:00 and 21:00, with nearly 60 percent of collisions reported between 17:00 and 11:00 (fig. 9). The largest proportion of elk crossings occurred between 5:00 and 7:00 (18%); 83 percent of crossings were made at nighttime between 19:00 and 7:00 (fig. 9). A higher proportion of EVC (59%) occurred relative to crossings (33%) in the evening hours (17:00-23:00), while a lower proportion (19%) occurred during morning hours (3:00-9:00) relative to crossings (34%). We found that 34 percent of EVC occurred within a one-hour absolute departure from sunrise or sunset, and 55.5 percent occurred within a two-hour departure period (fig. 10). Similarly, 35 percent of deer collisions occurred within a one-hour departure, and 50 percent, within two hours of sunrise or sunset (fig. 10).

Determination of high EVC and crossing sections
Our calculations defined high EVC incidence sections as those with >15 EVC from 1994-2004 (mean = 12.3), and high crossing sections as those with >180 weighted crossings (mean = 135.1). All six of the identified high EVC sections (of 28 total) will have a bridged passage structure (underpass or bridge) in place when highway reconstruction is complete, and passage structures will occur on seven of the nine identified high crossing sections (fig. 3). Combined, high EVC and crossing sections accounted for 11 different sections, of which 9 (81.8%) will have a passage structure in place upon highway reconstruction (fig. 3).

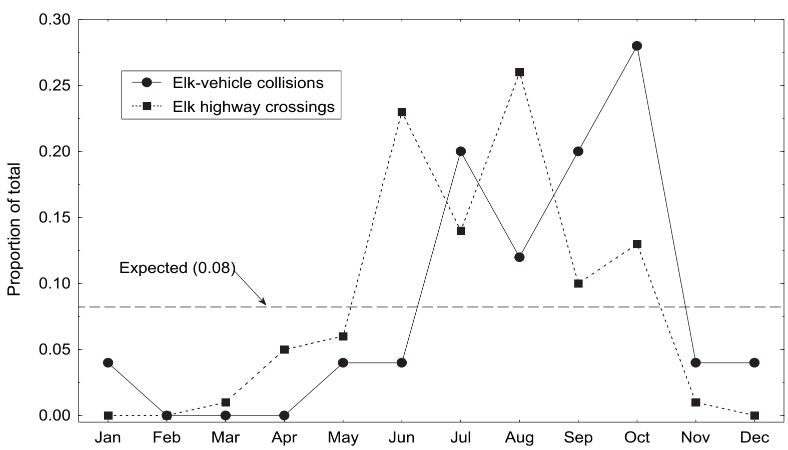

Figure 7. Proportions of EVC and elk highway crossings for bull elk by month along State Route 260, Arizona, USA. EVC occurred between 1994-2004, and elk crossings were determined from 8 bulls fitted with GPS telemetry collars between May 2002 and April 2004. Both observed EVC (?2 = 122.0, df = 11, P < 0.001) and elk crossings (?2 = 114.6, df = 11, P < 0.001) differed from expected values.

Discussion

The estimated proportion of wildlife killed by vehicles and recorded in WVC databases has ranged from 17 percent for deer (Forman et al. 2003), 25-35 percent for all wildlife species (Sielecki 2004), 50 percent for deer (Romin and Bissonette 1996b), to 80 percent for moose (*Alces alces:* Garrett and Conway 1999). The long-term ADOT database we used for our analyses included nearly 75 percent of all WVC that were documented along SR 260 during 2001-2004. Though smaller and causing less property damage than elk, 68 percent of deer collisions were nonetheless recorded in both databases. From 2001-2003, 88 percent of EVC were documented in both databases, but dropped in 2004 when we documented 10 calf EVC collisions not reported in the ADOT database.

EVC relationships to AADT and elk population estimates
We found that AADT and estimated elk population levels jointly influenced annual EVC along SR 260; based on partial regression coefficients, AADT had a stronger influence on EVC, as reported by Seiler (2004). Traffic volume has frequently been reported as a factor contributing to WVC for a wide range of wildlife (Inbar and Mayer 1999, Joyce and Mahoney 2001, Forman et al. 2003). Other studies have linked traffic volume and relative animal abundance to the incidence of WVC (Fahrig et al. 1995, Romin and Bisonnette 1996, Philcox 1999, Seiler 2004), including Gunson and Clevenger (2003) for elk in Alberta. In contrast to our study, Gunson and Clevenger (2003) found that mean EVC declined as traffic volume increased (r^2 = 0.82), though they believed that a decline in their elk population influenced this relationship. They also reported a positive relationship between elk abundance and EVC (r^2 = 0.75) independent of traffic volume.

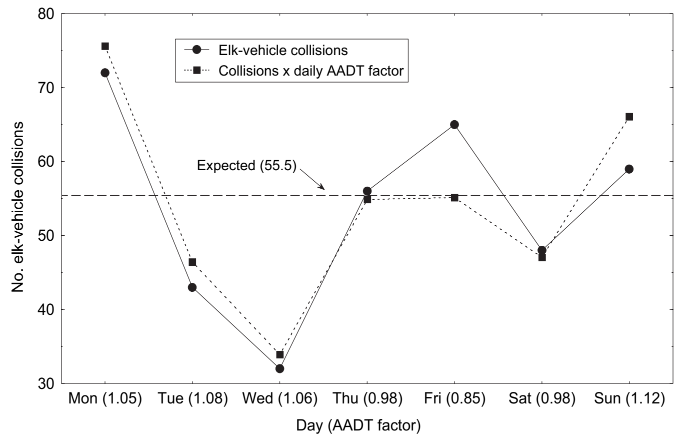

Figure 8. EVC frequency by day and EVC corrected with daily AADT factors accounting for differential traffic volume by day. Both observed EVC (X^2 = 22.0, df = 6, P < 0.001) and AADT-corrected EVC (X^2 = 20.7, df = 6, P < 0.001) differed from expected values. EVC occurred along SR 260, Arizona, USA, 1994-2004.

Using the mean annual increase in AADT of 17.8 percent/year (1994-2003; table 1), and holding the elk population constant at 2003 levels, our multiple regression model predicted that EVC would double from 34 in 2003 to 73 in 2006 without measures to reduce WVC. The potential increase in EVC could be far greater given a higher annual AADT rate of increase (e.g., 38% from 2002-2003) reflective of Arizona's current human population growth patterns, and justifies the extensive and costly measures to reduce the incidence of WCV on SR 260.

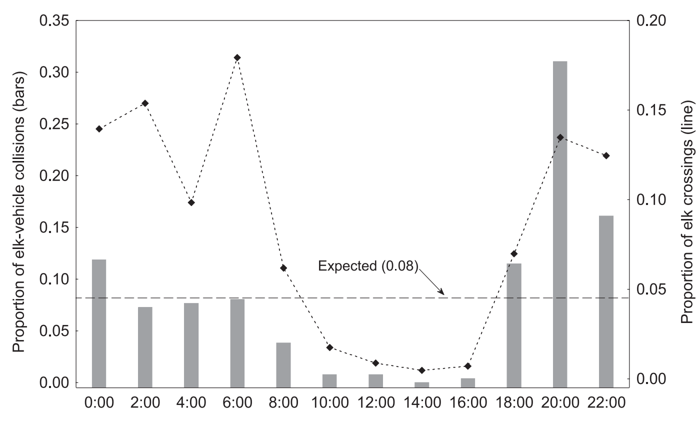

Figure 9. Proportions of EVC (bars) and elk highway crossings (dashed line) by 2-hour time interval along State Route 260, Arizona, USA. EVC occurred between 1994-2004, and elk crossings were determined from 33 elk fitted with GPS telemetry collars between May 2002 and April 2004. Both observed EVC (X^2 = 271.0, df = 11, P < 0.001) and elk crossings (X^2 = 672.2, df = 11, P < 0.001) differed from expected values.

Comparison of EVC by highway section and construction classes

Our mean EVC rate for all highway sections (1.1/km/year) exceeded those reported for Alberta (Gunson and Clevenger 2003) and British Columbia (Sielecki 2004), but was lower than the rate (1.6/km/year) reported by Biggs et al. (2004) in New Mexico. The comparative EVC rates for SR 260 validated the prioritization for reconstruction (Route 260-Payson to Heber EIS, ADOT Environmental Planning Section, Phoenix, AZ); PC Section 1st (1.7/km), CC Section 2nd (1.3/km), and KR Section 3rd (1.1/km). The two sections where reconstruction has not begun (LGV and DC) had a combined EVC rate of 0.4/km/year.

Hardy et al. (2003) stressed the value of conducting "before-after, control-impact" (BACI; Underwood 1994) assessments to determine the effects of highway construction and efficacy of measures to reduce WVC and promote permeability. Phasing of SR 260 construction among sections, presence of control sections, and the long-term ADOT database provided the opportunity to conduct such an assessment. To date, the PC Section was the only section where we compared after-construction EVC to those before and during highway construction; we will soon be able to make similar comparisons for the CC and KR sections.

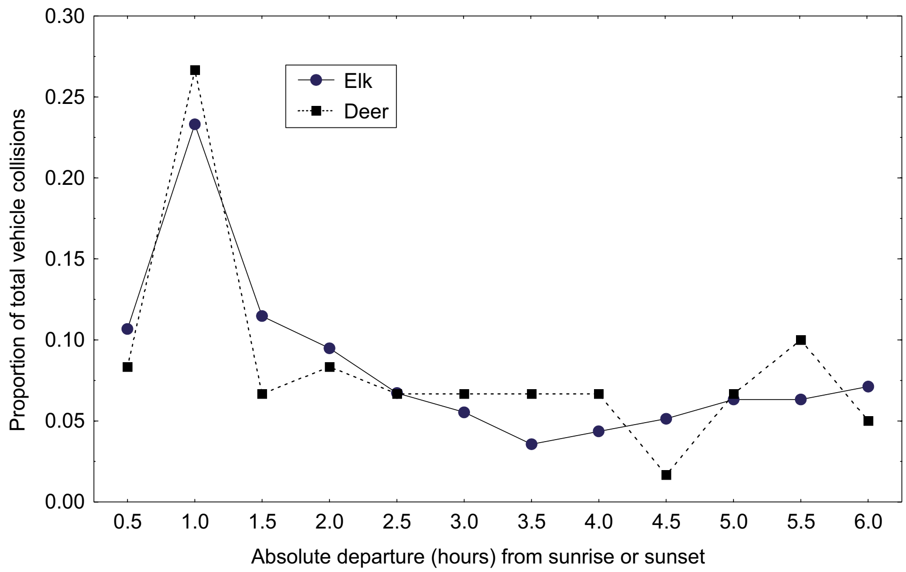

Figure 10. Absolute departure (by 0.5 hour increments) from sunrise or sunset for vehicle collisions with elk (solid line) and deer (dashed line) along SR 260, Arizona, USA, for collisions that occurred 1994-2004.

EVC frequency on the PC Section remained largely unchanged across all construction phases. Yet, given the 67-percent increase in mean AADT from before-construction levels (3,754.8 vehicles/day ±272.4) to an after-construction mean of 6,267 vehicles/day (±1,094.0), the two wildlife underpasses with limited ungulate-proof fencing and the bridge over Preacher Canyon have yielded benefit in maintaining EVC in spite of increased traffic levels. These measures have promoted elk permeability across SR 260, with 40 percent of weighted elk crossings for the PC Section having occurred below grade at the three passage structures, even with limited fencing.

The large increase in EVC on the CC Section during construction between 2003 and 2004 reflected opening of the highway to traffic before ungulate-proof fencing was completed, along with increased AADT and vehicular speed (Forman et al. 2003). While fence paralleling the highway was erected in spring 2004, fencing through the seven passage structures was not erected so as to tie them together prior to opening of all lanes to traffic. Elk continued to cross at grade or accessed the median of the divided highway, contributing to the rash of EVC. In the five months between when the CC Section was opened to traffic and the fencing completed (December 2004), we documented 38 EVC here. In the 10 months since fence completion along 57% of the CC Section, 8 EVC have been documented; 6 occurred along unfenced sections of the highway. We anticipate that a dramatic reduction in EVC will occur with the completion of fencing. Fencing's utility in reducing WVC is well accepted, especially in conjunction with effective passage structures (Ward 1982, Foster and Humphrey 1995, Clevenger et al. 2001), though Ward (1982) documented an increase in WVC in the first year after fencing was erected.

Comparison of EVC and elk highway crossings

GPS telemetry afforded us an unprecedented spatial and temporal assessment of elk highway crossing patterns and permeability (Dodd et al. *In review*), and allowed us to compare crossing patterns to EVC. With mean GPS fix accuracy to within ±12 m, and with >85 percent of our fixes within 20 m of known validation locations (Dodd et al. *In review*), GPS telemetry constituted a sufficiently accurate tool to assess elk crossing patterns and address our study objectives.

Spatial relationships
Several studies have demonstrated that WVC do not occur randomly, either spatially or temporally (Puglisi 1974, Bashore et al. 1985, Clevenger et al. 2001), including EVC (Gunson and Clevenger 2003, Biggs et al. 2004). Both our EVC and elk crossings patterns differed from a random distribution. Many spatial factors contribute to distribution of WVC (Farrell et al. 2002), including topography, wildlife concentrations and density (Hubbard et al. 2000), and highway proximity to preferred (Farrell et al. 2002) and seasonal (Romin and Bissonette 1996*b*, Gordon and Anderson 2003) habitats.

Though intuitive, we confirmed the relationship between the frequency of elk highway crossings (and weighted elk crossings) and EVC. The fact that weighted elk crossings accounted for more variation in the relationship points to the joint influence of crossing frequency, number of crossing elk, and the evenness in crossing patterns. Dodd et al. (*In review*) found that individual variation in crossing rates also influenced the likelihood of elk being involved in EVC; of the four collared elk killed in EVC, they represented 57 percent (n = 7) of those with >0.40 crossings/day, while no elk with <0.20 crossings/day (n = 18) or 0.20-0.40 crossings/day (n = 7) were killed in EVC.

Though our strongest relationship between weighted crossings and EVC was found at the highway-section scale, this scale provides limited management utility. The 1.0-km scale was optimal as it afforded relatively high "power" (r^2 > 0.7) and was refined enough to determine WVC and crossing patterns and plan mitigation measures to address WVC and permeability. At this scale, 9 of 11 (82%) high EVC or crossing segments have passage structures planned or implemented. The relationship between crossings and EVC points to the utility of using collision and road kill data as a surrogate measure of weighted crossings determined by costly GPS assessment.

The relatively weak relationship (r^2 < 0.3) between EVC and weighted crossings at the 0.16-km scale probably reflected inaccuracy in both GPS elk crossing segment determination and WVC reporting error, as found by Gunson and Clevenger (2003; mean reporting error >0.2 km).

Temporal relationships
We recorded a dramatic increase in the proportion of EVC occurring in fall (September-November); this increase greatly exceeded the proportion of highway crossings by all elk, though crossings also exceeded the expected proportions at this time (fig. 6). For bulls, an even greater spike in EVC occurred from July-October, with peaks in July and October (fig. 7). Gunson and Clevenger (2003) reported an increase in EVC in fall attributable to increased elk numbers from calf recruitment, and Biggs et al. (2004) reported increased EVC in fall and winter, with EVC in winter associated with snows and migrating elk. With deer, Romin and Bissonette (1996b), Hubbard et al. (2000), and Puglisi et al. (1974) attributed increased collisions in fall to breeding and sport hunting.

In our case, the seasonal increase in EVC probably reflected a combination of factors. First, the fall increase in EVC reflected an influx of migratory elk that moved from summer range atop the Mogollon Rim beginning in October (Brown 1990, 1994*b*); these elk were not represented in our GPS crossing data, possibly accounting for the lack of a comparable increase in crossings by all elk in fall (fig. 6). This increase in overall elk numbers, in addition to calf recruitment (Gunson and Clevenger 2003) probably accounted for the fall peak in EVC. Further, the onset of the breeding season in September and October coincided with peaks in the proportion of EVC for bulls and all elk combined, both with the highest proportion of EVC in October (fig. 6 and 7).

The influence of riparian-meadow habitats is reflected in seasonal fluctuations in EVC and elk crossing patterns. Most apparent were the strong associations between EVC and crossings to the proximity to riparian-meadow habitats. The original alignment of SR 260 abutting several streams and large meadow areas (fig. 1) has contributed to long-term wildlife-vehicle conflicts. Elk use of riparian and meadow habitats for foraging and watering, particularly during prevailing drought conditions, appeared to be a large determinant of where EVC and elk crossings occurred. Further, riparian areas and drainages are preferred travel lanes and corridors for elk (Skovlin 1982, Servheen et al. 2003).

We believe that the high proportion of bull EVC and crossings during late-spring and early-summer were tied to nutritional demands associated with antler growth (Bubenik 1982). Riparian-meadow habitats provide forage of highest nutritional quality, earlier in the growing season than adjacent forest habitats (Nelson and Leege 1982), and higher quality diets permit increased digestive rates and rumen turnover, allowing elk to feed more frequently (Green and Bear 1990). Increased movement of bulls to riparian-meadow habitats adjacent to SR 260 to feed probably influenced EVC and crossing patterns. While only four percent of the area within 1 km of SR 260 comprised riparian-meadow habitats, 20 percent of all bull GPS fixes occurred in such habitats, including 46 percent of the fixes in August (Dodd et al. *In review*). Cow elk also have high nutritional demands during lactation through the summer and fall (Nelson and Leege 1982); 38 percent of EVC involving cows occurred during September-November. As with bulls, we believe that cows best met their high nutritional demands by foraging in riparian-meadow habitats adjacent to SR 260, which contributed to EVC at this time.

Gunson and Clevenger (2003) reported greater numbers of female EVC, though the sex ratio of EVC was actually skewed toward bulls given their low bull:cow ratio. Romin and Bissonette (1996*b*) reported bias toward male deer in WVC, as did Joyce and Mahoney (2001) for moose. Relying on the year-long mean EVC sex ratio for SR 260 would lead us to conclude that EVC disproportionately affect the female segment of the elk population relative to the surveyed ratio.

However, in applying our GPS crossing data to address the EVC sex ratio only during the period when bulls crossed SR 260, EVC occurred in proportion to the ratio of the surveyed population.

Gunson and Clevenger (2003) reported more EVC on weekend days (Friday-Sunday) versus weekdays, attributable to high recreational and tourist traffic. Though SR 260 was subject to a similar traffic volume pattern, with highest volume on Friday and Saturday, the highest incidence of EVC occurred on Monday. On Friday, the daily AADT-adjusted EVC was below expected in spite of the highest traffic volume, suggesting that elk responded to the 25 percent traffic volume increase between Wednesday (lowest EVC incidence) and Friday. The incidence of Sunday EVC exceeded the expected level of accidents especially when adjusted by daily AADT factors, and by Monday (23% below Friday traffic volume) EVC incidence far exceeded the expected level. Thus, EVC (and AADT daily factor-adjusted crossings) appeared to reflect a behavioral response to avoiding high traffic volume on Friday and Saturday, followed by elevated EVC on Sunday and Monday despite lower traffic volume. Mueller and Berthoud (1997) hypothesized that highways with AADT levels between 4,000 and 10,000 present a strong barrier that would repel animals; above 10,000 vehicles/day, highways would become impermeable to most species. Brody and Pelton (1989) reported a negative relationship between black bear crossings and traffic volume, as did Waller and Servheen (2005) for grizzly bears (*U. arctos*). Our Friday and Saturday AADT levels often exceed 10,000 AADT, leading to lower than expected EVC and crossings reflective of behavioral adaptation by elk. Surges in EVC and crossings on Sunday and Monday probably reflected increased movements by elk following peak AADT days. Video camera surveillance of two wildlife underpasses on the PC Section found a similar pattern where elk use was below expected levels on Friday and Saturday and exceeded expected on Sunday and Monday, attributable to differential daily traffic volume (Dodd et al. *In review*).

Haikonen and Summala (2001) reported that a large peak in WVC, 46 percent of moose and 37 percent of whitetail deer collisions, occurred within three hours after sunset tied to circadian rhythms associated with light. We found an even more dramatic peak in WVC after sunset; 67 percent of EVC and 64 percent of deer collisions occurred within a three-hour departure of sunset. Gunson and Clevenger (2003) and Biggs et al. (2004) noted similar evening peaks in EVC, though the latter also noted a secondary peak in the morning tied to increased commuter traffic volume. Our morning EVC remained below expected levels though a third of elk crossings occurred between 3:00-9:00; SR 260 does not exhibit morning traffic as reported by Biggs et al. (2004). Green and Bear (1990) found that 38-60 percent of daily elk feeding activities occurred at dawn and dusk throughout the year, with the highest proportion of feeding at these times in the fall-winter when Gunson and Clevenger (2003), and Biggs et al. (2004), and we noted peak EVC.

Management Implications

Our comparison of EVC and highway crossings points to the high similarity in spatial patterns, and to a lesser degree temporal patterns, exhibited by elk along SR 260 assessed by the two methods. These similarities point to the utility and validity of using EVC data as a surrogate measure of weighted crossings determined by costly GPS assessment. It also underscores the value of WVC data in developing strategies to maintain permeability and increase highway safety (Romin and Bissonette 1996*a*, Farrell et al. 2002) by selecting the best locations of passage structures (Clevenger et al. 2002, Barnum 2003). Consistent tracking of WVC provides a means to assess the impact of highway construction on wildlife and to evaluate the effectiveness of measures to reduce WVC and promote permeability. We found that aggregating EVC patterns to 1.0-km segments proved to be a scale that optimized the strength of the relationship between EVC and elk highway crossings and management utility.

Our temporal EVC and crossing patterns reflect the influence of riparian-meadow habitats on elk movements and the conflict created between elk and vehicles with the original alignment of SR 260 adjacent to such habitats. Yet given this conflict, most SR 260 wildlife underpasses have been planned or constructed near riparian-meadow areas, which will contribute to their acceptance and use by elk and other wildlife (Clevenger and Waltho 2003, Servheen et al. 2003). Where fencing is erected to block crossings and funnel animals to underpasses (Clevenger et al. 2001), the attractive nature of riparian-meadow habitats will expedite learning by elk in their use of underpasses (Clevenger and Waltho 2003).

Gaining an understanding of EVC patterns and identifying relative collision potential associated with season, day, time, and relationships to traffic volume will provide highway planners insights to develop strategies to educate motorists of WVC risks as an important aspect of reducing collisions, human injuries, loss of life, and property damage.

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Effects of Gender and Season on Spatial and Temporal Patterns of Deer-Vehicle Collisions

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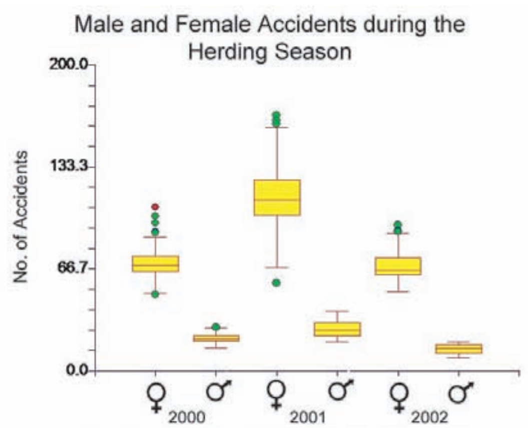
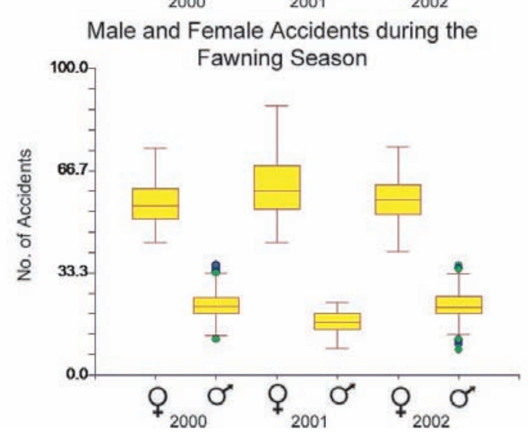
Abstract: White-tailed deer (*Odocoileus virginianus*) are a serious accident hazard, especially in suburban communities with high deer densities. Such areas are becoming more common as deer populations continue to grow throughout the northeastern United States. This study analyzed deer-vehicle collision data collected from police reports in Connecticut for 2000, 2001 and 2002. The purpose of this project was to integrate the use of standard crime mapping tools, multi-temporal remotely sensed vegetation imagery, human infrastructure, and the behavioral aspect of white-tailed deer to create a spatially explicit model of gender-specific deer-vehicle accident probabilities. We found marked differences between number, location, and seasonality of male and female accidents. Through most of the year, the number of males and females involved in accidents were relative to their proportion in the population. However, during the breeding season, there were a higher proportion of males involved in accidents. The spatial distribution of accidents involving deer also varied by season and sex – outside of the breeding season, accidents involving male deer were concentrated in a few key locations in the state. The difference in the spatial location of male and female accidents could be the result of resource partitioning exhibited by the species, with males occupying broader ranges in peripheral habitats. This model can be used to predict high risk areas as they change over the different seasons and design warning programs and adaptive education to these target areas.

Introduction

Nationwide, deer have been estimated to cause 1.5 million motor vehicle accidents annually, resulting in 1.3 million deer killed and $1.1 billion in vehicular damage (Conover et al. 1995). Deer-vehicle collisions (DVC) have also been estimated to result in 29,000 human injuries and over 200 fatalities annually (Conover et al. 1995). If the economic estimate of $1,313 for a hunter-harvested deer (Romin and Bissonette 1996) is applied to the estimated annual road-killed deer, then $1.7 billion in potential economic revenue is lost annually (Conover et al. 1995). Conover et al. (1995) also estimate that less than 50 percent of DVC are actually reported. State Farm Insurance reports that each DVC typically causes $2,000 in property damage, though it can exceed $10,000. Deer strikes are on the increase in the United States as human and deer populations are growing, and habitat continues to be fragmented. Perhaps local analysis of documented DVC could better predict time and place of such collisions by examining habitat preferences, seasonality, and gender differences in collision timing and location.





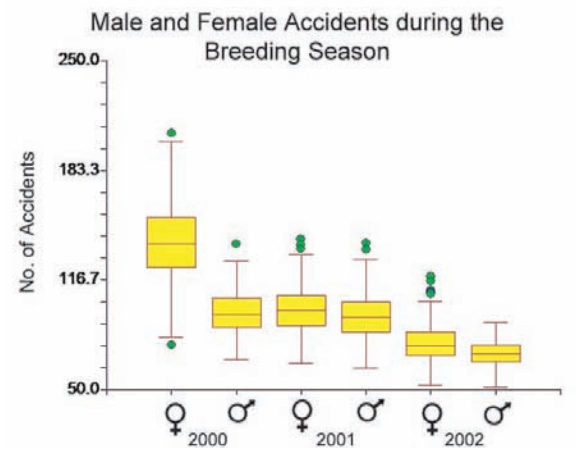


Figure 1. Seasonal differences in the number of accidents involving males and females – a. herding season; b. fawning season; c. breeding season.

In 2000, 3,123 legitimate deer-kill incident reports (DKIR) were completed in the state of Connecticut, 3,209 in 2001, and 2,571 in 2002. These numbers are on the increase from only 10 years ago. In Connecticut, the Department of Environmental Protection (DEP) gathers information about DVC by using these DKIR. These reports are kept by state and local police officers and conservation officers, and are filled out when a reported DVC occurs. Insurance claims pertaining to DVC will be paid only if the claim is accompanied by a DKIR. If vehicles sustain damage in a DVC, it is most likely that occupants will notify authorities to obtain and fill out a DKIR to make a claim to their insurance carrier. However, numerous DVC are never reported. Drivers of larger vehicles and trucks may not know if they struck a deer, and damage sustained to such a vehicle may be minimal. It has been estimated that there are probably closer to 18,000 deer killed annually by vehicles statewide (Kilpatrick 2004).

Overview and Methodology

The data were collected from reported DVC for 2000-2002, which is only a fraction of the actual number of accidents that occurred state-wide. Of the reported accidents, nearly half did not identify the sex of the animal. In 2000, 57 percent recorded the sex of the animal involved (n = 1,781); in 2001, 56 percent were reported (n = 1,801); and in 2002, 53 percent were reported (n = 1,369). The spatial coordinates of each accident were geo-coded using Street Atlas USA 2003 (DeLorme, Yarmouth, ME). The data were combined with topographic data from the national elevation dataset, vegetation data derived from the Landsat and MODIS satellite, road data from Connecticut Department of Transportation, and state and national census data. The project borrowed analytic techniques from crime mapping (CrimeStat® 3.0, Levine 2004), vegetation analysis using remotely sensed data (Lillesand et al. 2003), generalized spatial regressions (Lehmann et al. 2002), and a tree-based risk assessment method called recursive partitioning to analyze the data (Brieman et al. 1984).

We analyzed the data by seasons. For this study, seasons were broadly classified into three categories based on deer biology in Connecticut. January through April is the herding (or yarding) season, when sexually segregated herds are formed and most females are pregnant. This is followed by the fawning season from May through August. Males are generally alone or in small bachelor herds. The home-range of females with fawns shrinks to a fraction of its size during this season as fawns are nursed and the mother-infant bond is cemented (Ozoga et al. 1982, Scanlon and Vaughan 1985). Yearling deer are forced to disperse by expecting does, increasing their susceptibility to predation or vehicle collisions. Finally, the breeding season occurs from September through December. During this time, male home ranges expand significantly as they search for receptive does and defend territories.

We also examined the spatial distribution of accidents involving male and female deer during the three deer seasons by township. The point data for deer accident locations were interpolated using a kernel density smoothing process commonly used in the identification of crime and disease hotspots. The CrimeStat 2.0 software (CrimeStat® 3.0) was used to perform the estimation. This was done to overcome two issues. The first is that the deer location data were only accurate to about 100 meters, and thus an accident could be assigned to the wrong township without the kernel density estimator. The other issue is that the social and structural factors affecting the likelihood of the accidents at a given point are more likely a function of all of the townships very near an accident than just the township where each accident occurred (e.g., traffic patterns between towns, road density, etc.). The interpolation approach used will more accurately reflect these relationships. The data thus represent a localized statistical estimation of the density of accidents in that region.

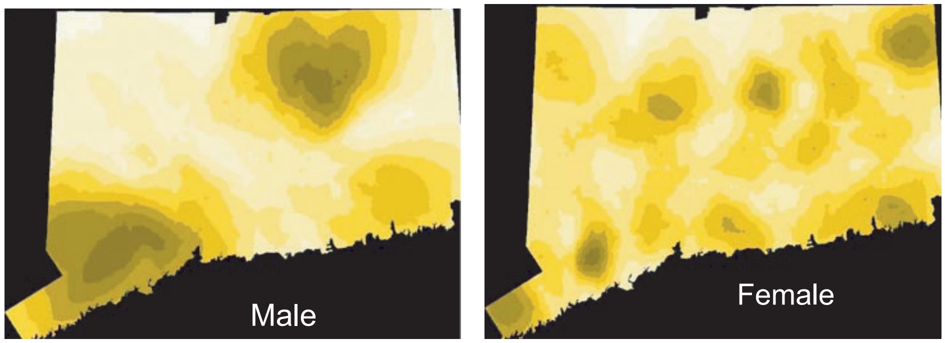


Figure 2. Spatial distribution of accidents during the 2001 herding season.

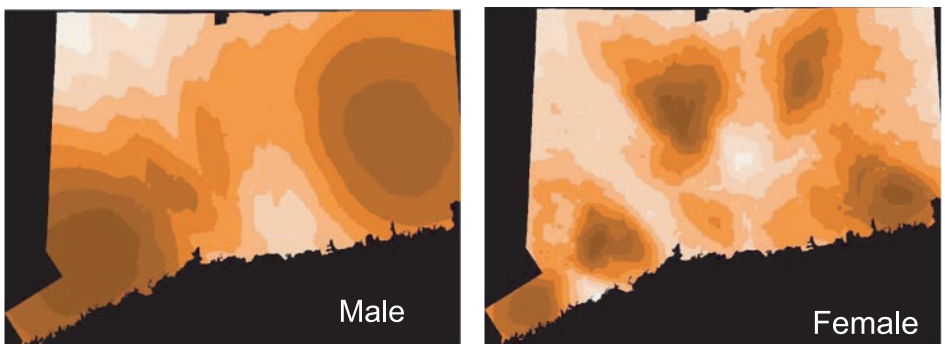


Figure 3. Spatial distribution of accidents during the 2001 fawning season.

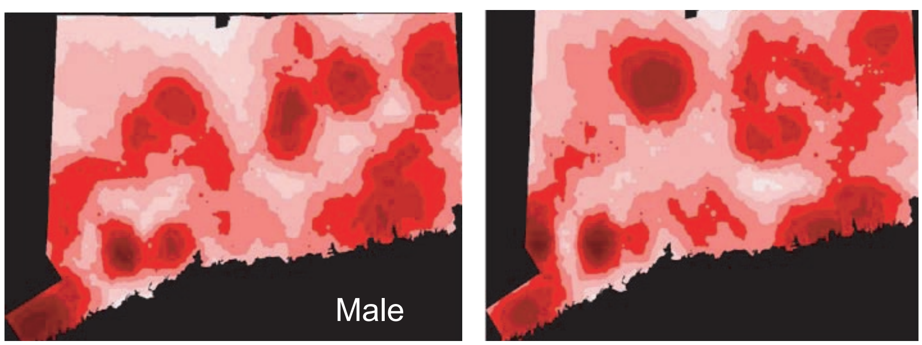


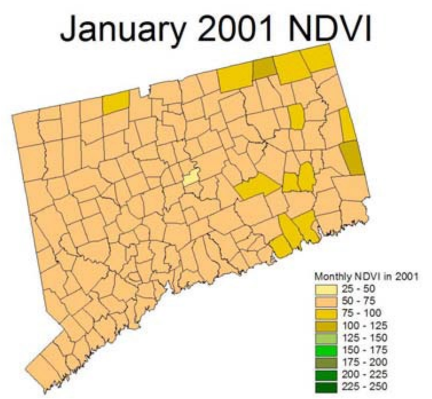
Figure 4. Spatial distribution of accidents during the 2001 breeding season.

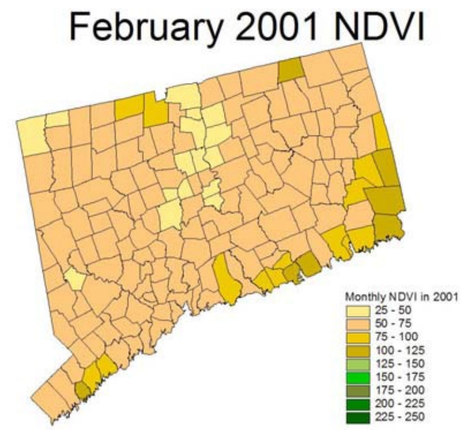
To examine the impact of vegetation on the spatial and temporal patterns of deer-vehicle collision, we used remotely sensed Normalized Difference Vegetation Index (NDVI) imagery. Monthly NDVI data were downloaded from the Global Land Cover Facility at the University of Maryland (http://glcf.umiacs.umd.edu). The vegetation index is calculated from the infrared and near infrared sensor on the MODIS satellite and has a spatial resolution of 250 meters per pixel. NDVI values, being a differenced ratio range from -1 to 1. Given that the images are quite large, the -1 to 1 values are rescaled to a 0-255 range to reduce the image storage requirements. The formula used was scaled_value=NDVI x 200 +50. These scaled index values are used in the NDVI analysis in this paper (e.g., see fig. 5 and table1 for a comparison table). These index values were queried and attached to the accident location for accident vs. NDVI analyses. One-kilometer buffers were also use in the 2001 analysis to determine if the localized NDVI gave different results than a regionalized NDVI. The results were qualitatively the same, so we stayed with the point assignment of values. Future analysis of landscape metrics will require buffering however. The ByteNDVI values were averaged over the township polygons for each township for analysis at the township level.

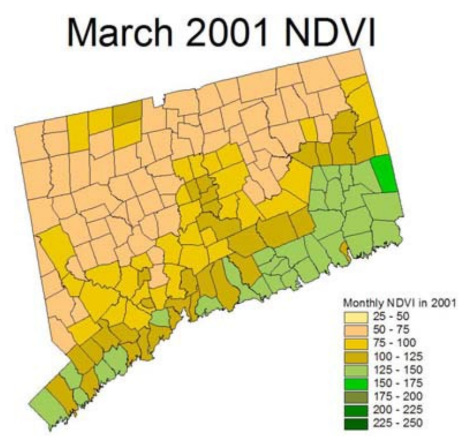
Results

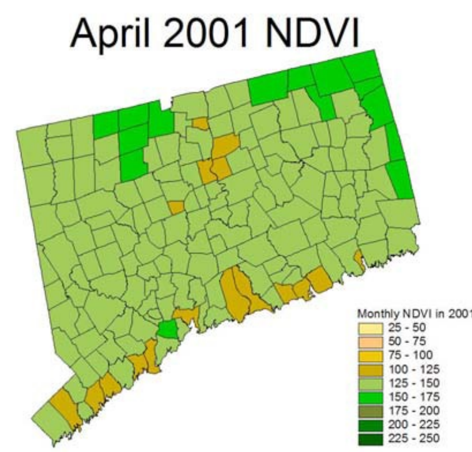
Statewide, 36 percent of recorded road-killed deer were male and 64 percent female for 2000. For 2001, 34 percent were male; 66 percent, female. The sex ratio of road-killed deer changed with the seasons (figs. 1a, 1b, and 1c). Females accounted for the majority of mortality throughout most of the year (fig. 1a, b), but male mortality increased through the breeding season (fig. 1c). These patterns appear to be consistent over the three years of the study.

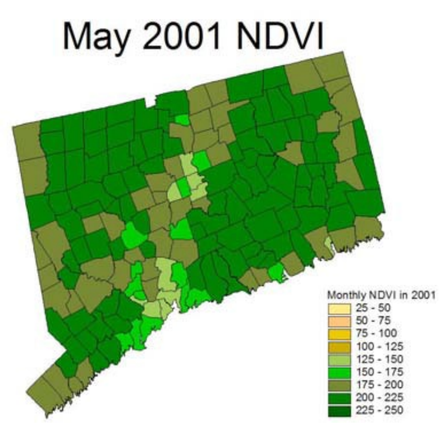
Deer-vehicle collisions throughout the months of September, October, November, and December accounted for 54 percent of the total collisions in 2000, 43 percent of the total in 2001, and 45 percent of the total in 2002. Increased DVC were witnessed between 0500 and 0900 hours and again between 1700 and 2100 hours for all three years of the study. For the year 2000, 18 percent of all DVC occurred between 0500 and 0900 hours, 36 percent occurred between 1700 and 2100 hours, and 56 percent occurred between 1700-0100 hours. For 2001, 18 percent of all DVC occurred between 0500 and 0900 hours, 33 percent occurred between 1700 and 2100 hours, and 54 percent occurred between 1700-0100 hours. For 2002, 17 percent of all DVC occurred between 0500 and 0900, 28 percent occurred between 1700 and 2100, and 42 percent occurred between 1700 – 0100 hours. We then compared deer density with the number of reported DVC. We gathered deer density data from the Connecticut Department of Environmental Protection aerial surveys for the12 management areas for 1999 and 2003 (Gregonis 2003). As expected, the number of accidents involving deer increased with increase in deer density ($r^2 = 0.4521$).

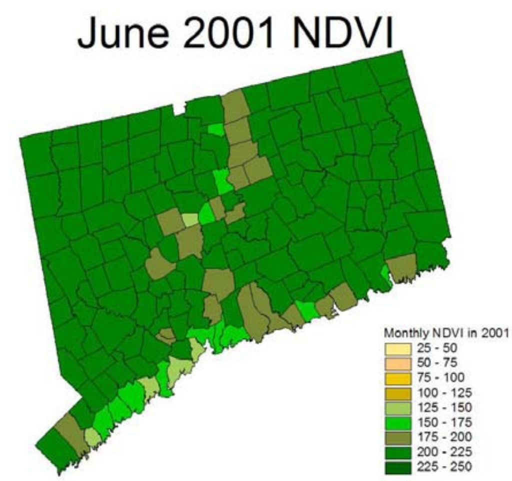












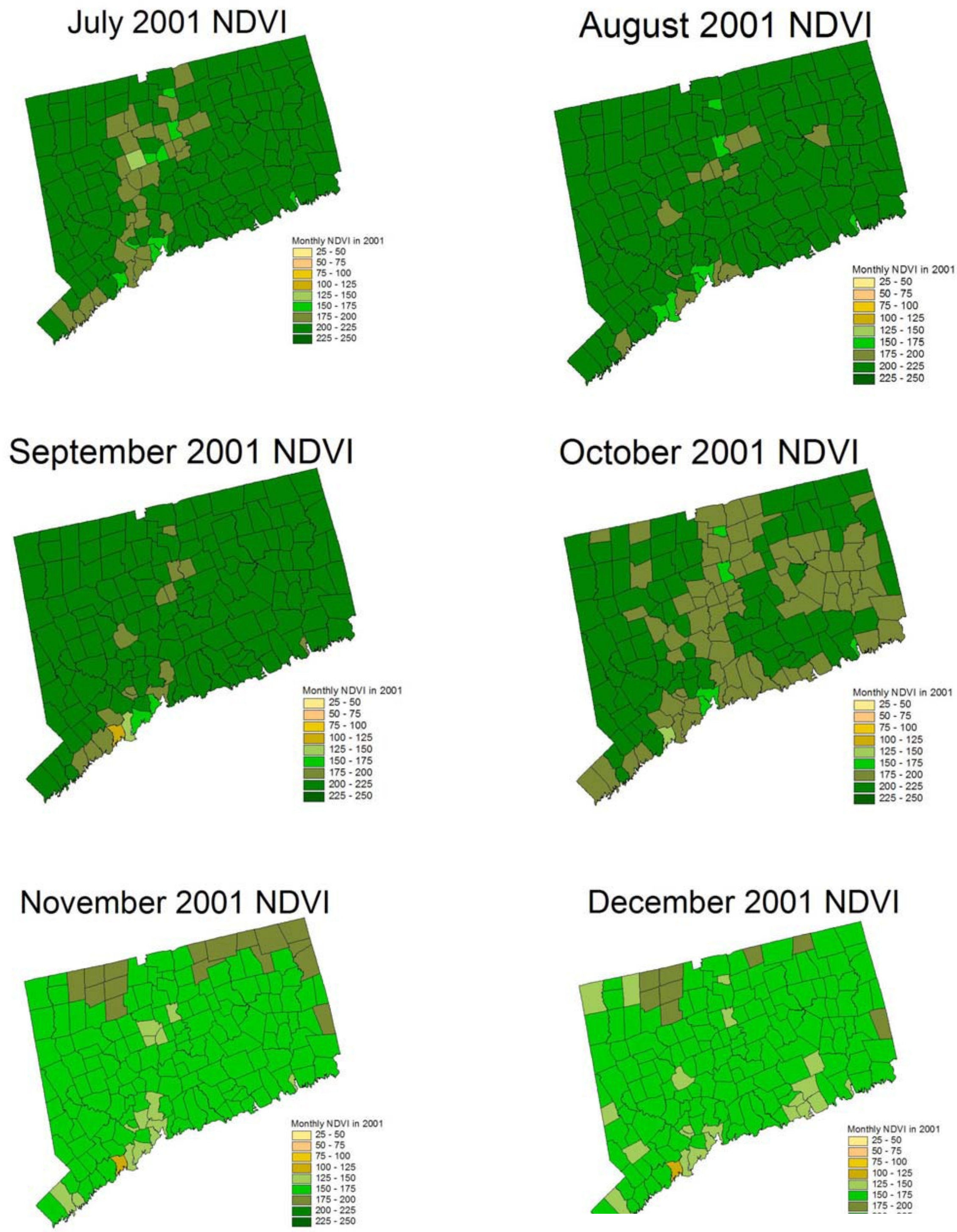


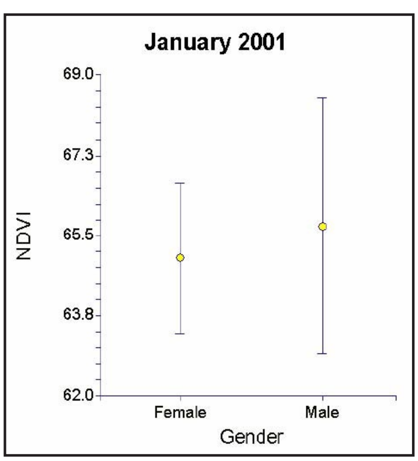
Figure 5. Maps of Connecticut representing the monthly NDVI data for 2001.

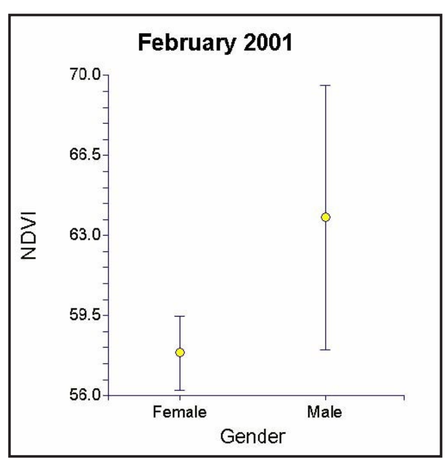
Table 1. Comparison of NDVI valued to scaled values

ByteNDVI	NDVI	Description
0	-0.25	No vegetation
10	-0.2	No vegetation
20	-0.15	No vegetation
30	-0.1	No vegetation
40	-0.05	No vegetation
50	0	No vegetation
60	0.05	Sparse Vegetation
70	0.1	Sparse Vegetation
80	0.15	Sparse Vegetation
90	0.2	Sparse Vegetation
100	0.25	Moderate vegetation covers
110	0.3	Moderate vegetation covers
120	0.35	Moderate vegetation covers
130	0.4	Moderate vegetation covers
140	0.45	Moderate vegetation covers
150	0.5	Moderate vegetation covers
160	0.55	Moderate vegetation covers
170	0.6	Moderate vegetation covers
180	0.65	Dense vegetation cover
190	0.7	Dense vegetation cover
200	0.75	Dense vegetation cover
210	0.8	Dense vegetation cover
220	0.85	Dense vegetation cover
230	0.9	Dense vegetation cover
240	0.95	Dense vegetation cover
250	1	Dense vegetation cover

We also found significant differences in the spatial distribution of accidents involving males and females in the herding season (fig. 2a, b) and the fawning season (fig. 3a, b). Male accident hotspots outside of the breeding season were restricted to one to two locations statewide. Female accident hotspots were more widely distributed throughout the state. However, during the breeding season, accidents involving both males and females were more evenly distributed spatially, and the location of the accident "hotspots" was similar between males and females (fig. 4a, b). The spatial location of these accident hotspots was consistent across multiple years.

Maps of Connecticut representing the monthly NDVI data for 2001 are presented in figure 5. To examine the impact of vegetation and seasonal vegetation changes on the location of accidents involving males and females, we compared the spatial distribution of male and female deer-vehicle collisions with the NDVI data for the same season (fig. 6). While there were significant changes in the NDVI values over the different seasons and between years, we found that females appeared to track more specific vegetation conditions as measured by NDVI, and through most of the year males covered a broader range of NDVI.





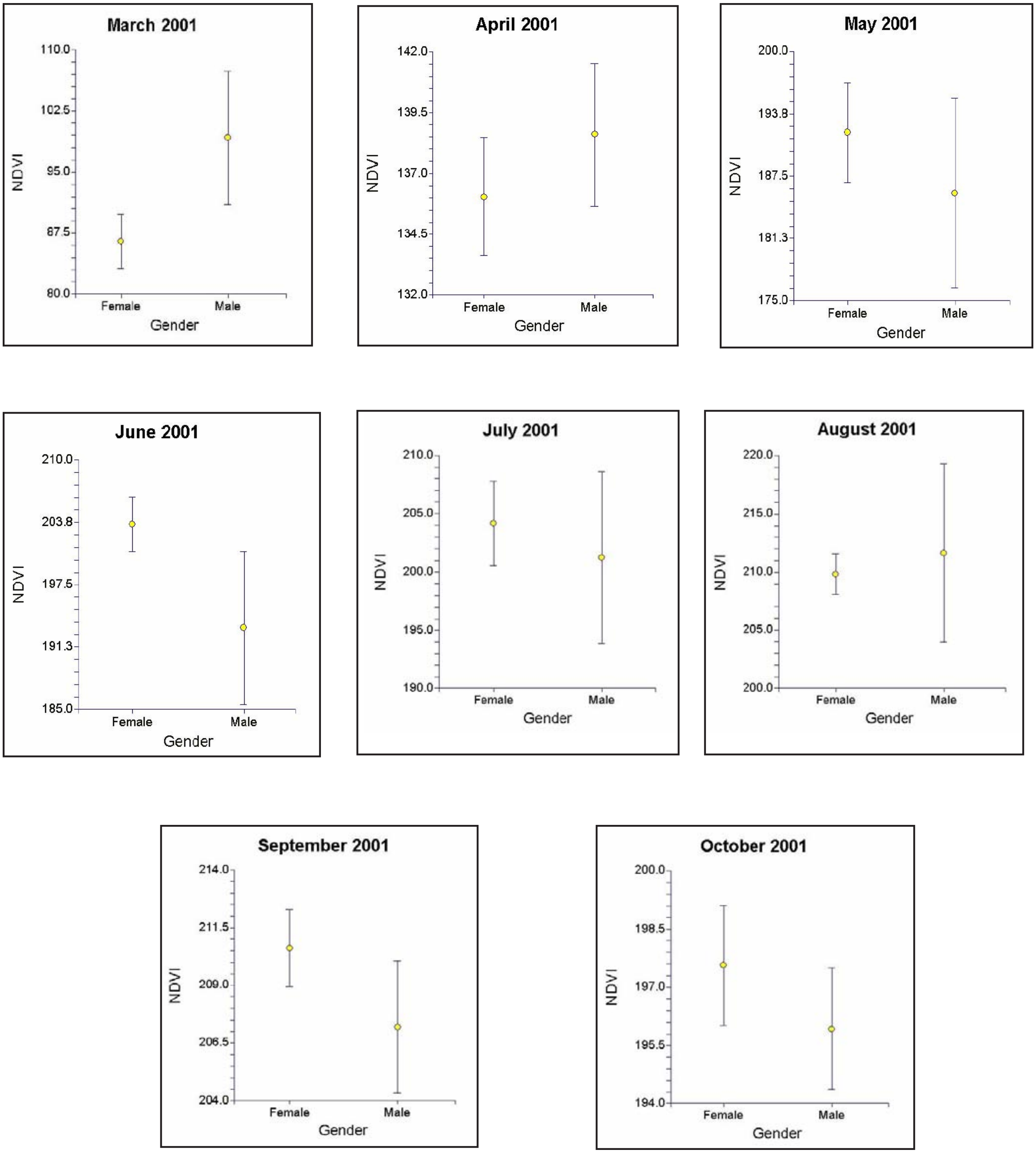


Figure 6. A comparison of the spatial distribution of male and female deer-vehicle collisions with the NDVI data for the same month.

Finally, we examined other factors that could potentially affect the movement behavior of males and females. We compared the distance between roads with the number of males and females involved in vehicle collisions (fig. 7). We found significant differences between males and females: accidents involving males were more likely to occur in areas of higher road density, with shorter distances between roads (Kruskal-Wallis $X^2 = 4.26$; $p<0.05$; fig. 7). Human density also had a significant effect on the number of males and females involved in accidents, with males having a higher incidence of accidents in areas of higher human density (Kruskal-Wallis $X^2 = 3.60$; $p=0.05$; fig. 8). Accidents involving males were also higher in areas of higher crime rate than areas where female accidents occurred (Kruskal-Wallis $X^2 = 4.06$; $p<0.05$; fig. 9). These results can be viewed graphically in figures 7-9 where the error bars are one standard error. Thus, if the bars do not overlap, there is roughly a significant difference at the 0.05 level.

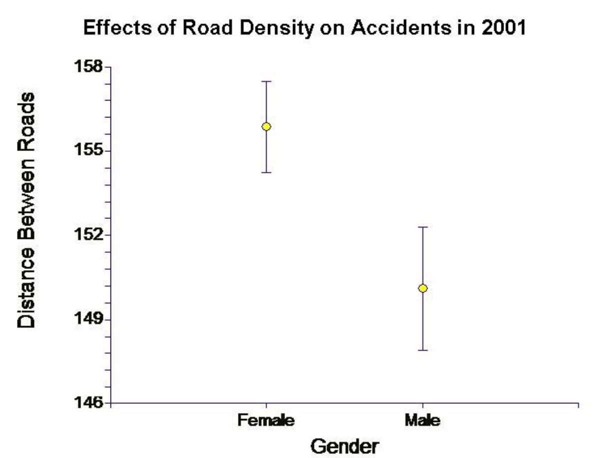


Figure 7. A comparison of the distance between roads and the number of males and females involved in vehicle collisions.

Conclusions and DVC Mitigation Recommendations

Seasonal differences between the number of accidents involving males and females differed significantly. Through most of the year, the number of females involved in accidents is higher than the number of males involved in accidents. This is most likely a result of there being a higher proportion of females in the population; long-term data on white-tailed deer have estimated the adult male:female ratio to be approximately 1:2 (Gavin et al. 1984, McCullough 1979). However, the number of males involved in accidents during the breeding season is higher than the number of females involved in accidents during the same period. Other studies have reported higher incidents of deer-vehicle collisions in the fall (Hubbard et al. 2000; Puglisi et al. 1974), which have been associated to increased movement in the breeding and hunting periods. While hunting could result in increased movement and thus increased collision rates involving all deer, the raise in buck-vehicle collisions is better explained by the enlarged home range size seen among male deer during the breeding season (Kammermeyer and Marchinton 1976, Welch 1960). The beginning of the breeding season also coincides with the time when the majority of yearling males have been known to disperse from their natal range (Kammermeyer and Marchinton 1976). Dispersal is associated with higher mortality and dispersing males would be more vulnerable to vehicle collisions since they are in unfamiliar territory (Case 1978, Feldhammer et al. 1986). The increased number of deer involved in accidents during dawn and dusk could be related to the peak movement time for deer. This pattern could also be related to traffic volume, but this study did not measure the corresponding traffic volume to make that comparison.

The observed differences in the spatial distribution of accidents involving males and females could be a result of resource partitioning or sexual segregation exhibited by white-tailed deer. Differences between the sexes of adult white-tailed deer in the use of resources or intersexual resource partitioning have been reported in many populations (McCullough 1979, 1985; Berier 1987; Verme 1988). While sexual segregation could potentially explain the differences in the location of accident hotspots between males and females, it does not account for the fewer number of accident hotspots involving males in the herding and fawning seasons. In fact, females have been reported to exhibit higher degree of site fidelity than males (Berier and McCullough 1990, Marchinton and Jeter 1967), with males occupying larger areas and consuming poorer quality habitat (Berier 1987, Weckerly 1993). Our results from the comparisons of accident locations with NDVI data indicate that male deer, in fact, do occupy a broader range of habitat types than females through most of the year (fig. 6). Male deer also have significantly larger home range sizes than females (Olson 1938, Carlsen and Farmes 1957), which in turn implies that they cover a broader range of habitat types.

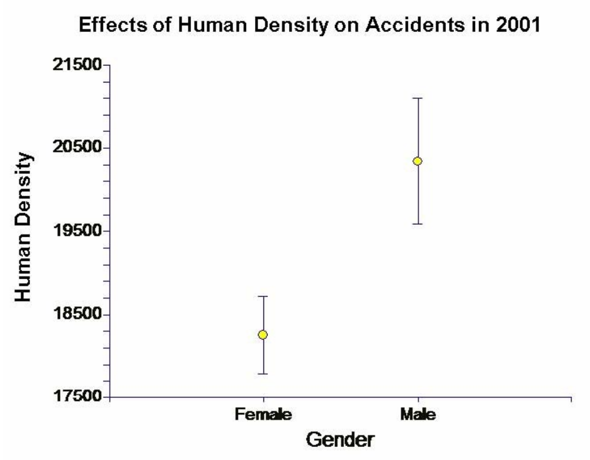


Figure 8. The impact of human density on the number of male and female deer involved in vehicle collisions.

Other factors that appeared to be related to the number and distribution of deer-vehicle collisions include distance between roads, human density, and crime rate. Distance between roads and human densities are related; we would expect to see a higher road density in areas of higher human density. We found more accidents involving males in areas of higher road density and higher human density. Similarly, there were significantly more accidents involving males than females in areas of higher crime rate. Areas of high road density, high human density, and increased crime rate (indicating poverty), could represent areas with poorer quality deer habitat. All these patterns could be a result of males covering a broader range of habitats, and being more willing to include peripheral habitat in their range (Berier 1987, Weckerly 1993).

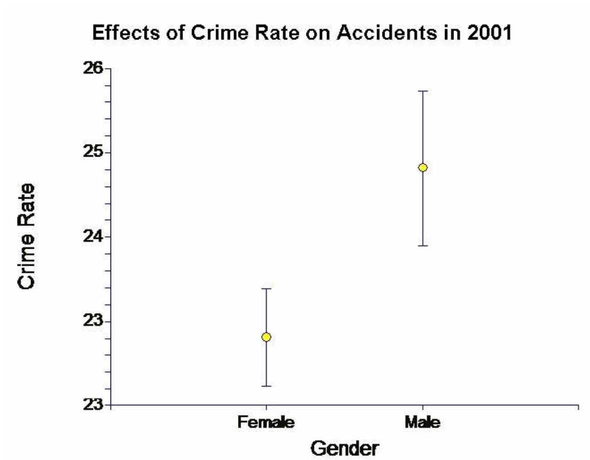


Figure 9. The relationship between crime rate and the number of males and females involved in vehicle collisions.

Numerous options have been explored nationwide to reduce the number of DVC with mixed results. Deer whistles are a popular and inexpensive option available to the public. These whistles are fixed to the front bumper of a vehicle, and airflow from the moving vehicle creates a sound at 16 to 20 kHz to warn animals of approaching vehicles. There is no research to show deer are startled by sound at any particular frequency or decibel level (DeNicola et al. 2000). One study showed that deer whistles did not alter deer behavior enough to prevent them from crossing highways (Romin and Dalton 1992). It was suspected that animals could not hear the sound of the whistle over the sound of the oncoming engine. Thus, it can be assumed that deer warning whistles are not an effective strategy to avoid deer. People who use such devices should not rely on them to avoid deer, and should remain alert when driving wooded roads during twilight hours.

Light reflectors are also devices that have been used to try to deter deer from roadsides. These devices deflect the headlights of oncoming vehicles parallel to the road, thus creating a "wall" of light that may or may not discourage deer from crossing. Usage of these reflectors has had mixed results (Gilbert 1982, Gladfelter 1982, Schafer and Penland 1985, Ford and Villa 1993). Even if reflectors are effective, they can only function in the presence of an oncoming vehicle, allowing deer behavior to go unaltered in the absence of vehicles (Putman 1997).

Reed et al. (1975) found that an underpass in west central Colorado was successful in permitting about 61 percent of a local mule deer (*Odocoileus hemionus*) population to migrate safely under the highway. Foster and Humphrey (1995) found that fencing and a series of underpasses constructed to permit crossing of Florida panther (*Felis concolor coryi*) along Highway 84 (Alligator Alley) were also successful in allowing bobcat (*Lynx rufus*), white-tailed deer, raccoon (*Procyon lotor*), alligator (*Alligator mississipiensis*), and black bear (*Ursus americanus*) to safely cross. However, highway underpasses are difficult to construct under already existing roads in urban areas. They are also very expensive.

Fencing has been proven effective at reducing DVC along stretches of highway in Colorado (Ward 1982), Minnesota (Ludwig and Bremicker 1983), and Pennsylvania (Feldhamer et al. 1986). Fencing must be 2.4 to 3.0 m high and inspected regularly, as deer can and will utilize openings in the fence and will crawl between the fence and the ground. Fencing is a proven and cost-effective solution along short lengths of highway, but can get expensive and laborious over long stretches. Fencing should be utilized in areas of high DVC.

Static road signs alerting motorists about the possible presence of deer in the area are often are ignored as there are so many of them, and few motorists have actually been involved in a DVC in the vicinity of these signs (Putman 1997). Pojar et al. (1975) experimented with a lighted and animated deer crossing sign in Colorado. They found no difference in the number of DVC with the sign on and with the sign off. Average vehicle speed decreased 4.83 km/hr (3.00 mph) with sign on, 10.09 km/hr (6.27 mph) with sign on and three deer carcasses placed on the road, and 12.63 km/hr (7.85 mph) with carcasses in place and signs off.

The results here suggest that spatio-temporal models can be used to predict high risk areas based on season and vegetation conditions. While current deer signs do not help people get a search image for deer or get them to slow down very much, carcasses appear to have a substantial impact on speed. Thus, targeted impact-based warning signs and displays can be used to create a search image approach be used to minimize deer vehicular accidents. Our research suggests that these targeted displays can be moved to the appropriate hotspots based on changing vegetation and seasonal conditions.

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Evaluation of a Highway Improvement Project on Florida Key Deer

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Abstract: Deer-vehicle collisions (DVCs) are a concern in the recovery of the endangered Florida Key deer (*Odocoileus virginianus clavium*) on Big Pine Key, Florida. Since the 1960s, nearly half of the total deer mortality has been attributed to DVCs; the majority of these mortalities occurring along the United States Highway 1 (US 1) corridor. In 2002, the Florida Department of Transportation completed modifications to a 2.6-km segment of the US 1 corridor that included fencing, experimental deer guards, and underpasses designed to prevent deer entry into the roadway and minimize DVCs. We evaluated the effectiveness of highway modifications in reducing Key deer-vehicle collisions pre- and post-project using long-term mortality data. Overall US 1 DVCs remained unchanged due to DVC increases along the unfenced section of US 1 on Big Pine Key; even though highway modifications (i.e., deer guards, fencing, and underpasses) reduced Key deer-vehicle collisions by 83–95 percent both post-project years. Experimental deer guards minimized deer crossings to six deer crossings the first post-project year and three crossings the second year. As a result, we recommend experimental deer guards in combination with fencing (and underpasses when applicable) can benefit wildlife in urban/suburban settings while maintaining human safety.

Introduction

Deer-vehicle collisions (DVCs) have increased in the United States, Canada, and Europe in recent years (Groot Bruinderink and Hazebroek 1996, Romin and Bissonette 1996, Putman 1997, Forman et al. 2003). In addition to human dangers associated with DVCs (Conover et al. 1995, Forman et al. 2003), local deer populations can be significantly impacted (e.g., Florida Key deer [*Odocoileus, virginianus clavium*], Lopez et al. 2003b). Since it is unlikely deer populations will decrease in the near future, methods to reduce DVCs will become increasingly important with continued suburban sprawl (McShea et al. 1997, DeNicola et al. 2000), increasing roadways, and higher traffic coinciding with wildlife activity (Foreman et al. 2003).

Florida Key deer are the smallest subspecies of white-tailed deer in the United States (Hardin et al. 1984), occupying 20–25 islands in the Lower Florida Keys (Lopez 2001). Approximately 65 percent of the overall population is found on Big Pine Key (BPK, Lopez et al. 2004). Since the 1960s, DVCs have been the single largest Key deer mortality factor accounting for >50 percent of annual losses (Silvy 1975, Lopez et al. 2003b). Because of this, United States Fish and Wildlife Service (USFWS) and Florida Department of Transportation (FDOT) biologists have attempted to address DVCs on United States Highway 1 (US 1) which bisects BPK (fig. 1). In 1994, the Key Deer-Motorist Conflict Study was initiated by FDOT to evaluate alternatives for reducing DVCs along the US 1 corridor (Calvo 1996). Furthermore, in 1995 the level of service on BPK (i.e., ability to evacuate residents during a hurricane) was found to be inadequate (Lopez et al. 2003*a*). The two objectives of the Key Deer-Motorist Conflict Study were to evaluate methods to (1) decrease DVCs and (2) improve US 1 traffic flow. Final study recommendations included (1) construction of barriers (fences) with two wildlife crossings (underpasses) along an undeveloped segment of US 1 on BPK, and (2) an extra northbound lane through the developed segment of US 1 (hereafter US 1 corridor project; Calvo 1996). The developed "business" segment was not fenced due to potential economic losses (i.e., restricted business access in an area with a tourist-based economy, Calvo 1996, Lopez et al. 2003*a*).

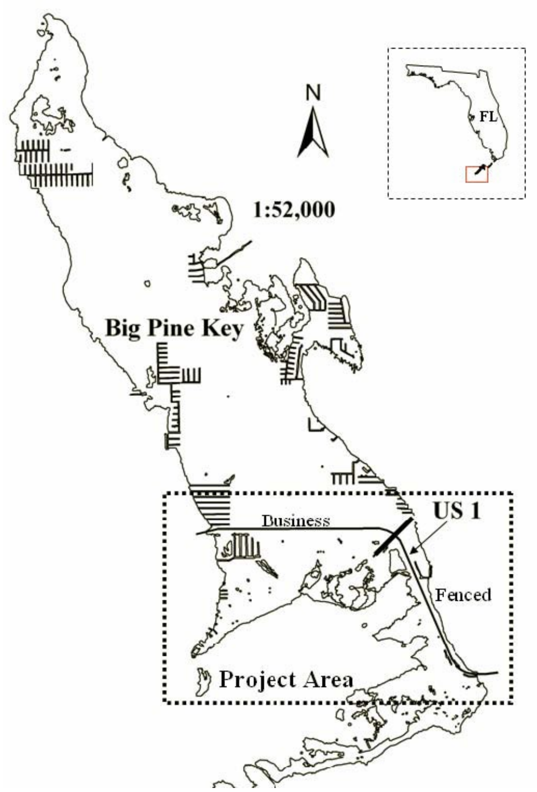

Figure 1. The study site (dashed line) including United States Highway 1 (US 1, 5.6 km) divided into business (3.1-km) and fenced segments (2.6-km) on southern end of Big Pine Key, Monroe County, Florida.

Fencing in combination with wildlife crossings has proven to successfully reduce DVCs in many parts of the country (Bellis and Graves 1971, Reed et al. 1975, Falk et al. 1978, Ford 1980); however, for exclusion fencing to be effective, access management (e.g., fence ends, side roads) is a critical factor (Peterson et al. 2003). Traditionally, modified cattle guards or "deer guards" that allow unrestricted vehicle access are used to exclude deer at fence ends (Reed et al. 1974, Reed et al. 1979, Woods 1990, Sebesta 2000). Traditional deer guards, however, posed a hazard to pedestrians and cyclists in the US 1 corridor project, and were unproven in supporting heavy vehicular loads (Peterson et al. 2003). Peterson et al. (2003) recommended a standard bridge grating material which was reported to be 98 percent efficient at excluding Key deer access during baited pen trials (fig. 2).

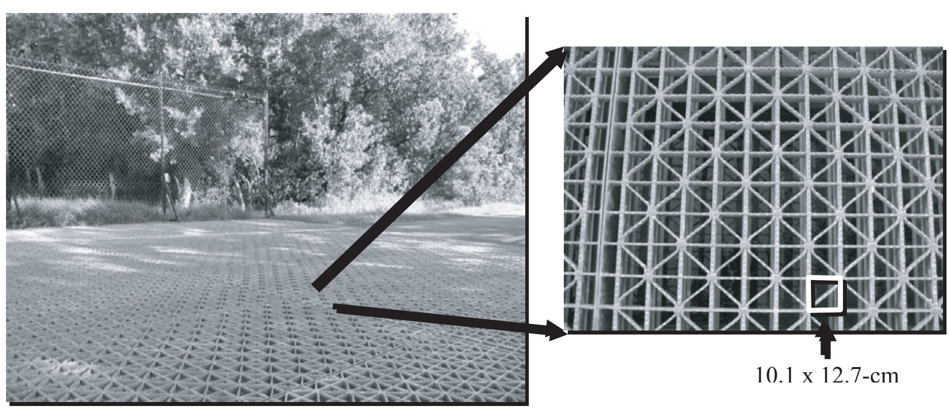

Figure 2. Experimental deer guard (*n*=4) and close up of standard bridge grating material used in US 1 improvement project.

In 2002, construction of the 2.6-km fenced segment, two underpasses (2.9 x 7.6 x 14.2-m), four experimental deer guards (7.8-m wide; Peterson et al. 2003), and extra 1.4-km traffic lane were completed (fig. 3). With the US 1 corridor project completed, the objective of our study was to evaluate the effectiveness of fencing and experimental deer guards in reducing Key deer-vehicle collisions. Specifically, our study objectives were to compare (1) pre- and post-project fence US 1 DVCs and (2) deer access into the fenced segment of project area.

Study Area

Our study was conducted on the southern half of BPK, Florida (fig. 1). US 1 is a two-lane highway that links the Keys to the mainland with an estimated annual average daily traffic volume of approximately 18,000 vehicles/day (Florida Department of Transportation data, Monroe County, 2004). US 1 bisects BPK on the southern half of the island. Maximum speed limits are 72 km/hr during the day and 56 km/hr at night. The fenced section of US 1 accounts for approximately 46 percent of the US 1 roadway on BPK (fig. 3). The unfenced section included west of extra lane, extra lane, and east of extra lane segments (fig. 3). The west of extra lane, extra lane, and east of extra lane segments account for 14 percent, 23 percent, and 17 percent of the unfenced section, respectively.

Methods

Deer-vehicle collisions

Since 1966, USFWS biologists have recorded all known Key deer mortalities on all roads on BPK via direct sightings, citizen and law enforcement reports, and observation of turkey vultures (*Cathartes aura*, Lopez et al. 2003b). Age, sex, and body mass were recorded for each animal, and all road-related deer mortality locations were entered into a geographic information system (GIS) using ArcView (Version 3.2).

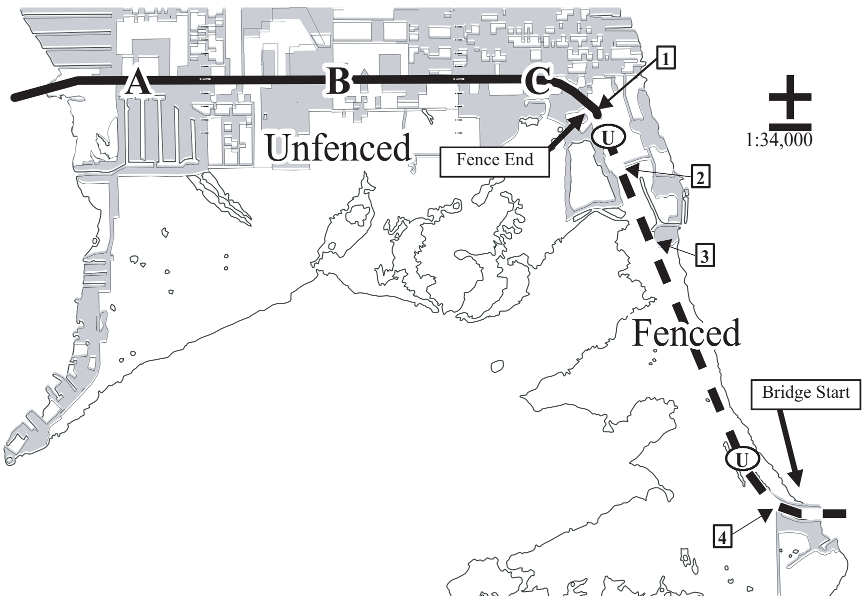

Figure 3. The US 1 corridor project (5.6-km) on Big Pine Key, Florida is divided into unfenced (3.1-km, solid line) and fenced (2.6-km, dashed line) segments. The unfenced road section consists of an extra line (1.4-km [B]) in between two 0.8-km road sections (A, west) and (C, east). The fenced section includes 2 underpasses (denoted by U) and 4 experimental deer guards (indicated by arrows and numbered). Gray areas denote developed areas.

Using the USFWS Key Deer Refuge mortality data, pre-project (1996–2000) DVCs were compared to post-project (2003–2004) DVCs. US 1 road improvements on BPK included (1) an extra traffic lane in the unfenced section of US 1 that was hypothesized would increase DVCs and (2) a fenced section with associated underpasses and deer guards that was hypothesized would decrease DVCs. We compared US 1 DVCs by individual road segments in addition to overall findings (fig. 3). Key deer mortality data from 2001–2002 were excluded to avoid biases during the construction phase of the project.

Deer crossings

Since the completion of the US 1 corridor project (February 2003), USFWS biologists have recorded the number, age, sex, and point of entry of all known deer inside the fenced segment based on direct sightings and local law enforcement reports. Removal of deer from the fence segment was conducted when necessary using maintenance exit gates (n = 16) installed during the project.

Results

Deer-vehicle collisions

We found that annual DVCs within the fenced section decreased 83–91 percent the first post-project year and 91–95 percent the second post-project year (fig. 4). Conversely, we found DVCs in the east of extra lane unfenced segment increased 21–112 percent the first post-project year but returned to pre-project levels the second post-project year (C, fig. 3). DVCs within the extra lane segment also were found to be greater than pre-project levels the first post-project year (21–112% over pre-project levels) and then returned to pre-project levels the second year (B, fig. 3). West of extra lane segment DVCs increased both post-project years with DVC increases of 10–266 percent and 80–500 percent for the first and second post-project years respectively (A, fig. 3). Overall US 1 post-project DVCs remained similar to pre-project levels during both post-project years.

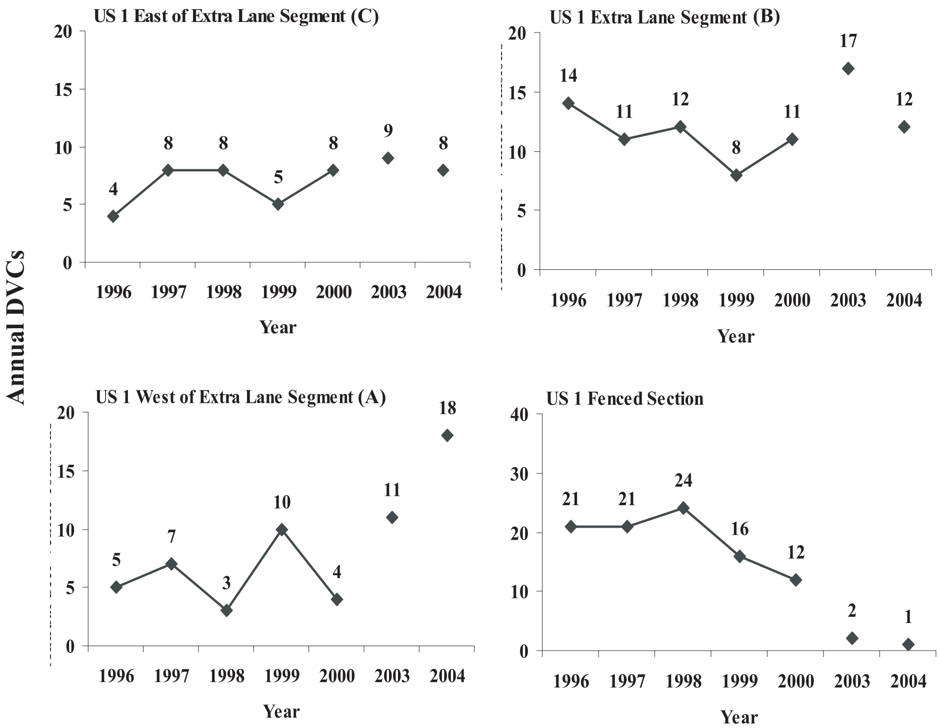

Figure 4. Annual US 1 Key deer-vehicle collisions pre-project (1996–2000) and post-project (2003–2004) by road segments (segments correspond with those in fig. 3).

Deer crossings

The first post-project year, eight deer entries into the fenced segment were recorded (6 deer-guard crossings, 2 side-gate entries). All (n = 6) of recorded deer guard crossings involved adult deer (4 males, 2 females). The eight deer incidents resulted in two Key deer mortalities within the fenced segment of the project (n = 1, vehicle collision; n = 1, severe injury during removal attempt which required euthanasia). The second post-project year, the number of deer reported inside the fenced section decreased to three deer (2 adults, 1 yearling) with one entry event resulting in mortality.

Discussion

Deer-vehicle collisions

Previous studies utilizing fencing and underpasses have proven success in reducing deer mortality 60–95 percent (Reed et al. 1982, Ludwig and Bremicker 1983, Woods 1990). In our study, the post-project decrease in DVCs along the fenced section of 83–91 percent indicates that fencing, underpasses, and deer guards were also successful in reducing Key deer-vehicle collisions. As is the case with many deer exclusionary fencing projects, 100-percent effectiveness (i.e., no deer inside the fence) was not achieved and is likely an impractical goal (Woods 1990, Putman 1997). With the understanding that some deer will cross into the roadway, safe removal of incidental deer from the fenced section becomes essential.

We found an overall increase in DVCs along the unfenced section of the US 1 corridor project with varied post-project DVC changes within individual unfenced road segments. Previous studies have shown an increase in mortality associated with fence ends (Ward 1982, Feldhammer et al. 1986, Clevenger et al. 2001). The first post-project year east of extra lane segment DVCs increased by 29 percent, which returned to pre-project levels the second-year (fig. 3). We attribute this decrease in DVCs to deer using the underpasses to traverse US 1 instead of crossing at the fence's end (fig.3). The addition of the extra 1.4-km traffic lane in the corresponding segment (fig. 3) may be responsible for the post-project collision increases along the extra lane and west of extra lane segments. Although the increase in mortality in response to the extra lane was predicted to occur due to the associated increased traffic flow (higher average speeds, more vehicles/hr) and reduced visibility (Lopez et al. 2003*a*), the increase in DVCs along the west of extra lane segment was not expected to occur. The reason for the increase in DVCs in the west of extra lane segment is not fully understood at this time. We will continue to monitor DVCs along the unfenced section west of extra lane segment and all of US 1 to better determine the overall long-term impacts of the extra lane on Key deer-vehicle collisions.

Deer crossings

Deer crossed the experimental deer guards six times during the first post-project year and three times during the second post-project year. Although pen trials found the deer guards to be 98-percent effective, we were unable to determine how many crossing attempts occurred during the post-project period. The finding of almost all deer crossings involving adults supports the theory that larger hoof sizes allow for more successful crossings (Peterson et al. 2003). Other factors that may explain some of the deer crossings are a fencing adjustment period and Key deer sociobiology. Previous fencing studies have found that an acclimation period exists with wildlife fencing structures (Reed et al. 1975, Clevenger 1998). Additionally, Key deer are known to have strong site fidelity (Lopez 2001). These two factors resulted in deer crossings as attempts were made to revert to pre-fence movements and ranges. We believe the number of deer crossings should decrease as older deer acclimate to the location of crossings and as younger deer establish ranges surrounding the fencing project.

Management Implications

Post-project data indicate the US 1 corridor project can reduce DVCs provided that responsible handling of deer incidents is maintained. Although overall US 1 DVCs did not change due to increases in the unfenced section, we believe collisions will decrease as deer movements stabilize. With the Key deer population on BPK believed to be approaching or near carrying capacity (Nettles et al. 2002) and traffic levels increasing, it is likely that DVCs along other BPK roads will become a greater concern for USFWS biologists in the future. Unable to fence all roads on BPK, different strategies to reduce DVCs in these areas will need to be evaluated.

Deer guards proved effective at reducing deer access into the fenced segment of US 1 with no compromise of human safety. As more DVC issues develop in other suburban-type habitats, restricting deer access without interfering with human activities will become more important. The US 1 corridor project demonstrates one design for addressing these issues.

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OptiFlux: A Tool For Measuring Wild Animal Population Fluxes for the Optimization of Road Infrastructures

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Abstract: In West European countries natural habitats are often fragmented. In those countries fragmentation is both characterized by an increase in the number of habitat fragments and a decrease in their size, leading to animal population isolation. The geometry of linear infrastructures (e.g., roads, railways) is not so much a cause of destruction of animal habitats, but rather it acts more as a barrier between fragments. If we consider linear infrastructure as a barrier in landscapes, it is important to study biological fluxes between landscape features before deciding the final route of such infrastructures. OptiFlux development is based on the "resistance concept," developed by G. Pain for his Ph.D. (2001) for SCETAUROUTE and the French Ministry of Environment and the Ministry of Transport.

OptiFlux is an automatic GIS space analysis device. It is designed for the prediction and identification of the effects of linear infrastructure on the territorial occupation and viability of the animal populations concerned. OptiFlux can also be used to assess the relevance of fauna passages and, consequently, to optimize their final location and quantities. OptiFlux is crossing land use and environmental data, correlated with the ecological requirements of the species studied. OptiFlux is based on a population viability analysis, applying the SCETAUROUTE Arc View GIS standard. The innovative aspect of OptiFlux is its automated diagnostic approach, with the cross-relation of space and biological data. There are three direct applications for the tool:

- Identification of routes having least impact on wild animal population flows
- Optimization of the number/location of fauna passages for the benefit of wild animals
- Simulation of the positive effect of the fauna passages proposed

OptiFlux provides a preliminary approach for a quick identification of the critical areas to be taken into account for design and estimation of the infrastructure. However, it does not eliminate the need for expertise and verification of the results obtained by a field biologist. OptiFlux is a project optimization instrument, helping with the decision making process, concerning the necessity and relevance of the improvements retained. It is also a tool that provides images of future scenarios once the project is realized.

OptiFlux has been tested on many species, such as *Mustela lutreola*, *Osmoderma eremita*, species of major importance in terms of the European wildlife heritage (threatened species), and *Capreolus capreolus*, *Cervus elaphus*, *Sus scrofa*, species encountered in the majority of projects. Several organizations have already expressed interest in this tool, such as the ONCFS (French National Hunting and Wildlife Authority), various French motorway companies, the IAURIF (Ile de France Regional Urban Planning and Development Institute), and the Direction Régionale de l'Equipement du Nord Pas de Calais.

Introduction

The research program for OptiFlux was launched following research developed for a Ph.D. thesis (G. Pain 2001). The Ph.D. was directed by J. Baudry (Institut National de Recherche Agronomique - INRA), co-financed and co-directed by SETRA (Service d'Etude Technique des Routes et Autoroutes), the French Ministry of Environment and SCETAUROUTE[1]. This research has led to the development of a software tool capable of analyzing both landscape and spatial structures of an animal population. This software was named "LandPop" (**Land**scape to **Pop**ulation spatial structure) and has remained at the testing stage on virtual landscape and virtual species.

However, "LandPop" was a complex tool that could not be used easily outside research laboratories. It quickly reached its limits for infrastructure projects. That is why SCETAUROUTE has decided to launch a second phase for this research program. It was decided to design a new tool, based on "Landpop," that would be easier to use and immediately operational for infrastructure studies (highways, railroads, canals, etc.).

I chose to develop OptiFlux with a GIS (Arcview). Development and test phases took place between 2002 and 2004. OptiFlux was developed and tested by the environmental department of SCETAUROUTE and experts for the animal species concerned.

Concept

The OptiFlux concept is based on an evaluation of the spatial distribution of an animal population according to its ecological requirements. OptiFlux also allows the evaluation of the effect of a project that modifies landscape compositions and that contributes to territory fragmentation.

The OptiFlux concept requires knowledge of landscape ecology principles, such as habitats (i.e., the quality of the environment in relation to the species' ecological requirements) and ecosystem functioning (i.e., the natural habitat's role in the species' ecology, feeding, breeding, migration, etc.).

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[1] **SCETAUROUTE SA (EGIS Group)** is a French consulting firm which works all over the world. Founded in 1970 by the major French toll motorway companies to create a center of excellence in the field of motorway engineering, SCETAUROUTE has accumulated experience in project management, design, construction supervision, and assistance to highway and motorway operations at an unique scale. SCETAUROUTE has now extended its activities towards other transport infrastructures, in particular urban, railways, airports, navigable waterways projects, optical fibres and pipelines.

The OptiFlux concept is also based on the resistance of the natural environment to an animal species presence. This resistance is a variable resulting from various factor combinations, such as the frequentation or avoidance of a natural habitat, the death rate, and the energy spent in migrating within this natural habitat.

The natural habitat of the species is considered as being the most favorable; whereas, habitats that show the highest resistance rates are impassable obstacles, such as transport infrastructures, especially when they are fenced or when the traffic is very heavy. Intermediate rates are given according to the attractiveness of the habitat for the species.

Table 1. Excerpt of a species sheet: resistance values

Type of ground occupation	Entrance	Source of database		Class of resistance	Resistance coefficient
		Code CLC (niveau 3)	Code CB		
Continuous urbanization		111		strongly avoided	10000
Discontinuous urbanization		112		strongly avoided	10000
Arable land		211		Neutral	
Vine		221		Neutral	
orchards		222		Neutral	
Meadow		231		Neutral	
Agricultural territories with natural vegetation		243		Neutral	
Forest of deciduous trees		**311**		**Strongly preferred**	**1**
Forest of conifers		**312**		**Strongly preferred**	**1**
Mixed forest		**313**		**Strongly**	**1**

At this stage the scientific knowledge about species biology is fundamental. This knowledge conditions the assignment of the resistance coefficient given to every type of habitat. (MCR– Knaapen et *al.* 1992). It results in the MCR (Minimal Cumulated Resistance). The MCR gives weighted distances that are not the shortest possible but that reflect the resistance of the habitat crossed. These MCR would also give a “weighted cost.”

The dispersion equation would have the following form: $MCR = D_{ij} \times r$ where:

- D_{ij} = covered distance between i and j in different habitats
- r = resistance coefficient of every crossed habitat

If $r = 1$, then $D_{ij} = Dmax$, if $r=100$, then $D_{ij} = Dmax/100$

Dispersion rates are meaningful only if resistance has biologic reality.

The use of this tool is making possible diagnostics on very large study areas. For this purpose, it is necessary to use geographic data of land uses. Many databases are available (Corine Land Cover, Corine Biotop, etc.) and also several regional databases, like SIGALE in the Nord Pas de Calais Area, for example. The right scale for the spatial database is fundamental because it influences the result’s precision and validity. It has to be adapted to the species’ territory scale. For that reason some studies require a customized database scale to the dimension of the study area. Small study territories, such as the ones used for insects or amphibians, are good examples.

Examples

I chose three examples that illustrate the importance of the spatialized database in order to have good quality results. The choice of the spatialized database depends on the dimension of the vital area of the species to be studied.

Large mammal case: the Red Deer (*Cervus elaphus*)
As the Red Deer occupies a large territory (2000 ha), it is necessary to use a database such as Corine Land Cover.

Figure 1 shows a large territory extending on approximately 300 km. The Red Deer habitat appears in green, while favorable habitat for daily migration appears in yellow, and the dispersion, in brown.

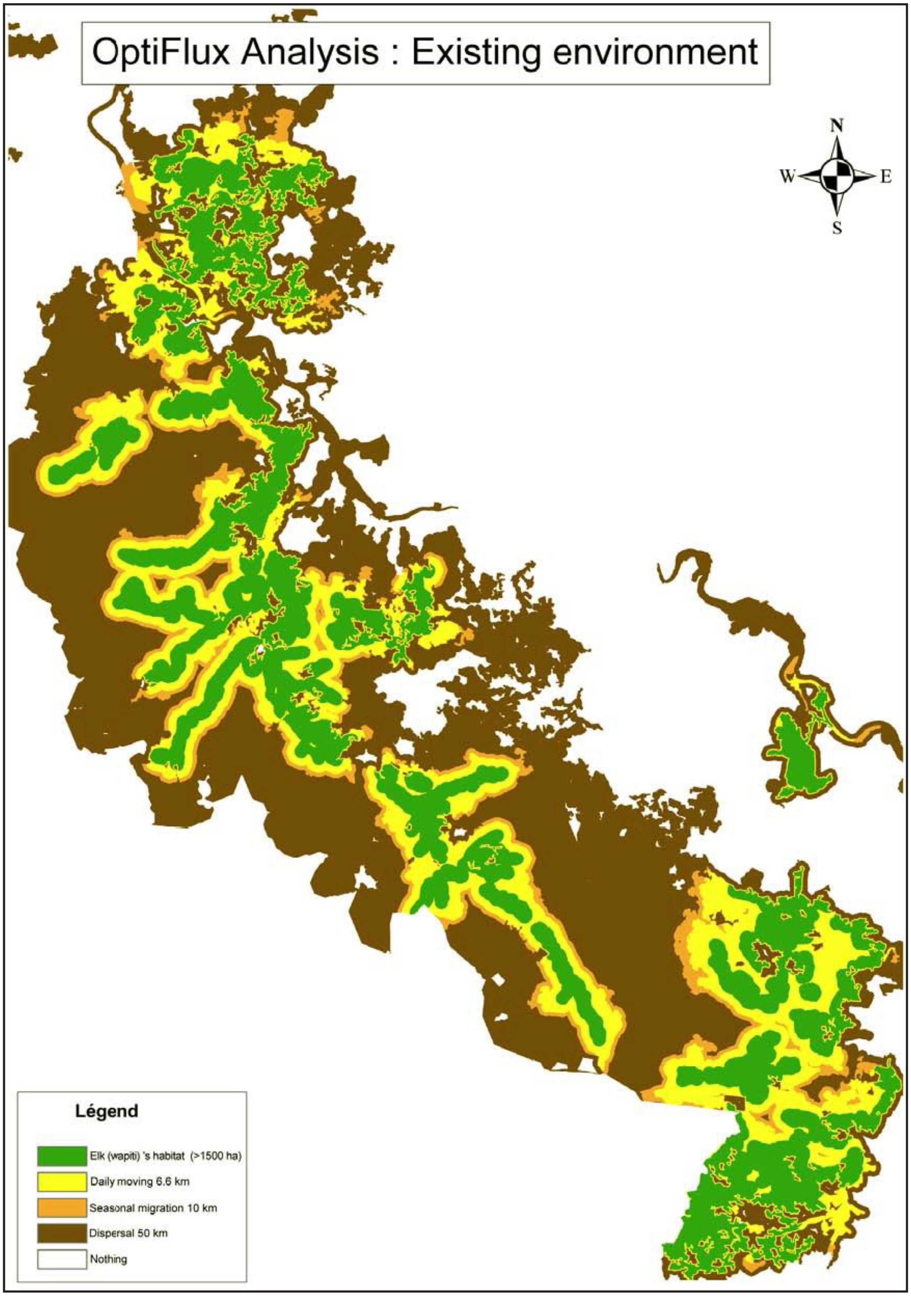

Figure 1. OptiFlux analysis: existing environment.

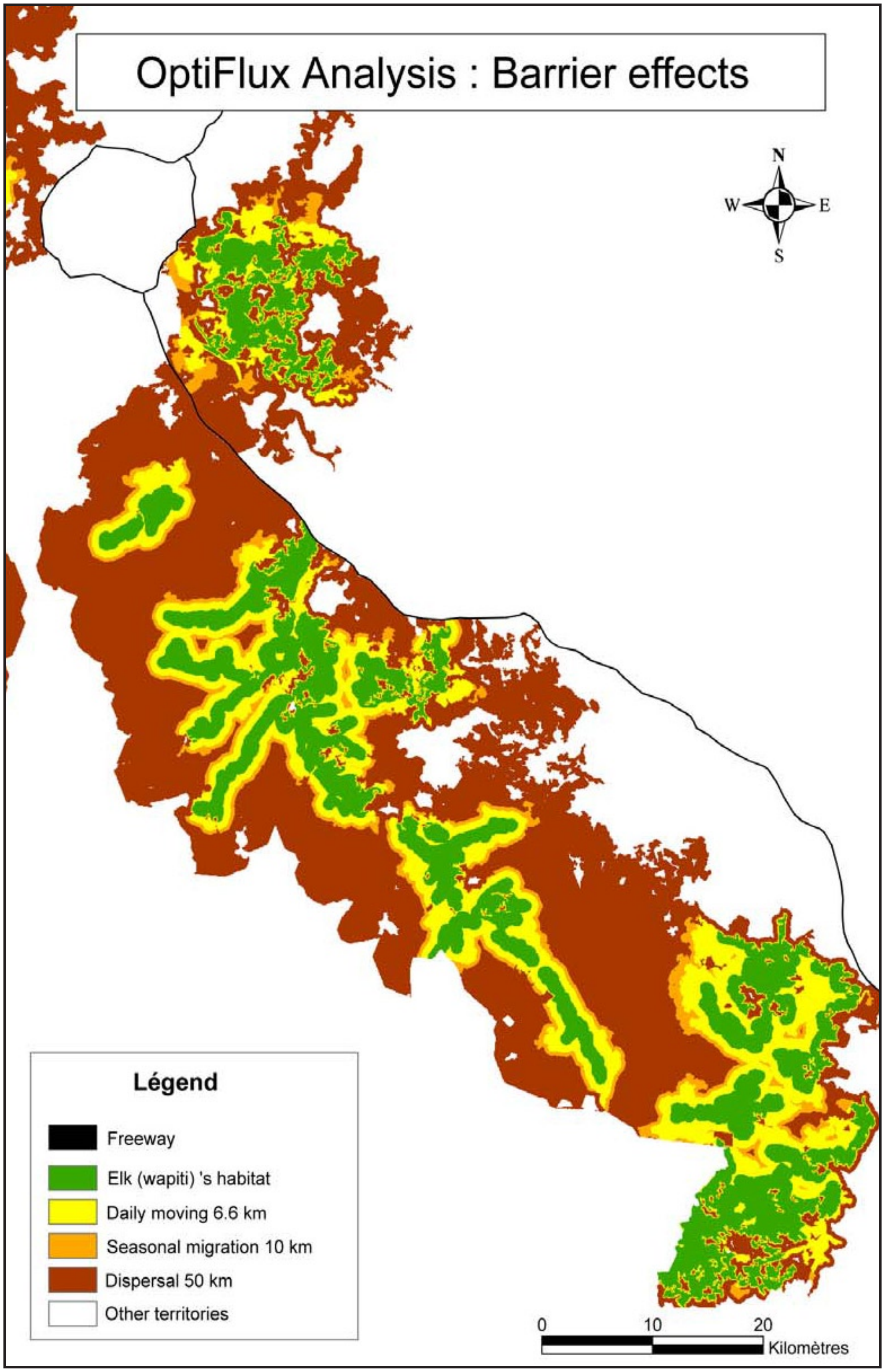

Figure 2. OptiFlux analysis: barrier effects.

In figure 2, the infrastructure crosses this territory from one side to the other. It is a fenced freeway that constitutes an impassable barrier for animals. Impact simulation is shown.

The territory disappearance forecast for the species and the significant reduction of the habitat available for the species can be also observed.

It is the territory fragmentation that could lead to genetic isolation of some animal populations.

In the next step (figure 3), OptiFlux is used to locate the best position for fauna passages. When three fauna passages are installed, connectivity of existing habitats is almost totally kept. A few biological corridors are not restored, but they do not link centers of habitats.

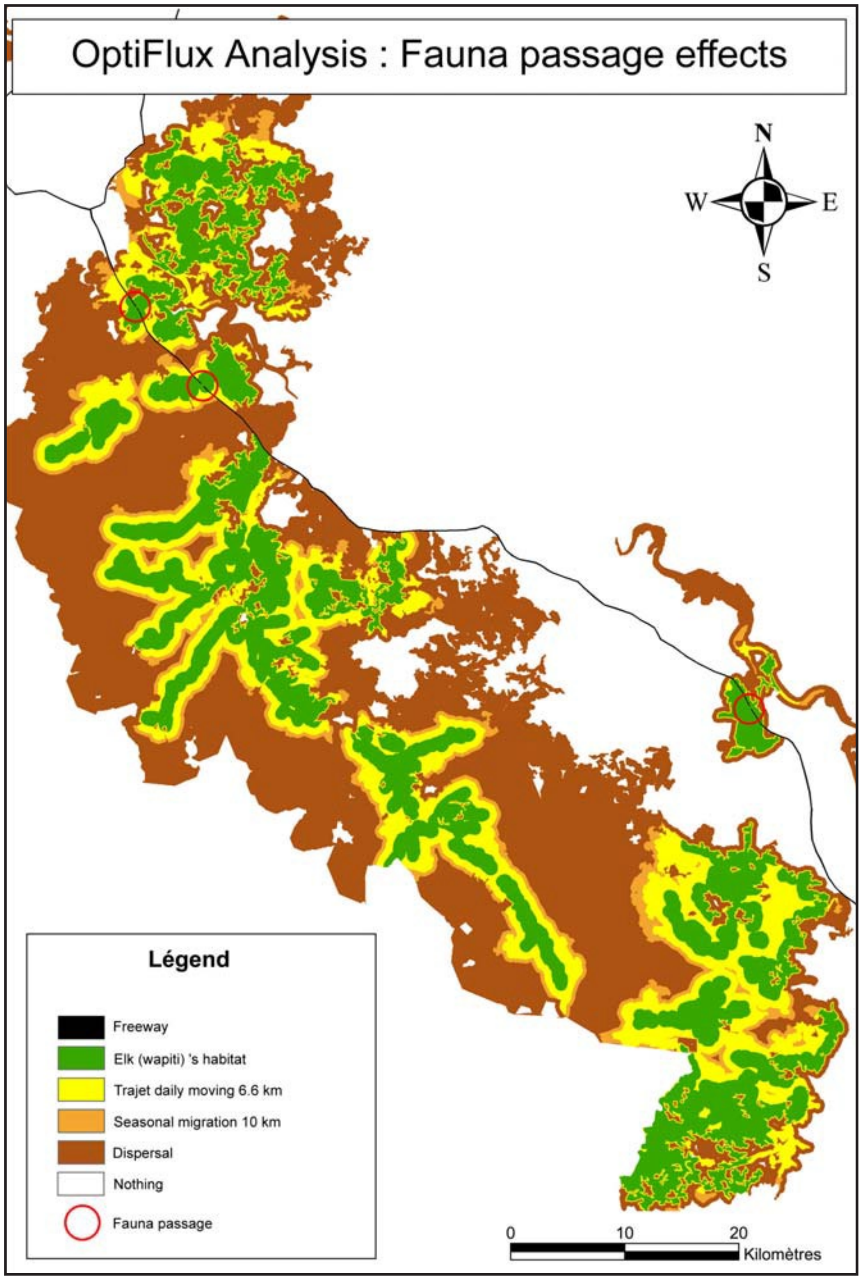

Figure 3. OptiFlux analysis: fauna passage effects.

Thus, at a study stage, simulations on OptiFlux show the best locations for fauna crossover passages for efficient restoration of significant biological corridors. This is particularly useful if, for financial reasons, all of them cannot be implemented.

Small mammal case: the European mink (*Mustela lutreola*)

The European mink is a small territory species (25 ha). Its territory is closely linked with wet habitats that minks almost never leave. For that reason, it is necessary to use a more detailed database, such as Corine Biotope. In our case study, we have used an existing and customized database, constructed to study land value. This was built from aerial photos and site visits for verification. The following map shows likely migration of the European mink.

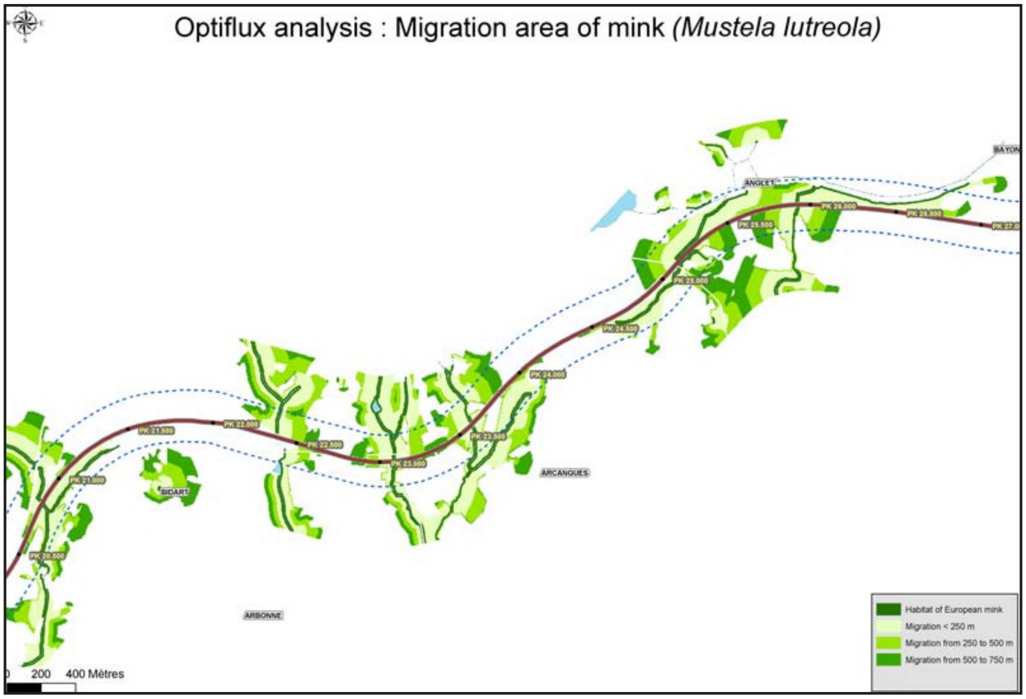

Figure 4. OptiFlux analysis: migration area of mink (*Mustela lutreola*).

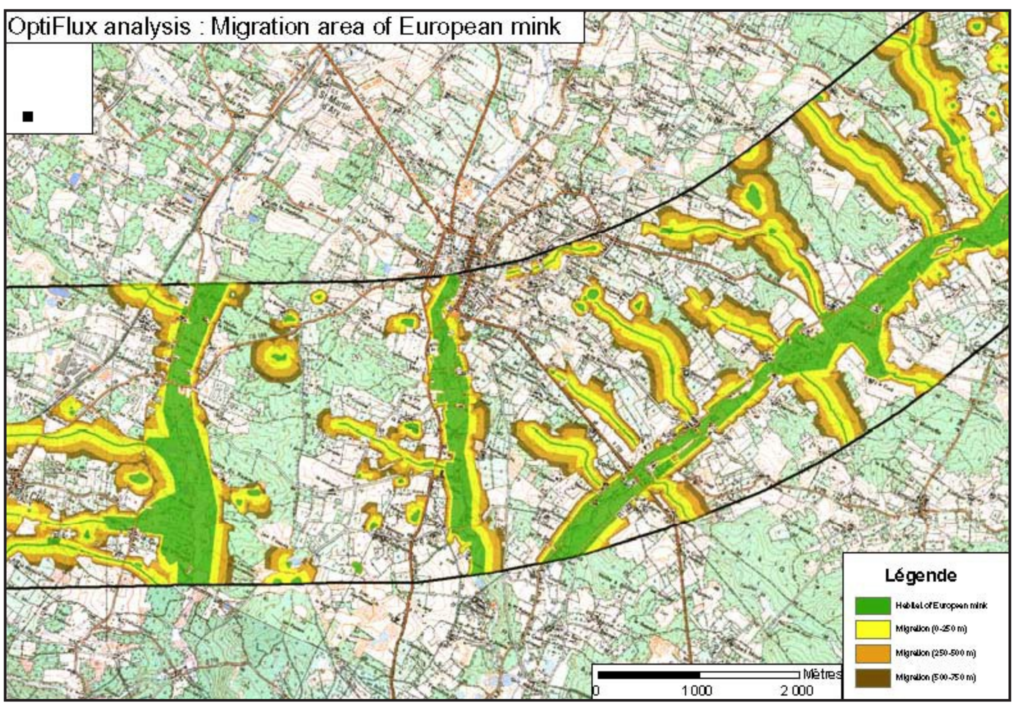

Figure 5. OptiFlux analysis: migration area of European mink.

The results obtained with OptiFlux have been controlled by a French mink expert, and it appears that they are coherent with the species' known dispersion.

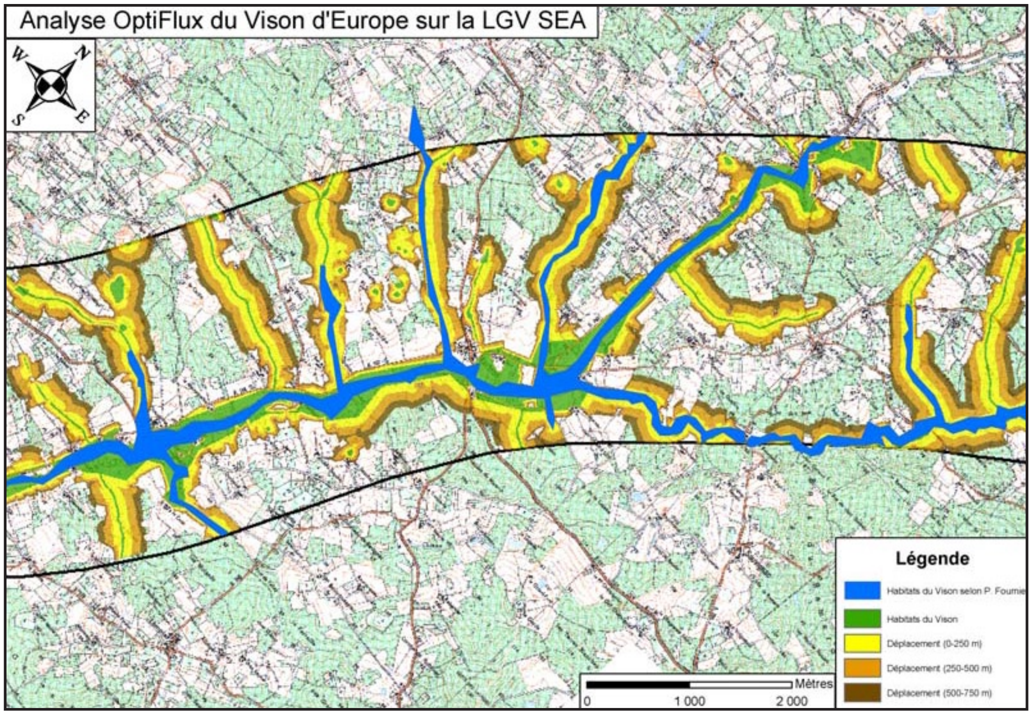

Figure 6. Analyse OptiFlux du Vison d’Europe sur la LGV SEA.

Therefore, on the same principle as that for the Red Deer, we can obtain the same simulations.

Insect species: the Hermit beetle (*Osmoderma eremita*)
The Hermit beetle (*Coleoptera Scaraboidea*) is a species that has a small dispersion area (approximately 500 m). This map (fig. 7) shows, on a 50-km stretch of freeway, locations where the hermit beetle is present or potentially present. The spatialized database was put together at a scale of 1/5000e for land acquisition studies. We have reused and completed it with biological data on the quality and structure of hedges. For financial reasons, it was not possible to implement its habitat everywhere (network of hedges). Choices were needed. To the right, connected areas showing either a definite presence or probable habitats for the Hermit beetle are shown.

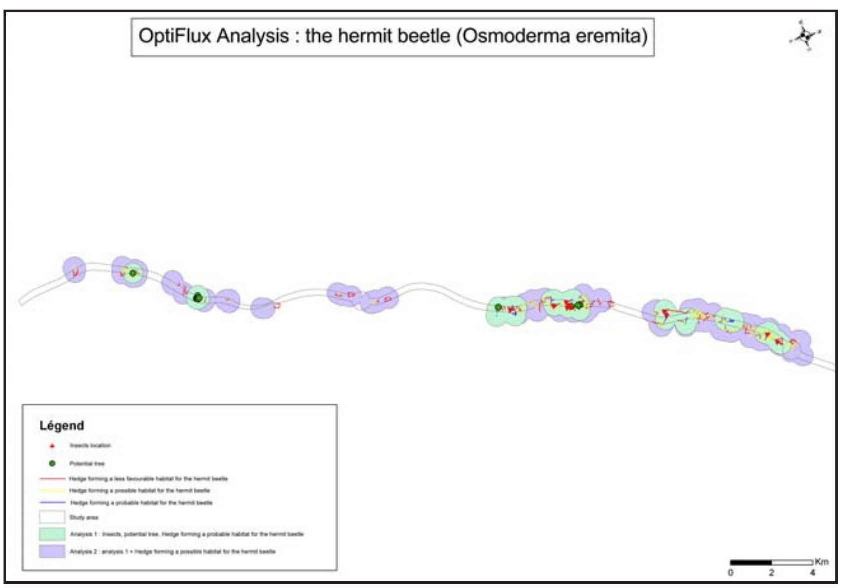

Figure 7. OptiFlux analysis: the hermit beetle (*Osmoderma eremita*).

It is only in these locations that hedge networks have been implemented in order to recreate habitat connectivity, essential for the specie’s expansion.

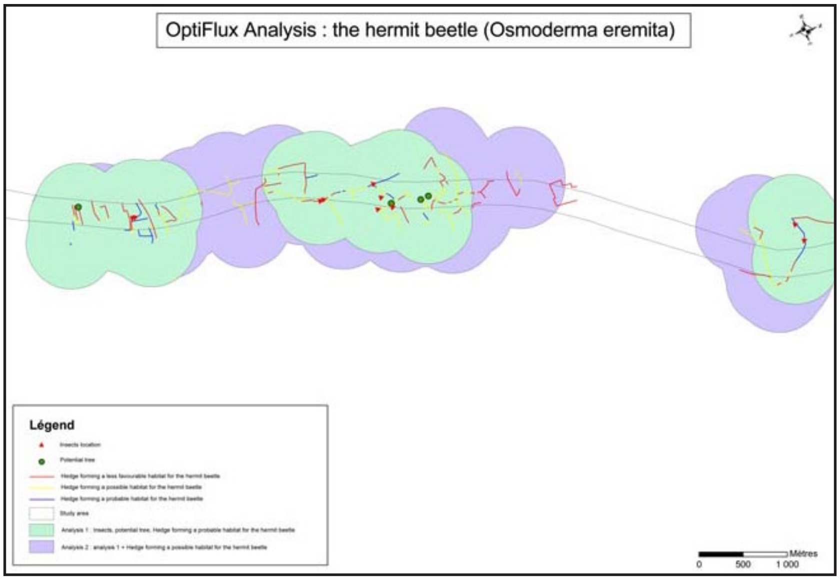

Figure 8. Zoom from figure 7.

OptiFlux helped us to select the locations where mitigation measures should have been realized in order to restore the Osmoderma eremita habitat connectivity with the best value.

Conclusions

The innovative aspect of OptiFlux is its automated diagnostic approach, with cross-relation of spatial and biological data, on large territories and at the initial stages of the project. It is a user-friendly tool (much more so than LandPop) that uses ArcView (GIS) and a plug-in called "Spatial Analyst."

OptiFlux provides a preliminary approach for a quick identification of the critical areas to be taken into account for design and cost estimate of the infrastructure. However, it does not eliminate the need for expertise and verification of the OptiFlux results made by a field biologist.

OptiFlux is a project optimization instrument, which helps in the decision-making process, concerning the necessity and relevance of the improvements retained. There are three direct applications for the tool:

- Identification of routes having the least impact on wild animal population fluxes and their habitats.
- Optimization of the number and location of fauna passages for the benefit of wild animals, and reduction of the points of conflicts between infrastructures (road, highway, railway) and biological corridors.
- Simulation of the positive effects of the proposed fauna passages or biotopes (amphibian ponds, for example) for a better choice of installations and for a better re-establishment of the connectivity of the habitats.

We are currently using this tool for the mammal group and we are continuing to develop the biological database (species sheet). We are working in particular on the taxonomic groups of amphibians and the birds.

Biographical Sketch: Dr. Philippe Thiévent (Ph.D. biology/entomology) is the technical manager of the Environment Department of SCETAUROUTE (EGIS Group). He is an internationally recognized expert on environmental impact assessment of major projects. He takes part in many French and European work groups targeting the improvement of transport infrastructures and their integration in the environment. Dr. Thiévent also participates in the development of technical guides on these subjects. He develops activities relating to recreation or improvement of river banks by methods of "ecological engineering," activities relating to the study of natural habitats' severance and fragmentation, and activities related to associated mitigation techniques.

Probabilistic Measure of Road Lethality

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Abstract: Throughout the world, the effects of highways and railroads on wildlife have been of great concern to scientists, land and wildlife managers, and the public, for over 80 years. Through these years, many researchers have sought to understand and mitigate the negative impacts of roads through theoretical and empirical research. However, to our knowledge, no one has investigated the underlying probability theory that likely governs the extent to which linear transportation features result in wildlife mortality. One reason may be that the number of factors potentially influencing observed patterns of road mortality can be quite large and can quickly become intractable. Our objective here was to suggest that the lethality of linear transportation features to wildlife is governed primarily by two factors: traffic volume and time spent on the roadway. Using a simple Poisson model of expected vehicle arrival times, we estimated the probabilities of animals successfully crossing roads under different traffic volume and animal mobility constraints. We used actual vehicle counts from two study areas as examples, and used a study of grizzly bears along a major railroad and highway to illustrate these concepts. We discuss the usefulness of this approach to conservation problems, and place it in context with other efforts to quantify the occurrence of wildlife mortality due to highways. Our hope is that these ideas will clarify and advance the search for solutions to what previously has been an intractable problem.

Introduction

Throughout the world, the effects of highways and railroads on wildlife have been of great concern to scientists, land managers, and the public (Forman 2000). The automobile has long been recognized as a causal agent of mortality, and efforts to quantify this mortality go back over 80 years (Stoner 1925). Many investigators have continued these efforts through the years (Davis 1934, Dickerson 1939, Bellis and Graves 1971, Garland and Bradley 1984, Clevenger et al. 2003). More recent theoretical developments in island biogeography and landscape ecology have increased concern about maintaining connectivity within and between wildlife populations (MacArthur and Wilson 1967, Forman 1995). Theoretical and empirical research shows that highways and railroads can fragment wildlife habitats, with potentially negative consequences (Noss et al. 1996). Numerous studies have quantified the movement patterns of wildlife across linear transportation features (e.g., Foster and Humphrey 1995, Hewitt et al. 1998, Gibeau 2000). However, to our knowledge, no one has investigated the underlying probability theory that likely governs the extent to which linear transportation features result in wildlife mortality.

One reason may be that the number of factors potentially influencing observed patterns of road mortality can be quite large. Possible factors include those unique to species, such as mobility, food preferences, and behavior. They may also include factors relating to population status, including density, age structure, sex ratio, and cyclic patterns of reproduction and movement. Other factors may be related to habitat, such as spatial positioning of crucial resources like water or breeding areas, or seasonal changes in climate, presence of attractants, or occurrence of flood, fire, and drought. Still more factors apply to the linear feature itself, including type (railroad, two-lane road, four-lane divided highway), design (width, tortuosity, grade), and capacity (speed and volume). Also affecting mortality are elements of driver behavior (attentiveness, reaction time) and vehicle type (large truck or passenger car). The list of confounding factors may be limited only by imagination.

Our objective here is to suggest that the risk that linear transportation features pose to wildlife is governed primarily by two factors: traffic volume and time spent on the roadway by wildlife. Roadkill often occurs when vehicles and animals attempt to occupy the same space at the same time. Most of the factors listed above might affect if or when an animal decides to cross a road, but once the animal begins crossing, largely deterministic processes take over. We used a study of grizzly bears along a heavily used railroad and highway to illustrate the usefulness of this approach.

Methods

Traffic engineers have developed a rich body of theory to describe traffic pattern and flow (Garber and Hoel 1999, Troutbeck and Brilon 2002). Gap-acceptance theory has been developed to allow highway engineers to quantify the process of vehicles from minor traffic streams merging into major streams. Usually, drivers will not merge unless there is a gap in traffic sufficient to accommodate their own vehicle – the critical gap. The occurrence of gaps in traffic greater than or equal to the critical gap depends on the arrival times of vehicles at the area of intersection. Numerous models have been proposed to describe the patterns of vehicle arrival at intersections, but for light to medium traffic volumes, the Poisson model is often used (Garber and Hoel 1999:205). In the Poisson model, vehicles are assumed to arrive at random times independently of each other. The number of arrivals in any interval of length *t* seconds has a Poisson distribution with mean μ = average number of arrivals per t seconds. That is, the probability of *x* arrivals during any interval of *t* seconds is

$$P(x \mid t) = \mu^x e^{-\mu} / x!, \quad x = 0,1,2,\ldots \qquad (1)$$

Since $\mu = \lambda t$, where λ is the mean number of arrivals per second, we can rewrite equation (1) as

$$P(x \mid t) = (\lambda t)^x e^{-\lambda t} / x! \qquad (2)$$

Let T be the number of seconds from any point in time until the next vehicle arrival. Then, by equation (2),

$$P(T > t) = P(\text{no arrivals in next } t \text{ seconds}) = P(0 \mid t) = e^{-\lambda t}, \quad t > 0 \quad (3)$$

and

$$P(T \le t) = 1 - e^{-\lambda t}, \quad t > 0 \qquad (4)$$

that shows that T has an exponential distribution. Note that the time until the next arrival is independent of the time since the last arrival. This is the “memoryless” property of the exponential distribution and the Poisson model. Our interest here is determining the probability of animals successfully crossing a highway. If we assume that the critical gap *h* is the time (in seconds) necessary to cross one lane of traffic, then, by equation (3), the probability that an animal will successfully cross the lane is

$$P(T > h) = P(0 \mid h) = e^{-\lambda h} \qquad (5)$$

where λ is the average number of vehicles per second for one lane. Crossings of multiple traffic lanes are considered independent events, and, therefore, the probabilities are multiplicative. A successful crossing of one lane depends on the traffic volume in that lane and does not influence the success or failure of crossing additional lanes.

The critical gap may vary greatly between and within species. A running deer (*Odocoileus* spp.) may cross a lane of traffic in a fraction of a second, or it may stand spellbound in the traffic lane for many seconds. We displayed the chances of mortality under these varying scenarios by plotting 1-P(0|*h*) against time (or the critical gap *h*) for several different values of λ. Therefore, we implicitly assume that roadkill is an instantaneous event uninfluenced by avoidance behaviors of animals or drivers.

The value of λ, the mean number of vehicles per second, is estimated from observed traffic counts as V/S, where V is the total number of vehicles observed over S seconds. The value of λ will vary over the course of a day, week, or year. Separate estimates may be necessary for different times during the day and different times of year. For example, if animals are crossing primarily during low-volume periods, using an average volume over time periods where traffic volume varies considerably will obviously give spurious results. In addition, the estimated probability of a successful crossing from equation (5) using an average value of λ will underestimate the average probability of success averaging over the individual values of λ.

Between 1998 and 2001 we conducted a study examining the highway-crossing behavior of grizzly bears along US Highway 2 (US-2) and a portion of the Burlington-Northern Santa Fe railroad in northwestern Montana (Waller and Servheen, in press). During that study we continuously monitored road and rail traffic volume and direction. We found that grizzly bears crossed US-2 and the railroad primarily at night. Highway traffic volumes were much lower at night than during the day, while railroad traffic volumes were higher at night. We used this traffic volume data in equation (5) to calculate the probability of being struck on US-2 given lane crossing times of 0.3 seconds to 2 minutes. We chose to use lane width to calculate crossing times rather than vehicle width because the former is constant over long stretches of highway, whereas vehicle width varies significantly by vehicle type. Representative observed single-lane traffic volumes on US-2 were 21 vehicles/hr at night during those hours when grizzly bears crossed, 44 vehicles/hr overall, and 89 vehicles/hr during daytime. For comparison, we also calculated the probability of mortality on the Trans-Canada highway in Banff National Park, given a published average daily traffic volume of 25,000 vehicles per day (Gibeau 2001). Lacking more specific data, we assumed that this traffic was distributed evenly over a 24-hr period and across four traffic lanes.

We also used equation (5) to estimate the probabilities of being hit given movement rates representative of differing modes of crossing or species with differing levels of mobility. We chose movement rates of 13.7 m/s, which would approximate that of an ungulate or bear running at top-speed – 4.6 m/s, which approximates a large animal trotting across the road; 1.5 m/s, approximating a large animal walk; and 0.15 m/s, which might represent a very slow-moving species, such as a turtle or snake.

Railroad traffic can be considered in the same manner as highway traffic, but differs in the distribution of arrival times between cars. Railroad cars, when strung together in a train, have exceedingly short gaps between them. The gaps are much shorter than one would observe in all but the heaviest traffic. These short gaps are then followed by much longer gaps between trains. One of the criticisms of using the Poisson distribution to model vehicle gaps is that under heavy-traffic situations it tends to overestimate the number of gaps less than one second (Garber and Hoel 1999). These short gaps generally do not occur in highway traffic due to the tendency of drivers to maintain longer gaps out of concern for safety. However, for train car spacing, gaps less than one second do occur as the rule. Therefore, we have also used the Poisson distribution to model the probability of being struck by a train.

An alternative would be to treat the train as a single vehicle. Such a treatment would implicitly assume that railroad kills occur only as the result of contact between the animal and the leading engine of the train. No empirical data exist on the specific manner in which wildlife are killed by trains, but anecdotal reports suggest that animals are killed while trying to pass underneath moving trains. In many cases, the bottoms of train cars may be 1-1.5 m above the ground due to the height of their wheels. This configuration allows animals to easily see underneath passing trains. Should a passing train separate social animals, such as a herd of ungulates or family group of bears, individuals may attempt to cross under the passing cars. Such occurrences suggest that using an individual car-based approach is appropriate. Treating an entire train as one vehicle would likely underestimate the true probability of mortality. We use records of bears killed on US-2 and the adjacent railroad, as well as other literature, to support our arguments.

Results

Animals crossing US-2 at night have a high chance of crossing successfully, whereas those attempting to cross the Trans-Canada highway have a high probability of dying in the attempt (table 1, figure 1). A recent study of grizzly bear movements along the Trans-Canada highway found that very few grizzly bears attempted to cross (Gibeau 2000). Using an average rail traffic volume of 1.2 75-car trains per hour in equation (5), we calculated that the probability of being hit by a train duplicates the probability of being hit while crossing US-2 during the day. The probability of being struck increases with increasing traffic volume for species having different movement rates (figure 2). Species incapable of moving quickly, or those predisposed to pausing in the roadway, are more likely to be hit.

According to this model, bears crossing the railroad are approximately four times more likely to be hit than those crossing US-2 at night. During our grizzly bear study along US-2, no grizzly bears that we know of were hit on US-2, but three were struck and killed by trains, including two marked study animals. At a larger scale, 13 grizzly bears were killed by trains between West and East Glacier, Montana, during the period 1992-2002, and only two were struck by cars (C. Servheen, unpublished data).

Table 1. Probability of being struck on US-2 or Trans-Canada highway given time on roadway

Seconds in Roadway	% Chance of roadkill – US2, night	% chance of roadkill – US2 average	% chance of roadkill – US2 day	% chance of roadkill - TransCanada
0.333	0.376	0.76374	1.522	9.154
0.667	0.751	1.5216	3.020	17.469
1.000	1.124	2.2737	4.496	25.024
1.333	1.495	3.0201	5.949	31.887
1.667	1.866	3.7607	7.380	38.122
2.000	2.235	4.4958	8.789	43.786
2.333	2.602	5.2252	10.177	48.931
2.667	2.968	5.9490	11.544	53.606
3.000	3.333	6.6673	12.890	57.853
3.333	3.697	7.3801	14.216	61.711
3.667	4.059	8.0875	15.521	65.216
4.000	4.419	8.7894	16.806	68.400
4.333	4.779	9.4860	18.072	71.292
4.667	5.137	10.177	19.319	73.920
5.000	5.493	10.863	20.547	76.307
5.333	5.849	11.544	21.756	78.476
5.667	6.203	12.219	22.946	80.446
6.000	6.555	12.890	24.119	82.236

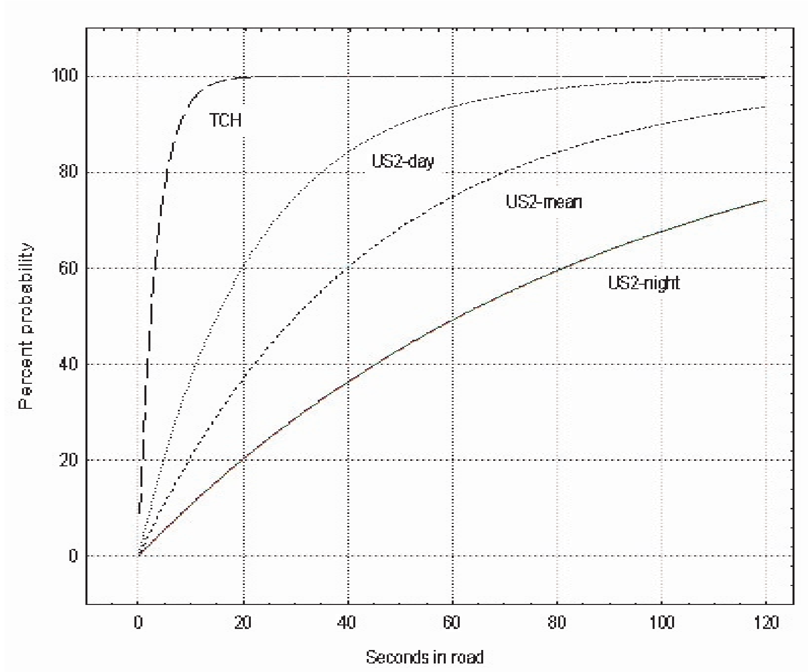

Figure 1. Percent probability of being hit by a vehicle during t seconds in roadway given the following traffic volumes: TransCanada Highway (TCH), 260 vehicles per hour (v/h) * 4 lanes; US-2 daytime, 89 v/h * 2 lanes; US-2 mean, 44 v/h * 2 lanes, US-2 night, 21 v/h * 2 lanes.

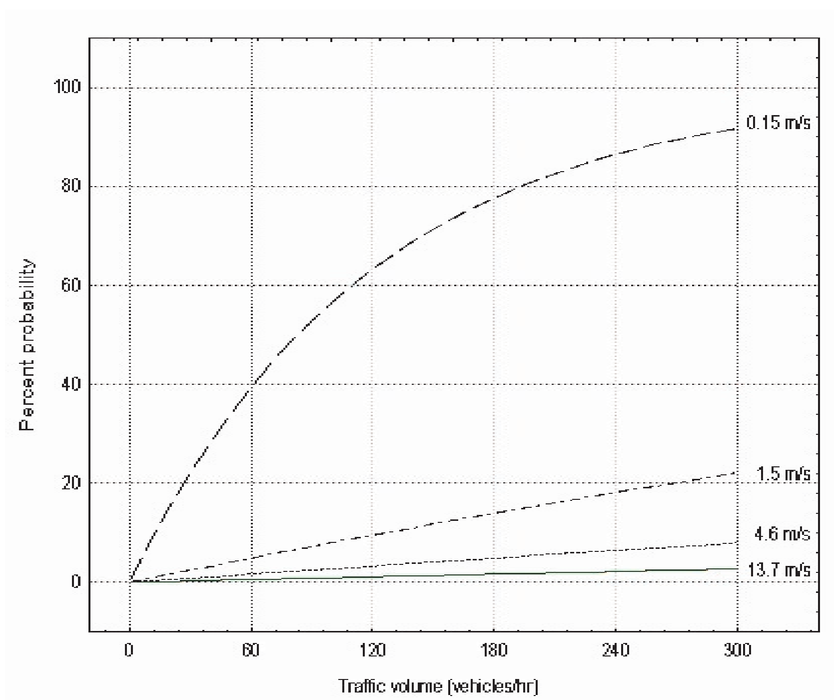

Figure 2. Percent probability of being hit by a vehicle given various traffic volumes (v/h) and movement rates (m/s).

Discussion

Vehicle speed is not a factor in this model; however, speed has never been definitively implicated as a factor leading to higher roadkill rates. Only two studies have directly examined the effect of speed on roadkill rates. Gunther et al. (1998) concluded that speed was the most significant factor affecting roadkill rates in Yellowstone National Park, but he did not measure traffic volume. Bertwistle (1999) studied the effect of vehicle speed on collisions with bighorn sheep and elk in Jasper National Park. He found that reduced speed zones were associated with more collisions with bighorn sheep and fewer with elk. He acknowledged the possible influence of traffic volume, but does not evaluate its role in the frequency of collisions.

Vehicle speed is usually confounded with road capacity. Roads must be designed to accommodate higher vehicle speeds, and such designs often carry higher traffic volumes. Gilbert and Wooding (1996) showed an increasing trend in the number of black bears killed on highways in Florida with concurrent increases in traffic volume on those same highways. Although vehicle speed does not affect arrival time given a governing distribution such as the Poisson, speed may influence the probability of roadkill by limiting the ability of drivers to make evasive maneuvers and by decreasing the time wildlife has to react to approaching vehicles. However, we believe that the influence of speed is small. Roadkill was recognized as a serious problem at a time when vehicle speeds seldom exceeded 40 km/hr (Stoner 1925).

Management Implications

These results allow biologists and highway planners to objectively evaluate the risk of roads and highways to wildlife without having to produce actual records of mortalities. In fact, the risk a particular roadway may pose to any species, extant or not, can be quantitatively assessed. Because this model deals with the instantaneous probability of intersection, it can apply to any species entering the traffic stream. However, use of this model requires qualitative assessment of the speed at which an individual animal may cross each traffic lane. For example, biologists may wish to evaluate the danger of a particular roadway to an endangered species prior to augmentation or reintroduction. For rare, wide-ranging species, such as fisher (*Martes pennanti*), lynx (*Lynx lynx*), wolverine (*Gulo gulo*), wolves (*Canis lupus*), or grizzly bear (*Ursus arctos*), each road mortality may have noticeable demographic affects, yet one may never observe enough road mortalities to make confident decisions concerning risk.

Further, this approach is useful given a wide range of actual traffic distributions. In this paper, we limited discussion to an assumed Poisson distribution of vehicle arrival; however, one can easily document any traffic pattern with empirical data and calculate probabilities associated with successful crossings. Jaeger and Fahrig (2004) recently modeled persistence times of hypothetical populations confronted with fenced and unfenced roadways. Fencing is often considered as a means to mitigate high wildlife mortality, but may increase the barrier affect of the roadway. Jaeger and Fahrig (2004) examined the trade-off between mortality, road avoidance, and movement, and found that at roadkill probability levels of 80 percent or more, fencing increased population persistence. While they caution that their results are qualitative, combining their work with ours allows further exploration of alternative conservation actions.

We stress that readers should not confuse the probability of roadkill with the rate of roadkill. Any of the factors cited above may affect the observed rate of mortality. Species rare or absent along roads are unlikely to be killed on them regardless of traffic volume. Conversely, species congregating along roads due to the presence of an attractant, such as salt, forage, carrion, or spilled grain, may likely be found killed despite low traffic volumes. Observed roadkill results from the interaction of risk (probability) and opportunity.

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Reliability of the Animal Detection System Along US Hwy 191 in Yellowstone National Park, Montana, USA

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Abstract: Animal detection systems use high-tech equipment to detect large animals when they approach the road. Once a large animal is detected, warning signs are activated urging drivers to reduce their vehicle speed, be more alert, or both. Lower vehicle speed and increased alertness may then lead to fewer and less severe collisions with, for example, deer (*Odocoileus sp.*), elk (*Cervus elaphus*), or moose (*Alces alces*)). For this study, we investigated the reliability of the animal detection system installed along US Hwy 191 in Yellowstone National Park, Montana, USA. The system was designed to detect elk and stored all detection data, including the detection zone in which the detection occurred, and a date and time stamp. Interpretation of the detection data suggested that at least 47 percent of all detections were related to animals crossing the road. However, animals walking in the right-of-way or medium-sized mammals (e.g., coyotes, *Canis latrans*) do not generate a clear detection pattern, and were, therefore, classified as "unclear." Therefore, the 47 percent should be regarded as a minimum estimate. The timing and direction of travel of crossing events, indicated by detections on opposite sides of the road, matched local knowledge about the behavior of the elk, suggesting that the system was able to detect large animals, specifically elk, and that the data were interpreted correctly. We also compared the spatial distribution of the crossing events with snow tracking data. The spatial distribution of the crossing events and elk tracks showed a close match, again suggesting that the system was able to detect elk, and that the data were interpreted correctly. Almost 87 percent of all elk crossings recorded through snow tracking could be linked to a crossing event detected by the system. However, medium-sized mammal species, such as coyotes and wolves (*Canis lupus*), were not or rarely detected. Furthermore, we identified the presence and location of blind spots (potentially 17.8% of the total length covered by the sensors). Blind spots were defined as locations where the system failed to detect a human crossing between the sensors. Most of the blind spots were due to curves and slopes that caused the detection beam to shoot too high above the ground. The total time for which the flashing warning lights would have been activated was estimated at one hour and 13 minutes per day, a marked difference compared to permanently activated warning signs. Most crossing events (72.6%) were completed within three minutes, and the median duration of a crossing event was one minute and 29 seconds. If the warning signs would be activated for three minutes after the last detection, the signs would have been continuously activated for 88.1 percent of all detection intervals (i.e., time between consecutive detections) during crossing events. Similarly, 78.1 percent of all crossing events would have had the warning signs continuously activated while the crossing was in process. We conclude that the system reliably detects large animals, especially elk, but the system does not detect all elk that cross the road, e.g., because of blind spots. In addition, a three-minute activation period for the warning signs appears to be a good balance between keeping the signs turned on while elk are in the process of crossing the road, and not presenting drivers with activated warning signs longer than necessary.

Introduction

Animal detection systems use high-tech equipment to detect large animals when they approach the road. Once a large animal is detected, warning signs are activated urging drivers to reduce their vehicle speed, be more alert, or both. Lower vehicle speed and increased alertness should then lead to fewer and less severe collisions with, for example, deer (*Odocoileus* sp.), elk (*Cervus elaphus*), or moose (*Alces alces*).

There are about 30 locations throughout Europe and North America that have or had an animal detection system in place (Huijser and McGowen 2003, Huijser and McGowen in prep.). Data on the effectiveness of animal detection systems are scarce, but data from Switzerland suggest that animal detection systems may lead to an 82-percent reduction in the number of ungulate-vehicle collisions (Kistler 1998, Romer and Mosler-Berger 2003, Mosler-Berger and Romer 2003). Nonetheless, in order for such systems to be effective, they must first detect large animals reliably. Few studies have documented such reliability data (e.g., Gordon et al. 2001, Kinley et al. 2003).

In this study, we investigate the reliability of the animal detection system installed along US Hwy 191 in Yellowstone National Park, Montana, USA. In addition, we investigate the characteristics of crossing events detected by the system to evaluate the period of time for which the warning signs should be activated once a large animal is detected.

Methods

Study site

In October and November 2002 an animal detection system was installed along US Highway 191 in Yellowstone National Park, between West Yellowstone and Big Sky, Montana, USA. The system was installed along a 1.6-km (1 mi) road section (mile posts 28.0-29.0) (figure 1). This two-lane road is located in a valley and runs parallel to the Gallatin River. Adjacent mountain slopes are mostly forested while the valley is dominated by grasslands and shrubs along the river banks. However, the north side of the road section with the animal detection system (detection zones E, B, C, 4 and 7, see figure 1) has trees (mostly lodgepole pine, *Pinus contorta*) on both sides of the road within 9 m (30 ft) from the pavement. The rest of the road section is more open and has steep slopes, especially on the west side of the road.

The lands on the east side of the river, where the road section with the animal detection system is located, are part of Yellowstone National Park. The lands on the other side of the river are mostly National Forest Service lands. A section of private land, the Black Butte Ranch, is located adjacent to part of the study site on the west side of the river. The access road to the ranch connects to US Hwy 191 about midway in the road section with the animal detection system (figure 1). A parking area for a trailhead is located on the west side of the road, about 600 m (0.37 mi) farther to the north. The trail itself starts on the east side of the road. Furthermore, there is a pullout on the west side of the road about 150 m (493 ft) south of where the access road to the ranch connects with US Hwy 191. The elevation of the site is about 2,073 m (6,800 ft), and annual average snowfall is about 305 cm (120 in). Winter driving conditions include heavy snowstorms and an icy and snow-packed road surface with heavy winds and temperatures well below -30 ºC (-22 ºF).

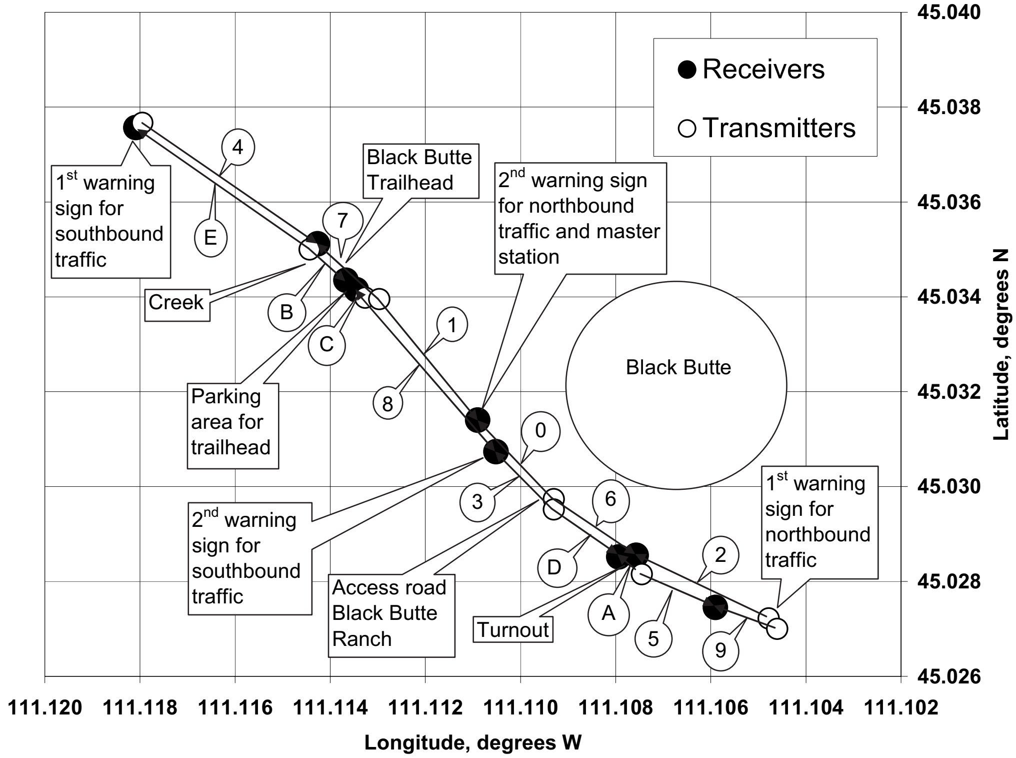

Figure 1. Schematic layout of the animal detection system and major road and landscape features at the study site (Source: STS). The numbers and letters represent the codes of the individual detection zones.

US Hwy 191 has two lanes that are 3.7 m (12 ft) wide with asphalt road surface. The shoulder width varies between 0.6-1.2 m (2-4 ft). The clear zone is usually 6.1 m (30 ft) wide, but steep slopes are closer to the road along certain sections. The right-of-way on the west side of the road has a steep slope for about 500 m (0.31 mi). The road has some curves within the section with the animal detection system. The speed limit is 88 km/h (55 mi/h), but the average vehicle operating speed is around 113 km/h (70 mi/hr) (Gunther et al. 1998; speed readings by WTI-MSU, November 2002). The average annual daily traffic volume (AADT) is about 2,545 vehicles with about 13 percent truck traffic (estimated in 2000). Traffic volume peaks in July (4400 ADT), mostly because of tourists that visit the area.

The area is home to many large mammal species including elk, moose, bison (*Bison bison*), mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), black bears (*Ursus americanus*), grizzly bears (*U. Arctos*), coyotes (*Canis latrans*), and wolves (*C. lupus*). The majority of the recorded animal-vehicle collisions in this area involve elk (table 1).

Table 1. Number of recorded road-killed large animals between 1989 and 1998 at and adjacent to the road section with the animal detection system (Source: Yellowstone National Park)

Mile marker	Total recorded road kill	Moose	Elk	Mule deer	Black bear	Wolf	Coyote	Beaver	Raccoon
27-28	38	0	30	4	0	0	2	2	0
28-29	67	2	56	2	0	1	5	0	1
29-30	29	1	21	1	1	1	4	0	0

The valley and surrounding slopes are an important wintering area for elk, and most elk-vehicle collisions occur during the winter season (Source: Montana Department of Transportation; Yellowstone National Park). However, the number of elk wintering in the valley and along US Hwy 191 and the number of elk-vehicle collisions may have decreased during the last several years (Pers. com. Russel Rooney, Montana Department of Transportation). It may be that this reflects a true decrease in population size, but it is also possible that the elk are more dispersed than before, perhaps because of the presence of wolves in the area (White and Garrott 2005). Currently, most of the elk seem to move across the road in the fall (November-mid December) when they migrate to lower elevation areas, and in the spring (mid March-mid May) when they migrate to higher elevation areas as the snow melts off. Elk that spend the winter along the Gallatin River and the surrounding slopes typically spend the day bedded down on the forested slopes (Pers. com. Greg and Sara Knetge, caretakers Black Butte Ranch). In the evening the elk travel down the slopes to the valley bottom to forage on grasses and shrubs along the river. In the early morning hours they move up the slopes again. Hence, there seems to be a concentration of elk crossing the road in the evening and early morning.

Animal detection system

The animal detection system was manufactured by Sensor Technologies and Systems (STS), Scottsdale, Arizona, USA. After installation (October-November 2002), the system experienced a range of technological challenges, and it was not until November 2004 that the system appeared to function as originally intended (Salsman and Wilson in prep.).

The system is based on a "break-the-beam" principle (see Huijser and McGowen, 2003). This break-the-beam system consists of transmitters that send modulated low-power microwave radio signals (around 35.5 GHz) to receivers. When an animal's body breaks the beam, the receiver signal output is decreased, indicating a detection. The paired transmitters and receivers (sensors) cover 1,609 m (1 mi) along both sides of US Hwy 191 between mile marker 28.0 and 29.0 (figure 1).

Break-the-beam systems require a clear line of sight between a transmitter and its receiver. The maximum range of the transmitters is 402 m (1/4 mi). Thus, under ideal conditions, four sensor pairs (four detection zones) are needed to cover one mile on one side of the road. However, curves, slopes, and vegetation usually require additional sensors. The site along US Hwy 191 has a total of 15 detection zones (6 on the east side, 9 on the west side) (figure 1). The sensors are attached to metal or wooden poles, dependent on the total weight, size, and height of the equipment and poles. Poles with sensors are referred to as "stations." A station typically has either two transmitters or two receivers, facing in opposite directions. There are nine transmitter stations, and nine receiver stations (figure 1). One of the receiver stations situated in the middle of the array (see figure 1) also serves as the master station (see later). Most of the metal and wooden poles are located in the clear zone, 1-8 m (3.3-26.3 ft) from the edge of the pavement. Metal posts have concrete foundations and a break-away system, while wooden poles are placed directly into the ground with three holes located in the pole just above ground level allowing them to break-away in case of a collision. Each station is powered by its own solar panels. In some cases, the solar panels are mounted on a separate post to avoid tree shade or to reduce weight and size for the pole with the sensors. Batteries provide power during periods of darkness or snow cover on the solar panels, and the battery charge is maintained by the solar panels.

Most of the sensors are mounted about 1.2 m (4 ft) above the ground as this system is designed to detect elk. However, some sensors are situated higher or lower to compensate for slopes, rises, and low areas in the right-of-way. The "beam" of microwave radio signals is relatively narrow (3°) when it leaves the transmitter, and becomes several meters (yards) wide farther from the transmitter. When an animal's body breaks the beam in one of the detection zones, the receiver signal output is decreased, indicating a detection event. The receiver station then sends an UHF radio signal to the master station (see figure 1) to report the detection. Upon receiving the detection report, the master station sends a UHF signal to activate the flashing amber warning lights that are located on four of the stations (see figure 1).

When activated, the flashing lights alert the drivers that a large animal may be on or near the road at that time. There are four stations with warning lights: two for southbound traffic and two for northbound traffic (figure 1). The warning lights are accompanied by black-on-yellow warning signs that say "wildlife crossing," "next 1 mile," or "next ½ mile" when flashing. The system is programmed to activate the three warning lights that are closest to the zone in which the detection occurred. If no new detections occur, the warning lights are turned off after three minutes. If the signal in a detection zone is blocked continuously for more than 12 minutes the additional detections from that detection zone are ignored and the warning lights are deactivated, unless new detections are reported from other detection zones. Once the beam is no longer blocked, the detection zone concerned becomes active again.

Drivers are informed of the presence and function of the system by white on green information signs, one for each travel direction, about 322 m (0.2 mi) before the first station. The signs say "animal detection test section ahead." In addition, there is another white-on-green information sign for each travel direction that says "end test section" at the last station. However, during the research period (26 January 2005–5 March 2005) the warning lights were left unplugged, and the warning signs were not attached; we wanted to have a thorough understanding of the reliability of the system before presenting drivers with warning lights and signs.

The system records all detections and saves them at the master station. Detection events are broadcast using the UHF radio system, in real-time, so that the animal detection system operation can be monitored on site using a portable data radio connected to a computer (e.g., laptop). The system also saves the date and time for each change in beam status (i.e., the beginning and end of a break-of-the-beam are recorded as two changes in beam status), the detection zone in which the detection occurred, and a code for the activation of the flashing warning signals. In addition, the logging system maintains and reports statistics associated with the operation of individual elements of the system.

These statistics include radio link failures, radio link signal levels, beam break summaries, and logging memory status. The data can be downloaded on-site (memory card, direct physical link to laptop, or radio link to laptop), or from a remote location through a modem and land-based phone line. When an animal crosses the road, it typically results in four records: two on each side of the road that mark the beginning and end of the break-of-the-beam. If the animal crosses the road straight, the detections occur in the zones that are on opposite sides of the road. Based on the location of the detection zones and the date and time stamp, one can determine the location, direction, and timing of the crossing event.

Reliability

Data interpretation

The detection data from 26 January 2005 until 5 March 2005 were extracted from the system. We interpreted the data patterns for thee periods: 26 January 2005–14 February 2005, 18 February 2005–21 February 2005, and 25 February 2005–5 March 2005 (30 days total). We distinguished seven categories (table 2). Detections caused by researchers working at the field site were excluded from all analyses. Each "day" started and ended with the arrival of the researchers at the site (usually in the morning hours) or, if the researchers did not visit that day, a "day" started and ended at noon (12:00).

The interpretation of the data based on the detection patterns is at least partially subjective and subject to errors. This is particularly true for the category "unclear." Although certain detections may seem random and do not seem to fit any particular pattern, they may very well be related to real-world events. For example, an animal walking in the right-of-way may trigger the system, but the animal may not cross the road and may not trigger the system on the other side. Alternatively, the animal may also cross the road much farther up or down the road, thus producing seemingly unrelated detections. In addition, the beam with the microwave signals is not at a constant height above the ground. Rises or low areas, slopes, and curves result in areas where the beam may shoot over an animal's body or where it is very close to the ground (e.g., 45 cm (18 in)). Thus medium-sized mammals such as coyotes, but also relatively large mammals such as elk, may be detected in some areas and not in others, resulting in seemingly isolated and unrelated detections. Furthermore, traffic can also cause isolated detections, especially in detection zones 8, 9, and 1 where the beam is relatively close to the edge of the pavement (for location of the detection zones see figure 1). Thus, vehicles that drive on the edge of the pavement can also cause detections that may not fit any particular pattern, and these may be classified as "unclear" as well.

Table 2. Detection data categories

Category	Definition
Animal crossings	All detections that showed "something" crossed the road and triggered the system in detection zones on opposite sides of the road. This is synonymous with the term "crossing event". Note: we included detections in the right-of-way that seemed to be related to the crossing (i.e. detections immediately before and after the crossing of the actual pavement).
Traffic/snowplow	A series of consecutive detections in adjacent sections with the direction of travel. The detections may be caused by snow spray from snow plows, signal reflections from large vehicles (buses/trailers) or vehicles driving close to the edge of the road.
Traffic Black Butte Ranch	All detections in detection zone 3 between 7:00-23:00 that had no match on the other side of the road.
Trailhead	All detections in detection zone 7 between 7:00-19:00 and that had no match on the other side of the road.
Error	Detections associated with a failed radio report or detections that occur simultaneously in adjacent sections.
Unclear	Detections that do not fall in any of the above categories and that cannot be readily explained based on the data patterns alone.

Other interpretation problems occur when several animals cross the beam at the same time, i.e., within two seconds of each other. These crossings will be recorded as one beam break event rather than several. Thus, the number of "animal crossings" or "crossing events" (see table 2) detected by the system can underestimate the actual number of animals that crossed the road. This is especially true for gregarious species, such as elk. This underestimation does not affect the functioning of the system, but it is one of the factors that complicate data interpretation.

Snow tracking
We conducted daily snow tracking sessions on both sides of the road for the full 1,609-m (1 mi) road length covered by the animal detection system for three periods: 26 January 2005—14 February 2005, 18 February 2005—21 February 2005, and 25 February 2005—28 February 2005. The visits were mostly conducted in the morning hours. On the first day of each session we did not record any tracks, rather only erased all tracks present in the snow with a rake. Thus, there were 25 days of snow tracking in total. On the following days for each session, we recorded and erased all new tracks of large animals that crossed in between the transmitters and receivers of the animal detection system since the last visit. When an animal appeared to have crossed the road we specifically looked for a matching track on the other side of the road. The snow track data were compared to the detection data saved by the animal detection system to further investigate system reliability.

Snow tracking is not without error either. In our area snow tracks may have been covered by fresh snow, snow spray from snow plows, or the wind may have caused snow to fill in the tracks. Snow tracks may also have disappeared or fainted as a result of snow melt, or the snow may have disappeared altogether in certain areas, especially on the west and south facing slopes of the road bed. In addition, some animals may not have left tracks when there was a hard icy crust on top of the snow. Furthermore, the direction of travel of the animal may have been misinterpreted because of unclear snow tracks, and the number of animals traveling in a group and animals that step in each others tracks may have been miscounted or improperly estimated. Finally, some tracks may have been simply overlooked. In some cases, such tracks may have been identified the next day; in other cases, they may never have been identified.

Blind spots
Blind spots are areas within the road section equipped with the system where large animals may pass between sensors without being detected. We tested for such potential blind spots by using a human (170 cm (5 ft 7 in)) as a model for elk. We passed through the detection zones at 20-m (21.9 yard) intervals on 5, 7, and 13 February 2005. We recorded the location and time of each passage and compared these notes with the detections recorded by the system. We walked well past the detection zone and allowed for a minimum of three minute intervals between consecutive passages to avoid desensitization of the beam. Locations on which the system failed to pick up the model were identified as "blind spots."

Reliability norms
In the previous sections we described the different methods used to investigate system reliability. However, we must also define what we consider reliable. For this study, we used a range of parameters to describe how reliable we found the animal detection system to be (table 3). First, we found it important that "crossing events" (see earlier) could be identified in the detection data (through data interpretation) and that the system was able to detect large animals continuously during the period investigated without abundant false detections generated by the system (based on data interpretation). We also found it important that the timing and direction of travel for crossing events would match local knowledge about the behavior of large animals in the area, specifically elk. Furthermore, we wanted to see that elk crossings recorded through snow tracking could be linked to a crossing event detected by the system. We wanted to see this percentage be at least 80 percent, and preferably 100 percent. Therefore, we defined different levels of reliability for this quantitative parameter (see table 3). Finally, we found it important that the system not have blind spots where it would fail to detect a large animal approaching the road.

Table 3. Parameters and definition for reliability norms

Parameter	Definition
Crossing events	Reliable: crossing events can be identified through interpretation of the data patterns. Unreliable: crossing events cannot be identified through interpretation of the data patterns.
System failures	Reliable: the system is able to detect large animals continuously during the period investigated without abundant false detections generated by the system or system failures (based on data interpretation). Unreliable: the system is not able to detect large animals continuously during the period investigated or abundant false detections are generated by the system or the system experienced general failures (based on data interpretation).
Local knowledge	Reliable: the crossing events match local knowledge about the behavior of large animals, especially elk. Unreliable: the crossing events do not match local knowledge about the behavior of large animals, especially elk.
Snow tracking	Absolute reliability: 100% of the elk crossings recorded through snow tracking can be linked to crossing events detected by the system. High reliability: 80%-99% of all elk crossings recorded through snow tracking can be linked to crossing events detected by the system. Medium reliability: 60%-79% of all elk crossings recorded through snow tracking can be linked to crossing events detected by the system. Low reliability: <60% of all elk crossings recorded through snow tracking can be linked to crossing events detected by the system.
Blind spots	Reliable: there are no blind spots in the road section equipped with the system. Unreliable: there are blind spots in the road section equipped with the system.

The warning signs and lights were not visible to the public during our study period. However, we were able to quantify how long the lights would have been activated given the number and timing of the recorded detections. In addition, the detection data were used to evaluate how long the warning lights should be activated after a detection occurs.

Activation period per day
We counted the number of detections, regardless of the potential cause, for each day between 26 January 2005–14 February 2005, 18 February 2005–21 February 2005, and 25 February 2005–5 March 2005 (30 days total). We also calculated the detection intervals (i.e., the time elapsed between consecutive detections). The number of detections per day, the detection intervals, and the three-minute activation periods (see “animal detection system”) allowed us to calculate the total period per day for which the warning signs would have been activated in order to evaluate whether the system’s real time warnings were more dynamic and different from permanent warning signs that drivers may habituate to and that are not considered very effective (e.g., Pojar et al. 1975, Sullivan and Messmer 2003).

Activation period after a detection

Even though the warning lights were unplugged and even though the warning signs were not attached during the study period, the system was initially programmed to activate the warning lights for three minutes after a detection occurred (see also "animal detection system"). If a new detection occurred before the three minutes had passed, e.g., after one minute and 45 seconds, then the warning light clock started again, leaving the warning lights activated for an additional three minutes. In this example, the warning lights would have been activated for four minutes and 45 seconds total.

The three-minute activation period was based on best professional judgment, as we did not know how long it would take large animals (especially elk) to cross the road or how frequently they would be detected during such a crossing. However, we did know we wanted the warning lights to remain active while the animal (elk) was still in the process of crossing the road, and we also knew we did not want to present drivers with activated warning lights longer than required. Keeping the warning signals on for a long time after a detection may jeopardize driver confidence in the system, as the animals may no longer be visible in the immediate vicinity of the road, hence increasing the likelihood that drivers will ignore the warnings signals the next time they pass through a road section equipped with the system.

Thirty days of detection data were used to calculate the duration of crossing events (based on data interpretation, see "data interpretation") and the detection intervals for these crossing events (26 January 2005–14 February 2005, 18 February 2005–21 February 2005, and 25 February 2005–5 March 2005). These data provided us insight into the optimal activation period for the warning lights when a detection occurs.

Results

Reliability

Data interpretation

A scan of all the detection data showed no indication of "down time" for the animal detection part of the system between 26 January 2005 and 5 March 2005. The number of detections per day did not show a consistent increase or decrease in the periods investigated (figure 2). However, the number of detections was relatively high on 5-14 February and on 3-4 March 2005. The total number of detections per day varied between 16 and 139, with a median of 47 detections per day (figure 2).

Almost 47 percent of all detections were classified as crossings, 25 percent were classified as unclear, and 14 percent were classified as traffic on the Black Butte Ranch access road (figure 3). A small number of the detections (0.3%) seemed to be related to hikers or skiers at the trailhead in detection zone 7 (for location see figure 1). During the periods investigated, nine percent of all detections were classified as caused by snow plows or other traffic, and five percent of all detections were classified as errors.

The detection data that were classified as animal crossings were split into west- and eastward movements, based on which side of the road the movement was first and last detected. Then the detection data were grouped per hour (figure 4). Most of the westward movements occurred between 22:00 and 5:00 with a peak between 1:00-2:00 Most of the eastward movements occurred between 1:00 and 8:00 with a peak between 6:00 and 8:00.

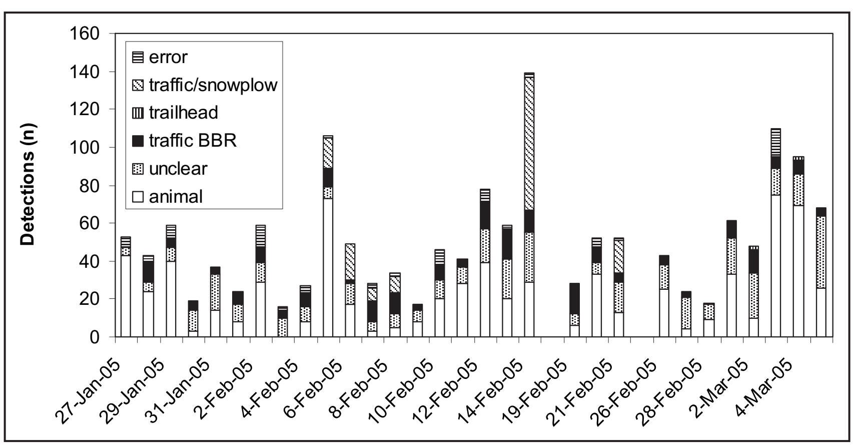

Figure 2. The number of detections per day between 26 January 2005 and 14 February 2005, 18 February 2005 and 21 February 2005, and 25 February 2005 and 5 March 2005.

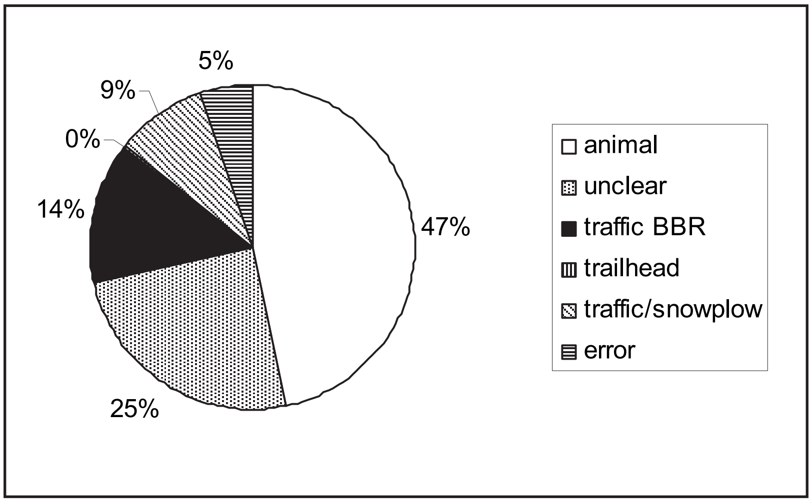

Figure 3. The percentage of detections per category (n total = 1533) between 26 January 2005 and 14 February 2005, 18 February 2005 and 21 February 2005, and 25 February 2005 and 5 March 2005.

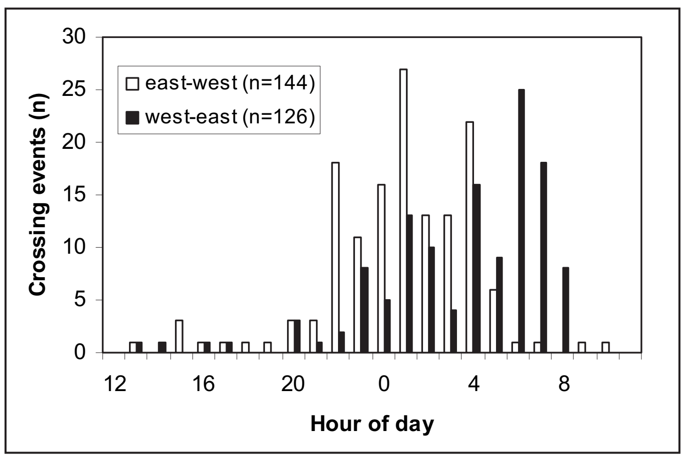

Figure 4. The number of crossing events detected by the system per hour of day for east and westward movements between 26 January 2005 and 14 February 2005, 18 February 2005 and 21 February 2005, and 25 February 2005 and 5 March 2005.

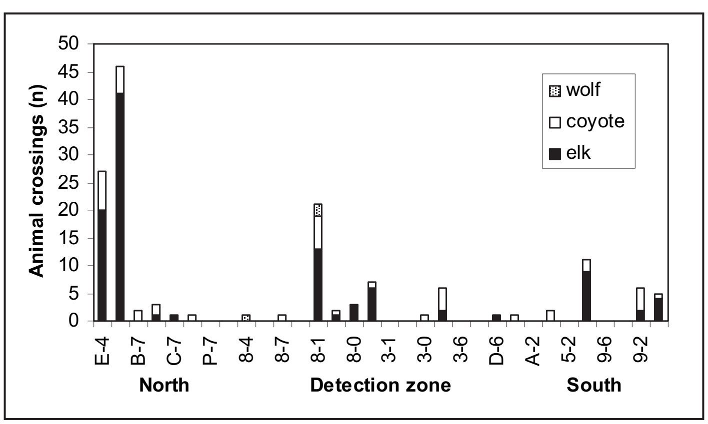

Figure 5. The number of recorded crossings for elk, coyote and wolf through snow tracking between 26 January 2005 and 14 February 2005, 18 February 2005 and 21 February 2005, and 25 February 2005 and 28 February 2005. See figure 1 for the exact location of the detection zones.

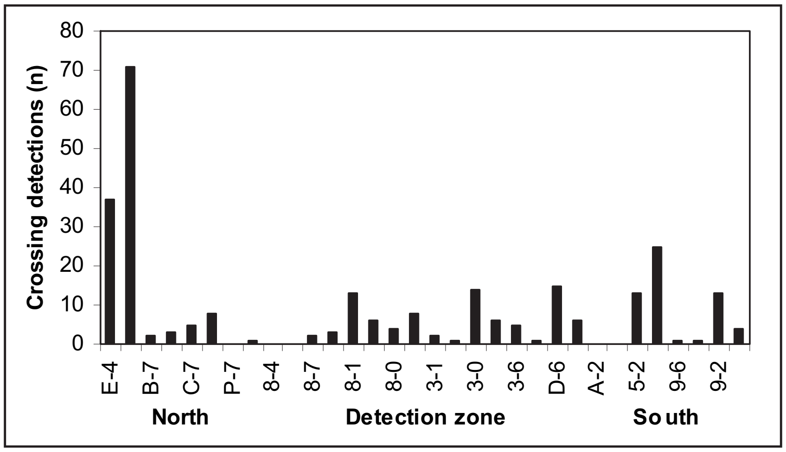

Figure 6. The number of crossings based on interpretation of the detection data between 26 January 2005 and 14 February 2005, 18 February 2005 and 21 February 2005, and 25 February 2005 and 28 February 2005. See figure 1 for the exact location of the detection zones.

Snow tracking

Within the investigated period we encountered the tracks of three medium or large mammal species. We only counted clear animal crossings characterized by snow tracks approaching and leaving the road on opposite sides. Tracks indicating clear crossing were encountered for the following species: elk (n=104), coyote (n=41), and wolf (n=3).

For an overall comparison of the spatial distribution between the detection data and the snow tracking data we plotted the animal crossings recorded through snow tracking for each detection zone combination (figure 5), and we did the same for the crossing events recorded by the system (figure 6). The pattern of crossing frequencies for the different detection zone combinations was similar for the detection and snow tracking data, especially for elk. Most crossings occurred between detection zones E and 4 on the north end of the road section covered by the system. The snow tracking data confirmed that it is mostly elk that crossed the road there. Coyotes crossed throughout the road section covered by the system, while the limited number of wolf crossings all occurred in detection zone 8 (see figure 1 for location).

A day-by-day and detection zone-by-detection zone comparison showed that 87 percent of all recorded elk crossings and 2 percent of all recorded coyote crossings were detected by the system (table 4). However, some elk crossings were not detected by the system (table 5). In addition, not all crossing detections by the system could be confirmed through snow tracking. Matching snow tracks were found in only 38.4 percent of all crossing detections (56 out of 146).

Table 4. The number of recorded crossings for elk, coyote and wolf through snow tracking between 26 January 2005 and 14 February 2005, 18 February 2005 and 21 February 2005, and 25 February 2005 and 28 February 2005, and the number and percentage of these crossings detected by the animal detection system

Species	Snow track crossings (n)	Detected (n)	Detected (%)
Elk (*Cervus elaphus*)	104	90	86.5
Coyote (*Canis latrans*)	41	1	2.4
Wolf (*Canis lupus*)	3	0	0

Table 5. The detection zones where elk crossings were recorded through snow tracking but not by the system, between 26 January 2005 and 14 February 2005, 18 February 2005 and 21 February 2005, and 25 February 2005 and 28 February 2005

Detection zones	Direction of travel	Snow track crossings (n)		Detection zones	Direction of travel	Snow track crossings (n)
0-8	East-west	5		1-8	East-west	1
8-1	West-east	4		4-E	East-west	1
0-3	East-west	2		7-B	East-west	1

Blind spots
The animal detection system detected the human model on most locations in most detection zones (figures 7 and 8). However, there was a very substantial blind spot in detection zone 8, and to a lesser extent in detection zones B, 0, 3, 6 D, 5, 2 and 9 (see figure 1 for location), potentially 17.8 percent of the total length covered by the sensors.

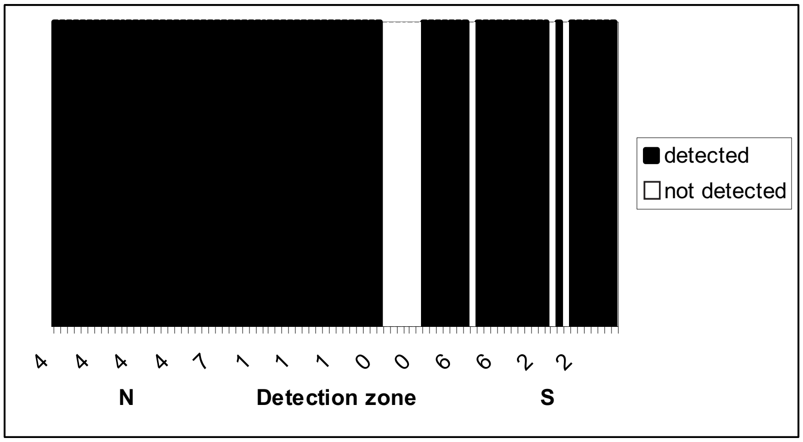

Figure 7. Blind spots of the detection zones on the east side of the road (compare to figure 1 for exact location).

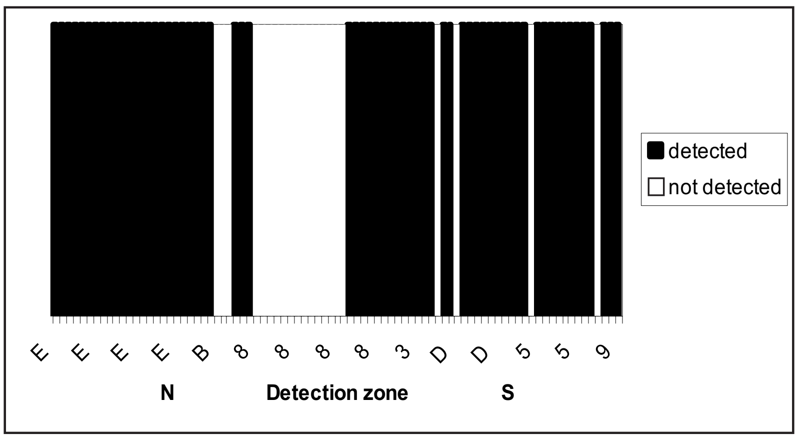

Figure 8. Blind spots of the detection zones on the west side of the road (compare to figure 1 for exact location).

Reliability norms
The system was found to be reliable with regard to the presence of clear crossing events in the detection data, the absence of indication of system failures, and the match between the timing and direction of the crossing events and local knowledge about the behavior of the elk (table 6). In addition, the system was found to be highly reliable with regard to the percentage of elk crossings detected by the system (87%); however, the reliability with regard to this parameter was not absolute. Finally, the system was found to be unreliable with regard to the presence of blind spots.

Table 6. Reliability evaluation of the animal detection system

Parameter	Definition
Crossing events	Reliable: crossing events could be identified through interpretation of the data patterns.
System failures	Reliable: the system was able to detect large animals continuously during the period investigated without abundant false detections generated by the system or system failures (based on data interpretation).
Local knowledge	Reliable: the crossing events matched local knowledge about the behavior of large animals, especially elk.
Snow tracking	Highly reliable: 87% of all elk crossings recorded through snow tracking could be linked to crossing events detected by the system.
Blind spots	Unreliable: there were blind spots in the road section equipped with the system.

Warning signs

Activation period per day
The flashing warning lights were programmed to flash for three minutes after the last detection. If we assume that there was at least a three-minute interval between consecutive detections, the flashing warning lights would have been activated for 141 minutes (2:21 h) on a day with 47 detections (see figure 2). However, most detections were highly clustered and had much shorter time intervals between them (figure 9). The median interval between consecutive detections was one minute and 33 seconds, resulting in 73 minutes (1 h 13 min) of activated warning lights on a day with 47 detections.

Activation period after a detection
Most crossing events (72.6%) took less than three minutes to complete (from the first to the last detection), but some crossing events took much longer (figure 10). In addition, crossing events involving multiple individuals (based on the patterns in the detection data) tended to take longer than crossing events that suggested that only one individual crossed. However, it is quite possible that the latter category could have included crossing events where multiple individuals traveled close together, as these would have only caused one detection on each side of the road. Overall, the median duration of a crossing event was one minute and 29 seconds.

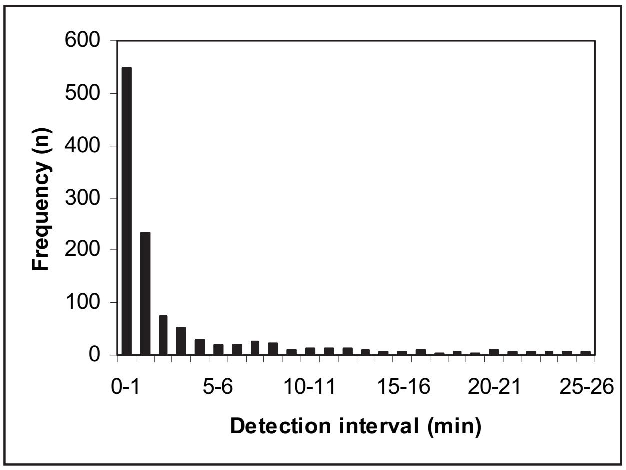

Figure 9. The frequency distribution of the detection interval between consecutive detections for the detections between 27 January 2005 and 14 February 2005, 19 February 2005 and 21 February 2005, and 26 February 2005 and 5 March 2005. Note: the graph was cut off at 25 min; the longest detection interval was 17 h 39 min.

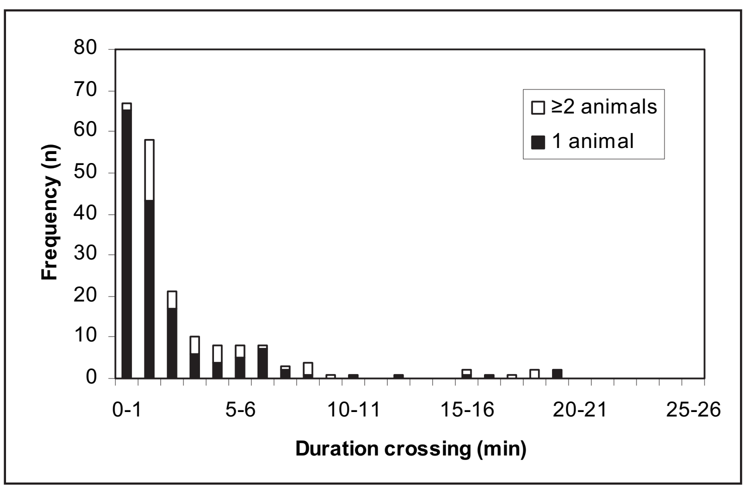

Figure 10. The frequency distribution of the duration of crossing events between 27 January 2005 and 14 February 2005, 19 February 2005 and 21 February 2005, and 26 February 2005 and 5 March 2005. Note: the graph was cut off at 25 minutes; the longest duration of a crossing event was 1 h 10 min.

Most detection intervals (65.7%) for crossing events were less than one minute (figure 11). The median detection interval was 38 seconds. The line representing the cumulative percentage of the detection intervals (figure 11) indicates that 88.1 percent of all detection intervals for crossing events would be covered if the warning lights remain activated for three minutes after the last detection. Should the warning lights remain active for four minutes after the last detection, this percentage would increase only slightly from 88.1 to 90.8 percent. However, decreasing the warning period to two minutes would result in a more substantial change from 88.1 to 81.8 percent.

We also categorized each crossing event based on the longest detection interval for each crossing, and how long of a warning period (in minutes) after a detection would have been required to keep the warning lights continuously activated while the crossing event was still in process (figure 12). For example, if the longest detection interval during a crossing event was two minutes and 41 seconds, then a three-minute warning period would have been required to prevent the warning lights from having turned off before the crossing event was completed. With a three-minute warning period, 78.1 percent of all crossing events would have had the warning lights continuously activated during the crossing event (figure 12). Increasing the warning period to four minutes would result in a slight increase from 78.1 to 82.6 percent. However, decreasing the warning period to two minutes would result in a more substantial change from 78.1 to 68.2 percent.

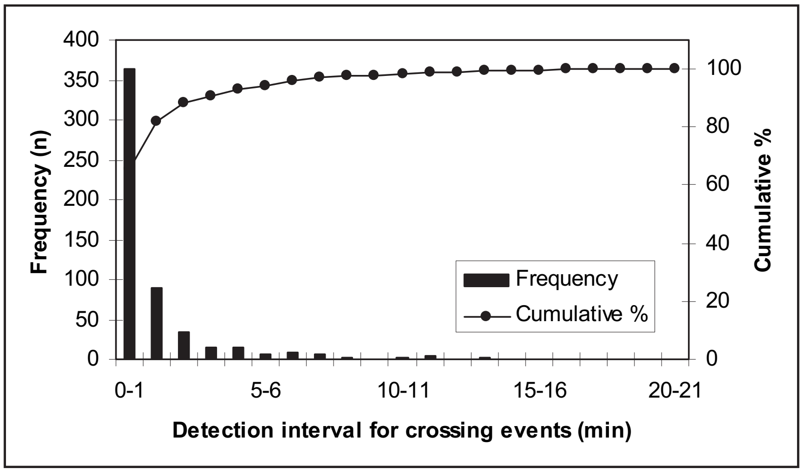

Figure 11. The frequency distribution of the detection interval between consecutive detections for the crossing events between 27 January 2005 and 14 February 2005, 19 February 2005 and 21 February 2005, and 26 February 2005 and 5 March 2005. The line represents the cumulative percentage of all detection intervals (see text).

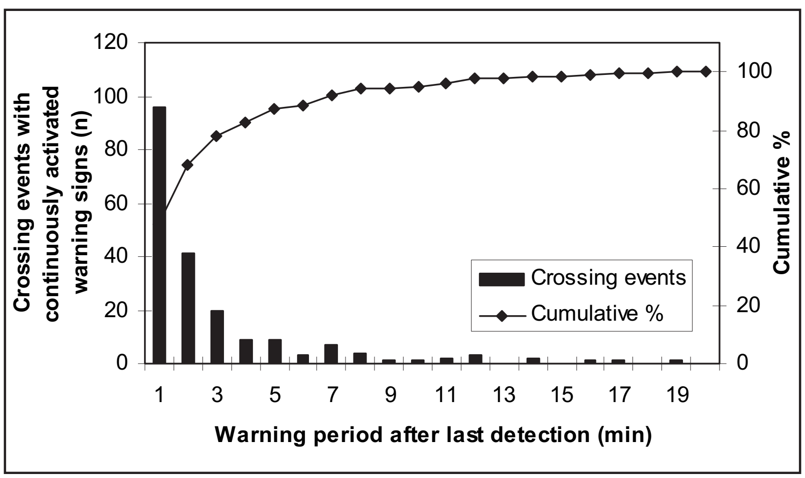

Figure 12. The number of crossing events with continuously activated warning signs (warning lights remain active during the entire crossing event) given a certain warning period after the last detection. The results are based on the crossing events between 27 January 2005 and 14 February 2005, 19 February 2005 and 21 February 2005, and 26 February 2005 and 5 March 2005. The line represents the cumulative percentage of all crossing events (see text).

Discussion

Reliability

The patterns in the detection data indicated that at least 47 percent of all detections were related to animals crossing the road. However, it is likely that some of the detections currently classified as “unclear” were also related to animal movements. Therefore, the 47-percent value should be seen as a minimum estimate. The percentage of suspicious detections, potential system-generated errors, was estimated at five percent and was mostly due to failed radio reports from detection zone 5 and 9 (see figure 1 for location). The station that has the receivers for these two detection zones may suffer from a lack of a straight line of sight with the master station and signal reflection off a rocky slope. However, within the investigated periods there was no indication of a high number of highly suspicious detections or false detections generated by the system. The system seems to have been detecting animals between 26 January 2005 and 5 March 2005 without system failures, and the system seems to have been stable during this period.

The distribution of detected animal crossings over the day and the direction of travel matched local knowledge about the behavior of the elk herd (see methods). The elk usually spend the day on the forested slopes. In the evening the elk travel down the slopes and cross the road to feed on the grasses and shrubs in the valley bottom. In the morning they leave the valley bottom, cross the road, and travel up the forested slopes. The match between the patterns in the detection data and local knowledge seems to confirm that the system is able to detect large animals, specifically elk. In addition it suggests a correct interpretation of the detection data and a correct identification of crossing events.

The number of detected crossing events for each detection zone combination matched the number of recorded elk crossings through snow tracking closely. Detection zones E and 4 (see figure 1 for location) had cover close to the road and were by far the most heavily used zones by elk when they cross the road. This is also where the majority of all crossing events were detected by the system. Again, this seems to confirm the ability of the system to detect elk, and it also suggests a correct interpretation of the detection data.

Almost 87 percent of all elk crossings recorded through snow tracking could be linked to a crossing event detected by the system. Assuming that the crossings detected by the system are indeed caused by animals, 38 percent of these detected crossings were confirmed through snow tracking. These percentages, especially the second one, may not seem high or high enough, but there are errors associated with both interpretation of detection data and with snow tracking (see methods). These percentages also suggest that elk or other large mammals crossing the road may be more reliably identified through interpretation of the detection data than through snow tracking, at least under the conditions that were present at the study site (see methods). Medium-sized mammal species, such as coyotes and wolves, were not or rarely detected by the system.

The system detected a human model passing through the detection zones on most locations. However, we identified a substantial blind spot in detection zone 8 and to a lesser extent in detection zones B, 0, 3, 6, D, 5, 2 and 9 (see figure 1 for location), potentially 17.8 percent of the total length covered by the sensors. The blind spots in detection zones 8, B, 3, and D are the result of curves and slopes that make the beam shoot over the head of the model in some areas. The blind spots in detection zones 5 and 9 may be related to radio failures rather than true blind spots. The blind spots in detection zones 0, 6, and 2 require additional investigation, as the terrain seems relatively level and straight. It is not unlikely that the detections missed in detection zones 0, 6, and 2 were the result of desensitization of the beam; they may not be true blind spots. Nevertheless, the test indicated that the system should be able to detect elk passing through the detection zones on most locations, especially where they cross most frequently (detection zones E and 4).

The presence and location of blind spots in the system, especially in detection zones 8 and B, may also explain why some of the elk crossings were not detected by the system. Indeed, 11 of the 14 elk crossings that were not detected by the system were located in detection zones 8 or B. This suggests that the 87-percent detection rate for elk (see earlier) could be substantially higher (up to 97%) if the blind spots of detection zones 8 and B are addressed.

Warning signs

The total time that the flashing warning lights would be activated for was one hour and 13 minutes per day, based on a median of 47 detections per day and a median detection interval of one minute and 33 seconds. This is a marked difference with permanently activated warning signs, which tend to be ignored by drivers. The real-time activation of the warning lights after a detection could potentially lead to increased driver response.

Most crossing events (72.6%) were completed within three minutes, and the median duration of a crossing event was one minute and 29 seconds. The interval between the detections that occurred during a crossing event was typically less than one minute (65.7%), with a median of 38 seconds. However, longer detection intervals did occur, and “only” 88.1 percent of all detection intervals for crossing events would be covered if the warning signs are activated for three minutes after the last detection. With a three-minute warning period after the last detection, 78.1 percent of all crossing events would have had the warning lights continuously activated during the crossing event. One may be tempted to increase the duration warning time from three to, for example, four minutes, but this would only result in a marginal improvement in coverage of the detection intervals for crossing events (2.7%) and the number of crossing events with continuously flashing lights (4.5%), while making the warning signals substantially less time specific (an increase in warning period after the last detection of 33.3%).

Conclusion

The patterns in the detection data suggest that most detections by the system were probably related to real-world events and that at least half of all detections appear to be related to large animals, specifically elk, approaching or leaving the road. In addition, the patterns in the detection data show no indication of system failures or abundant false detections, the crossing events detected by the system match local knowledge about the behavior of the elk, the spatial distribution of the elk crossings observed though snow tracking matches that of the crossing detections, and a high percentage of all elk crossings observed through snow tracking could be linked to crossing events detected by the system. We conclude that the system detects large animals reliably. However, depending on the location, and potentially also depending on the conditions (e.g., weather), the system does not detect all large animals that approach or leave the road.

We also conclude that the total period of time per day for which the warning lights would be activated is relatively short, especially when compared to permanently activated warning signs, potentially resulting in increased driver response. Furthermore, the three-minute period for which the warning lights are activated after a detection appears to be a good balance between keeping the warning lights on while the animal (elk) is still in the process of crossing the road, and not presenting drivers with activated warning lights longer than necessary.

Despite our conclusions, we recognize that other researchers or transportation agencies may want to evaluate additional or different reliability parameters than those used for this study. We also recognize that others may want to see a higher or lower level of reliability for an animal detection system, especially in relation to potential liability issues in case of an accident. In addition, we realize that it is up to the responsible transportation agency to decide what the optimal warning period for an animal detection system should be.

Recommendations

Even though we concluded that this animal detection system appears to detect elk reliably, there are blind spots in the system as a result of design errors. For future projects we recommend that the location of the posts and sensors, especially at curves or slopes, are carefully evaluated to ensure that the detection beam stays close enough to the ground to be able to detect the target species. However, even if the location of poles and sensors is carefully evaluated, one should never assume that an animal detection system detects *all* animals that approach or cross the road under *all* circumstances. Therefore, one should avoid the use of warning signs that suggest that elk are only present on or near the road when the warning signals are activated. Instead, we suggest using signs that urge drivers to increase their alertness (see Katz et al. 2003), indicating that drivers should always be alert and that they should always be prepared to stop for large animals on or near the road, regardless of whether the warning signs are activated.

We also recommend that the blind spots in detection zones 8 and B (see figure 1) are addressed though the installation of additional posts and sensors. Furthermore, we recommend a further evaluation of the blind spots in the other detection zones to evaluate whether they are real and how short (isolated) blind spots may be addressed. Furthermore, the number of unsuccessful radio contacts for some stations should be reduced (especially for detection zones 5 and 9, see figure 1), either by moving the master station to the west side of the road or through more fundamental changes to the communication system.

The following recommendations are based on experiences that were not reported in this manuscript. However, we do feel that they are important, as they relate to the reliability and robustness of the system. We learned that the brackets that hold the sensors in place can break as a result of extreme temperature fluctuations. These brackets should be secured or replaced to avoid potential false detections or system downtime. In addition, periodic vegetation management is required. High, wet, and moving vegetation can result in false detections, they can cause a serious reduction in signal strength, and they may result in the temporary deactivation of the detection zone concerned.

Furthermore, we recommend developing standards for the reliability of animal detection systems, and we encourage the testing of other animal detection system technologies from various manufacturers. We also suggest investigating the effectiveness of a variety of warning signs and signals with regard to driver response and potential liability for transportation agencies in case of an accident. Despite the encouraging results from Swiss research (Kistler 1998, Romer and Mosler-Berger 2003, Mosler-Berger and Romer 2003), more and better data are required on the effectiveness of animal detection systems, especially with respect to the potential reduction in animal-vehicle collisions. We also recommend keeping log books to document the operation and maintenance costs of animal detection systems. Finally, we recommend miniaturization of animal detection systems to address landscape aesthetics concerns and safety issues for equipment placed in the right of way.

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Upgrading a 144-km Section of Highway in Prime Moose Habitat: Where, Why, and How To Reduce Moose-Vehicle Collisions

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Abstract: In Quebec, as throughout North America, the number of vehicles on roads and the daily distances travelled increase continuously. At the same time, populations of moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*) have reached unprecedented levels in this province. For example, the moose population increased from 60,000 to 100,000 animals in Quebec between 1990 and 2002. Hence, moose-vehicle collisions have increased and caused numerous human injuries and fatalities in recent years in Quebec. The main objective of our study was to identify roadway, habitat, and moose population features that correlated with the reported number of moose-vehicle collisions (MVCs) and propose measures to reduce risks to motorists. Our study was implemented in the context of a planned project to upgrade a two-lane primary artery to a four-lane divided highway, located north of Québec City that bisects a wide forested area, the Laurentides Wildlife Reserve (LWR). Moose population and habitat variables were obtained from harvest, aerial inventory data, and aerial photos. Other variables were also measured from digital data layers using the ArcView GIS. Habitat suitability was computed using digital layers from ecoforestry maps and ArcView Spatial Analysis. Roadway variables were collected in the field or extracted and computed from digital layers with AutoCad and InRoads software packages. Moose-track surveys were also conducted monthly from June to September 2004 along the major conflict zone.

Moose densities varied between 1.0 moose/10 km^2 in the center of the 144-km Highway 175 to 8 individuals/10 km^2 in its southern and northern portions. We estimated that between 573 and 860 moose were roaming within 5 km on each side of the highway in 2004. A controlled hunt and high quality habitats following forest exploitation and natural perturbations occurring within the LWR are likely to be major contributors to this growing population. Our data analysis using AIC showed that four variables explained most variations in the number of MVCs among 1-km sections. These variables were (1) the slope complexity of the adjacent landscape, (2) the total length of rivers, streams, and brooks located within a 250-m buffer zone on each side, (3) the habitat suitability for forage within a buffer zone of 1 km on both sides, and (4) the proportion of steep (> 3-m high) road cuts. During fall and early winter habitat features were strongly related to the number and location of MVCs, whereas the influence of slope complexity was greater during summer. However, annual and seasonal models explained a limited amount of the variance in the number of MVCs ($R^2 < 0.288$) and could not be used efficiently to identify conflicting sections and set management priority. The longest and the most hazardous section tallied 25 km, which was surrounded by high-quality moose habitat. Track surveys in the summer of 2004 showed frequent movements across the highway, but little clustering. Because we could not find strong relationships between MVCs and road and habitats features, we used the numbers of recorded MVCs to delineate 5-km sections and establish actions to be taken to reduce risks. The top priority hazardous zone, which encompasses 25 km, will be fenced during the upgrading project and combined with two major underpasses.

Introduction

Vehicle-ungulate collisions have increased in North America and Europe, causing an increased number of human injuries and deaths, as well as considerable material damage (Forman et al. 2003). Moose-vehicle collisions (MVCs) have tremendous impacts due to the large size of this species: the individual weight ranges from 360 to 600 kg (794 - 1,323 pounds), and its center of gravity is very high. On a 193-km one-lane highway located north of Québec City, moose accounted for 90 percent of all vehicle collisions with wildlife (n = 346) that caused human injuries between 2000 and 2004. Seventeen percent of MVCs caused severe injuries or were fatal to motorists (Quebec Ministry of Transportation unpublished data).

Given the high probability of injuries and human death resulting from MVCs, the Canadian Provinces, Alaska, and northern countries are implementing mitigation measures along roadsides to eliminate or reduce MVCs in hazardous areas (McDonald 1991, Joyce and Mahoney 2001, Väre 2002, de Bellefeuille et Poulin 2003, Redmond 2005). However, little information is available on road, landscape, moose habitat, and population characteristics that relate to MVCs. Joyce and Mahoney (2001) found a relationship between MVCs and traffic volume, but results remained unclear about their relationship with moose density. An understanding of causes and patterns is deemed necessary to improve our knowledge of features related to MVCs and our design of effective management strategies.

The main objective of our study was to identify roadway, habitat, and moose population features that related to the number of MVCs, and to propose management designs that would help reduce the collision rate. Our study was implemented in the context of a planned project to upgrade a two-lane primary artery to a four-lane divided highway beginning in 2005. This project is located in a large forested area where moose is the dominant ungulate species and of particular concern for road and safety managers.

Study Area

Our research took place in the Laurentides Mountains, located 35 km (22 mi) north of Quebec City in south central Quebec (figure 1). The study area covered approximately 9,000 km2 (3,475 mi^2) where mountainous and rolling landscapes with numerous lakes dominate. Sections of two provincial parks (De la Jacques-Cartier, Des Grands Jardins) and the Laurentides Wildlife Reserve (LWR) also are located in our study area. Altitude varies between 163 and 859 m. Snow precipitations occur between September and April and add up to 593 cm on average. The mean annual temperature varies between 14.8 °C and -15.3 °C.

Our study area presents two distinct ecological regions. The central area shows higher elevations (732 m to 859 m, km 105 to 176) where the vegetation is largely dominated by black spruce (*Picea mariana*) and balsam fir (*Abies balsamea*). North and south of the latter area where elevations are lower, the forest canopy is composed of mixed stands of balsam fir and white birch (*Betula papyrifera*) or trembling aspen (*Populus tremuloïdes*). Forests within the LWR are currently harvested for paper and lumber production, affecting approximately 37 km^2 per year. Spruce budworm outbreaks also significantly affected young forested stands over the past 50 years.

Wolf (*Canis lupus*) and black bears (*Ursus americanus*) represent the other big game species present in the area. White-tailed deer only occur in limited numbers in the most northern and southern part of the study area. A small population of woodland caribou (*Rangifer tarandus*) (approximately 200 individuals) also is present in the eastern section of our study area. Controlled hunting of moose and black bear occurs in the LWR, and harvest levels are relatively low. Human development is limited to the few hunting and fishing cabins provincially owned and rented between May and October. The last aerial inventory of moose in LWR in 1994 revealed density estimates ranging from 1.0 per 10 km^2 in the central part of LWR to around 8 per 10 km^2 in the best habitats located in the northern and southern parts of our study area. We suspect that the density in LWR exhibited an increase as in adjacent territories (2-fold, Portneuf Wildlife Reserve, Banville 2004), and may contain as many as 10 moose/10 km^2 in the most suitable habitats.

A 144-km north/south two-lane highway built in the early 1950s bisects our study area (Highway 175). The annual average traffic volume was between 3,300 to 4,800 vehicles per day in 2000. The summer average traffic volume varies between 4,600 and 6,300 vehicles per day.

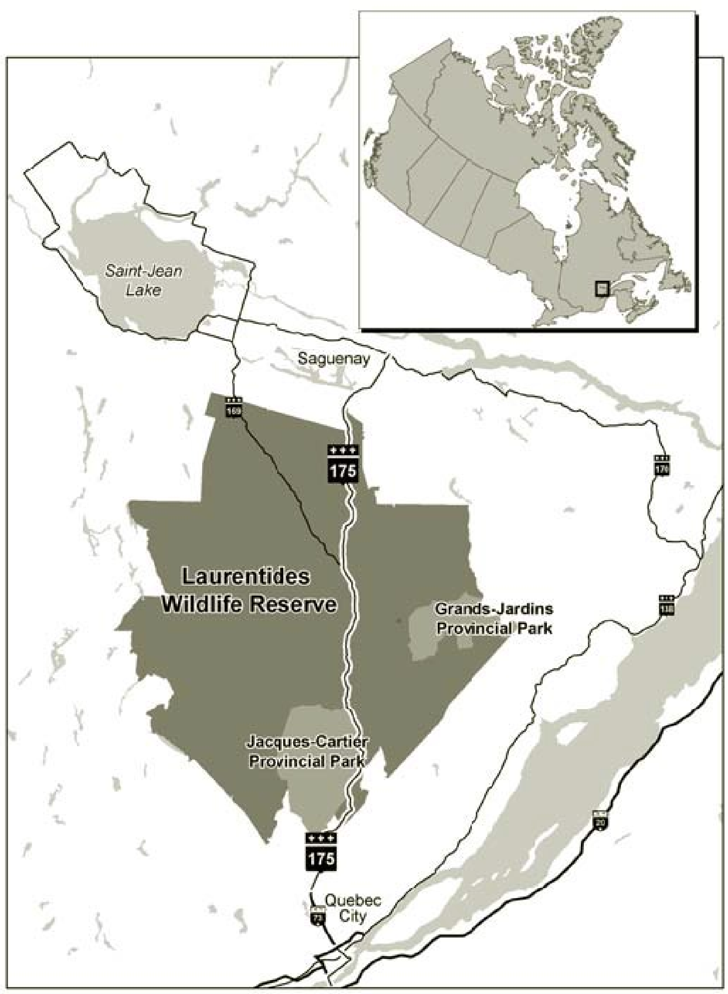

Figure 1. Location of study area and Highway 175 in the Laurentides Wildlife Reserve, Province of Québec, Canada.

Methods

Data collection

Moose-vehicle collisions

We obtained existing MVC data between 1991 to 2001 from the Quebec Ministry of Transportation (QMOT). The QMOT uses and cross validates two sources of data to produce a database on wildlife-vehicle collisions. The first source is the vehicle accident form completed by the Sureté du Québec police officers at each collision site. The second one corresponds to the form completed by QMOT maintenance staff and contractors when collecting wildlife road-kills. In each case, the reported locations of MVCs were to the nearest landmark or to the nearest kilometre posting. Accuracy is unknown, but it is probably similar to that (516 m) reported in Alberta (Gunson and Clevenger 2003).

Road features

The 144-km highway was divided in 1-km sections to which we associated several variables obtained either from the field or derived with the InRoads software using the horizontal alignment database of the existing roadway. Variables derived from field work corresponded to the average distance from the paved road to forest cover, percent length of the 1-km section in road cuts higher than 3 m, percent length of the 1-km section in road fills higher than 3 m, and length of auxiliary lanes. Other variables such as percent length of the 1-km section in light curves (< 500 m radius) or strong curves (> 500 m radius), curve and tangent length within the 1-km section also were obtained using the alignment database of the roadway.

Moose population and landscape characteristics

We obtained data on distance between moose wintering areas in January 2000 and the 1-km section, number of moose seen in wintering areas, distance to the nearest harvest site (1990-2002) from the QMOT and the Québec Ministry of Natural Resources and Wildlife (QMNRW) and incorporated them as spatial data layers into our GIS ARC-INFO geographical database.

Using updated ecoforestry databases from the QMNRW, we modeled a moose habitat suitability index using ArcView GIS (ESRI, Redlands, California, USA) in 1km^2 grid cells 5 km each side of the roadway. The habitat suitability model included two components linked to the forest stand capability to produce forage (radius < 5 km) and to the amount of edges between forage and cover habitats (Dussault et al. 2002). We also obtained the number of ponds, total length of streams and rivers, wetland area, and number of used saltwater pools within 250 m on each side of the 1-km sections from QMOT. We included topographic features such as the mean slope and its standard deviation within a 500-m radius using the Spatial Analyst program extension in ArcView.

Track surveys

We conducted monthly track counts in June, July, August, and September 2004 along the roadway on a 30-km section associated with a high number of recorded MVCs in the northern part of the LWR (km 189.5 to km 220.5). Surveys only occurred <2 days after strong rainfall or thunderstorms to ensure a minimum of detectable fresh tracks. Those weather events tend to improve identification of fresh tracks while erasing old ones. Track counts were conducted on foot or bicycle simultaneously on both sides on the roadway. Each track was either considered to have crossed or to have paralleled the roadway. We used a GPS with a 6- to 10-m accuracy to obtain track locations.

Data analysis

We used multivariate analyses to identify relationships between the total number of MVCs reported for each 1-km section and road characteristics, moose, and landscape features. Prior to MVC modelling, we generated two correlation matrices using variables related to road characteristics and to moose and landscape features, respectively, to avoid autocorrelation among variables and to obtain an acceptable proportion of samples or 1-km section (n = 143) to independent variables (Tabachnick and Fidell 2001).

Our first model included all MVCs reported for all seasons to examine the situation globally. We also performed seasonal models to determine if links between variables and MVCs differed between fall and summer.

We used both multiple and logistic regressions to ensure that selection of analytical tools did not influence results and selected management actions. For the multiple regression analyses, we selected the most significant variables related to the number of MVCs using both Akaike Information Criteria (AICc) and least square means (LSM, $P < 0.10$). Variables entered the model using forward selection procedure. R^2 in logistic regressions corresponded to the Nagelkerke pseudo-R^2.

In order to narrow variables that may be related to MVCs and understand why such a relationship exists, we identified variables found significant in at least two of the three regression models. We also set the probability level at 0.10 to ensure inclusion of any variable potentially related to numbers of MVCs. All mean values are presented with their associated standard error. We analyzed data using SPSS 11.5.

Results

Moose-vehicle collisions

Between 1991 and 2001, a yearly average of 38.6 (± 5.9) MVCs were reported for the 144-km section of Highway 175 (figure 2). Of these MVCs, 65 percent occurred between May and August, whereas 26 percent happened during September and October (figure 3). Over 75 percent of all MVCs occurred whether in the southern or the northern part of the roadway (figure 4).

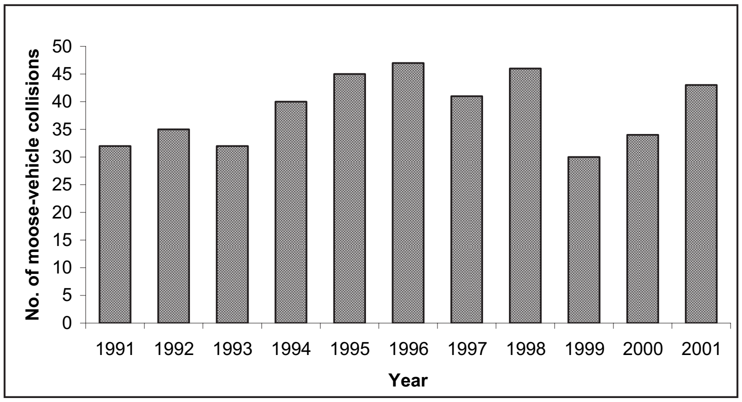

Figure 2. Number of moose-vehicle collisions along Highway 175 between 1990 and 2001 (n = 425).

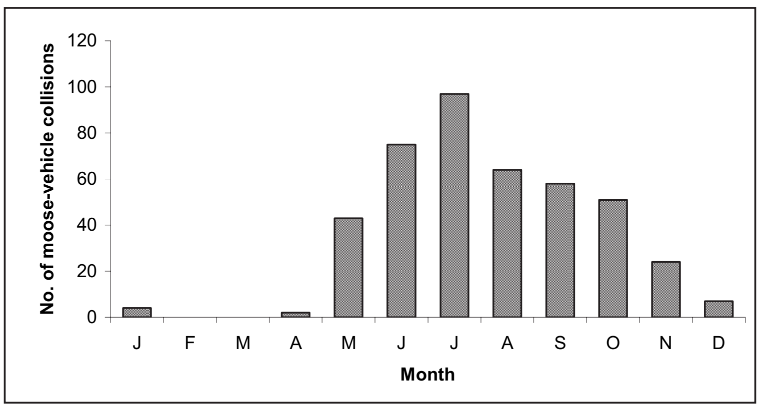

Figure 3. Number of moose-vehicle collisions along Highway 175 by month between 1990 and 2001 (n = 425).

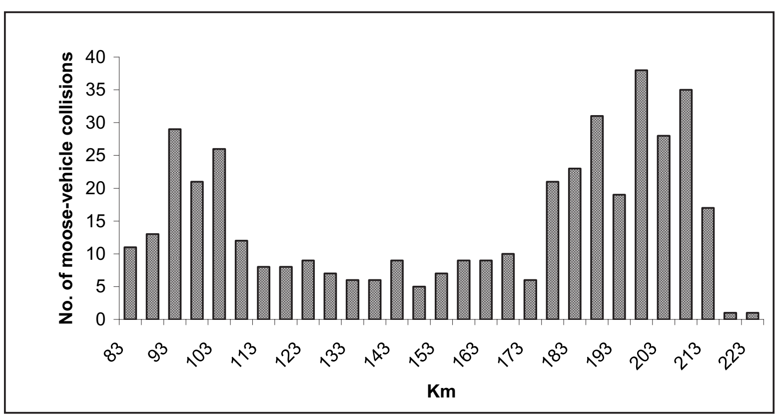

Figure 4. Number of moose-vehicle collisions along Highway 175 by 5-km sections
(south to north kilometre mark) between 1990 and 2001 (n = 425).

Variable selection

Correlation analyses revealed a strong relationship among two groups of variables related to roadway characteristics (tables 1 and 2). The first group included total length of guard rail, total length of curve, total length of tangent, percent length of section in light curve (>500m radius), percent length of section in strong curve (<500 m radius), and width of right of way. The second group was composed of percent length of the 1-km section in road cuts lower than 3 m, percent length of the 1-km section in road cuts higher than 3 m, percent length of the 1-km section in road fills lower than 3 m, and percent length of the 1-km section in road fills higher than 3 m. Some variables were highly correlated with others and were kept for further analysis because we believe that they might be specifically influential on the number of MVCs. These variables corresponded to total length of section in curve, percent length of the 1-km section in road cuts higher than 3 m, and percent length of the 1-km section in road fills higher than 3 m (table 1). We also detected a strong correlation among the variables related to moose habitats and population. Following correlation analyses, we selected eight variables to be used in further statistical analysis (table 2).

Global model

Four variables exhibited significant relationships with MVCs at least in two of the regression models (table 3). Globally, we found a negative relationship between MVCs and the percent length of the 1-km section located in road cuts over 3 m and the standard deviation (complexity) of the slope in the vicinity of a given 1-km section. However, we found that MVCs were related positively to the abundance of nearby streams and rivers and the index relating to the forest stand capability to produce forage (radius < 5 km).

Table 1. Pearson correlation coefficients among road variables in each 1-km section of Highway 175 (km 84 to 227)

Variable	A	B	C	*D*	E	F	G	H	*I*	*J*
Total length of auxiliary lanes (A)										
Total length of guardrails (B)	0.13									
Total length of tangent (C)	- 0.04	- 0.10								
Length in curve (D)*	*- 0.03*	**0.15****	**- 0.91**							
% length in curve > 500 m radius (E)	- 0.02	**0.26**	**- 0.24**	***0.28***						
% length in curve < 500 m radius (F)	- 0.01	0.00	**- 0.78**	***0.84***	**- 0.28**					
Mean distance between paved surface and forest cover (G)	0.04	0.24	**- 0.17**	***0.18***	**0.22**	0.06				
% length in road fills <3 m (H)	**- 0.16**	**- 0.49**	0.08	*- 0.09*	**- 0.15**	- 0.01	- 0.10			
% length in road fills >3 m (I)	*0.06*	***0.54***	*0.02*	*- 0.01*	***0.15***	*- 0.08*	*- 0.07*	***- 0.62***		
% length in road cuts <3 m (J)	0.05	**- 0.31**	0.00	*- 0.06*	- 0.08	- 0.01	- 0.06	**- 0.18**	***- 0.31***	
% length in road cuts >3 m	*0.09*	***0.42***	*- 0.12*	*0.19*	***0.13***	*0.11*	***0.25***	***- 0.52***	***0.14***	***- 0.45***

*Correlation coefficients significant at P < 0.05 represented in bold.
**Variables retained for regression analyses represented in bold.

Table 2. Pearson correlation coefficients among moose population and habitat variables in each 1-km section of Highway 175 (km 84 to 227)

Variable	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Number of salt pools (A)																		
Distance to nearest recorded moose harvest site (B)	- 0.09																	
No. of ponds within 250 m of road section (C)	**0.21**	0.02																
Total area of regenerated forest stands within 1 km of row (D)	- 0.09	**- 0.13**	0.06															
Habitat suitability index of edges between forage and cover habitats for moose (radius < 5 km) *(E)*	0.05	**- 0.39**	0.00	**0.42**														
Habitat suitability index related to the forest stand capability to produce forage (radius < 5 km) *(F)*	- 0.07	**- 0.62**	- 0.07	**0.38**	**0.56**													
Total length of streams and rivers located within 250 m of the 1-km section *(G)*	0.03	- 0.03	- 0.13	- 0.11	- 0.02	0.07												
Mean slope in a 500 m radius (H)	0.05	**- 0.22**	- 0.02	0.09	**0.33**	**0.24**	**0.11**											
Standard deviation of the slope (I)	- 0.05	0.03	0.03	0.05	**0.23**	- 0.01	0.10	**0.79**										
No. of wintering areas near each 1-km section in January 2000 (J)	- 0.02	**- 0.18**	0.02	- 0.02	- 0.01	0.10	- 0.10	- 0.10	- 0.04									
Mean distance of wintering area to road section (K)	- 0.06	- 0.02	- 0.04	- 0.08	**- 0.14**	- 0.10	0.00	- 0.01	0.03	**0.44**								
Number of stream and river crossings (L)	0.00	0.03	- 0.06	0.05	0.10	- 0.11	**0.33**	**0.19**	0.16	- 0.10	- 0.02							
% of ROW in scrubland (M)	- 0.12	**- 0.48**	- 0.07	- 0.04	0.11	**0.57**	- 0.03	- 0.01	- 0.10	**0.26**	0.05	- 0.10						
% of ROW composed of wetlands (N)	- 0.02	- 0.01	0.03	**0.18**	**0.19**	0.01	0.13	**0.20**	**0.33**	- 0.05	- 0.03	0.10	- 0.08					
% of adjacent forest cover in coniferous stands (O)	0.11	**0.57**	0.03	0.03	- 0.13	**- 0.69**	- 0.01	- 0.02	0.10	**- 0.22**	0.04	**0.26**	**- 0.66**	- 0.03				
% of adjacent forest cover in mixed stands (P)	**- 0.14**	**- 0.39**	- 0.01	**- 0.20**	0.09	**0.59**	- 0.03	- 0.05	- 0.11	**0.15**	- 0.04	**- 0.33**	**0.62**	**- 0.15**	**- 0.81**			
% of adjacent forest cover in deciduous stands (Q)	- 0.09	**- 0.32**	- 0.07	- 0.05	0.00	**0.46**	- 0.05	- 0.11	**- 0.19**	**0.30**	- 0.01	**- 0.23**	**0.53**	- 0.09	**- 0.59**	**0.47**		
% of adjacent forest cover in regenerated stands (R)	0.05	**- 0.32**	- 0.06	**0.21**	0.11	**0.28**	0.08	0.09	- 0.10	0.01	- 0.06	0.11	**0.15**	- 0.06	**- 0.35**	- 0.11	0.00	
Total surface area of wetlands within 1 km of road section	0.03	**0.26**	- 0.02	- 0.07	**- 0.29**	**- 0.28**	0.10	**- 0.44**	**- 0.30**	0.11	0.11	0.01	- 0.12	- 0.09	0.10	- 0.07	- 0.07	- 0.12

*Correlation coefficients significant at P < 0.05 represented in bold.
**Variables kept for regression analyses represented in bold.

Table 3. Probabilities of nonsignificant effects on MVCs (ln transformed) that occurred on Highway 175 for 8 explanatory variables using multiple regression [AIC selection (AIC rank and weight) or LSM] and logistic regression (3 classes : 0-3, 4-7, and 8-16 MCVs; 2 classes (A) : 0-7 and 8-16 MCVs and 2 classes (B) : 0-3 and 4-16 MCVs)

Variable	Multiple regression		Logistic regression		
	AIC_c	**LSM ddl = 143**	**3 classes dl = 2**	**2 classes (A) dl = 1**	**2 classes (B) dl = 1**
Standard deviation of the slope within a 500 m radius	**1 – 0.05 ***	**t = 3.17 p = 0.002**	X^2 = 0.58 p = 0.750	X^2 = 1.63 p = 0.201	X^2 = 1.53 p = 0.216
Habitat suitability index related to the forest stand capability to produce forage (radius < 5 km)	**2 – 0.18**	t = 1.44 p = 0.151	X^2 = 5.95 **p = 0.051**	X^2 = 5.98 **p = 0.014**	X^2 = 5.33 **p = 0.021**
% length of 1-km section in road cuts > 3m	**3 – 0.36**	t =1,90 p = **0.059**	X^2 = 2.78 p = 0.249	X^2 = 2.96 **p = 0.085**	X^2 = 1.58 p = 0.209
Habitat suitability index of edges between foraging and cover habitats for moose (radius < 5 km)	4 – 0.29	t =0.72 p = 0.472	X^2 = 0.64 p = 0.727	X^2 = 1.24 p = 0.267	X^2 = 0.05 p = 0.830
% length of 1-km section in road fills > 3m	5 – 0.10	t = 1.65 p = 0.102	X^2 = 2.46 p = 0.292	X^2 = .1.12 p = 0.290	X^2 = 2.37 p = 0.124
Number of used salty pools	6 – 0.02	t =0.02 p = 0.985	X^2 = 2.88 p = 0.237	X^2 = 2.76 **p = 0.097**	X^2 = 0.51 p = 0.477
No. of wintering areas near each 1-km section in January 2000	7 – 0.01	t = 0.98 p = 0.330	X^2 = 1.04 p = 0.595	X^2 = 0.05 p = 0.820	X^2 = 0.02 p = 0.900
Wetland area within 1 km on each side of the 1-km section (km^2)	8 – 0.00	t =1.35 p = 0.179	X^2 = 2.69 p = 0.260	X^2 = 0.85 p = 0.357	X^2 = 2.03 p = 0.155
% area of right-of-way vegetation composed of scrubs	9 – 0.00	t = 0.95 p = 0.343	X^2 = 1.00 p = 0.606	X^2 = 0.45 p = 0.504	X^2 = 0.05 p = 0.830
Total length of 1-km section in curve	10 – 0.00	t =0.91 p = 0.363	X^2 = 1.36 p = 0.506	X^2 = 0.29 p = 0.590	X^2 = 0.18 p = 0.672
Total length of streams and rivers within 250 m on the 1-km section	11 – 0.00	t = 2.79 **p = 0.006**	X^2 = 11.26 **p = 0.004**	X^2 = 0.38 p = 0.534	X^2 = 9.75 **p = 0.002**
R^2	**-**	**0.103**	**0.288**	**0.097**	**0.164**

* Highlighted variables correspond to those included in the selected model (lowest AICc)

The 3-class logistic regression corresponded to the model explaining the highest proportion (about 30%) of the variance in MVCs among 1-km sections along Highway 175 compared to the other models (table 3). Variables related to moose habitat features had the stronger influence on MVCs.

Seasonal models

We noticed no difference in the spatial distribution of MVCs among 1-km sections and among seasons. However, fewer MVCs occurred within the central part of the 144-km Highway on a yearly basis. During summer, only two variables, the standard deviation of the slope within a 500-m radius (P = 0.002) and the total length of streams and rivers within 250 m (P=0.041) were related to MVCs. If the regression model for the summer was significant, it explained very little of the variance in MVCs among 1-km sections (R^2= 0.085).

Our fall model also was significant (P= 0.001), and provided a better predictive power (R^2 = 0.140) than the summer model. Five variables were found to have a significant contribution to the model. The percent length of 1-km section in road cuts > 3 m (P = 0.011), the total habitat suitability units of edge between forage and cover units for moose (P= 0,012), and the percent length of 1-km section in road fills > 3 m (P = 0.029) were negatively related to MVCs. Total habitat suitability units of forest stands to produce forage for moose (P < 0.001) and total length of 1-km section in curve (P= 0.040) were positively related to MVCs. The winter model provided similar results as the fall model, as well as similar proportion of explained variance in MVCs (P < 0.001, R^2 = 0.137). The total number of habitat suitability units of forest stands to produce forage for moose was positively related to MVCs (P < 0.001), whereas the total number of habitat suitability units of edge between forage and cover units for moose and percent length of 1-km section in road fills > 3m had a negative influence on MVCs.

Track surveys

We recorded highest density of moose tracks in June, which decreased by half afterward until September (table 4). We recorded most tracks over the same sections every month (km 205-209 and km 195 to 198, figure 5). There was a highly significant correlation between tracks recorded in July to September 2004 and the total number of MVCs by 1-km sections between 1990 and 2001 ($r = 0.49$, $n = 31$, $p < 0.05$). When counting only fresh tracks and correcting for the number of days since heavy rains, we estimated that at least 50 moose crossed these high-risk sections every day in June, compared to about 30 moose in September.

Table 4. Number and density by km of moose tracks recorded between June and September 2004 along km 189.5 to 220.5 on Highway 175, Province of Quebec

Date	Highway sections surveyed	Total no. of moose tracks	Tracks per km
June 16	km 194.5 to 210.5	173	10.81
July 20	km 189.5 to 220.5	185	5.96
August 26	km 189.5 to 220.5	140	4.52
September 23	km 189.5 to 220.5	134	4.32

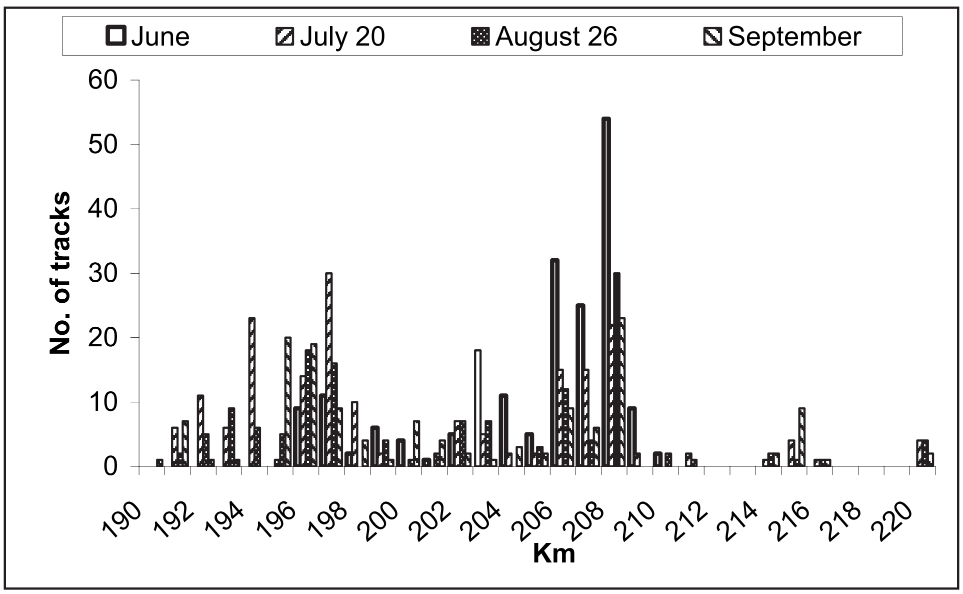

Figure 5. Total number of moose tracks recorded on both roadway shoulders in June to September 2004 between km 189.5 to 220.5 of Highway 175.

Discussion

We found that the number of moose-vehicle collisions along Highway 175 was related to specific moose habitat features, and landscape and road attributes. Most importantly, it seems that more collisions occur where the land surrounding a highway section shows less variation in topography. Moose may prefer to travel on flat or gently rolling landscape and thus are more likely to use highway sections in such varied topographic grounds. However, this relationship might only reflect differences in spatial distribution of preferred habitat and its effect on moose density. Less rugged and gently rolling landscapes are, in fact, predominant in the foothills of Laurentides Mountain range, which corresponds to the southern and northern part of the LWR. As elevation rises above 750 m, steep hills and mountains and broken topographic features become more common, the habitat suitability index decreases, and, consequently, the abundance of moose decreases as well.

Brooks, streams, and rivers seem to represent summer travel corridors for moose. Moose use these land features as they corresponds to areas of greatest food abundance and dense cover where they can protect themselves against thermal stress (Dussault et al. 2004). Del Frate and Spraker (1991) showed that moose sometimes travel along riparian zones during winter in Alaska. In some areas, moose also migrate from summer to winter habitats through river valleys (Sandegren and Sweanor 1988).

Stand productivity in moose forage nearby the highway also was related to MVCs. This variable probably reflects the summer moose density within a 5-km radius of road sections. Moose density adjacent to roadway was related to MVCs in a similar study encompassing Highway 175 and another 64 km of Highway 169 in the LWR (Dussault et al. 2005). MVCs also were related to moose density in Alaska (Modafferi 1991) and Newfoundland (Oosenbrug et al. 1991, Joyce and Mahoney 2001). Given the light hunting pressure and the application of a management plan protecting adult cows in the province of Quebec since 1994, moose density has increased province wide, (Lamontagne et Jean 1999). Forest harvesting of resinous and mixed stands in the northern and southern part of the LWR also has favored young shade-intolerant deciduous stands and, consequently, provided great forage habitat, such as trembling aspen, mountain maple (*Acer spicatum*), pin cherry (*Prunus pensylvanica*), and American mountain-ash (*Sorbus americana*).

Among road attributes, the presence of steeper road cuts was negatively related to the number of MVCs. Moose might not be naturally inclined to move on such slopes unless forage is readily available or they are forced to move in that direction by a predator. It is believed that moose may feel trapped in the ditches adjacent to high road cuts, which probably induces them to retreat in the forest. Steep cut slopes are being tested in Arizona to deter elk from getting access to roadways, but no results on the success of this measure is available so far (Dodd et al. 2003).

We did not find a clear relationship between MVCs and the number of used salt pools located along Highway 175. This is somehow surprising as moose are known to be strongly attracted to salt pools along Highway 175 (Jolicoeur et Crête 1994) and in other areas (Schwartz and Bartley 1991). Dussault et al. (2005) found a relationship between the presence of salt pools and MVCs. Their study including Highway 175 but also Highway 169, we suspect that the additional data encompasses an area of both high density of moose and salt pools due to poor drainage of ditches in this area. The QMOT is actually improving drainage of salt pools where possible, and covering them with rocks to deter moose from using these pools. They are also creating salt pools >1 km from the roadway, in an attempt to attract moose away. Monitoring is under way to test the efficiency of these measures, but such management techniques have given mixed results at best in prior attempts (Jolicoeur et Crête 1994, Child 1998).

Although we found that abundance of high quality habitat and streams and rivers near the roadway are related to MVCs, they explained little of its spatial variation. In a similar study, the statistical model also explained a small share (23%) of the spatial variance in MVCs (Dussault et al. 2004). The latter study identified moose density, the presence of salt pools, the presence of drainages perpendicular to (the roadway), and the mean slope around the road section as the primary variables related to MVCs.

The difficulty in obtaining strong predictive models probably lies within the random movements of moose. Moose travel great distances within 24 hours to find sufficient forage (Renecker et Schwartz 1998). Ongoing research in the LWR shows that mean summer home ranges of adult females and males, respectively, are 24.7 and 28.0 km^2, and daily movements average >1.5 km (UQAR and MNRWP 2004).

Yearlings and sub-adults generally travel greater distances than adults during summer as they disperse away from natal grounds. Courtois et al. (1998) observed that sub-adults travel almost twice the distance that adults do daily. Also, yearlings in the boreal forest of Ontario have shown ''long wandering movements'' toward new areas in which they never return subsequently (Addison et al. 1980). Preliminary data showed that moose hit on Highway 175 often were yearlings and sub-adults. Joyne and Mahoney (2001) also found that yearlings were predominant in reported MVCs in Newfoundland and Labrador.

Dispersion also is more prevalent where moose density is high or increasing (Hundertmark 1998, Courtois et Crête 1988, Rolley and Keith 1980). Hence, movement paths of dispersers are unlikely to be well defined in terms of habitat features or characteristics because they have not established their home ranges yet. Moreover, the presence of predators, like timber wolves and black bears, in LWR is likely to induce greater movements of moose as an anti-predator strategy (Courtois and Crête 1988).

Limited clustering of tracks recorded during summer 2004 in a hazardous zone of Highway 175 was coherent with the results of analyses and the limited capacity of regression models to narrow landscape and road characteristics related to MVCs at the 1-km scale.

Given our inability to find key variables explaining a large share of MVCs occurring on Highway 175, we proposed different levels of mitigation measures based strictly on the number of MVCs recorded from 1991 and 2001. We identified three specific high-risk zones (25, 15 and 14 km long) in the northern and southern portions of LWR where the MVC rate is above 0.50 MVC/year/km. We recommend that these road sections be fenced and underpasses provided and combined with all major river crossings during the upgrade project from a two-lane to a four-lane divided highway. In one of these three zones, specifications and drawings have been prepared and include two underpasses for moose, eight one-way gates near open ends of the fenced section, and Texas gates for forestry operations and most important access to fishing and hunting camps. Trails and salt pools will also be made on each side of the underpasses to attract moose and facilitate their movements under bridges and social interactions near passages.

Finally, given that moose density represents the most important variable related to MVCs, wildlife managers of LWR need to consider increasing harvest quotas. If they remain unchanged in the LWR harvest management plan, the ongoing increase in moose density is likely to continue as recent updated guidelines in timber management will undoubtedly favor conservation and improvement of moose habitats. For example, in northern areas of Highway 175 where the moose habitat is good but hunting pressure is high and not controlled, MVCs remain rare events. This observation demonstrates the importance of harvest regulations on moose density and its potential as a management technique to prevent MVCs.

Conclusion

The spatial distribution of MVCs along Highway 175 in LWR was found very difficult to predict using variables describing road, landscape, and moose population and habitat features. The most significant variables were (1) moose density as reflected by our index of habitat quality; (2) amount of brooks, streams, and rivers nearby; and (3) the importance of pronounced road fills and road cuts. Given our weak predictive power, we identified high-risk zones by looking at distribution of MVCs between 1990 and 2001, and we proposed measures to reduce MVCs within these areas. As the Highway 175 upgrading project begins soon, our management measures were integrated during the planning stage of the upgrade, which clearly is the best way to reduce both MVCs and the cost associated with the mitigation measures.

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Use of Video Surveillance to Assess Wildlife Behavior and Use of Wildlife Underpasses in Arizona

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Abstract: We used integrated, four-camera video surveillance systems to assess and compare wildlife use of five open-span bridged wildlife underpasses along a 30-km stretch of reconstructed highway in central Arizona. We determined passage rates (proportion of animals approaching and crossing through underpasses) and categorized behavioral responses exhibited during underpass approaches and crossings. Two underpasses have been monitored for over 2-1/2 years; both open into the same meadow/riparian complex, are only 225 m apart, but have different below-span characteristics and dimensions, providing an excellent opportunity to compare use by wildlife. Four underpasses, in place for 18 months, have been monitored for over one year; two of these allowed for monitoring before ungulate-proof fencing was erected in association with the underpasses. This allowed us to record pre- and post-fencing passage rates and behavior to assess the role of fencing in funneling animals to underpasses and influencing passage rates. At the two adjacent underpasses monitored over 2-1/2 years (December 2002-June 2005), we recorded eight species of wildlife totaling 3,914 animals, including 3,548 elk (*Cervus elaphus nelsoni*), 216 white-tailed deer (*Odocoileus virginianus cousei*), and 6 species of carnivores including 4 mountain lions (*Puma concolor*). Overall, elk passage rates averaged 0.62, while only 15 deer crossed the underpasses (0.075 passage rate). We detected significant differences in passage rate and behaviors indicative of resistance to crossing. One underpass with earthen 2:1 sloped sides has been used more by elk (1,908 elk) displaying less resistant behaviors and delay in crossing compared to one with concrete walls (598 elk). This information was used in an adaptive management context to minimize concrete walls and pursue alternatives to soil stabilization at a wildlife underpass currently under construction. At the three recently completed underpasses, monitored February 2004-June 2005, we recorded 10 species of wildlife totaling 1,703 animals, including 860 elk, 367 white-tailed deer, 194 mule deer (*O. hemionus*), and 7 species of carnivores. Elk passage rates to date averaged 0.35, with the passage rate at two underpasses exceeding 0.50 and two below 0.27. Both white-tailed and mule deer regularly used the newer underpasses with passage rates of 0.40 and 0.29, respectively. Ungulate-proof fencing was completed through the underpasses in December 2004, and we continue to monitor wildlife response and changes in passage rates since this fencing was erected. Video surveillance constitutes a valuable tool in quantifying wildlife use of underpasses and assessing the effectiveness of underpasses and fencing. Continued monitoring will allow us to assess long-term use of passage structure.

Introduction

With the ever-increasing importance of finding ways to get wildlife safely across a highway it is necessary to share information obtained from current studies to assist in future wildlife-vehicle collision mitigation efforts. In this paper we share measurements, descriptions, and photos of wildlife underpasses and preliminary data obtained during monitoring to allow researchers to draw their own conclusions as well.

The main objectives of this paper are to (1) discuss the use of video surveillance to monitor wildlife underpasses, (2) describe the five wildlife underpasses monitored and provide data and photos for each, (3) provide data obtained from pre- and post-fencing monitoring at wildlife underpasses, and (4) discuss possible design and placement criteria that may affect wildlife underpass use.

Methods for Monitoring Wildlife Underpasses

Wildlife video surveillance system components and camera orientation

We used integrated, four-camera wildlife video surveillance systems to monitor each of the six underpasses. Two cameras were oriented in a manner to document approaches by wildlife within approximately 50 m of the underpass, one camera was placed in the underpass to assess usage and behavior within the underpass, and one camera was oriented toward the highway to assess traffic (fig. 1). A quad screen splitter allowed for simultaneous viewing of all four cameras (fig. 1). Eight to twelve infrared illuminators were incorporated to allow night-time viewing of wildlife. Infrared photo-beam triggers encompassed the area around the underpass to allow video recording only when wildlife was in the area. Systems comprised both solar and 120-volt A.C. power sources converted to 12-volt to operate equipment.

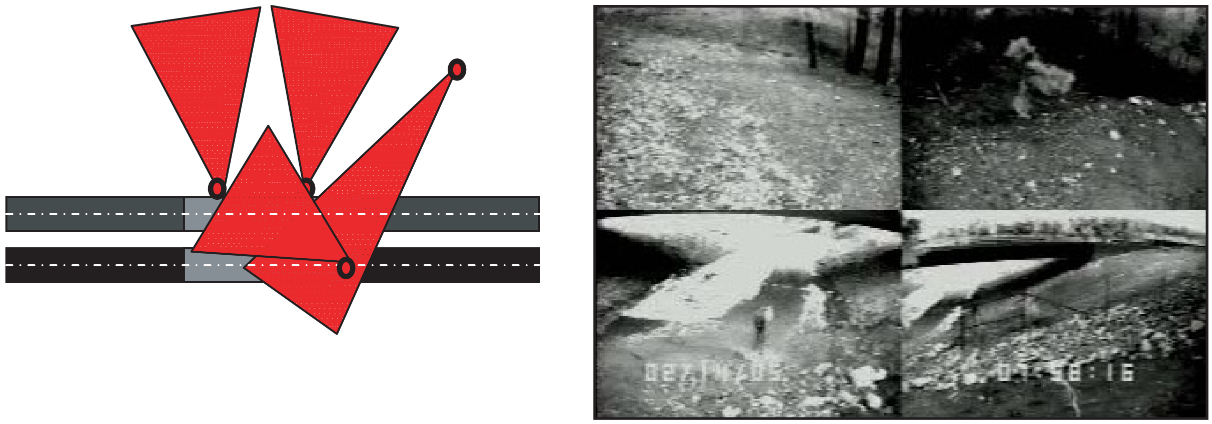


Figure 1. Typical camera orientation and quad screen view of 4-camera wildlife video surveillance systems.

Data collected from wildlife underpass video analysis
The following information was collected for each wildlife observation (UP=underpass):

Date	Tape Time	Time Start
Time End	Total Time	Camera Off Time
Species	Sex	# approach UP
# Use UP	Dir. of Travel	Time approach to cross
Delay level during cross (3)	# did not cross	# enter UP and retreat
# exhibit flight	# standing/milling	# feeding
# did not approach	# vehicles total	# in UP with veh. overhead
Reaction to veh. (4)	Type of veh. (semi / car)	Pre-fencing behavior (4)

Calculation of passage rates
Passage rate is determined by the following equation: # use underpass/# approach underpass. Approaches are classified when animals come within approximately 50 m of the mouth of the underpass and show movement toward the underpass. Passage rate is only calculated from the side of the underpass the cameras are oriented. Any wildlife using the underpass from the other side are documented but not incorporated into the passage rate.

Dimensions and Descriptions of Wildlife Underpasses Monitored by Video Surveillance

Preacher Canyon section
The Preacher Canyon section consists of two wildlife underpasses and one large bridge along an 8-km section of highway. We focused our monitoring efforts on the two wildlife underpasses that are located within only 225 m of each other, allowing wildlife access to the same riparian meadow (Little Green Valley) and providing a unique opportunity to compare usage and behaviors associated with the underpasses. These two underpasses have been complete since 2001, and we have monitored them with video surveillance for approximately 2-1/2 years.

West Little Green Valley Underpass
Year completed: 2001
Dimensions: -Span distance - 37.7 m
-Maximum height - 11.5 m
-Width at floor - 16.0 m
-Total length (approach to approach) - 110.6 m
Features: -Divided highway (11.0-m atrium between bridges)
-Mechanically stabilized earth (MSE) walls to 6.4 m height
-Limited (400-m) wildlife-proof fencing along highway linking the underpass to the East Little Green Valley Underpass
Total Usage: **623 animals** Passage Rate: **53.5%** Total Monitoring: **31 months**

Figure 2. West Little Green Valley Underpass.

East Little Green Valley Underpass

Year Completed:	2001
Dimensions:	-Span distance - 37.7 m -Maximum height - 6.8 m -Width at floor - 9.6 m -Total length (approach to approach) - 52.7 m
Features:	-Divided highway (11.0-m atrium between bridges) -2:1 sloped earthen sides -Limited (400-m) wildlife-proof fencing along highway linking the underpass to the West Little Green Valley Underpass (fencing tied into abutments)
Total Usage:	**1,955 animals** Passage Rate: **70.1%** Total Monitoring: **31 months**

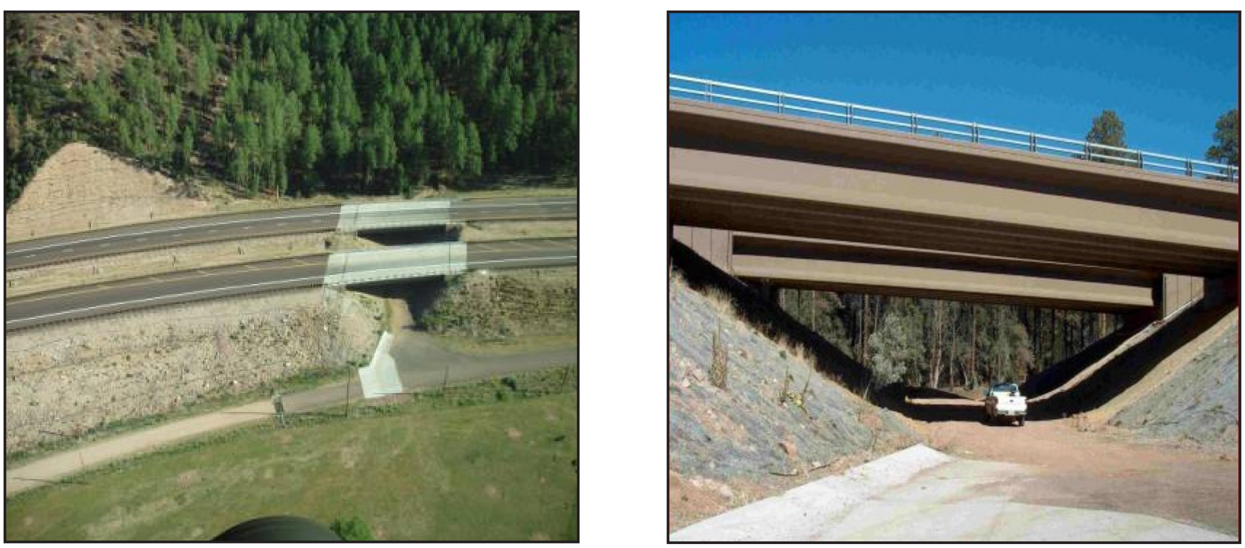


Figure 3. East Little Green Valley Underpass.

Christopher Creek section

This is the second phase of the highway upgrade and is approximately 8 km in length. This section incorporates four wildlife underpasses and three large bridges to accommodate wildlife passage. This section was completed in 2004, and we have monitored three of the crossing structures with video surveillance for 15 months and will continue to monitor for a minimum of two more years.

Pedestrian -Wildlife Underpass

Year Completed: 2004

Dimensions: -Span distance – 34.2 m (east-bound)
31.9 m (west-bound)
-Maximum height – 6.8 m
-Width at floor – 7-9 m
-Total length (approach to approach) - 128 m

Features: -Divided highway (47.9-m atrium between bridges)
-This underpass also serves as a pedestrian underpass linking 2 communities (Christopher Creek and Hunter Creek)
-Wildlife-proof fencing extends >2 km to the east, funneling animals to the underpass; to the west, large, steep fill slopes and right-of-way fencing at the top of the slope behind a guard rail should also serve to funnel animals to the underpass.

Total Usage: **407 animals** Passage Rate: **63.3%** Total Monitoring: **15 months**

Figure 4. Pedestrian-Wildlife Underpass.

Wildlife Underpass #2

Year Completed: 2004

Dimensions: -Span distance – 39.9 m
-Maximum height – 10.0 m
-Width at floor – 8-10 m
-Total length (approach to approach) - 118.8 m

Features: -Divided highway (31.9-m atrium between bridges), with the bridges offset (fill material was removed to improve the sight distance through the atrium)
-2:1 sloped earthen sides
-Wildlife-proof fencing extends >2 km in each direction, funneling wildlife toward the underpass. Fencing through the underpass was completed mid-October 2004 (15 m wide)

Total Usage: **281 animals** Passage Rate: **31.6%** Total Monitoring: **15 months**

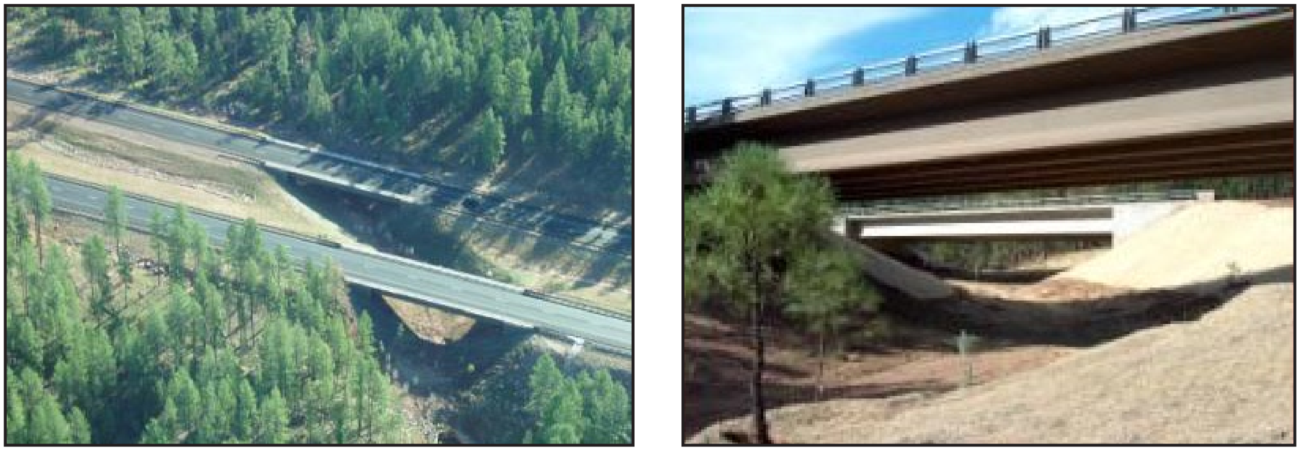


Figure 5. Wildlife Underpass #2.

Wildlife Underpass #3

Year Completed:	Late 2003
Dimensions:	-Span distance – 37.7 m
	-Maximum height – 5.1 m
	-Width at floor – 10 m
	-Total length (approach to approach) – 63.9 m
Features:	-Undivided highway (no atrium),
	-2:1 sloped earthen (rip-rap rock) sides
	-Wildlife-proof fencing extends 0.5 km in each direction, funneling wildlife toward the underpass. Fencing ties into the bridge abutments.
	-This underpass is located in close proximity (<0.25 km) to an ADOT maintenance yard and residence (directly in line with the north underpass approach), potentially limiting wildlife use
Total Usage:	**111 animals** Passage Rate: **37.7%** Total Monitoring: **15 months**

Figure 6. Wildlife Underpass #3.

Preliminary results of wildlife usage at the 5 wildlife underpasses

Table 1. All animals documented near each underpass, number using each underpass, and passage rates associated with each underpass

			Elk	Whitetail	Mule Deer	Black Bear	Mtn Lion	Coyote	Grey Fox	Raccoon	Other	Total
Wildlife on Video	West	(2.5 yrs)	1023	72	9	0	0	12	7	1	19	1143
	East	(2.5 yrs)	2525	143	2	2	4	58	26	5	6	2771
	Ped-Wildlife	(1.2 yrs)	296	281	30	2	1	5	18	133	3	769
	Wildlife 2	(1.2 yrs)	455	57	154	0	0	6	13	3	0	688
	Wildlife 3	(1.2 yrs)	51	29	4	0	0	0	1	89	1	175
	Total		4350	582	199	4	5	81	65	231	29	5546
□□sing Crossing	West	(2.5 yrs)	598	5	0	3	5	0	0	1	11	623
	East	(2.5 yrs)	1908	10	0	12	14	1	0	4	6	1955
	Ped-Wildlife	(1.2 yrs)	175	166	11	1	0	4	7	42	1	407
	Wildlife 2	(1.2 yrs)	127	32	110	0	0	4	6	2	0	281
	Wildlife 3	(1.2 yrs)	9	11	2	0	0	0	1	88	0	111
	Total		2817	224	123	16	19	9	14	137	18	3377
Passage Rate (%)*	West	(2.5 yrs)	56.8	11.6	0.0	NA	NA	50.0	61.6	100.0	66.6	53.5
	East	(2.5 yrs)	74.2	3.4	0.0	100.0	50.0	22.7	63.6	100.0	80.0	70.1
	Ped-Wildlife	(1.2 yrs)	57.0	60.0	14.3	0.0	0.0	50.0	50.0	60.4	33.0	63.3
	Wildlife 2	(1.2 yrs)	16.2	38.5	40.5	NA	NA	60.0	38.5	0.0	NA	31.6
	Wildlife 3	(1.2 yrs)	10.6	21.7	33.3	NA	NA	NA	NA	90.6	NA	37.7
	Total		45.3	27.0	17.6	50.0	25.0	45.7	42.7	75.2	44.9	52.0

* Passage rate calculated by cross/approach from camera side of underpass only

Comparison of Usage and Behaviors by elk at 2 Adjacent Wildlife Underpasses

We assessed and compared usage and behaviors at the east and west underpasses at Little Green Valley (see descriptions above) for a period of >2-1/2 years. The east and west underpasses are located within 225 m of each other. They allow wildlife access to the same riparian meadow and a unique opportunity to compare two different types of structures (fig. 7). The east underpass has natural 2:1 earthen slopes (fig. 3), while the west underpass incorporates walls (fig. 2). For this analysis, we focused on elk since their numbers were high, and the elk were large enough to allow us to readily see behaviors. During the 31 months we documented 3,543 elk in the vicinity of the two underpasses.

Figure 7. Aerial photo of the adjacent West (left) and East Little Green Valley underpasses on the Preacher Canyon section. These 2 underpasses are only 225 m apart, allowing for a unique opportunity to compare underpass designs.

Crossings and passage rates

Crossings at the east Little Green Valley underpass were greater than 3 times that of crossings at the west underpass. At the east underpass 1908 elk crossed through versus 598 through the west. This difference in usage holds true whether elk are entering or leaving Little Green Valley. Comparisons of the 2 underpasses over time show that the number of animals that approached each underpass from the camera side was roughly equivalent for the first 6 months, then begins to favor the East Underpass, while crossings were always higher at the east underpass (fig. 8).

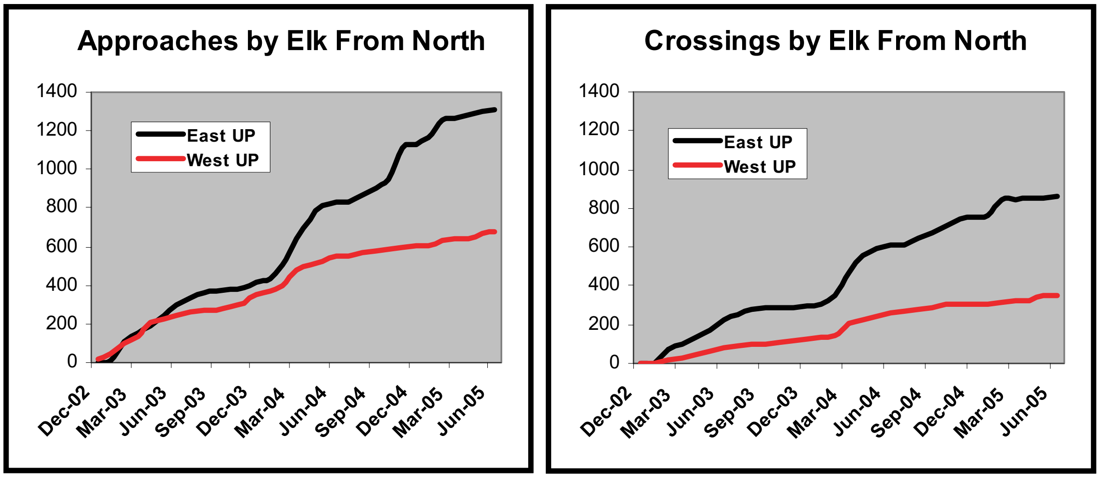


Figure 8. Approaches and crossings from camera side of east and west underpasses at Little Green Valley.

Behavioral comparison of the two underpasses at Little Green Valley

Of the individual elk that approached from the camera side of the underpasses, we identified four negative behaviors: (1) would not cross, (2) obvious delay in crossing, (3) enter underpass and retreat, and (4) alarmed flight from area. The percentage of elk that showed these negative behaviors were all higher at the west underpass (fig. 9).

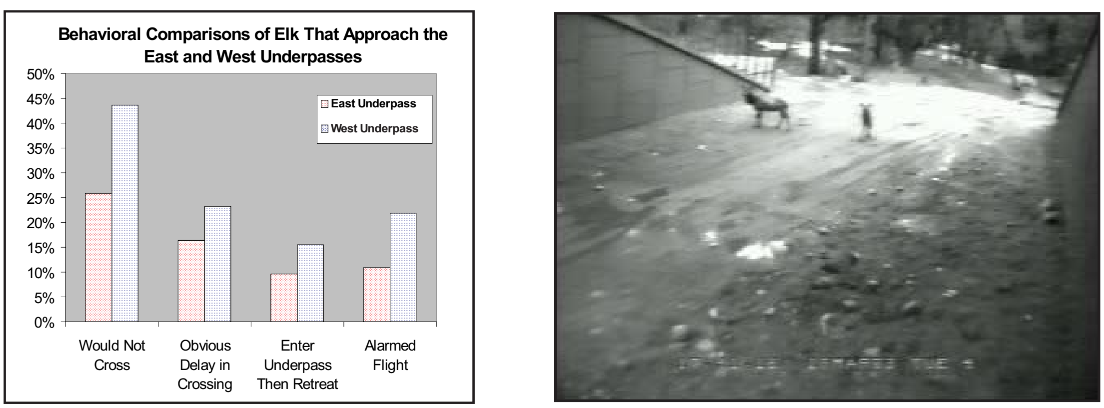


Figure 9. Comparison of 4 negative behaviors associated with elk approaching each underpass and an example of elk showing hesitation immediately prior to fleeing from the area, and exhibiting an unsuccessful crossing.

Possible reasons for differences in usage and passage rates

Below is a list of a few possible reasons for the differences that occur in usage and behaviors between the East and West underpasses at Little Green Valley.

1. Natural slopes versus MSE walls – The walls may provide an unnatural feel for wildlife using them.
2. Sound / Echoes created by walls – Sound was tested at the A-weighted scale, no significant difference in decibel levels.
3. Tunnel effect / Openness ratio – The west underpass is twice the length of the east, reducing the openness.
4. Ledges for predators to hide on walls – Some animals may fear the possibility of predators hiding on the ledges of the walls (fig. 10).
5. Differences in lighting of the 2 underpasses.

Figure 10. A common sight at the west underpass of elk looking up at the top of the walls, possibly for predators.

Adaptive management process at work
Arizona Game and Fish Department (AZGFD) met with Arizona Department of Transportation (ADOT) and Tonto National Forest to share the data obtained from the comparison of the east and west underpasses at Little Green Valley (fig. 7). The data were used to make recommendations for changes to the Indian Gardens wildlife underpass that was in the final planning stages. The underpass, now currently under construction, has significantly less MSE wall and has been widened to minimize tunnel effect and to potentially increase wildlife usage. AZGFD will begin video monitoring of the Indian Gardens wildlife underpass in fall of 2005.

Monitoring Ungulate-Proof Fencing Associated With Wildlife Underpasses

We monitored two wildlife underpasses for eight months prior to and six months following the completion of ungulate-proof funnel fencing. The two underpasses were constructed on a four-lane divided highway with a wide median (figs. 4 and 5).

Pre-fencing
Prior to completion of ungulate-proof fencing, we monitored the movements of 701 elk and deer in proximity to the two sets of underpasses for eight months. Of the 496 animals that approached from the camera side, 42 percent crossed over the highway versus using the crossing structure. Of the remaining elk that went through the first underpass 63 percent of those left via the median still crossing one set of lanes. Overall, only 20 percent of the elk and deer that crossed the highway corridor successfully crossed using both underpasses.

Post-fencing
Once installation was completed at the two underpasses, elk and deer could no longer cross over the highway in the area of the wildlife underpass, nor enter or leave via the median. Passage rates of elk and deer increased from 20 to 57 percent following installation of fencing. Mean daily usage by elk and deer more than doubled following installation of fencing (fig. 11).

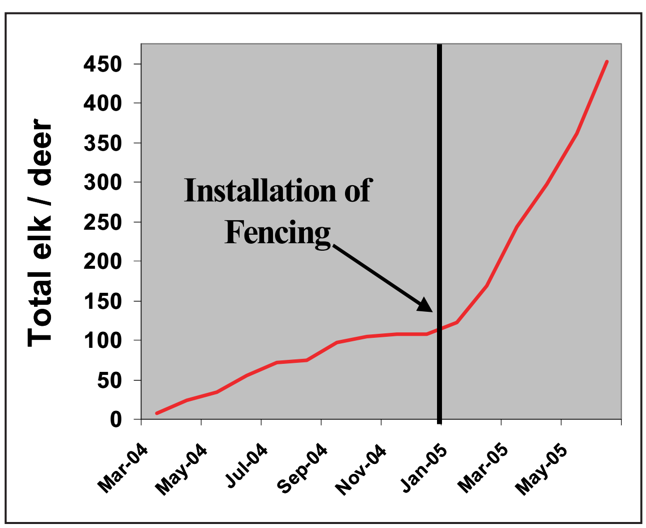
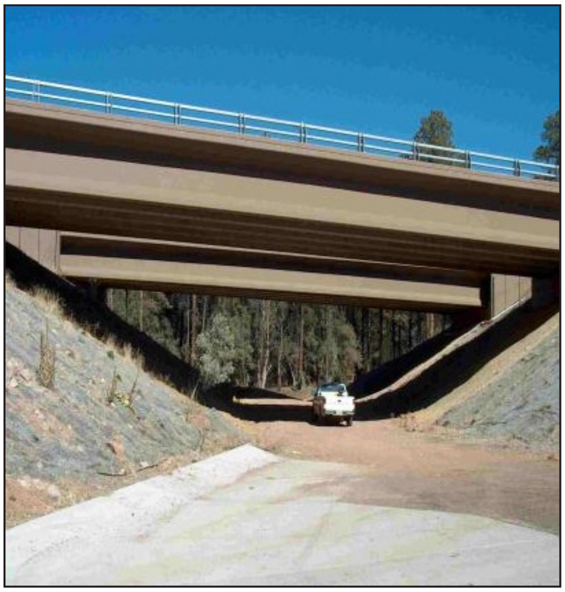
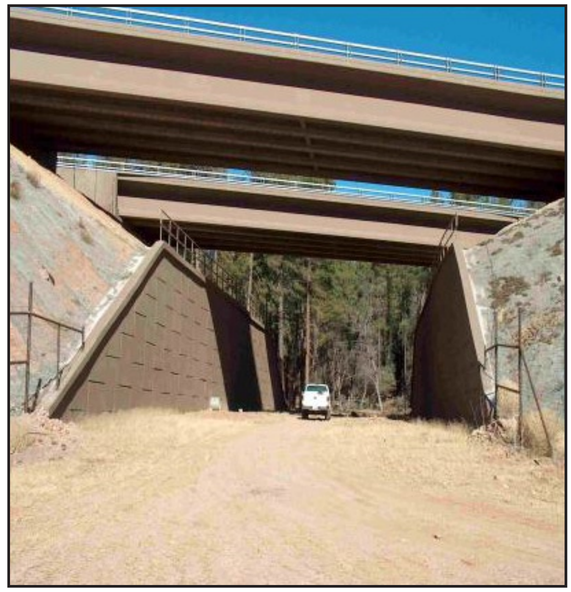


Figure 11. Cumulative usage by elk and deer of 2 wildlife underpasses during pre- and post- ungulate-proof fencing.

Underpass design and placement affecting wildlife underpass usage
Placement and designs of underpasses can be important in the success of a wildlife underpass. Below are some examples describing possible reasons why differences in usage or passage rates may exist at the underpasses along State Route 260.

Example 1: Above are the 2 underpasses located within 225 m of each other and feeding into the same riparian meadow (see figs. 2 and 3 for details). The one on the left has had >3X the number of elk and a relatively higher passage rate. Why? Tunnel effect / openness ratio? Unnatural feel of concrete walls? Ledges for predators to hide?

Example 2: Above is an underpass (see fig. 6 for details) that has shown very little use and very low passage rates (except for raccoon (*Procyon lotor*), this is probably due to the placement of the structure being so close to human activity. This underpass also lacks an atrium, forcing animals to cross under four lanes at once.

Example 3: Above are 2 underpasses that have had about the same number of deer approaches (see figs. 3 and 4 for details). The underpass on the left has only a 3% passage rate for deer, while the one on the right is at 59%. Some possible reasons for this may be the lack of cover on one side of the underpass on the left, or the large atrium created by the wide median at the underpass on the right, allowing deer to “take a break” before crossing under the second set of lanes.

Example 4: Above are 2 underpasses within about 2 km of each other (see figs. 4 and 5 for details). The underpass on the left has a passage rate for elk at about 27%, while the one on the right is about 59%. One possibility may be the offset of the underpass on the left minimizing the point where an elk can see all the way through the underpass. The width of the medians is approximately the same size (photos are taken at different heights). Long-term monitoring here may be important to determine if passage rate increases over time as elk learn these structures.

Conclusion

This portion of the Arizona State Route 260 project illustrates the value of using video surveillance as a method of assessing wildlife underpass use. Many behaviors that are documented by this method would not be readily seen with other methods. Data gathered from video surveillance allow us to make changes on future underpass designs and placements.

Fencing associated with wildlife underpasses is necessary to maximize effectiveness of the underpasses. Elk and deer preferred to cross the highway rather than use both sets of lanes without fencing. In our case passage rates for elk and deer increased approximately 40 percent, and continue to increase as wildlife learn underpass locations. Long-term monitoring is important to see changes in usage over time.

Design and placement, as well as knowledge of local species, can be very important in the ultimate success of a wildlife crossing structure. Different species may react differently to features such as cover on either side of an underpass, ledges, lack of visual openings through the underpass, tunnel effect or openness ratios, human activity, etc. Long-term monitoring can help determine if animals adapt to whatever design or placement is used.

Acknowledgements: Special thanks for funding and support from ADOT, FHWA, and USFS.

Biographical Sketches: Jeff Gagnon is a wildlife specialist for the Research Branch of Arizona Game and Fish Department. Mr. Gagnon's current research is focused on the Arizona State Route 260 Wildlife-Highways Interaction Project. He obtained his B.S. in biology–fish and wildlife management in 1998 from Northern Arizona University and is currently working on an M.S. in biology focusing on relationships of traffic levels to elk movements and distributions.

Norris Dodd has worked for the Arizona Game and Fish Department for 26 years, the past 11 as a wildlife research biologist. Since 2001, he has been working on wildlife-highway relationships research and management, focusing on the State Route 260 project in central Arizona. Mr. Dodd received his bachelor and master's degrees from Arizona State University. He is a past president of the Arizona Chapter of The Wildlife Society.

Amanda Manzo is a research intern for the Arizona Game and Fish Department on the Arizona State Route 260 Wildlife-Highways Interaction Project. She obtained her B.S. in science education from Northern Arizona University and is currently working on an M.S. in forestry/wildlife focusing on the habitat factors associated with elk highway crossings.

Ray Schweinsburg has served as a research program supervisor for the Arizona Game and Fish Department for 12 years and has been involved with the Arizona State Route 260 Wildlife-Highways Interaction project since 2001. Mr. Schweinsburg has also been involved in extensive research in the Canadian arctic, including his work on polar bears.

What Features of the Landscape and Highway Influence Ungulate Vehicle Collisions in the Watersheds of the Central Canadian Rocky Mountains: A Fine-Scale Perspective?

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Abstract: Wildlife-vehicle collisions represent an additive source of mortality to wildlife populations, in addition to other mortality, such as predation and disease. The trends of increasing traffic volumes and road densities will only magnify the mortality impacts of roads on large mammals and other vertebrates. In this study, we examined the descriptive and spatial aspects of ungulate-vehicle collisions (UVCs) in the Central Canadian Rocky Mountains (CCRMs). We then specifically addressed the landscape and highway characteristics associated with the UVCs in four major watersheds: the Bow Valley, Kananaskis Valley, Kicking Horse Valley, and Kootenay Valley, each with differing road-types, topography, and habitat. We grouped the factors associated with vehicle collisions into three groups: combined, landscape-animal, and highway-vehicular-animal. The combined model included all variables, the landscape-animal model included factors that influence whether an animal makes it to the roadway, and the road-vehicular model included factors that influence the probability of an interaction between the animal and the vehicle. Between 1999 and 2003 all kill sites were initially measured with a Global Positioning System (GPS) (accuracy <3 m) and later revisited to measure all field measurements. Many other studies have looked at the factors associated with wildlife vehicle collisions; however, our study is unique in that we were able to revisit exact collision sites (accuracy <10 m). There were a total of 546 ungulate mortalities on all highways in the watershed with the majority occurring in the Bow Valley followed by the Kicking Horse Valley, and Kananaskis Valley, and the least occurring in Kootenay Valley. The distribution of kills was correlated with the traffic volumes on each road-type. Further, UVC distributions differed significantly from random distributions along all road types in each watershed. Type of habitat was the most important variable in explaining UVCs in the combined, landscape and Bow watershed models. UVCs were less likely to occur in open water, rock, and closed coniferous forest relative to open habitat. The proportion of open vegetation in the Bow Valley positively influenced wildlife mortality, while in the Kicking Horse watershed it negatively influenced mortality. Width and traffic volume were significantly positively correlated with the occurrence of UVCs in the combined model and Bow model, respectively. Elevation was a significant factor in the combined, landscape, Bow, and Kootenay watersheds, having a negative correlation on ungulate mortality. The proportion of open habitat positively contributed to kills in the Bow; whereas, it negatively influenced kills in the Kicking Horse. The three grouped models were ranked differently in their ability to predict the observed likelihood for UVCs. The combined model was the most important model in predicting the occurrence of UVCs, followed by the landscape model, and lastly the road-vehicular-animal model. Our findings show that kills do not occur randomly in the landscape. Different scales of analysis, i.e., ecoregion or watershed perspective, can influence which variables are important in contributing to the spatial distribution of UVCs. Further, different groups of variables, i.e., roads and motorist related factors, or landscape and animal behavior factors, may contribute differently to the spatial occurrence of UVCs. The factors contributing to UVCs along each landscape and highway are critical for developing knowledge-based mitigation for reducing effects of vehicle collisions on large animal populations and increasing public safety on highways.

Introduction

Roads are a formidable linear feature within the landscape directly impacting wildlife populations through vehicle collisions. These collisions represent an additive source of mortality to wildlife populations, in addition to other mortality, such as predation and disease. Further, these collisions are a considerable threat to traffic safety, socio-economics, animal welfare, and wildlife management and conservation (Child and Stuart 1987, Lavsund and Sandegren 1991, Romin and Bissonette 1996, Groot-Bruinderink and Hazebroek 1996, Schwabe et al. 2002).

Wildlife biologists can begin to assess the degree to which road mortality may impact wildlife populations by recording the number and location of wildlife-vehicle collisions on different road-types. Kill locations are often reported to local departments of transportation and natural resource agencies by way of police reports completed for insurance purposes or by maintenance workers directly recording the location of animal kills when removing carcasses. Spatial error can vary depending on protocol developed by the collecting agency. Most published studies focus on the features of road sections with high collision rates (Bashore, Tzilkowski, and Bellis 1985; Finder, Roseberry, and Woolf 1999; Hubbard, Danielson, and Schmitz 2000; Joyce and Mahoney 2001; Nielsen, Anderson, and Grund 2003; Seiler 2003). This study is unique because our analyses are based on each UVC location as measured by research personnel using a Geographic Positioning System (GPS).

For years wildlife-vehicle collisions have been a problem in the CCRM national parks and a cause for concern among park managers and transportation planners (Damas and Smith 1982, Woods 1990, Banff-Bow Valley Study 1996, Woods et al. 1996). The long-term trend and prospects are for increasing traffic volumes on the Trans-Canada Highway and other primary roads in the parks (Parks Canada Highway Service Center, unpublished data).

In order to effectively mitigate highways for wildlife and motorist safety, managers need to determine the causes of wildlife-vehicle collisions and whether they are best explained by parameters relating to roads and motorists, or landscape and animal behavior. We described the spatial distribution of UVCs in the CCRMs and more specifically in the four major watersheds, the Bow Valley, Kananaskis Valley, Kicking Horse Valley, and Kootenay Valley, each with differing road-types, topography, and habitat. We then examined numerous habitat and landscape variables that are thought to influence the occurrence of vehicle collisions.

Methods

Study area

This study was carried out in the CCRMs, approximately 150 km west of Calgary, in southwestern Alberta and southeastern British Columbia (fig.1). The study area encompassed 11 400 km^2 of mountain landscapes in Banff, Kootenay, and Yoho national parks and adjacent Alberta provincial lands. We divided the landscape into four major watersheds: the Bow Valley, Kananaskis Valley, Kicking Horse Valley, and the Kootenay Valley.

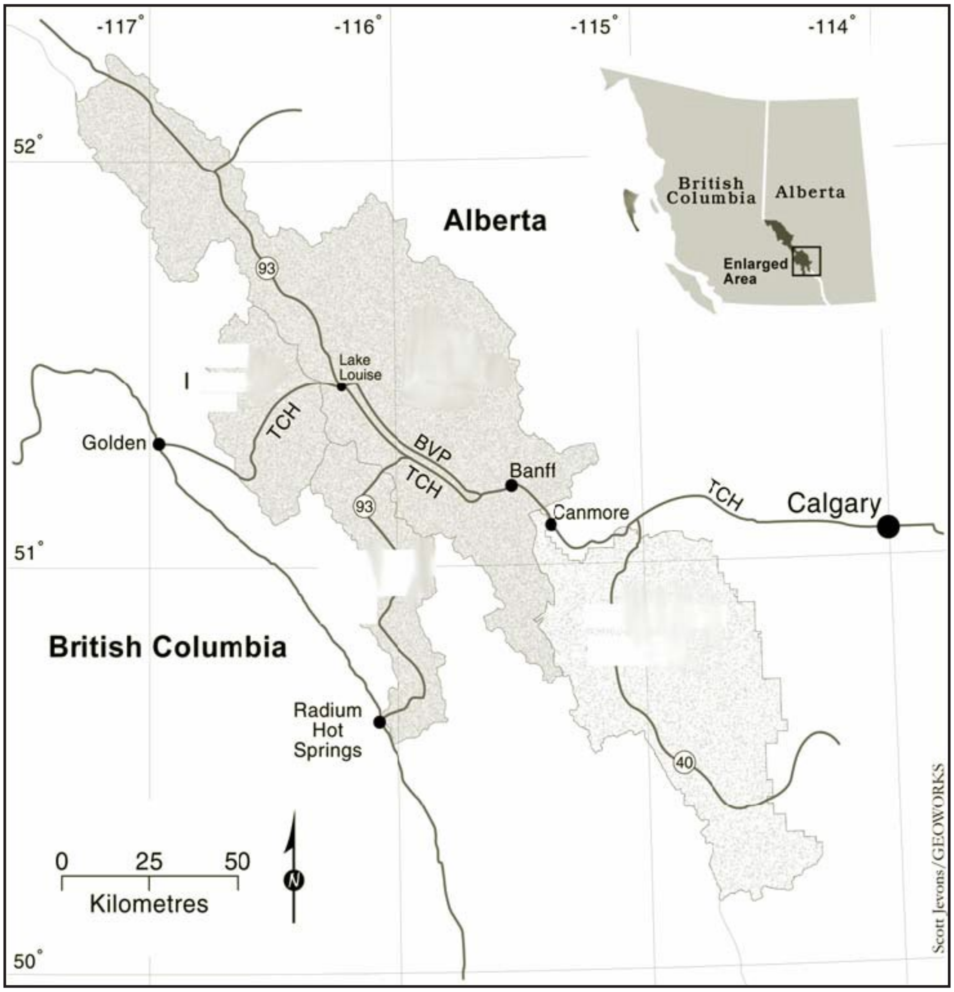


Figure 1. Location of study area and highways within the four major watersheds used to examine factors contributing to ungulate vehicle collision in the Central Canadian Rocky Mountains.

The Trans Canada Highway (TCH), extends west to east within the study area, running along the floors of two watersheds, the Kicking Horse in Yoho National Park (YNP) and the Bow in Banff National Park (BNP) and neighboring provincial lands. The TCH shares the Kicking Horse Valley with the township of Field (population <500), the Kicking Horse river, and the Canadian Pacific Railway. Annual average daily traffic volume (AADTV) on this 44.6-km stretch of two-lane highway in 1998 was 4,600 vehicles. The TCH continues eastward along the floor of the Bow, sharing the valley bottom with the Bow river, several small towns (population <10,000), numerous secondary roads, and the railway. The western segment of highway (32.7 km) still remains two lanes and has an AADTV of 7,000 vehicles, while the portion of highway east of BNP in neighboring provincial lands (37.4 km) is four lanes with an AADTV of 14,000 vehicles in 1998 (Parks Canada Highway Service Center, unpublished data). The Kananaskis and Kootenay watersheds have no major town sites, or railways, and both share their valley bottom with a two-lane highway, 50.2 and 101.0 km, respectively, with traffic volumes of approximately 2,000 vehicles per day in 1998 (Parks Canada Highway Service Center and Alberta Infrastructure, unpublished data). All highways in this study were two (90 km/hr) to four lanes (110 km/hr) and unmitigated (no fence or wildlife crossing structures).

The geography of the central and eastern portions of the study area is dictated by the geology of the Front ranges of the Rocky Mountains. The parallel and shale valleys create a landscape much more conducive to north-south than east-west movements. The few large valleys, the Bow Valley being the most prominent, that dissect the Front and Central ranges are recognized as critical, not only in maintaining regional-scale, east-west movements of animals, but also in providing a vital link between the valleys nested through out our study area, i.e., the Kootenay and Kananaskis valleys. For the same reasons the Bow Valley is also one of the most important transportation corridors in the region. This geography along with the transportation corridors associated with each watershed influences the distribution and movement of wildlife in the region.

Situated within the Front and main ranges of the Canadian Rocky Mountains, the study area has a continental climate characterized by long winters and short summers (Holland and Coen 1983). The roads in our study area traverse montane and subalpine ecoregions. Vegetation consisted of open forests dominated by Lodgepole pine (*Pinus contorta*), Douglas-fir (*Pseudotsuga menziesii*), white spruce (*Picea glauca*) Englemann spruce (*Picea englemannii*), trembling aspen (*Populus tremuloides*), and natural grasslands.

Data collection

Since January 1999 we maximized wildlife-vehicle collision (WVC) reporting and its accuracy. We contacted all parties responsible for collecting and reporting WVCs within our study area: Banff-Kootenay-Yoho national parks and the province of Alberta (Bow Valley and Kananaskis Country). Cooperators included national park wardens, provincial park rangers, and the private highway maintenance contractor (Volker-Stevin).

We provided cooperators with colored pin-flags to be carried with them in their vehicles. After collecting road-killed wildlife they were advised to mark the site by placing a pin-flag in the right of way and report back to us via telephone, fax, or email. Most accidents were pinflagged and reported to us within 48 hours.

The reported location of WVCs was recorded by the collaborators by describing the location with reference to a nearby landmark (e.g., 0.3 km west of BNP east gate). The true location of a WVC was acquired by visiting the accident site, recovering the pin-flag, and obtaining the actual location by measuring the odometer distance from the same reported landmark to the pinflag. The Universal Transverse Mercator (UTM) grid co-ordinates of the site were obtained using a differentially correctable Global Positioning System (GPS) unit (Trimble Navigation Ltd., Sunnyvale, California, USA) with high spatial accuracy (=<3m). The UTM co-ordinates were recorded in a database, along with date of kill and information regarding the number, species, sex, and age of the wildlife involved.

Factors contributing to wildlife collisions

We only used ungulate road mortality data for this study because these species were involved in 76 percent of the total mortalities (carnivores and ungulates). These included white-tailed deer *Odocoileus virginianus*, elk *Cevus elaphus*, mule deer *Odocoileus hemionus*, deer *Odocoileus* sp., moose *Alces alces*, and bighorn sheep *Ovis Canadensis*. A total of 546 ungulate-vehicle collisions were GPSed between August 1997 and November 2003. We compared the site-specific attributes of 499 observed locations to attributes of 729 random locations along the sampled roads. We only used 499 observed sites because 47 kills in Kootenay were not used as they had occurred prior to roadside vegetation clearance along a 23.9-km stretch of road. Random points were distributed along each roadway in proportion to the number of observed kills in each watershed. At least an additional 20 percent of observed locations were included as random points in each watershed.

At each sampling point we measured 24 variables to be used as probable factors explaining road-kill occurrence (for definition, see table 1). Fourteen of the variables were grouped as landscape-animal interaction variables, and 10 were grouped as road-vehicular interaction variables. Landscape-animal variables included factors that influence whether an animal makes it to the roadway. The road-vehicular variables include factors that influence the probability of an interaction between the animal and the vehicle.

Depending on accuracy and efficiency each variable was either measured in the field or in ArcView 3.3 GIS (Environmental Systems Research Institute, 1999). Field measurements were derived at each site by revisiting each UTM location with a GPS unit (Trimble Naviagation Ltd., Sunnyvale, California, USA) between April 2003 and February 2004. The spatial accuracy of the location of the measured site-related variables with the actual location was (<9m). A laser range finder (Yardage Pro® 1000, Bushnell® Denver, CO) was used to measure distance to cover and the inline and angular visibility. Vegetative cover, habitat, topography, and slope were all estimated visually.

Field visibility variables measured the extent to which a motorist could see ungulates on the right of way or, conversely, how far away an oncoming vehicle could be seen from the side of the highway. Field visibility was defined as the shortest distance along the highway at which an observer, standing at a distance perpendicular to the pavement edge, could no longer see an oncoming vehicle. Since, in most cases, it could not be determined from what side or which direction a vehicle struck an animal, four visibility measurements were taken at the pavement edge at each site, two facing each direction, on both sides of the highway. The average of the four visibility measurements were taken to calculate an in-line and two angular measurements (5-m and 10-m transect from pavement edge) (table 1).

Distance from data points to each landscape feature was calculated in ArcView 3.3 GIS using various physiographic layers. Highway spatial and elevation data were collected along each road approximately every 25 m, by driving at 50 km/hr and recording a GPS location every one second. Elevation data were obtained from a GPS unit for the observed points; whereas, elevation was extracted from the GPSed highway layer for the random points.

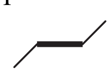
Change in elevation (table 1) was measured as the distance from each point where there was an inflection in the highway elevation profile which exceeded more that 3 m. The change in curvature (table 1) was measured as the distance from each point where the absolute difference between the straight line length and the curved line length exceeded 0.2 m over a stretch of at least 50 m. A distance of 1000 m was assigned as the distance measurement if the required change in elevation or curvature was not reached. This cut-off distance was chosen since in the field the range finder did not operate beyond that distance. Means were calculated from distance measurements taken from both directions at each point. A second mean in-line visibility (table 1) was calculated by taking the average of the shortest distance between curvature and elevation from each direction of the point. A Spearmans rank correlation was used to see if mean in-line visibility measurements taken in the field were similar to mean in-line visibility generated with the computer.

Table 1. Definition and description of variables used in the analysis of factors explaining

Variable Name	Definition	Continuous/Categorical
Landscape-animal		
Habitat Class[a]	Dominant habitat within a 100-m radius on both sides of the highway measured as open (O)-meadows, barren ground; water (W)-wetland, lake, stream; rock (R); deciduous forest (DF); coniferous forest (CF); open forest mix (OFM)	Categorical
Topography[ac]	Landscape-scale terrain measured as flat (1), raised (2), buried-raised (3), buried (4), part buried (5), part raised (6)	Categorical
Forest cover[a]	Mean percentage (%) of continuous forest cover (trees > 1 m height) in a 100-m transect line perpendicular to the highway, taken from both sides of the road	Continuous
Shrub cover[a]	Mean percentage (%) of shrub cover (trees and shrubs < 1 m high) in a 100-m transect line perpendicular to the highway, taken from both sides of the road	Continuous
Openess[a]	Mean percentage (%) of area devoid of vegetation (rock, gravel, water, pavement, etc.) in a 100-m transect line perpendicular to the highway, taken from both sides of the road	Continuous
Cover[a]	Mean distance (m) to vegetative cover (trees and shrubs > 1 m high) taken from both sides of the road	Continuous
Roadside slope[a]	Mean slope (°) of the land 0-5 m perpendicular to the pavement edge taken from both sides of the road	Continuous
Verge slope[a]	Mean slope (°) of the land 5-10 m perpendicular to the pavement edge taken from both sides of the road	Continuous
Adjacent land slope[a]	Mean slope (°) of the land 10-30 m perpendicular to the pavement edge taken from both sides of the road	Continuous
Waterways[b]	Distance (m) to the nearest waterway (river, stream, or creek) that crossed the road	Continuous
Human use[b]	Distance (m) to the nearest human use feature along the highway	Continuous
Railway[b]	Distance (m) to the nearest railway	Continuous
Powerline[b]	Distance (m) to the nearest powerline	

Table 1 (continued).

Elevation[b]	GPS height (m)	Continuous
Road-Vehicular-Animal		
Traffic Volume[b]	Annual Average Daily Traffic Volumes from 1980 to 2000 for each road type in the BOW watershed, measured as high (1) and low (2)	Categorical
Barrier 1[a]	Number of jersey and guard rails at the site measured as 0, >1	Categorical
Barrier 2[b]	Distance (m) to the nearest jersey or guardrail barrier	Continuous
Width[a]	Distance (m) from one side of the highway pavement to the other	Continuous
In-line visibility field[a]	Mean distance at which an observer standing at the pavement edge could no longer see passing vehicles taken from each direction on both sides of the highway	Continuous
Angular visibility 1[a]	Mean distance at which an observer standing 5 m from the pavement edge could no longer see passing vehicles taken from each direction on both sides of the highway	Continuous
Angular visibility 2[a]	Mean distance at which an observer standing 10 m from the pavement edge could no longer see passing vehicles taken from each direction on both sides of the highway	Continuous
Change in curvature[b]	Mean distance at which the absolute difference of the curved line length minus the straight line length changed by a magnitude of 0.2 m along a segment of at least 50 m, taken from each direction	Continuous
Change in elevation[b]	Mean distance where there was an inflection point in the road elevation profile, of at least 3 m, taken from each direction	Continuous
In line visibility-GIS[b]	The mean shortest distance between the change in curvature and the change in elevation from each direction, indicating a loss in the line of sight	

[a]Variable measure obtained from field measurement
[b]Variable measure obtained from a geographic positioning system and geographic information system or other source
[c] (1)flat  (2)raised  (3)buried-raised 

(4)buried  (5)part-buried  (6)part-raised 

Data analysis

Spatial distribution
We tested whether ungulate collisions were distributed randomly by comparing the spatial pattern of collisions with that expected by chance, in which case the likelihood of collisions for each road section would show a Poisson distribution (Boots and Getis 1988). We divided each road type in each watershed into 100-m segments and recorded presence (1) or absence (0) of the observed points in each highway segment. We used a Kolmogorov-Smirnoff one-sample test to determine whether the empirical distribution differed from a Poisson distribution. We also used a X^2 test to determine if obvious UVC aggregations were significant based on road length.

Univariate Analyses
We used univariate analyses to identify which of the continuous variables (unpaired t-tests) and categorical variables (X^2 contingency tests) significantly ($p<0.05$) differed between accident and control sites with all the data. Because some of the selected variables only pertain to specific watersheds these analyses were repeated within each of the four main watersheds: Bow, Kootenay, Kicking Horse, and Kananaskis. The significance of each differentiated class within the categorical variables was evaluated using Bailey's confidence intervals (Cherry 1996).

Model Building
We grouped the significant variables for the combined dataset and each watershed subset into reduced models and used multiple logistic regression analyses (Hosmer and Lemeshow 1989) to identify which of the above selected parameters best predict the likelihood of UVC occurrence. Further, we ran the logistic regressions on the two *a priori* model variable sets (table 1) representing parameter combinations as a function of landscape and road variables. We used stepwise (backward) regression procedures to allow variables to be removed from the equation until the ensuing new model was not significantly more informative than the previous one. We compared the landscape and road models with the combined model with Akaike's Information Criterion (AIC) and Akaike weights (w_i) to determine which variable grouping was most important in determining the occurrence of UVCs (Burnham and Anderson 2002). We used the log-likelihood ratio test (Hosmer and Lemeshow 1989) to determine significance of models to discriminate between UVC and random locations based on location attributes.

Significance of explanatory variable coefficients was based on chi-square tests of Wald statistics (Hosmer and Lemeshow 1989). Standardized estimate coefficients were calculated by multiplying logistic regression coefficients (B) by the standard deviation of the respective variables to assess the relative importance of the explanatory variables within the model. Odds ratios were examined to assess the contribution that a unit increase in the predictor variable made to the probability of a collision occurring (Tabachnick and Fidell 1996). Hosmer-Lemeshow goodness-of-fit test statistics were included to see how well the model predicts the dependent variable. We also included the cross-validation classification accuracies for the combined observed and random points for each model. The Combined, Bow, Kootenay, and the two grouped models were validated with 20 percent of the data not included in their development, and these cross validation classification accuracies are included. The Kicking Horse model was not validated due to low sample size.

Prior to performing the regression analysis we tested potential explanatory variables for multicollinearity (Menard 1995). Where variables were correlated ($r>0.7$) we removed one of the two variables from the analysis. Final models and variable coefficients with a p-value <0.10 were considered significant. Distance between the road and landscape elements or linear features was log(e) transformed to correct for non normality. We used the SPSS statistical package version 13.0 for all statistical analyses (SPSS 2004), and we used Microsoft Excel and ArcView GIS 3.3 (Environmental Systems Research Institute 1998) for all other analyses.

Results

Ungulate-vehicle collision composition
There were a total of 546 ungulate mortalities on all highways in the watersheds with the majority occurring in the Bow watershed (56%), followed by Kootenay (21%), and the least occurring in Kananaskis (12%) and the Kicking Horse (10%). When taking into account roadway length, the majority of kills occurred in the Bow Valley (4.82 kills/km), followed by the Kicking Horse and Kananaskis with 1.30 kills/km, and the least occurring in Kootenay with 1.13 kills/km. This did follow traffic volume trends, which were highest in the Bow watershed, followed by the Kicking Horse, Kananaskis, and Kootenay. Deer (consisting of mule deer, white-tailed deer, and unidentified deer) were most frequently involved in collisions comprising 58 percent of the kills, followed by elk (27%), moose (7%), bighorn sheep (3%), and others (mountain goats and unknown ungulates) (5%). Fifty percent of the moose and big-horn sheep kills occurred within the Kootenay watershed.

Spatial distribution
UVC distributions differed significantly from random distributions along all road types in each watershed (Kolmogorov-Smirnov one-sample test, Bow; d=0.715, Kootenay; d=0.940, Kicking Horse; d=0.892, Kananaskis; d=0.874, all P<0.01). Kills in Kootenay showed a significant aggregated distribution on the cleared section of highway with 60.0 percent of the kills occurring along a 23.9-km (22.9%) stretch of road (X^2=63.9, P<0.0001). The road in this section bisects key ungulate ranges in the valley bottoms of the montane region, with elevation less than 1,240 m (Poll et al.

1984). Due to this aggregation of UVCs, we addressed specific questions as to what landscape and road-vehicular factors contribute to this non-random distribution of collisions in our study area.

Factors contributing to ungulate-vehicle collisions

Univariate Analysis

Table 3 shows the results of the univariate comparison of each environmental variable thought to be contributing to the probability of UVCs. Seventy-one percent of the landscape variables and 30 percent of the road-related variables were significant in detecting differences between UVC sites and non-accident control sites within all the datasets (table 3).

Within the combined and the Bow datasets the significant landscape variables between observed and random sites were habitat class, topography, amount of cover, slope, and elevation. The Bow was the only watershed that had mortality sites within open habitat. In the Bow, collisions occurred more frequently in open, open forested, and deciduous forest areas, and less frequently in coniferous forest and with rock cliffs or open water present. The positive relationship between openness and distance to cover with collision occurrence further illustrates the higher probability of kills occurring in cleared habitat. The opposite relationship occurred in the Kicking Horse where there was less open space where kills occurred. In the Kicking Horse, kills occurred less frequently than expected at open water sites, and the opposite occurred in the Kananaskis watershed. In the Bow, kills occurred in terrain that was flat, and fewer than expected occurred in steeper topography when it was found on both sides or one side of the highway. Topography was significant in the Kootenay and Kananaskis watersheds; however, none of the differentiated categories was significant. Roadside, verge, and adjacent slopes were significant in the Bow, with more kills than random occurring at smaller grades in all three cases. Where the railway was present (Kicking Horse and Bow) kills occurred farther away than the random points, and this was significant in the Bow. Road-kills significantly increased at lower elevations in the combined, Bow, and Kootenay watersheds.

The road-vehicular-animal variables that significantly influenced UVC occurrences in the combined and Bow watersheds were the distance to a barrier (guardrail and jersey) and the width and traffic volume along the highway. More kills occurred at higher traffic volumes and increased road width within the Bow. Traffic volume was not compared in the other watersheds due to the absence of variability within each study area. Kills occurred closer to barriers in the Bow and Combined datasets. None of the in-line and angular field visibility measurements was significant between kills and control locations. Further, the change in elevation and curvature generated in a GIS were not significant in all the watersheds. The mean field line of sight was significantly correlated with the mean GIS line of sight ($r=0.69$, $P<0.01$).

Model Building

To reduce inter-correlation between the variables (Zar 1988), we omitted the percentage forest cover from further analyses as they were highly correlated ($R>0.70$) with percentage openness. The logistic regression results were not reported for Kananaskis, as the model was insignificant.

Table 3. Results from the univariate comparison of the factors contributing to UVCs at the 499 observed and 729 random locations for the entire study area and each watershed. Mean values are shown for quantitative variables, and frequencies for each differentiated type are shown for categorical variables, along with their associated P-values. Only those values that were significant (P<0.05) are displayed.

Variable	Combined (n=499)			Bow (n=310)			Kootenay (n=67)			Kicking Horse (n=57)			Kananaskis(n=65)		
	Obs	Ran	P-value	Obs	Ran	P-value	Obs	Ran	P-value	Obs	Ran	P-value	Obs	Ran	P-value
Landscape-Animal															
Habitat			<0.0001			<0.0001						0.009			0.003
Open	46	21		46	23										
Water	70	115		42	77					9	19		8	2	
Rock				2	7										
Decid forest	58	31		50	26								4	7	
Conif forest	193	237		67	104										
Open forest mix	127	84		102	72										
Topography			<0.0001			<0.0001			0.013						0.043
Flat	289	237		223	177										
Buried-raised	52	77		13	26										
Part-buried	93	121		42	66										
Forest cover	48	53	0.002	37	45	<0.0001									
Openess	46	41	0.003	55	47	<0.0001				29	39	0.020			
Cover	39	33	0.006	47	37	<0.0001									
Roadside slope	10	13	<0.0001	7	10	<0.0001									
Verge slope	10	11	0.033	7	9	0.026									
Adjacent land slope	12	15	0.004	9	11	0.035									
Railway				861	680	0.0001									
Elevation	1344	1389	<0.001	1350	1406	<0.0001	1276	1340	0.009						
Road-Vehicular-Animal															
Traffic Volume						<0.0001									
High				255	151										
Low				55	159										
Barrier 2	686	1142	<0.0001	588	1361	<0.0001									
Width	32	23	<0.0001	43	30	<0.0001									

Table 4. Results from the logistic regression analyses for the Combined, Landscape, Road-animal vehicular and watershed models with their ranking of significant (*P*<0.10) standardized estimate coefficients and their sign. Numbers indicate rank of importance of variable. Sign indicates influence variable or variable level has on the probability of a road kill occurring, (-) negative correlation or (+) positive correlation. Hosmer and Lemeshow goodness of fit test, validation results, Akaike Information Criterion (AIC) and Akaike weights (w_i) are also included.

Variable	Combined	Landscape	Road-vehicular-animal	Bow	Kootenay	Kicking Horse
Habitat						
Water	1-	2-				
Coniferous forest	2-	3-				
Rock	4-	1-		1-		
Openness						1-
Roadside slope		5-		3-		
Width	5+		2+			
Barrier 2			1-			
Elevation	3-	4-		4-	1-	
Traffic Volume						
High				2+		
Hosmer and Lemeshow test	0.444	0.601	0.192	0.857	1.000	0.410
AIC	1244	1248	1260			
? AIC	0	4	16			
w_i	0.88	0.12	<0.0002			
Model development & validation accuracies (%)	64.9 61.8	65.5 59.9	61.9 62.2	66.2 65.3	71.2 64.7	63.6

The three grouped models ranked differently in their ability to predict the observed likelihood for UVCs (table 3). The combined model ranked highest according to AIC weights (w_i=88%), followed by the landscape model (w_i =0.12%), and lastly the road-vehicular-animal model (w_i < 0.0002%). The addition of extra variables in the combined model did not have a negative effect on its relative AIC weight. For the three grouped models, the Hosmer and Lemeshow statistic was highest for the landscape model, followed by the combined model, then the road model. The predictive capabilities of all three models were similar, correctly classifying 61.9-65.5 percent of the selected points. Model validation accuracies ranged from 59.9-62.2 percent. Validation accuracies were low because all three models had difficulty correctly predicting the observed points (< 45%) but scored high when classifying the random points (> 75%).

The two watershed models (Bow and Kootenay) and the three grouped models were statistically significant (all *P*<0.0001). The Kicking Horse Model was also significant (*P*<0.05). For all watersheds the Hosmer and Lemeshow goodness of fit was highest for the Kootenay (test statistic=1.000), followed by the Bow (test statistic=0.857), and then Kicking Horse (test statistic 0.410). The overall cross-validation accuracies were highest for the Kootenay model (71.2%-model development and 64.7%-validation). The combined and Kicking Horse models scored the lowest goodness of fit test statistics and overall cross validation accuracies below 65 percent in model development and validation.

Type of habitat was the most important variable in explaining UVCs in the combined, landscape and Bow models. UVCs were less likely to occur in open water, rock, and closed coniferous forest relative to open habitat. In the combined model water was ranked as the most important variable, and kills were 63 percent less likely to occur at wet areas. Kills were also less likely to occur in coniferous forest and rock in the combined and landscape models. Further, width was a significant positive correlation of the occurrence of UVCs in the combined model. In the Bow, the presence of rock decreased the likelihood of kills occurring by 92 percent relative to open areas. In the Bow, ungulates were 95 percent less likely to be killed in areas of lower traffic volumes (Banff National Park versus provincial lands). Elevation was a significant factor in the combined, landscape, Bow, and Kootenay models, having a negative influence on ungulate mortality. In the Kicking Horse, openness was the only variable significant in the model and had a negative influence on UVC probability.

Discussion

Spatial distribution

We are not aware of any published analyses that have used collision data with such a high degree of accuracy (< 10 m). Our study is unique in that we adopted a site-based approach to data collection in order to preserve the high spatial accuracy of kill sites. Many studies estimate their reporting error to be > 500 m, and, as a result, look at road sections as hotspots of road mortality (Bashore, Tzilkowski, and Bellis 1985; Finder, Roseberry, and Woolf 1999; Hubbard, Danielson, and Schmitz 2000; Joyce and Mahoney 2001; Nielsen, Anderson, and Grund 2003; Seiler 2003). Clevenger et al. (2003) showed that the range of scales of small mammal road kill clustering differ on road types and is dependent on the intensity of the distribution. Our results show that UVCs are not occurring randomly in each watershed, and the degree of aggregation depends on the local characteristics within each watershed. Other studies show road kills tend to be spatially aggregated with a small percentage of locations accounting for a large proportion of kills (Puglisi et al. 1974, Bashore et al. 1985, Hubbard et al. 2000, Malo et al. 2004). This was evident in Kootenay where the road-kill rate was low relative to the other watersheds; however, when viewed at a finer scale, the majority of kills (60%) occurred on a small section of highway (22.9%). Clevenger et al. (2003) and Spooner et al. (2004) used a more sophisticated approach to analyze spatial data, which would be useful here to further explore the spatial distribution of the UVCs in our study area and in each watershed.

Factors contributing to ungulate-vehicle collisions

The combined and Bow watershed models shared many of the same significant variables. Factors contributing to road-kill occurrence in the Bow watershed weighted heavily in the combined model since the majority of kills (62%) occurred in the Bow. For this reason, reduced models were used to examine each watershed separately. However, sample sizes were low along the extensive roadways in the Kooteney, Kananaskis, and Kicking Horse watersheds, which may explain the lack of significant variables. Kootenay originally had a relatively high number (n=114) of mortalities; however, 47 kills were excised from analysis since they occurred prior to the clearing of the highway. The cleared section was within the valley bottom of the Kootenay River where terrain was less steep and the highway was notably straighter (Poll 1989). By removing these kills from only this location, some of the significant variables characteristic of this region may have been lost in the analysis.

The degree of habitat variability was much less in the Kootenay, Kananaskis, and Kicking Horse watersheds when compared to the Bow watershed. None of these watersheds had open habitat on both sides of the highway, and the Highway 93S in Kootenay only bisected pine spruce forest and open water. Other studies have shown that where preferred habitat is extensive common deer kills have been more randomly distributed (Bellis and Graves 1971, Allen and McCullough 1976, Bashore et al. 1985, Feldhamer et al. 1986). Kills in these three watersheds may have occurred more randomly in the road network due to the apparent homogeneous habitat, especially in Kananaskis and Kicking Horse where there was not an obvious aggregation of road kills.

The majority of UVCs occurred in the Bow Valley provincial region and were positively associated with all open habitat variables. Open grassland habitat was abundant from high levels of development and a wide transportation corridor that would attract animals to the highway corridor (Bellis and Graves 1971, Puglisi et al. 1974, Carbaugh et al. 1975, Bashore et al. 1985, Lehnert and Bissonette 1997). Bashore et al. (1985) had a similar result in that as the overall habitat became less wooded, the chances that the highway would be a high kill area increased. Further, Bellis and Graves (1971) showed that animals along an interstate in Pennsylvania are attracted to cleared areas associated with the highway right of way and increased development, which provide a valuable source of forage in forested regions.

Conversely, the extent of openness was a negative factor on UVCs in the Kicking Horse, although very little open grassland habitat existed in this region. This result can be interpreted as fewer kills than expected occurring at human-use areas, highway pull-outs, and open wet areas that were classified as open areas. Other studies have also shown that animals avoid the proximity of humans at points where they cross roads, preferring to approach roads hidden by tree and shrub cover (Bashore, Tzilkowski, and Bellis 1985; Jaren et al. 1991; Clevenger et al. 2003; Seiler 2003; Malo et al. 2004).

Elevation was the only significant variable in the Kootenay logistic regression model, and more kills than expected occurred in lower elevations characteristic of the lower montane habitat. The sheer number of collisions in this section of habitat underscores the importance for mitigation across the highway valley bottom to allow for safe east-west movement of ungulates across a critical habitat range (Poll 1989). The already existing highway right of way was cleared of forest growth on both sides of a 23.9-m section of highway within the low montane habitat with the intention of creating more visibility for motorists to react to animals crossing the highway (Alan Dibb, Parks Canada, pers. comm.). Studies have shown that clearing of vegetation provides an alternative source of forage for ungulates (Poll et al. 1984) and attracts animals to the road (Bellis and Graves 1971, Puglisi et al. 1974, Carbaugh et al. 1975, Bashore et al. 1985, Lehnert and Bissonette 1997). Clearing vegetation may improve driver line-of-site; however, if the majority of accidents occur at night (Joyce and Mahoney 2001, Gunson et al. 2001), then this effort remains futile.

More kills than expected occurred on flatter grades of highway right of way from 0-30 m away from the road. In addition, there was a higher probability of collisions where the landscape terrain was flat, rather than raised or buried on either side. This is a similar result to Clevenger et al. (2003), which showed that optimum crossing points for small mammals were situated where roads run level with the adjacent landscape, and Malo et al. (2004), which showed collisions are rare where roadsides have high embankments (> 2 m). This was the only region where kills occurred at flat grades in relation to the highway. In the Bow region, provincial land has a higher area of lower montane habitat across the valley bottom, i.e., 92 percent of a 2-km section of landscape surrounding the roadway is < 1,240 m. Animals in the other watersheds have to navigate a relatively more constricted valley lending to steeper landscapes close to the roads, i.e., less than 70 percent of the landscape was < 1,240 m.

Barriers are used by highway planners when the likelihood of a vehicle leaving the road is greater than in other locations, e.g., curvature in the highway or where conditions in the landscapes present a higher risk of injury for vehicles leaving the highway, such as open water and steep topography (Terry Hale, NYDOT engineer, pers. comm.). Kills occurred closer to jersey barriers and guardrails in the Bow where these barriers were frequently used along the roadway due to high traffic volumes and speeds. Because the presence or absence of barriers was not a significant variable in the Bow this result suggests that animals are funneled toward road crossing points close to barrier ends by features within the landscape, i.e., open water areas. This variable would have to be further explored, i.e., where are the barriers in relation to landscape features to better interpret if this result is a function of road-motorist factors or due to features evident in the surrounding landscape.

It was expected that UVCs would occur at points in the highway where the driver visibility is impaired by changes in elevation and curvature along the road network. In this study, all the field in-line and angular visibility measurements did not contribute to the occurrence of UVCs probably for several reasons. Vehicles tend to slow down along these sections of highway, which allows more time for drivers to react to crossing animals even though the driver may not see the animal as quickly as in a straight, flat section. Secondly, more animal-vehicle collisions occur at night (Joyce and Mahoney 2001, Clevenger et al. 2001) when deer activity (Kinley and Newhouse 2003) and moose activity (Joyce and Mahoney 2001) are higher than in midday. The line of sight may not be a factor for drivers at night when in most cases the animal is not seen before the collision occurs. Bashore et al. (1985) also had unexpected results where the in-line visibility was positively correlated to the occurrence of road kills, and related this to an increase in speed at straighter sections of highway. However, when the shortest distance of all the angular and in-line measurements was used, it was negatively related to the probability of vehicle-deer accidents (Bashore et al. 1985).

Many studies have shown that linear landscape elements, such as riparian corridors, ditches, steep slopes, or ridges, as well as fences, may funnel animals alongside or across the roadway, increasing the probability of collision (Bashore et al. 1985, Feldhammer et al. 1986, Madsen et al. 1998, Finder et al. 1999, Hubbard et al. 2000). In this study, we found that the presence of a waterway drainage perpendicular to the roadway was not significant in all watersheds. This can largely be explained due to the presence of a bridge associated with some of the water crossings, which may have provided a tunnel for wildlife to traverse the highway (e.g., in the Kicking Horse, 53 percent of the waterways used in the analysis allowed underground passage for animals). Similarly, Seiler (2003) found that the risk of collision was higher where private roads connected to the main road, but the risk decreased where tunnels or bridges separated the intersecting roads. In addition, many of the water crossings were associated with steep topography typical of mountain landscapes, which may cause animals to travel the highway corridor in search of more level crossing locations.

Model building

It is interesting that the majority of variables that were significant were the landscape-animal interaction variables and the Akaikes weights and goodness of fit scores were higher for the landscape model than the road-related model. However, the Akaikes weight was highest for the combined model, indicating all variables were important in determining road-kill occurrence. This suggests that there may have been some important road-related variables, i.e., driver behavior, signage, traffic speed, etc., not included in the analysis, which may strengthen the applicability of the road-vehicular model.

The combined model did not perform as well as the individual Bow model probably because the model had more difficulty predicting which variables were associated with kills since the landscape heterogeneity differed between the provincial lands and the National Parks. The validation accuracies were not as high in this analysis as in other similar studies analyzing road-kill occurrence (Clevenger et al. 2003, Seiler et al. 2004). Typically, habitat type is homogeneous in the National Parks of the CCRMs, which may have made it difficult to predict spatial patterns of UVCs with fine-scale variables, such as differing habitat types and extent of forest measures. However, broad-scale landscape variables, such as elevation, were excellent predictors of collisions within the CCRMS. Further, there may have been several pertinent variables missed from the model, such as animal abundance measurements.

Summary

The predictors of UVCs found in this study might be extrapolated to other areas of mountain parks with similar landscapes and mammal species. Models must be extrapolated to other study areas with caution and should be used as a starting point to predict vehicle collisions, but they may need to be refined at each study area. The scale of measurements is important, as well as the scale of the region being modeled. Variables can be described and measured in an infinite number of ways, especially between different observers. The initial selection of road- and landscape-related factors should be done by biologists who know their study area and target species well. Sensitivity analyses should be performed to determine how scale and measurement of variables change the outcome of the model.

Management implications

This study has shown that the more open habitat in the Bow watershed led to key ungulate-vehicle collision hotspots. Further, the high Akaike's weighting of the landscape model suggests managers should concentrate on factors in the landscape that draw animals to the roadside; however, most of the time this is not possible since local flat terrain and habitat funnel animals to roadsides. In this case, mitigation measures such as fences and crossing structures should be used that have proved effective in decreasing animal collisions while allowing animals to safely traverse transportation corridors in the Mountain Parks (Woods 1990, Clevenger and Waltho 2000, Clevenger et al. 2001) and in Spain (Mata 2004). At the very least, managers can limit the area of cleared palatable grasslands within transportation corridors that would attract animals to roadsides regardless of local topography and habitat.

The high cost of physical structures such as overpasses limits their installation to a few sites (McGuire and Morrall 2000), which may make it difficult to place these structures along an extensive stretch of highway. The aggregations of kills in the Kootenay and the Bow provincial lands along certain stretches of highway make it easier to pinpoint the location of effective mitigation measures, such as fencing, crossing structures, or infra-red animal detection systems (Kinley and Newhouse 2003).

Biographical Sketches: Kari Gunson is a wildlife research biologist who is currently working on her Ph.D. in environmental science and forestry at the State University of New York. Her research is investigating the effects of roads on herpetiles in New York State. Previously she was subcontracted by Parks Canada to examine the effects of roads on wildlife populations in the Banff-Bow Valley and the surrounding national and provincial parks. She is a graduate from the University of Calgary, Alberta, and has a master's degree in conservation biology from the University of Capetown, South Africa. Her research in South Africa used landscape ecology and resource economics in a geographic information system (GIS) to determine the economic importance and sustainability of use of wetland plant resources within the local community.

Tony Clevenger is a wildlife research ecologist at the Western Transportation Institute, Montana State University (Bozeman, Montana) and has been studying road effects on wildlife populations in the Banff-Bow Valley and the surrounding national and provincial parks since 1996. Dr. Clevenger is a graduate of the University of California, Berkeley, and has a master's degree in wildlife ecology from the University of Tennessee, Knoxville, and a doctoral degree in zoology from the University of León, Spain. He is currently a member of the U.S. National Academy of Sciences Committee on Effects of Highways on Natural Communities and Ecosystems.

Bryan Chruszcz completed his B.S. in biology at Queen's University in Kingston, Ontario, and his M.S. in ecology at the University of Calgary. His M.S. research examined the foraging, roosting, and thermoregulatory ecology of bats in the badlands of southeastern Alberta and in eucalypt forests in Queensland, Australia. Mr. Chruszcz has spent the past six years working as a wildlife ecologist for the Trans-Canada Highway Wildlife Research Project in Banff National Park. He is currently working as a wildlife ecologist and consultant on a variety of projects across western North America.

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Chapter 10

Wildlife and High Speed Rail

California High Speed Rail Proposal: "High Speed Rail and Wildlife"

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Abstract

The California High Speed Rail (HSR) Proposal is in the initial planning phase. In response to increasing population and an overtaxed transportation network, a 700-mile HSR proposal has been proposed to link major metropolitan areas in the state. The HSR proposed would be devised of state-of-the-art technology, travel at a maximum speed of 220 miles, a 50-foot right of way, and include at-grade, aerial, and tunnel alignments. The entire length of the at-grade alignments would be fenced. Due to sophisticated communications systems, trains would be frequent, with options for local as well as long-distance use. Travel times are comparable to, and in some cases surpass, door-to-door travel times for driving or flying alternatives.

The Final Environmental Impact Report/Statement (FEIR/S), which was released in August 2005, concludes that the HSR option leads to decreased energy consumption, reduced air pollutant emissions and improved air quality, uses less land, and has fewer overall impacts to sensitive habitats and water resources than either the option to continue with currently planned transportation projects or to expand existing highways and airports. A major concern in terms of wildlife is the impact of the fencing on wildlife movement and migration corridors. The California HSR Authority has decided to relegate the analysis of this impact to the project-level environmental documents. There is a recognized concern that this approach will fail to provide the landscape-level analysis necessary to accommodate the wildlife movement needs.

The environmental review process revealed several areas of controversy. For the northern mountain crossing connecting the Bay Area to the Central Valley, there was a concern that the Altamont Pass alignment, which tracks I-580, was not included as an option. As a result, the HSR Authority will be working with groups in the Bay Area on an additional EIR/S to specifically choose the alignment on this crossing.

A second area of controversy is the southern mountain crossing, which connects the Bakersfield to Los Angeles stations. Seismic and tunneling constraints caused the southern mountain crossing to be chosen, which cuts east into the West Mojave Desert with a station in Palmdale instead of following I-5 directly south. This decision was made despite major concerns of direct and growth-inducing impacts to the West Mojave Desert. Those with a desire to decrease impacts to public lands or to expand the growth in the city of Palmdale were in support of this option.

The third area of controversy concerned impacts on parks, wildlife areas, and recreational resources. As a result, no alignments were chosen through Henry Coe State Park, Don Edwards San Francisco Bay Wildlife Refuge, or San Luis State Recreation Area. Additionally, alignments which occur adjacent to state parks will occur on existing rail corridors, and other concerns will be considered at the project level.

The final area of controversy was the growth-inducing impact of the stations themselves. All stations are required to serve as multi-modal sites.

Identified environmental impacts will be avoided, minimized, and mitigated. Nearly 70 percent of the alignments will occur on existing transportation corridors and rail lines. Only 24 percent of the alignment will be at-grade in new corridors. Underpasses and overpasses will be designed during the project-level analysis, and tunneling will occur in mountainous habitat in major portions of the undeveloped alignments. Mitigation will be determined at the project-level but may include project-design changes, contribution to a conservation bank or natural management area, relocation of sensitive species, and construction of wildlife underpasses, bridges, and/ or culverts. The FEIR/S also outlines specific mitigation strategies to be employed at the project level for plant communities, biological resources management plans, sensitive plan species, invasive species, wildlife movement and migration corridors, and jurisdictional waters and wetlands.

For details on the California High Speed Rail Proposal, please visit the California High Speed Rail Authority's website at: www.cahighspeedrail.ca.gov

Biographical Sketch: Cynthia R. Wilkerson is a conservation biologist with the California office of Defenders of Wildlife. She has been with Defenders for over three years and has developed and implemented on-the-ground wildlife conservation campaigns focusing on reducing conflicts between humans and bears, desert habitat and species conservation, regional conservation planning, and road ecology. The species covered by this work include the black bear, Channel Island fox, San Joaquin kit fox, desert tortoise, Mohave ground squirrel, and Pacific fisher. Ms. Wilkerson has an undergraduate degree in conservation biology from the University of Washington and a master's of science in wildlife ecology and conservation from the University of Florida. As an undergraduate, she formed a non-profit research organization in British Columbia's Great Bear Rainforest and conducted fieldwork on the acoustic behavior of song sparrows, plant ecology, marbled murrelets, and northern goshawks. Her master's research focused on the importance of isolation to temporary wetlands and included field work as well as spatially-implicit modeling. Ms. Wilkerson's professional interests and experience include natural resource group facilitation and conflict resolution, regional conservation planning, landscape and spatial ecology, and conservation policy.

Potential Ecological Impacts Analysis of California High Speed Rail

Dick Cameron (dcameron@tnc.org), The Nature Conservancy, co-authors **Mike White** and **Jerre Ann Stallcup**, with additional material on behalf of **Kristeen Penrod**, Southcoast Wildlands Project

Abstract

The Nature Conservancy and the Conservation Biology Institute conducted an analysis of the potential environmental impacts of the proposed California High Speed Rail project as detailed in the 2004 Draft Programmatic Environmental Impact Report. The analysis intended to match the scale of the programmatic EIR in order to inform comments and to create a synoptic view of the project with select focal examples of potential impact areas for non-governmental organization partners and funders. An initial, more thorough, analysis covered areas outside of the Bay Area alignments. The question of choosing the high speed rail modal alternative versus the increased highways and airports or no action alternatives was not addressed.

The analysis utilized GIS and was based on high speed rail alignment data, including information on structure (bridge, tunnel, trench) and spatial alignment relative to right of ways (in, adjacent, new). For each geographical region and subset, proposed options were analyzed in terms of their ecological impacts. Data layers used were: public land and private conservation land (2003), wetlands and vernal pools, The Nature Conservancy portfolio conservation areas, the California Natural Diversity Database, potential wilderness, and potential wildlife linkages. Impacts from construction as well as operations and maintenance were included. Direct impacts include removal of vegetation, wildlife mortality, water pollution, noise, light, and vibration. Indirect impacts include changes in surface and groundwater flow, wildlife behavior and movement, potential changes to disturbance, invasion of exotics, growth inducement, and potential benefits associated with restoration opportunities.

An example of the analysis results is displayed, detailing the scope and specificity of the report output. The results indicate that special areas for concern are: habitat fragmentation for wide-ranging species in the southern Sierra Nevada and Transverse Ranges; Orange and San Diego counties in terms of threatened and endangered species, lagoons, interior stream habitats, and wildlife linkages; wetlands and vernal pools in the Central Valley; and the Western Mojave Desert in terms of growth inducement and impacts to groundwater.

The EIR did not provide sufficient information to make a decision on preferred routes. Although a system-wide assessment is the time to consider range-wide effects on ecosystems and species, the programmatic EIR deferred many analyses to project-level review, which is constrained to a specific geography to such a degree that many issues would be ignored.

In order to take advantage of the opportunity to restore connectivity with the high speed rail project, it is recommended that wildlife crossing structures should be: located along natural travel routes, with suitable habitat and topography for target species; designed to accommodate different taxonomic groups; located every 1.5 to 2 kilometers; aligned with crossing structures on Interstates and highways; integrated with sound walls to reduce the adverse affects of noise, vibration, and light on wildlife movement; and integrated with fencing where beneficial to guide animals toward crossing structures.

The overall analysis suggests that there are several thematic areas in need of further consideration at broad scales. Opportunities exist to restore movement barriers, and these options should be further explored. Overall, the EIR/S inadequately analyzed major environmental impacts including noise, light, invasive species management, and wildlife linkages and potential to restore connectivity. The authors conclude that interagency collaboration between the High Speed Rail Authority, transportation agencies, and land management agencies (USFS, BLM, State Parks), and the development of a long-term coordinated plan will improve the project ecologically.

Southeast High Speed Rail (SEHSR): A Case Study

William Gallagher, SEHSR Core Team Member (www.sehsr.org)

Abstract

An overview

With tremendous economic and population growth, the Southeast needs a comprehensive, multi-modal transportation system. High speed rail service will provide business and leisure travelers with a competitive and affordable alternative to air and automobile travel for trips of 100 – 500 miles.

High speed rail in the Southeast will mean top speeds of 110 mph, using advanced energy efficient diesel locomotives, with average trip speeds of 85 – 87 mph. Virginia, North Carolina, South Carolina, and Georgia have joined forces with their business communities to form a four-state coalition to develop a high speed rail network connecting their states with Washington, DC, and the Northeast. This rail network will be developed incrementally, upgrading mainly existing rail rights-of-way and requiring few new right-of-way acquisitions. Environmental, planning, and engineering work is further along in the Washington–Richmond–Raleigh–Charlotte section of SEHSR, where local track and infrastructure upgrading is already taking place, shortening travel times and providing greater capacity and trip reliability.

Tiered environmental process

North Carolina and Virginia, working with FHWA and FRA, completed the Tier I EIS for the Washington–Charlotte portion of SEHSR in October 2002. This study phase examined the need for the project and looked at potential impacts on natural and manmade environments along nine possible route alternatives. Twenty-six public workshops and 18 public hearings were held to solicit feedback on the project. Meetings were regularly held with local and state leaders, railroads, state and federal planners, and resource agencies as part of the process.

The purpose and need developed during this phase included: provide affordable transportation options; ease the growth of congestion of alternate travel modes; improve air quality; improve transportation safety and provide efficient energy use; and minimize environmental impacts.

The Tier II EIS is currently underway for the Petersburg, VA–Raleigh, NC, portion of SEHSR, providing a detailed analysis of possible local impacts, including station spacing, and location and capacity of the trackage infrastructure.

The Aftermath of Hurricane Ivan: Reconstructing Roadways While Recovering Species

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Abstract

Reconstructing roadways following Hurricane Ivan presented both challenges and opportunities for protected-species recovery. A major challenge was balancing the desire for rapid restoration of major transportation linkages with the regulatory need to minimize harm to rare coastal species. Animals like the Perdido Key beach mouse (PKBM) were already severely impacted by the storm and additional losses could have affected their continued survival. Lessons learned from Ivan will assist state and federal transportation agencies, state resource agencies, the Federal Emergency Management Agency (FEMA), and the U.S. Fish and Wildlife Service (FWS) in responding to future natural disasters.

Hurricane Ivan made landfall as a Category 3 storm on September 16, 2004, passing between the cities of Mobile, Alabama and Pensacola, Florida with the eye located just west of the Alabama-Florida line. Storm surge, winds, and waves resulted in heavy damage to many miles of coastal roadway, major bridges, numerous residential and commercial structures, state and federal park facilities, and coastal habitat for federally protected species. Winds were in excess of 111 mph. The tidal surge was 12-14 feet, with a peak wave height of 53 feet. Erosion occurred inland for up to 200 feet. Road damage in Florida included the collapse of a portion of the I-10 bridge, damage to bridge approaches, and extensive pavement destruction on SR 292, SR 399, and US 98 in Santa Rosa and Escambia counties. Some of the protected species and their critical habitat that occur in the area include the Gulf sturgeon, PKBM, piping plover, and nesting beaches for sea turtles.

Road repairs began after the storm using Endangered Species Act (Act) Emergency Consultation Procedures. Recognizing that emergency road work could affect remaining beach mouse habitat, the FWS and Florida Fish and Wildlife Conservation Commission (FWC) distributed road-repair guidance for county, state, and federal transportation agencies. After initial contact by the Florida Department of Transportation (FDOT) for specific projects, the FWS provided recommendations to minimize effects on listed species or their critical habitat. In situations where listed species or critical habitat may have been adversely affected by the emergency response, formal consultation takes place after the emergency work is completed. Normal consultation procedures on repair work began once the emergency situation was past. In preparation for future emergencies, guidance on Emergency Consultation Procedures is provided on the FDOT Central Environmental Management Office's website at: http://dot.state.fl.us/emo/ as well as the FDOT's Permitting Handbook.

The framework of Florida's new Efficient Transportation Decisions Making (ETDM) process assists in providing a rapid response to emergencies. ETDM designates specific personnel within the natural resource agencies to coordinate transportation-project review. Having a central point of contact prevents time lost in determining consultation responsibility.

Emergency restoration funds received by counties, state agencies, the Federal Highway Administration (FHWA), and FWS have greatly assisted in hurricane and endangered-species recovery efforts. State park facilities at Perdido Key and Big Lagoon are being rebuilt as an interagency cooperative effort between the Florida State Parks, FHWA, and FDOT. Roads are being repaired or replaced as needed. Sea oats and other dune vegetation are being planted to re-establish dunes, providing both improved habitat and protection from future storms. New fencing along park boundaries will help control parking and direct visitor access, preventing the continual "wear and tear" on dunes by pedestrian traffic. Control of predators attracted by storm-debris piles is also underway.

In states prone to fire, flood, hurricanes, and other catastrophic events, it helps to have a plan in place before a natural disaster strikes! Resource agencies should have a central point of contact for transportation projects, which often require coordinating multi-species and multi-county concerns. Rapid completion of damage assessments by state and federal biologists is needed to acquire the emergency funds critical for restoring habitat after a natural disaster. Finally,

a willingness to cooperate between agencies is essential to achieving multi-agency goals in emergency situations. The experience of Hurricane Ivan demonstrates that crucial transportation systems can be restored rapidly while incorporating measures to protect our invaluable natural resources.

Biographical Sketch: Mary Mittiga is an ecologist and has worked since 1998 with the U.S. Fish and Wildlife Service in Panama City, Florida. Her current position as transportation liaison is dedicated to review of transportation projects and policies, including NEPA review, ESA consultations, streamlining initiatives such as ETDM, regional-conservation planning, and Clean Water Act Section 404 review. Mary holds a bachelor's degree in biology from the College of Wooster in Wooster, Ohio and a master's degree in environmental engineering from Florida State University, Tallahassee, Florida.

Vicki Sharpe currently works in the Central Environmental Management Office of the Florida Department of Transportation (FDOT) as the State Transportation Ecologist. Since 1989, she has been employed by state government agencies in Florida to manage environmental programs involving a broad range of ecological issues related to phosphate mining, surface-transportation planning, and large-scale development projects. She has more than 10 years of emergency-management experience serving various functions in response to hurricanes and other natural disasters. Vicki manages the statewide wildlife and ecology programs for FDOT. Her primary interests include wildlife and fish-habitat initiatives, habitat connectivity, landscape ecology, long-term regional conservation planning, and overall natural-resources and ecosystems management. She is also the Project Manager for environmental-research projects funded by the agency pertaining to wildlife and habitat research.

Assessing Functional Landscape Connectivity for Songbirds in an Urban Environment

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Abstract: Worldwide, urbanization is recognized as a leading cause of species extinction because of its role in rapid and permanent habitat loss and fragmentation. This study investigates how habitat fragmentation caused by urbanization and transportation corridors affects the movements—and ultimately, the occurrence—of songbirds within a human-impacted landscape.

In spring and summer 2005, I used audio playbacks to measure the willingness of birds to cross small-scale features such as roads, railways, rivers, and transportation bridges over riparian corridors within the urban landscape of Calgary, Alberta, Canada. Preliminary results indicate a negative correlation between the likelihood of forest-dependent birds crossing roads, rivers, and bridges over riparian corridors and the width of the gap in vegetation associated with these features. In contrast, railways appeared to be highly permeable for forest birds, probably due to their relatively narrow width.

This study is still in its earliest stages. Subsequent phases of the project include: (1) using translocations to measure the permeability of larger-scale elements of the landscape such as freeways and neighbourhoods of various ages and densities, (2) developing individual-based, spatially explicit models aimed at depicting functional landscape connectivity among the city's natural areas, and (3) exploring the relationship between landscape connectivity and bird species occurrence within these natural areas.

Background and Purpose

In fragmented landscapes, biodiversity is often dependent on habitat connectivity because without it, the exchange of genes and individuals is constrained and small, isolated populations become at greater of risk of extinction (Soule 1986). Movement is a process of central importance to the persistence of species in fragmented landscapes because it underlies dispersal and colonization (Belisle and Desrochers 2002).

In the past decade, a limited number of studies have attempted to elucidate the effects of linear features and gaps between habitat patches on the movement of birds. Taped playbacks of mobbing calls have been successfully used to lure birds across selected small-scale features such as roads or meadows (Rail et al. 1997, Desrochers and Hannon 1998, St. Clair et al. 1998, Belisle and Desrochers 2002, St. Clair 2003). In larger-scale experiments, territorial birds have been translocated and their return trip documented (Belisle and St. Clair 2001). Both playback and translocation techniques have made it possible to standardize the motivation of birds to cross different landscape elements so that their permeability can be quantified and compared.

The primary purpose of this research project is to investigate how habitat fragmentation caused by urbanization and transportation corridors affects the movements—and ultimately, the occurrence—of songbirds within a human-impacted landscape. The study is being carried out in Calgary, Canada's fastest growing city.

Methods

I used an audio recording of a Black-capped Chickadee (*Poecile atricapillus*) and a Red-breasted Nuthatch (*Sitta canadensis*) to lure birds across selected small-scale features of the urban landscape and thus assess their willingness to cross these features. Each trial involved attracting birds to an origin speaker and then to a destination speaker located on either side of a potential barrier. Immediately upon turning the origin tape off, the destination tape was turned on and the response of each bird noted. A response was considered positive if a bird moved from the origin to the destination within six minutes from the time the destination tape was turned on.

This year's playback experiments, conducted from May 2 to August 26, 2005, focused on four features: (1) roads of varying widths and traffic volumes, (2) railways (including transit lines), (3) transportation bridges over riparian corridors, and (4) rivers. Each trial across a feature was paired with a control trial conducted in similar habitat conditions, but in continuous forest cover.

Preliminary Results

Only data collected during the breeding season (May 2 to June 15, 2005) have been analyzed thus far. During this time, a total of 325 birds responded to playback experiments in 103 separate trials. Black-capped Chickadees were the most common species to respond, representing 63% of the total responses. Only chickadees and nuthatches were included in the analyses, as they were the only family groups represented by a sample size of at least 25 individuals. Logistic regression showed that the probability of chickadees and nuthatches crossing roads quickly decreased as the trial distance exceeded 30 m. At 50 m, these birds were 60% less likely to cross roads than they were to travel through continuous forest. At 80 m, this difference increased to 80%.

A similar, but slightly less pronounced, pattern was found for bridges over riparian corridors and rivers. In contrast, chickadees and nuthatches were equally as likely to move across railways as they were through continuous forest.

Discussion

These preliminary results suggest that gap width is one of the most important factors affecting the willingness of forest-dependent birds to cross features in the urban context. For most features, as the gap in vegetation increased, the likelihood of a positive response decreased. The high permeability of railways was likely due to their narrow width, which resulted in a vegetation gap of less than 20 m.

Vegetation height also appeared to be a key factor affecting movement, particularly in relation to bridges and roads. The presence of tall trees on either side of a bridge appeared to facilitate movement as birds typically attempted to cross over the structure, from treetop to treetop. Chickadees and nuthatches almost never flew under a bridge. Tall trees on either side of busy roads also appeared to make it easier for these birds to cross above moving traffic.

Next Steps

In the next several months, I will conduct multivariate analyses to better elucidate the factors affecting the permeability of urban features to the movements of forest-dependent songbirds. I will then compare the breeding-season playback data to more recently collected post-fledging data to examine seasonal differences in movement behavior. Playback experiments will also be conducted in winter 2006 to further explore seasonal-movement patterns.

Because the spatial scale of playback experiments is constrained by the distance at which sound will carry, starting in spring 2006 I will use translocations to assess the permeability of larger landscape features such as freeways or residential neighborhoods of different ages and densities. Each translocation experiment will consist of capturing a territorial male bird in a mist net, moving it a distance of 200 m to 2 km and documenting its return trip to its home territory. Using these empirical data, I will then determine functional landscape connectivity among natural areas through the use of individual-based movement modeling within a GIS environment.

A final component of the project will be to examine the relationship between functional landscape connectivity and species occurrence. To this end, breeding bird surveys are being conducted over multiple years to determine the presence or abundance of bird species within selected natural areas. Through regression analysis, I will then explore how functional connectivity and patch-specific attributes (such as area and habitat quality) affect the composition of songbird communities within the city's natural areas.

Significance

Through the use of playbacks and translocations this study will provide novel, empirically-based information on the permeability of urban-landscape elements (including transportation corridors) to the movement of birds. Anticipated applications of the study's results include the development of guidelines aimed at facilitating the movements of songbirds across transportation corridors and urban areas, as well as the identification of priorities for restoration or preservation of habitats important to the movements of songbirds.

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Biographical Sketch: Marie holds a master's degree in environmental design (environmental science) from the University of Calgary, in addition to undergraduate degrees in education and engineering. In fall 2004, she undertook a Ph.D. in ecology at the University of Alberta. Her research focuses on the movements of songbirds in the urban landscape of Calgary, Alberta and is supported by several prestigious scholarships including a National Science and Engineering Research Council Postgraduate Scholarship and an Alberta Ingenuity Studentship Award.

Marie has over 11 years of teaching experience, including almost five years as an instructor of biology, ecology, environmental science, physical geography, and geology at Mount Royal College and the University of Lethbridge. She has also worked part-time as a wildlife consultant over the past several years, focusing on the effects of human activities and facilities on the movements of wildlife. Her most important contributions include modeling wildlife-movement corridors for elk, bighorn sheep and grizzly bears in the Radium Hot Springs area in southeastern British Columbia (her master's work), and developing a management strategy aimed at facilitating movements of large- to mid-sized mammals in the Lake Louise area in Banff National Park. Most recently, in 2004 she co-authored a report addressing the effects of exclusionary fencing on the movements of mammals in the Lake Louise area of Banff National Park, Alberta.

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Bird-Protection Walls: An Innovative Way To Prevent Bird Strikes?

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Abstract: Bird strikes have been known for a long time as a severe negative effect of vehicular traffic. While the phenomenon has been studied for a couple of decades, the prevention of road kills has not been solved yet reassuringly. Of the several methods applied to reduce the collision risk, this study examined solid bird-protection walls that are pitched to raise the flight path of the small songbirds that cross the road.

Most specifically, the study examines the effects of applying bird-protection walls on the number of bird strikes and on the behavior of birds. The research area was situated along a four-lane motorway in Eastern Hungary, Central Europe. Extensive fieldwork was carried out in order to map the local breeding and migrant avifauna and to learn their substantial reactions to the barriers in their flying path. In parallel with observing live birds, road kills were also registered during the whole period of the study. The collected data were analyzed in function of the location of walls, of the relevant bird habitats, and of the technical parameters of the examined road section.

The results? Some issues related to road kills and identified the group of the most-threatened bird species. Several causes of the high risk of bird strikes could be determined and, surprisingly, none of them seemed to be handled efficiently by building these types of physical barriers.

The final results of the study are expected to become public at the end of the year.

Introduction

Several researchers have been discussing the patterns and ecological significance of road kills (Briggs et al. 1994, Primack and Standovar 2001, Hirvonen 2001, Erritzoe 2002), some have also studied those factors that seemed to give rise to the collisions (Erritzoe et al. 2003). Although it would have been a logical approach, crossed migration routes have not been mentioned in European studies so far among the main reasons of the high number of bird strikes. In Central and Eastern Europe, a significant number of passerine species migrate in large volume. They fly from tree to tree at a height of 5-10 meters from the ground surface. Their migration paths usually run along watercourses or long strips of forests and the birds flock together during their movement. Since (theoretically) a migration path crossed by a road can result in numerous road kills, the examined bird-protection instruments were designed at the intersections of the motorway and ecological corridors that were considered relevant in the migration of small songbirds. The walls are simply meant to raise the flight path of migrating birds that cross the roads at the height of the vehicles.

This study examines how effective these bird-protection walls are as regards to both the total number of bird strikes and the behavior of birds. In the paper we address several issues related to the ecological impacts of transportation on birds, especially those that are closely connected with road kills.

We report on: (1) what bird species are especially threatened by road hits, (2) which birds tend to avoid the motorway, (3) how birds react to the walls, (4) whether the number of bird strikes is lower behind the walls than anywhere else, (5) what species can really profit from this protection, and (6) whether the efficiency of the walls differs significantly in case of different types of habitats.

The study was funded by the Hungarian National Motorway Company (NA Rt.), who built the walls at the examined road sections. The project is divided into two phases; the first phase was the present research, while the second phase is expected to corroborate and refine the results of the first phase and it will aim at estimating the future risk level of bird strikes on the next, newly built road sections.

Study Area

We conducted this phase of the survey along a 7-km-long section of a four-lane East Hungarian motorway. This motorway is the only fast connection between the capital city and the Eastern part of the country, with an increasing traffic volume of around 5,000 to 11,000 vehicles per day.

The study area belongs to the ancient flood plain of River Tisza and it is occupied primarily by ploughlands, saline grasslands, and riparian vegetation. The first bird-protection walls in the country were built here, at four points of this road section, in December 2002.

Except for a short section of a few hundred meters length, the motorway was placed on an embankment here. It crosses the River Tisza that is belted by a riparian forest, a smaller watercourse in the midst of the study area, and a few pastures with a fishpond in the background.

Methods

In similar studies, the number of bird strikes are compared before and after the implementation of the examined measure. As the bird-protection walls and the motorway were constructed at the same time, another approach had to be chosen to evaluate the level of protection provided by the walls.

Our hypothesis, initiated from the planned function of the walls, was: if the transportation threatens the migrating birds and the walls were placed exactly at the migration routes, there must not be road-killed migrant birds anywhere along the whole road section. Naturally, non-migrant, e.g., feeding birds may still be hit behind the walls or at the unprotected sections.

If a significant number of migrating birds were killed at the unprotected sections and none of them were killed behind the walls, migrant birds would indeed be at a high risk of road kills, but the walls would not entirely secure their migration routes. In the third case, i. e., if there were a number of road-killed migrant birds behind the walls, that would indicate the incapability of the barriers, provided there were not other road kills along the unprotected sections.

Considering the potential discrepancy between numbers counted and numbers killed (Slater 2002), the initial hypothesis needed further indirect reinforcement based on other type of data than the sheer number and distribution of bird casualties. Primarily, a better understanding of the local migration paths and the migrant bird species, as well as their behavior, seemed to be essential. Similarly to the vagrant and migrant species outside the migration period, the role of the resident fauna could not been disregarded either. Also, several studies have demonstrated the vulnerability of breeding birds in the vicinity of roads (Reijnen and Foppen 1995, Reijnen et al. 1996).

To get an insight into all the above-mentioned issues, the study area was determined as a 400-400 m wide zone along each side of the road. Within this area, the bird habitats were classified and all the migrant, vagrant, and resident species were observed. The study area was divided into four easily recognizable zones (corresponding zones on both sides of the highway were combined): from the mid-line of the road up to the wildlife fence (on a par 10 m from the edge of the road), from 10 m to 50 m, from 50 m to 100 m, and from 100 to 400 m. We monitored and categorized the behavior of birds near the motorway in the zones within 100 m and tried to identify those human and non-human factors (e.g., traffic disturbance, habitat qualities) that significantly influenced their move. Behavior covered both birds' reaction to the traffic and characteristics of their move near the motorway. Their typically observed behavior was feeding, resting, breeding, crossing the road on their daily routes, and avoiding cars in motion.

From the point of view of the study, the most relevant factors were the typical approach distance and the typical height of the flight over the road.

The comparison of bird-counting data for sections farther than and within 100 m from the road helped us to select those species that are disturbed heavily by the traffic; these did not come closer to the motorway. According to our hypothesis, the crossing heights above the road surface were regarded as species-specific and a distinctive part of the behavior of birds. To select those species that tend to fly low over the road, we also recorded how many times and at what height (below 3 m, below 10 m, or higher) each perceived individual bird crossed the road above the walls and at the sections without walls.

The road-killed birds comprised the last source of data, which were registered in the function of the road sections. The data came from two sources. In the survey, we checked the roadside on foot one to three times every week during the whole study period. Technicians from the Hungarian National Motorway Management Companies also ran over the motorway by car at least twice a day, every day. They looked for animals bigger than a dove and only on the pavement. Thus, only a limited amount of valuable data was gathered during their work. Despite the different sampling method, their database helped us to obtain a quite-useful overview about road hits of larger birds like raptors and owls throughout the whole year.

Data Analysis

Since we managed to collect more than 5,000 occurences and behavior data altogether through the autumn and spring migration term, the database could be analyzed statistically. Both spatial and temporal distribution of the collected data was assumed to have great relevance, according to our examination approach.

The 3D spatial distribution of birds was drawn around the examined road section. As several authors (Briggs et al. 1994, Reijnen et al. 1997, Hirvonen 2001, Gutzwiller and Barrow 2003) have already pointed out, bird occurences perpendicular to the road are related to traffic disturbance. The second axis of spatial distribution (parallel with road) explains how the habitats of various quality influence the abundance of birds which are affected by the traffic. The typical flight height of the birds not only helps to estimate the theoretical risk of collisions, but we can obtain data on niche segregation among birds or on an aspect of species-specific behavior, i.e., how birds react to the traffic (they can be halted abruptly when they perceive the approaching cars and fly higher or can fly very high, excluding the possibility of any interference with ground transportation).

When more than 50 distinct occurrences data were available for a particular species, we set up three diagrams for the spatial distribution of the given birds around the road (as described above). The results were further refined by the perceived individual behaviors and the uncertainty in perception.

Despite the relatively large amount of data, the qualitative evaluation seemed to have a similar significance in those cases where we had little quantitative information on a given species or when a specific behavior form was experienced equivocally in the case of several species, but with no statistical significance. If these findings corresponded to our preliminary background knowledge of the given bird species, limited consequences could be drawn from the perceived individual, except for characteristic behavior.

The road kills were evaluated in function of the road length, of nearby habitats, and of the location of walls. The number of bird strikes was calculated for the protected and unprotected sections in the proportion of the total length of the examined motorway section.

Results

Altogether, the shorter or longer presence of 123 bird species could be demonstrated on this small area. Most of these species crossed the motorway at least once. The overwhelming majority of data was collected in spring, because of the favorable weather.

The spatial distribution of birds around the examined road section clearly indicated which birds approach the motorway and tend to cross at the height of the vehicles in motion and which birds avoid the busy traffic at a safe height.

From the three diagrams of spatial distribution, collision risk could be estimated for each species, as summarized briefly in the following. If the given bird approached the road frequently and if it mostly preferred crossing below 3 meters, it could be considered potentially threatened. The hot spots of high risk were selected on the basis of the distribution data along the road section.

The protection walls were considered efficient in the case if these potentially threatened birds all raised their flight path above 3 meters at the walls and if they did not dip down behind the walls onto the road. Also, in those road sections where there were not any walls, the threatened species could not usually fly over the road above 3 meters.

After the analysis, we found no proof that any of the four walls could prevent the striking of birds. On the contrary, the present structure of walls contributed to the slight increase of road kills. First of all, the solid walls formed windproof places for birds behind the walls at open grasslands (two documented hits). Secondly, raptors could sit on top of the walls and wait for the road-killed victims and small rodents that looked for dropped crop seeds on the road (two documented cases). Thirdly, birds could not see behind the walls, so flying over and dipping down abruptly behind the walls resulted in high-risk situations (one documented case of hits of 28 barn swallows in one group just before our study).

Road kills could be divided into three groups of birds: birds of prey, feeding passerines, and casual victims from other taxons. The birds most frequently hit in the survey period are listed below.

Table 1. List of most-frequently hit birds in the survey period

Tree Sparrow	**Bird species**	**Latin name**	**Number of road killed birds**
Barn Swallow	*Hirundo rustica*	20	
House Sparrow	*Passer domesticus*	12	
Long-eared Owl	*Asio otus*	4	
White Wagtail	*Motacilla alba*	4	
Corn Bunting	*Miliaria calandra*	4	
Buzzard	*Buteo buteo*	3	

As initially expected, the distribution of road kills showed no evenness. The highest number of victims, however, was found at the only resting place in the examined section. The number of road kills behind the walls was lower than anywhere else, but the difference cannot be regarded as significant. The migrant species accounted for half of the total number of road-killed birds, but the majority of these birds were killed before or after their migration.

Discussion

In conclusion, at this phase of the study, the following can be stated:

1. Unlike the initial assumption, migrant passerines are not threatened directly by the traffic. It is true that migrating birds were killed by cars at certain points of unprotected road sections, but they gave only less than 3% of total road kills. The majority of the species in migration were observed flying at a safe height over the motorway. Daily moves between breeding/resting and feeding place led to more victims from this group of birds before and after their migration.
2. The present structure of walls does not fulfil the original bird-protection goals. They are not efficient protection instruments at all for any bird species in an open landscape, but with a slight modification they can be useful in those sites where dense, tall vegetation (e.g., a forest) is located close to the road at both sides.
3. The number of road kills itself proved an insufficient source of information in the survey. The number of road kills varies year by year. The victims can be found and identified statistically only in an unreliable way. The reasons for bird strikes can be numerous, in addition to the crossed migration routes. The risk of road kills can be estimated more precisely from a combined analysis of the classified behavior of types of birds and a habitat survey.
4. In the measured range of traffic density (3,500-10,500 cars/ day) the available resources relevant for birds (e.g., food) have a more-significant role in the presence and abundance of birds than traffic. Several bird species prefer the embankment, road surface, and bridges to the surrounding habitats for feeding and breeding. These birds will be killed by the vehicles in higher number than those birds that cross the motorway by chance.

While several results of the study have been outlined, further in-depth analysis of the database is needed to conclude the research. It is expected at the end of the year, after the present and upcoming field-work phase.

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Biographical sketch: Csaba Varga is a conservation consultant and coordinator of projects, including ecological impacts of transportation, for BirdLife Hungary Land Stewarship Advisory Service. He obtained a M.Sc. in ecology in 1994 and he has been involved in environmental-impact studies ever since. Csaba's current research focus include niche segregation of birds on motorways and population biology of owls affected by the traffic. Akos Monoki is the leader of a biodiversity-saving target program for the Nimfea Environment and Nature Conservation Association. Bence Barsony is a dedicated voluntary conservationist and member of the Nimfea Environment and Nature Conservation Association.

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California Innovation With Highway Noise and Bird Issues

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Abstract

The California Department of Transportation (Caltrans) and environmental-resource agencies such as the U.S. Fish and Wildlife Service have been concerned for many years with highway construction and operation noise impacts to birds, especially to species listed under the Federal Endangered Species Act (FESA). Mitigation implemented to date in California is conservatively estimated in the tens of millions of dollars, without clear evidence of need or benefit. This issue frequently occurs with high-profile species such as the marbled murrelet (*Brachyramphus maroratus*) in Northern California, as well as the least Bell's vireo (*Vireo bellii pusillus*) and California gnatcatcher (*Polioptila californica*) in the southern part of the state. Other transportation agencies in the United States, such as the Oregon State Department of Transportation, have also been working to resolve the issue in their state. Our approach involves an integrated partnership with the Federal Highway Administration, federal and state resource agencies, and the scientific community that is based upon recent successful experience by Caltrans in fisheries hydroacoustics.

The 60 dB (A-weighted) Leq (1 hr) criterion is usually applied as a threshold to assess impacts without scientific justification. For many projects, mitigation (e.g., seasonal work restriction) for noise impacts to birds has been required, resulting in delays to project delivery for Caltrans and other transportation agencies in California. Other types of mitigation have included attenuation at the source, noise barriers to intercept the path, and out-of-kind compensation such as invasive exotic-vegetation removal. To ensure compliance with both the letter and spirit of applicable statutes, more information and scientifically justifiable noise thresholds are needed, particularly for FESA-listed species. These data and thresholds will facilitate coordination with our funding partners and resource agencies, provide guidance to Caltrans' staff, and better inform the public and other stakeholders.

We intend to identify existing data gaps and the research necessary to bridge them. The process is beginning with a literature synthesis by bioacoustic experts Drs. Arthur Popper and Robert Dooling of the University of Maryland, who are part of the interagency expert panel. Next, we will develop interim noise thresholds, as well as FESA consultation and compliance protocols. This will also involve the interagency working and management groups—the other two of the three integrated panels. A key role of the management panel will be to make final decisions in case of dispute. Based on our efforts, we will develop a strategic research plan to provide data needed to address key uncertainties related to bioacoustic impacts on birds, including refined effect thresholds, metrics for effect criteria, and protocols for monitoring noise sources.

We expect that our integrated partnership will develop cost-effective, scientifically credible noise thresholds, and evaluation protocols in a timely manner applicable throughout the United States and possibly elsewhere. These thresholds and protocols will provide mechanisms to avoid, minimize, and compensate for adverse effects to birds, as well as to facilitate efficient and economic implementation of highway-related activities.

Colorado Wildlife on the Move: A Wildly Successful Road Ecology Awareness Campaign

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Abstract

In Fall 2003, the Southern Rockies Ecosystem Project (SREP), in partnership with the Federal Highway Administration, the Colorado Department of Transportation (CDOT), and Colorado State University, initiated Linking Colorado's Landscapes to identify and prioritize wildlife linkages in the state of Colorado. As the education and outreach component to Linking Colorado's Landscapes, SREP launched "Colorado Wildlife on the Move," a driver-awareness campaign. The goal of the campaign was to educate the motoring public in Colorado about the hazard of wildlife moving across roads and to improve driver awareness, thereby reducing the number of collisions with animals.

To assess the magnitude of animal-vehicle collisions (AVCs) in the state of Colorado, SREP worked with CDOT to analyze data from 1993 to 2004, identifying where and when the most AVCs occurred. With the help of SREP, CDOT was also able to pull out species-specific AVC data. With this information, SREP designed a media campaign in partnership with CDOT, the Colorado State Patrol, Rocky Mountain Insurance Information Association, and Enterprise Rent-A-Car. The campaign was based on data that identified November as the most dangerous month for drivers and wildlife due to the extremely high number of AVCs. A media event was then timed for the beginning of November to bring greater attention to this issue during this critical time. SREP developed two outreach tools for the event: a driver safety tip sheet and an awareness poster, featuring photographs from famed Colorado wildlife photographers.

The campaign was a wild success: all five Denver TV stations were present and the story was aired 12 times on local TV over the next 36 hours. In addition, both local and national papers covered the story. Over the next two months, articles featuring information from the "Colorado Wildlife on the Move" campaign reached over three million people. To date, 58,000 driver safety tip sheets and 500 posters have been distributed in welcome centers, national parks, and Enterprise Rent-A-Car offices in 85 cities and 175 locations. The tip sheets have already been reprinted three times to meet these needs.

Because of the great success of this campaign and the obvious interest and need for additional safety tip sheets, SREP intends to continue its media events and tip sheet distribution on an ongoing basis. Press events will be held in November and June, the two most dangerous months for drivers and wildlife.

Combining Three Approaches to Quantify the Barrier Effect of Roads: Genetic Analyses

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Abstract

The movement and dispersal of animals between populations is an important component of wildlife ecology and has been described as "the glue that holds local populations together." Without adequate ability to disperse, the rate of movement of individuals and DNA between populations is reduced and these populations become isolated, increasing the risk of local extinction.

Most research addressing the barrier effect of roads and traffic has focussed on the use of crossing structures by wildlife. Our study is a first for Australia and represents a unique collaboration to quantify the barrier effect in a highly fragmented landscape and (subsequently) the success of mitigation.

The aims of the project are to use genetic techniques and empirical observations to quantify the barrier effect of roads on the movement and dispersal of mammals, reptiles, birds, and invertebrates and to assess the effectiveness of structures and road designs intended to mitigate the barrier effect. Quantitative modeling will also be implemented to predict the effects of reduced movement on population viability.
A range of genetic markers is available for use in population biology to measure dispersal. Microsatellites are hypervariable and sensitive enough to be able to detect genetic differentiation in the short term and at small spatial scales, and are therefore appropriate to investigate genetic substructuring due to the presence of roads. Genetic analyses will be used at different scales of resolution. The genic approach will be employed for identifying population substructuring and patterns of gene flow at the population level. The genotypic approach will be used for finer-scale observations of dispersal of individuals.

Direct methods still provide highly reliable data on dispersal parameters, although they rely on logistically difficult field observations. Trapping and radio tracking will be used in the present project to be combined with and strengthen the results obtained from genetic analyses.

Repeated trapping will provide life history information which can aid in understanding the genetic data and contribute to the population viability models. Radio tracking will be used to collect information on daily movements of mammals in relation to foraging as well as dispersal and to assess the effectiveness of mitigation structures.

Finally, quantitative population modelling will be conducted to estimate the effects of inhibited dispersal on population viability. Data from observations and genetic studies will be used to characterise populations in terms of age and stage structures, fecundity, survival, and dispersal. Data collected over three years will be used to characterise variability in the parameters to improve population modelling.

Biographical Sketch: Dr. Rodney van der Ree is the ecologist at the Australian Research Centre for Urban Ecology (ARCUE). He obtained his Ph.D. in 2000 from Deakin University, where he studied the impacts of habitat fragmentation on arboreal marsupials in northeastern Victoria. He used the principles of landscape ecology to investigate the response of fauna to a landscape where the habitat was arranged as a network of linear strips along roads and streams. Rodney now brings this knowledge and skill to ARCUE to investigate the response of mammals to urbanization. Rodney will be investigating the distribution and abundance of mammals within the greater Melbourne area, with a focus on the rate of species decline, their habitat requirements, and survival prospects.

Combining Transportation Improvements and Wildlife Connectivity on Freeway Rebuild in Washington's Cascade Mountains

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Abstract

Interstate 90 over the Cascades is a significant barrier to over 250 species of wildlife, including cougar, elk, deer, mustelids (otters, fishers, badgers, etc.), amphibians, and reptiles. In the vicinity of Snoqualmie Pass, urban development to the west and agriculture and resort development on the east has shrunk the forest connecting the north and south Cascades to less than 64.6 kilometers wide.

The Washington State Department of Transportation (WSDOT) is proposing to expand a 24.15-kilometer stretch of Interstate 90 just east of Snoqualmie Pass through a particularly critical zone for north-south wildlife corridors. Absent effective wildlife-crossing structures, the expansion would worsen the barrier by increasing roadkill and further isolating populations, thus inhibiting genetic exchange. However, the state has made ecological connectivity a project goal, along with increasing capacity, straightening curves, and repaving.

The I-90 Wildlife Bridges Coalition has been working with WSDOT, other public officials, transportation interests, and the public to promote high-quality wildlife-crossing structures. Such structures can also improve safety for motorists by reducing collisions that are sometimes fatal to humans, as well as wildlife.

Good data is available to inform where to build crossing structures. WSDOT and the US Forest Service collaborated on a study entitled I-90 Snoqualmie Pass Wildlife Habitat Linkage Assessment (Singleton and Lehmkuhl 2000) that used tracking and road-kill counts to map existing crossing activity. Additional relevant information comes from analysis leading to the Snoqualmie Pass Adaptive Management Area Plan and I-90 Land Exchange (US Forest Service, 1997 and 1999) and Washington State Dept. of Fish and Wildlife studies of cougar movements using radio collars.

Recent land acquisitions and national forest-management changes have dramatically improved the outlook for habitat quality near the project. In recent years, purchases, donations, and exchanges have brought more than 50,000 acres of land valued at $200 million into public ownership and protection. The Forest Service is committing to additional habitat restoration, such as road removal.

Two of the distinguishing features of the I-90 project are the prevalence of wetlands associated with the Yakima River and the variation in habitat as precipitation and elevation decline from west to east. A variety of structure types—from extended vehicle bridges, to box culverts, to overpasses specifically for wildlife—is required to allow both hydrological connectivity and connections for a diverse array of species. Preferred habitat conditions and existing movement patterns are balanced with site-specific design considerations, including cost, to establish a range of possible solutions to be presented in a draft environmental-impact statement due in spring 2005.

Given the intense competition for transportation funds, particularly big-ticket projects near urban areas, the I-90 Snoqualmie Pass East project will need broad-based support to obtain funding. To overcome the environmental community's general opposition to expanded freeways, the project will need to provide a high level of wildlife connectivity. Project proponents will also need to navigate anti-tax politics by joining in a diverse coalition of agencies, conservation groups, and shipping interests. The recent partnership to acquire habitat north and south of the project points the way.

The coalition has grown out of a history of grassroots activism and collaboration around the Central Cascades region. Citizen involvement has played a critical role in the management policies of this area. The I-90 project will be a greater success due to the high level of attention and input received from the public. Public involvement will have peaked in the spring of 2005 with the release of the Draft Environmental Impact Statement followed by five public comment hearings throughout Washington State. This input will be considered throughout the summer of 2005 and (hopefully) brought to a successful completion in the fall/winter of the same year.

Controlling White-Tailed Deer Intrusions With Electric Fence and Mat

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Abstract

White-tailed deer (*Odocoileus virginianus*) pose a significant threat to human health and safety. During 1990-2003, the average cost of a deer/aircraft collision was $38,000. Various methods of fencing and gating exist to reduce deer intrusions onto airports. We tested one style of electric fence (ElectroBraid) and an electric mat in separate tests on free-ranging deer in northern Ohio by measuring deer intrusions and corn consumption at 10 sites. The fence reduced mean daily deer intrusions by 88-99 % in each test when the fence was powered. When power was turned on and off within a four-week period, intrusions decreased 57%. Mean corn consumption differed between treated (< 2-6.4 kg/day) and control sites (15-32 kg/day). In the electric-mat test, deer intrusions at treated sites decreased 95% for the six-week treatment period. Control site intrusions initially decreased by 60%, but returned to pretreatment levels by week 3. Mean corn consumption was similar between treated (16.2 kg/day) and control sites (15.7 kg/day). Results suggest that the electric fence and electric mat, under the conditions of the tests, may significantly reduce deer intrusions.

Biographical Sketch: Thomas W. Seamans is a certified wildlife biologist for the USDA/Wildlife Services/National Wildlife Research Center field station in Sandusky, Ohio. Tom has spent the last 18 years conducting research focused on finding biologically sound solutions to conflicts between people and wildlife. He received a B.S. degree in wildlife science from Cornell University and a M.S. in wildlife management from Ohio State University.

Empowering Stewardship With Technology—The Oregon Statewide Bridge Delivery Program

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Abstract

The OTIA III State Bridge Delivery Program is part of the Oregon Department of Transportation's 10-year, $3 billion Oregon Transportation Investment Act (OTIA) program. In 2003, the Oregon legislature enacted the third Oregon Transportation Investment Act, or OTIA III. The package includes $1.3 billion for bridges on the state highway system. During the next eight to 10 years, ODOT's OTIA III State Bridge Delivery Program will repair or replace hundreds of aging bridges on major corridors throughout Oregon.

Oregon Bridge Delivery Partners (OBDP) is a private-sector firm that has contracted with the Oregon Department of Transportation to manage the $1.3 billion state bridge program. OBDP, a joint venture formed by HDR Engineering Inc. and Fluor Enterprises Inc., will ensure quality projects at least cost and manage engineering, environmental, financial, safety, and other aspects of the state bridge program.

Technology is a key factor in the ability to deliver over 350 bridges in eight years. Charged with seeking cost-effective delivery solutions as part of the state's Context Sensitive and Sustainable Solutions (CS^3) initiative, OBDP is developing a suite of tools that will aid the program in its different disciplines. Tools include a mobile, PDA-based field reporting tool, a web-based comprehensive permitting form, and a comprehensive GIS database. Unifying these projects and the program is an electronic document management system (EDMS). This is the program's document repository. It is web-accessible, extendible to agency and contractor staff, and acts as a "backbone" for other information-development projects.

Not only do such initiatives streamline standard delivery practices, but they provide a project database on which metrics can be derived to measure the impacts of the program from a number of perspectives. For example, the environmental database can be queried to measure the ecological "footprint" of one project or all.

Engineered Logjam Technology: A Self-Mitigating Means for Protecting Transportation Infrastructure and Enhancing Riverine Habitat

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Abstract

Transportation projects set within river valleys are susceptible to incurring economic and environmental costs when they fail to recognize and accommodate geomorphic processes. For example, overlooking natural processes such as channel migration can lead to costly protection measures that adversely impact aquatic habitat and further exasperate problems elsewhere. In situations where proposed protection measures may adversely impact endangered species, the resulting regulatory constraints can result in major delays and cost overruns. River-reach assessments and new engineering technologies can provide transportation managers with valuable tools to find sustainable solutions to develop and maintain transportation infrastructure in sensitive environments. Reach assessments provide valuable scientific information on how a river has changed through time and how it is likely to change with or without the implementation of a particular project. New "biomimicry" technologies such as engineered logjams, which emulate natural conditions, offer a self-mitigating approach that successfully achieves project goals and regulatory requirements. Since transportation corridors occupy significant portions of stream and river valleys, the cumulative affect of implementing this type of approach presents a cost-effective opportunity for sustaining and restoring ecological integrity throughout the world.

Scientific advancements in the understanding the role of woody debris in river ecology has led to increased efforts and regulations to restore natural wood function to rivers. There are numerous benefits and advantages of strategic, well-designed wood placement in rivers, such as: food-web support, increased hyporheic connectivity and exchange, creation of salmonid spawning and refuge-habitat rehabilitation, bank protection, grade control, and debris retention. Wood is often a required element in bank-protection design for obtaining environmental permits in the PNW. However, there are currently no industry standards and protocols for the re-introduction and management of wood in rivers. Wood placement for habitat enhancement has largely been done without adequate scientific and engineering design and little or no consideration of consequences such as future debris accumulation, channel change, flood inundation, and safety hazards. The lack of engineering standards and information on the structural performance and longevity of wood-debris habitat structures has hindered the development and application of wood-based structures to treat traditional river-engineering problems.

The long-term success of river restoration efforts will depend on well-designed projects and how human encroachment into fluvial domains is managed to tolerate natural processes such as channel migration and wood loading. Functional wood loading can have significant effects such as channel avulsions and increased flood frequency. While these processes have important ecologic benefits, they can adversely impact human development that is not prepared to deal with the consequences. Efforts to expand protection of riparian forests, delineate channel migration zones, and in-stream habitat restoration will all lead to more wood in rivers. Thus the hydrologic and geomorphic consequences will increase in the coming decades. We present a design protocol that includes geomorphic analysis of channel dynamics and riparian conditions, force balance (stability), hydraulics, scour, constructability, material specifications, cost projections, risk assessment, and liability. Engineered logjam technology presents a rigorous alternative for reintroducing woody debris and natural complexity to rivers, while also treating traditional problems such as bank erosion. Engineered log jam projects constructed over the last 10 years demonstrate that this technology is capable of providing sound solutions that protect highways and restore aquatic and riparian habitat.

Biographical Sketches: Timothy B. Abbe, Ph.D., L.E.G., L.H.G., director of river science and geomorphology, Herrera Environmental Consultants. Tim Abbe has 17 years of experience in geology, geomorphology, environmental restoration, applying engineering principles in environmental project design, and solving problems in urban fluvial and coastal environments. He has pioneered the development of engineered logjams, which are artificial structures that emulate naturally occurring stream structures to achieve particular purposes (e.g., bank protection, grade control, and sediment trapping). His work on engineered logjams has offered new technology to professionals who must comply with environmental regulations while solving traditional problems such as runoff and bank erosion.

Jennifer Black Goldsmith is a senior scientist with Herrera Environmental Consultants in Seattle. Ms. Goldsmith has 14 years of experience conducting natural-resource assessments throughout the Pacific Northwest. Her professional expertise includes water resources, water quality, geomorphology, and forestry. Ms. Goldsmith has extensive experience preparing water-resource analysis documentation for a variety of environmental impact statements, reach analysis, environmental assessments, and permit applications for a variety of projects.

EVALUATING HYDRODYNAMIC SEPARATORS

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Abstract: With the advent of both federal and state storm water management regulations, state and municipal highway departments must consider a broad array of Best Management Practices (BMPs) for meeting storm water treatment objectives for both new road construction and roadway-improvement projects. In recent years, a number of manufacturers have entered the marketplace with a variety of proprietary devices for treating storm water. One of the most common types of devices is the hydrodynamic separator (also referred to as innovative water-quality inlet, particle separator, or swirl concentrator). Evaluating these technologies for application in the highway setting requires consideration of a number of factors relative to these devices' treatment performance, inspection and maintenance requirements, and installation and operating costs.

The Massachusetts Highway Department (MassHighway), under a cooperative agreement with the U.S. Geological Survey, recently conducted a detailed field study of water-quality inlets (WQIs) located on the Southeast Expressway in Boston. That study provided valuable lessons regarding storm water sampling protocols and data analyses used to evaluate hydrodynamic separators. (These products generally consist of refinements in the design of the standard WQI.) This paper discusses the lessons learned and offers recommendations for evaluating the performance of proprietary designs within this class of BMP.

A variety of findings came out of the Southeast Expressway (SEE) Study that should be considered when evaluating "hydrodynamic separators." The study evaluated two separate WQIs, each of which received storm water discharges from deep-sump (four-foot) catch basins. It was found that the one continuously monitored deep-sump catch basin had an annual suspended sediment removal efficiency (SSRE) of 39%, whereas the annual average SSRE for two WQIs was 32% (based on the remaining load after flow through the catch basins).

Captured sediments were comprised predominantly of sand-sized particles. Residence time was the primary factor controlling the SSRE. To a lesser degree, antecedent conditions and volume of rain also affected the SSRE. Other findings were that metals and nutrients tend to concentrate on particles smaller than sand and that sediment resuspension occurred in both the catch basin and the WQIs.

In addition to the limited suspended sediment removal efficiency of the WQIs, the SEE Study found that the WQIs were ineffective at removing soluble pollutants, fine particles, floatable solids (debris and litter), and oils and grease. Prior to installing hydrodynamic separators, the operators of drainage systems and environmental regulators should obtain scientifically supportable data on the field performance of hydrodynamic separators. Based on the findings and experience obtained over the course of the SEE Study, MassHighway recommends the following key elements for validating the field performance of hydrodynamic separators:

- Collect field data that is both representative of the range of rainfall events and that is applicable to the conditions (e.g., ambient particle-size distributions) under which the BMP likely will be installed;
- When sampling, differentiate between the effects of "supernatant displacement" and active-particle removal by the separator (i.e., "hydrostatic" versus "hydrodynamic" separation). This requires flow-proportional sampling throughout each storm event;
- Account for antecedent conditions, bypass flows, and resuspension when calculating the SSRE;
- Sample a sufficient number of storms not only to obtain statistically significant data, but to include the full range of operating conditions to which the device will be subject;
- Analyze treatment performance by "Summation of Loads," which is the preferable method for accuracy and quality control;
- Sample storms sequentially, to allow for a mass-balance calculation;
- Include measurements of particle-size distribution in the sampling and analysis program to assess the removal efficiency of Total Suspended Solids (or, preferably, Suspended Sediment Concentration), as well as that of other contaminants associated with various particle-size fractions.

Hydrodynamic separators should also be evaluated relative to other potential limitations. For example, if these underground structures function to contain fuel spills, then they have the potential to create an explosion hazard. In addition, according to the literature, hydrodynamic separators also may create conditions suitable for breeding mosquitoes and bacteria or conditions that result in liberating nutrients and metals from captured sediments.

Based on its evaluation of WQIs and on the literature MassHighway has reviewed to date, further scientifically sound evaluation is necessary to demonstrate the effectiveness of hydrodynamic separators as primary-treatment devices. Although MassHighway has documented the limitations of the WQIs used along the Southeast Expressway (e.g., low overall removal of suspended sediment, particularly fine particles), hydrodynamic separators may be appropriate for pre-treatment and retrofit applications where sand is the target contaminant and where the operator has adequate maintenance capabilities.

Abbreviations

BMP: Best Management Practice

DOT: Department of Transportation

EMC: Event Mean Concentration

EPA: Environmental Protection Agency

PSD: Particle-Size Distribution

SEE: Southeast Expressway

SSC: Suspended Sediment Concentration

SSRE: Suspended Sediment Removal Efficiency

TSS: Total Suspended Solids

USGS: U. S. Geological Survey

WQI: Water-Quality Inlet

Introduction

The focus of this paper will be on a specific category of storm water Best Management Practices (BMPs) known as hydrodynamic separators (also known as innovative water-quality inlets, particle separators, or swirl concentrators). Hydrodynamic separators are flow-through structures with a separation unit to remove sediments and other pollutants. The separation of sediments depends primarily on settling and may be enhanced by the swirling action of flowing water and/or by modifying the flow path with a system of baffles. A number of devices accumulate and store settled solids in a manner designed to minimize resuspension of previously captured particulates.

In recent years, hydrodynamic separators have become increasingly common. MassHighway has considered this class of BMP for application in a number of settings and has had experience in the application and evaluation of these and similar devices. Based on this experience, MassHighway has identified a number of issues that should be considered by drainage-system operators and environmental regulators when assessing the performance of these devices and ultimately choosing the most cost-effective BMP (including both structural and non-structural methods) for treating storm water.

BMP Performance Evaluation

USGS-MassHighway study: evaluation of BMPs along the Southeast Expressway

During 1999-2000, MassHighway conducted a field study with the U.S. Geological Survey (USGS) to evaluate the treatment effectiveness of a deep-sump catch basin and two conventional water-quality inlets (WQIs) located along the Southeast Expressway (I-93) in Boston. The objectives of the Southeast Expressway (SEE) Study were to characterize the concentrations and loads of suspended sediment during a multitude of sequential storm events and to define the suspended sediment removal efficiency of two 1,500 gallon WQIs and one deep-sump catch basin (Smith 2002).

Water-quality analyses included metals, nutrients, organics, bacteria, and suspended sediment along with particle size. Two WQIs were sampled, using automated samplers to capture storm water events continuously—one for 10 months and the other for 14 months—for a total of 133 storms. A mass balance was computed based on measurements of the material captured (i.e., the measured inlet loading plus the mass of material captured equaled the measured outlet loading). Removal efficiencies were estimated using the "summation of loads" method.

Figure 1 presents a schematic diagram of the drainage BMPs evaluated by the SEE Study. As is typical of hydrodynamic separators, each had a bypass weir in order to minimize high velocities and the resuspension of sediment from within the device.

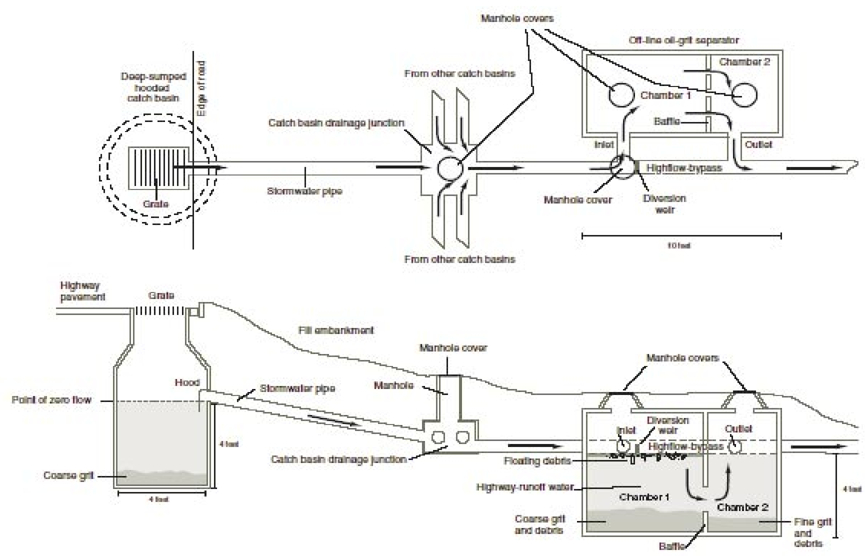

Figure 1. Schematic section of a deep-sump hooded catch basin and a 1,500-gallon off-line water-quality inlet.

Summary of Findings

1. The suspended sediment removal efficiency (SSRE) of the deep-sump hooded catch basin was found to be 39% over a 14-month period. The WQIs achieved a SSRE of 35 and 28%, for an average of 32%. However, if the removal efficiency of the catch basin is factored into this BMP "treatment train," then the SSRE of the WQIs averaged only 18% of the influent's *total* suspended sediment load.
2. WQIs and the deep-sump hooded catch basin captured predominantly sand-sized particles (i.e., greater than 0.062 mm). This finding has been attributed to the short residence times within the WQIs (fine particles have long settling times). The average retention times for the 1,500 gallon WQIs ranged from one hour to less than a minute. Therefore, residence time was the primary factor controlling suspended sediment removal efficiency.
3. Other factors affecting SSRE included: antecedent conditions (i.e., length of time between storms, which in turn affects particle settling time), rainfall intensity (i.e., if high, then large particles became dislodged and entered the runoff flows), and the volume of rainfall. The SEE Study found that for small events (< 0.2 inches of rain, where the total rainfall volume was less than 1,500 gallons) and also when there had been no rain for at least five days, that the WQIs removed more than 80% suspended sediment. When the antecedent dry period was only two days, then less than 40% of suspended sediment was removed. These observations again demonstrate the importance of residence time between storms.
4. Sediment resuspension occurred in both the catch basin and the WQIs, which reduced their sediment-removal effectiveness. Sediment capture also was reduced when high flows bypassed the WQIs. Resuspension and bypass flows each accounted for a similar level of total sediment loading: approximately 2 to 3%.
5. Metals and nutrients tend to concentrate on particles smaller than sand (<0.062 mm), in part due to their greater surface area (per unit weight). The WQIs were found to remove only 5 to 15% of most metals and nutrients from the influent.
6. The WQIs also were ineffective at removing dissolved pollutants, particle sizes finer than sand, floatable solids, and oils and grease (as well as total petroleum hydrocarbons).

BMP evaluation by manufacturers

BMP manufacturers offer a variety of supporting documentation regarding the treatment effectiveness of their devices. However, inconsistent sampling methods, lack of associated design information, and different reporting protocols make comparisons between devices difficult (Federal Highway Administration 2001). For example, individual studies often include the analysis of different constituents and do not use the same methods for data collection and analysis, and do not report equivalent information on BMP design and flow characteristics. This results in a range of BMP "efficiencies" reported in manufacturers' literature. In addition, the effectiveness of a hydrodynamic separator is oftentimes based on a low number of select storms or on limited sampling within each storm event. Thus, the available data for the various hydrodynamic separators do not appear to allow for comparison between other similar devices or other types of BMPs.

The SEE Study provided valuable experience in sampling and analysis methodology for a device that has a limited residence time. The following discussion highlights several sampling and analysis protocols that should be applied to future field-performance studies of other hydrodynamic separators in order to provide valid and comparable scientific basis for evaluating these devices' pollutant removal performance.

Storm Water Data—Quality Control and Analysis

Representative storms

The monitoring requirements of the National Pollutant Discharge Elimination System (for industrial activities) identify key characteristics that result in a "representative storm." According to these requirements, the total precipitation and duration of a "representative storm" should be within 50% of the average event for a given location, produce equal to or greater than 0.1 inches of precipitation, and have an antecedent dry period (i.e., less than 0.1 inches precipitation) of at least 72 hours (GeoSyntec et al. 2002). This sets up a worst-case scenario, where the runoff has a relatively high concentration of pollutants that have built up during the antecedent dry period. Unfortunately this sampling criterion can lead to bias in calculating the removal efficiency of storm water BMPs (as described further below, Displacement versus Treatment).

For BMP monitoring purposes, strict adherence to these criteria is not necessary and likely not desirable because there is no truly "representative storm." It is preferred that monitoring be performed under a wide variety of conditions and storms such that the storm water data represents the annual range of rainfall events (GeoSyntec et al. 2002). Different site conditions, such as seasonality, temperature, ambient particle sizes, runoff rates, precipitation volumes, durations, and intensities, all contribute to "make each storm a unique event" (Church et al. 1999). Therefore, all these variations should be considered when determining the period over which the monitoring program will be run, and are key to interpreting BMP monitoring data and predicting effectiveness (Muthukrishnan et al. 2004).

WQIs are particularly sensitive to variations in influent water quantity and quality, due to their small volumes and the relatively short retention times during flow events. Therefore, when evaluating any hydrodynamic separator, the sampling program should include an extended and continuous period of study covering the full range of events that would affect the unit's operation. For example, it was found during the SEE Study that about 90% of the sediment loading was carried in 10% of the storm events. Figure 2 illustrates the inlet and outlet sediment loads and how the SSREs varied from storm to storm, and were sometimes below zero when effluent loads exceeded influent loads (representing sediment resuspension, further discussed below).

In addition, any BMP monitoring programs also should provide a description of the statistical error and confidence of its findings. Obtaining statistically valid results requires a sufficient number of storms sampled to draw valid conclusions at high levels of confidence (Muthukrishnan et al. 2004). As described above, the SEE Study monitored a total of 133 storms—74 and 59, respectively, at two separate sites. Nonetheless, the USGS corroborated that a relatively high statistical confidence could be derived from just 15 to 20 sequential and continuously monitored storms. For example, by calculating the SSRE of 20 storms, a BMP monitoring program could predict (with 89% confidence) that the SSRE of the BMP will be lower than the minimum SSRE (of the 20 events) less than 10% of the time for all future storm events. For 15 and 10 storms, the confidence drops to 79% and 65%, respectively. Still, although sampling 15-20 sequential storms allows for a mass-balance computation, it may not be adequate for deriving contaminant loading estimates and average BMP performance on an annual basis because of the variability in hydrologic factors in the Northeast U.S.

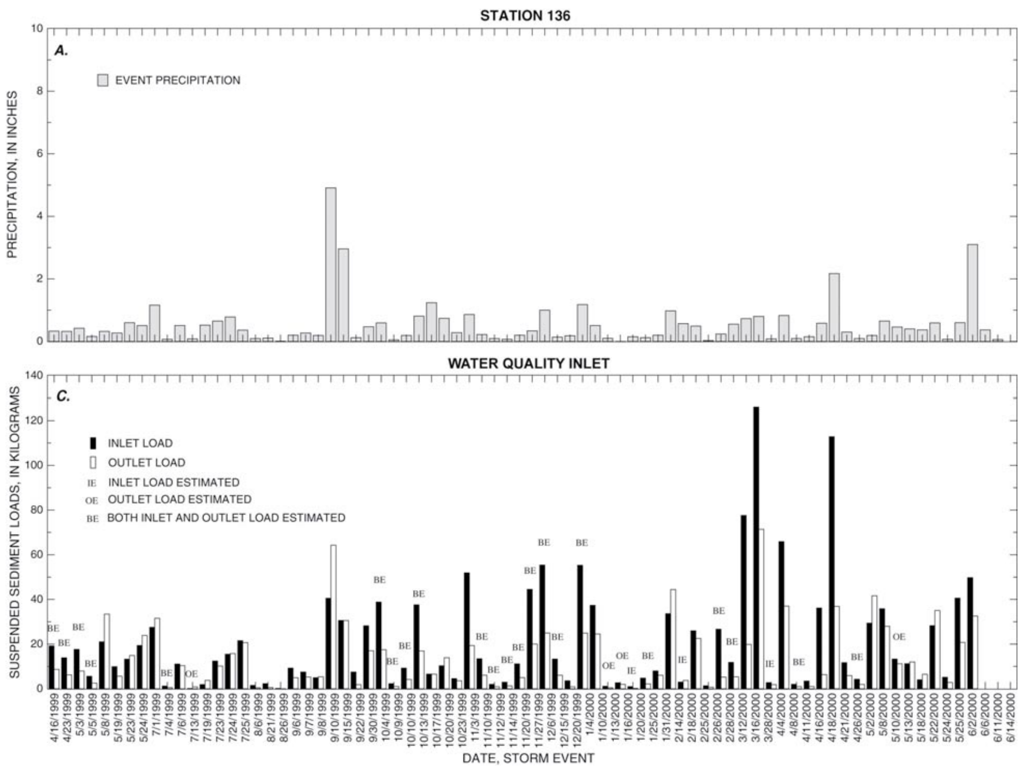

Figure 2. Precipitation and suspended sediment loading for long-term sampling period at a WQI.

Sampling frequency
The SEE Study measured the concentrations of various contaminants in the influent and effluent flows, which were observed to vary widely during the events sampled. If influent and effluent water quality were sampled only once at random during a storm (i.e., grab sample), or even at a preset time interval following the onset of a storm, the variations in water quality over the course of the storms could not have been measured. This would have been a significant source of error in calculating sediment loading, and therefore the treatment performance of the WQIs.

In addition, the SEE Study employed automatic sampling equipment to collect flow-proportional samples over the entire duration of each storm. The samples were analyzed to accurately calculate sediment loading and capture throughout the storm. This sampling methodology should always be used to evaluate hydrodynamic separators so as to account for all the variability in storm water quality and treatment performance.

Applicability of BMP performance to other sites
Site conditions can vary significantly from one location to another, which can affect storm water treatment performance by BMPs. Geographic variables such as climate, geology, hydrology, land use, and local water quality make each site unique (Berg 2002). Therefore, field studies should take place in settings that are representative of those where the respective BMP will most likely be used. This will increase the likelihood that the performance results will be authentically transferable to similar sites.

Examples of particular test sites of interest include a DPW maintenance yard with outdoor storage of sand, a well-maintained parking lot, a road with an eroding edge of pavement, a high-volume expressway, and a local service road. Note, however, how each of these sites may have varying types and volumes of sediment loading and other pollutants and that the treatment-evaluation results for a device at one type of site may not be readily transferable to another type of site (at least not without careful study design).

BMP performance historically has been evaluated in the context of a particular device being a stand-alone system. This probably does not reflect actual applications, however, because storm water BMPs almost always are used in conjunction with various upstream controls, most typically catch basins. According to the SEE Study, it was found that the upstream catch basins captured the bulk of the drainage area's coarse sediments. Specifically, if the WQIs were used as stand-alone BMPs, they would have captured up to 57% of total suspended sediment load. However, since the upstream catch basins captured 39%, the WQIs captured only 18% of the total annual sediment load. Therefore, to make findings comparable, all BMP evaluation studies should be designed in a way to correctly account for how the BMP performs when pre-treatment occurs upstream (e.g., through the use of catch basins). If the effects of pre-treatment are not incorporated into the BMP findings, then the calculations for total removal efficiencies will be incorrect.

Another variable that affects the comparability of BMP studies is the size of the area that drains to, and the flow rates that pass through, the BMP (particularly hydrodynamic separators). A smaller drainage area implies smaller storm flows, greater average device-residence times, and a likely reduction in rates of resuspension. All of these effects could result in a higher treatment efficiency for the hydrodynamic separator. The field study of a particular BMP should therefore be designed to reflect the drainage areas, flow rates, volumes, and other conditions that characterize the full range of circumstances anticipated for actual future application of the device.

Bypass flows and resuspension

Early discussions of storm water treatment theorized that if a storm water BMP is designed to treat the first 0.5 inch or inch of rainfall, then the majority of pollutants will be captured. Under this scenario, runoff volume in excess of this "first-flush volume" might be allowed to bypass the BMP untreated, under the assumption that the water is relatively clean (Berg 2002). However, for certain pollutants, such as nitrate, ortho-phosphate, bacteria, and sediment, the first-flush theory is weak or absent altogether (Schueler 1994). One major criticism of the first-flush theory is that it overlooks the effects of rainfall intensity. High-velocity flows resulting from high-intensity rainfall events are capable of transporting larger sediment particles and debris that is not often mobilized by more frequent, but less intense, storm events (Berg 2002).

Regardless, bypasses (such as a control weir within the drainage structure located just upstream of the BMP) are often considered necessary to diminish high flows that would otherwise move through storm water BMPs, especially hydrodynamic separators, and resuspend captured material. Bypasses can have a measurable effect on the ability of a BMP to remove constituents and, if set too low, may reduce the overall capture efficiency of the system as a whole. On the other hand, providing insufficient high-flow bypass risks the potential for resuspension of captured sediments and associated pollutants from within a separator. Minimizing resuspension is important because of the propensity of finer particles, which are associated with relatively higher concentrations of contaminants, to become resuspended selectively.

During the SEE Study, resuspension was observed within the WQIs during storm events with high flows and/or rainfall intensities (as depicted in figure 2 above). As illustrated in table 1, the amount of sediment resuspended from the WQIs was about 8% of that captured (2 to 3% of the total sediment loading at the drainage-outfall pipe). Coincidentally, the sediment load that bypassed the WQIs represented about 2 to 3% of the total loading.

Table 1. Conditions and frequency of resuspension and bypass

Description	Station 136 WQI	Station 739 WQI
Range of flows when resuspension was observed	0.46 to 0.97 cfs	0.41 to 2.81 cfs
Range of maximum 5-minute rain intensities during these storms	0.04 to 0.23 in	0.04 to 0.18 in
Number of events exceeding resuspending flows and intensities	33 (of 74)	22 (of 59)
Percentage of captured SSC resuspended	8%	8%
Percentage of total SSC load resuspended	2.8%	2.2%
Percentage of total SSC load bypassed	3%	2%

Disregarding bypass flows when evaluating BMP performance will result in misleading conclusions (Muthukrishnan et al. 2004). Comprehensive inflow and outflow measurements should be used in calculating the mass balance of contaminant loading, which includes the loading in bypass flows. This mass-balance calculation will provide the most accurate estimation of the BMP's overall efficiency.

Displacement versus treatment

As discussed above, the volume of storm water passing through the separator is a critical parameter in estimating the performance of hydrodynamic separators and differentiating between active contaminant removal and hydrostatic settling prior to the storm. For this reason, evaluations should avoid the use of random sampling or single-event sampling at a fixed time period of the storm. Flow-proportional sampling should be conducted over the full duration of each event (as well as over a full range of events) to account for the wide variability of influent and effluent water quality.

This potential source of bias was observed in the SEE Study when the WQI influent and effluent were sampled at the initial onset of a storm event. After the suspended sediment in the WQI had settled over the course of several days, the incoming turbid storm water pushed the clarified water out. The resulting effluent was cleaner than the influent because of "displacement" and not because of the dynamic removal of sediment within the WQI. In fact, in almost every case, as samples were taken later into the storms, there was much less difference in the suspended sediment concentrations between the influent and effluent samples.

In addition, assessing the performance of hydrodynamic separators based solely on very small rainfall events can lead to erroneous findings because of the "displacement" phenomenon. When a storm's volume (to the device) is less than device volume, the monitored effluent will reflect the storm water that had been stored from the previous event, rather than from the event under study. This would not represent the "flow through" operating characteristics of the device and could bias the estimate of overall performance. This bias can be overcome by monitoring a full range of storm events over an extended period and by taking flow-proportional samples throughout each event.

Laboratory partitioning error—SSC versus TSS

There currently is debate over the most appropriate analytical method for measuring the concentration of solids in storm water samples. The Total Suspended Solids (TSS) analysis requires extracting an aliquot from the original sample, which is then analyzed to determine the sediment concentration, whereas the Suspended Sediment Concentration (SSC) method uses the entire sample for the analysis. Although TSS has been widely used as a parameter in water-quality analyses (dating back to the 1970s and 1980s in the wastewater-treatment industry), the SSC method ensures that all material present in the sample is represented in the results.

In a study by the USGS, it was determined that in samples containing 25% or more of sand-sized particles, the TSS method consistently under-reported sediment concentrations when compared to the corresponding SSC samples. Because of its high settling velocity, sand-sized material is often under-represented in the aliquot drawn for the TSS analysis (Gray et al. 2000). Thus a new measurement of sediments, SSC, was developed and is now a standard water-quality analysis for the USGS (GeoSyntec et al. 2002). This method has been proven to measure sediment loads more accurately, and therefore BMP removal efficiencies (Berg 2002).

Since the SSC test is biased toward heavier particle sizes, TSS will provide a much more conservative measure of BMP performance. Therefore, it can be assumed that the average SSRE of 32% would have been even lower if the SEE Study had measured for TSS rather than SSC.

BMP efficiency computation

A number of different methods can be used to estimate the efficiency of BMPs. The most common method is the Efficiency Ratio method (GeoSyntec et al. 2002). The SEE Study used the summation of loads method, which was determined to be more appropriate for the evaluation of sediment removal efficiency of the WQIs. Based on the findings of this study, MassHighway recommends that this approach be used for evaluating the performance of other hydrodynamic separators.

Efficiency Ratio Method

The "efficiency ratio" is an estimate of the average event mean concentration (EMC) of pollutants over a given time period. EMCs are determined from flow-weighted composite samples in the field or derived from discrete samples. The method weights EMCs from all storms equally, regardless of the volume of the storm or the concentration of the parameter under study. The method is most useful where loads are directly proportional to storm volume.

Summation of Loads Method

The "summation of loads" method estimates efficiency based on the ratio of the sum of all influent loads to the sum of all effluent loads. The method assumes that the removal of material over the entire period of analysis is most relevant. The method also assumes that monitoring data are sufficient to represent the actual entire volume of loads into and out of the BMP under study for a long enough period to account for temporary storage and export of the study parameter.

In the SEE Study, where there was an extensive data set (based on 133 storm events), the summation of loads method was used because it accounted for the wide variation of concentrations over the course of storm events and among storm events, as well as the temporary storage and export of sediment from the WQIs. Further, the difference between inlet and outlet loads were directly estimated from this method (i.e., a mass balance could be determined) and compared with field measurements of sediment accumulation in the WQIs. This provided an ideal method for corroborating the test results.

By sampling every sequential storm throughout the SEE Study and then measuring total mass of sediment captured within the WQIs at the end of the study, a critical element of quality assurance was added to the data. This technique clearly showed the limitations of the WQIs in capturing sediment particles smaller than 62 µm and also was used to develop an accurate annual SSRE for these devices.

It also was found that the overall treatment efficiency of a BMP is a more meaningful measure than the average efficiency. The Massachusetts Department of Environmental Protection's Storm Water Management Policy requires that storm water management systems remove 80% of TSS on an average annual basis. Given this requirement and based on the experience from this study, the most appropriate measure of BMP effectiveness for long-term sediment removal is the summation of TSS (i.e., SSC) loads, provided that the storms sampled are generally representative of Massachusetts' typical storm distribution.

Particle-size distribution

The SEE Study indicated that residence time was a key factor in the sediment removal efficiency of the WQI. This conclusion was expected, given that the device depends on settling as its primary treatment process. Since the performance of a hydrodynamic separator is particularly sensitive to particle size and specific gravity and given the short residence time of most storm flows within such a device, any suspended sediment removal claim should include the particle sizes associated with the stated removal rates. Washington's guidance for evaluating innovative storm water BMPs provides a good example of the method for qualifying sediment removal rates (Washington State Department of Ecology 2004).

When BMPs are evaluated under laboratory conditions to determine their suspended sediment removal rates, the use of an appropriate particle-size distribution (PSD) representative of storm water becomes a pivotal component of the study. But without a standardized definition for PSD in "typical urban runoff," the TSS removal rate claims made by various manufacturers may not be comparable to one another. Particle-size determinations are especially important when testing the effectiveness of hydrodynamic separators because the larger the average particle size used for evaluation, the higher the treatment efficiency.

To address this issue, it is recommended that all BMP evaluations address removal rates by particle size, and that the particle-size fractions should comprise a standardized distribution established by the U.S. Environmental Protection Agency (Driscoll et al. 1986). The EPA report, based on an analysis of the National Urban Runoff Program data, presents a typical settling-velocity distribution for sediment found in urban runoff. Converting the settling-velocity distribution to particle sizes (using Stoke's Law and assuming a specific gravity of 2.65) shows that 90% of sediment particles in storm water are smaller than 69 ?m and only 20% of particles are larger than 40 µm (the size of very fine sand).

Since larger particle sizes settle more quickly than smaller ones (i.e., greater settling velocities), they are easier to remove from storm water. Therefore, the sediment removal performance of a BMP is highly dependent on the PSD. For example, several performance studies of hydrodynamic separators have been conducted in the upper Midwest and Northeast where deicing sand is commonly used. The sand, washed off during spring and summer storms, skewed the PSD to larger sizes not commonly found in the storm water that occurs in other parts of the country. Consequently, a lower level of efficiency may be observed if the same BMP is installed in areas where deicing sand is used less or not at all (California Stormwater Quality Association 2003).

The importance of the PSD in storm water was demonstrated in the SEE Study, where particle sizes in the sand range generally were not mobilized under low-flow conditions, but were under high flows. Hence, the WQIs were often most effective during the larger storms because there were more sand-sized particles in the storm water flows to remove.

It was estimated that throughout the SSE Study, more than half of the total sediment loads contained in the storm water fell below the 50-µm particle size range. Hence, it is unlikely that the WQIs could achieve 80% TSS removal when they are virtually incapable of capturing particles less than 50 µm in size. In addition, since pollutants have a higher affinity for absorption to finer sediment due to the fine particles' large surface area per unit volume (Horowitz and Elrick 1987), WQIs are presumed to also have low removal efficiencies for pollutants.

Other performance factors of concern

This paper has addressed the evaluation of WQIs in particular and future assessment of hydrodynamic separators primarily with respect to treatment removal effectiveness of suspended sediment. However, there are a number of other performance factors that must eventually be addressed to document the effectiveness of this class of storm water BMP. Some (but not all) of these factors were considered in the SEE Study, but all warrant further analysis by future research. These factors include:

1. Removal of dissolved pollutants and fine particles

   Little information is available for hydrodynamic separators treating pollutants other than suspended solids. As was found in the SEE Study, pollutants such as nutrients and metals, which adhere to fine particulates, as well as dissolved solids, were not significantly removed by the WQI device. Moreover, heavy storms may cause mixing and subsequent resuspension of any captured fine particles. More information is needed on hydrodynamic separators' ability to remove both fine particles and dissolved pollutants.

2. Removal of oil and grease

   Oil and grease in storm water typically are in the range of 5-10 mg/l. There is no comparative data that these units are capable of trapping oil and grease. The Utah Department of Transportation (DOT) does not recommend that hydrodynamic separators be used for treating and/or reducing oil and grease concentrations in typical urban storm water runoff for two reasons: by the time the oil reaches the device, it will have adhered to sediment and/or will have emulsified in the runoff, making it too difficult to separate. Further, oil and grease exist in very low concentrations in storm water, making it very difficult for these devices to treat them to even lower levels. Nonetheless, the Utah DOT will consider these systems for capturing oil and grease in high-loading areas ("hot spots") (Nichols et al. 2005).

   Silverman and Stenstrom (1989) also acknowledge the relative ineffectiveness of hydrodynamic separators in capturing oil and grease. They cite that 40% to 60% of oil and grease associated with urban runoff are in a dissolved or colloidal state. Thus, baffled BMPs that are designed to separate free-floating oil and grease may not provide effective treatment for this pollutant.

3. Removal of floatable solids

   During the course of the SEE Study, it was found that floatable debris was readily discharged from the WQIs. These devices might be more effective at floatable-solids removal if cleaned regularly (e.g., monthly), before the floatables become neutral-buoyant and flush out of the WQI. General performance of hydrodynamic separators for floatable-solids removal appears to require further study.

4. Containment of hazardous spills

   Spill containment should be considered carefully in coordination with local fire department personnel (and/or other "first spill response" entity) before installing a hydrodynamic separator. For example, trapping a large quantity of spilled gasoline in an underground structure may constitute a safety hazard that could outweigh the apparent benefits of "containment." MassHighway is not aware of studies that have addressed this concern.

5. Incubation of bacteria

   With a nutrient-rich medium, relatively stable temperatures, and a lack of UV light, hydrodynamic separators may breed bacteria. It is documented that storm-drain sediments can function as a reservoir of Fecal Coliform and Fecal Streptococci bacteria under warm conditions. This implies that displacement of collected storm water may release bacteria into the receiving water bodies (Marino and Gannon 1991). MassHighway is not aware of any studies that specifically address the potential for bacterial growth and export associated with this class of BMP.

6. Potential breeding habitat for mosquitoes

   An issue associated with storm water management that is receiving more and more attention is the potential public-health risk created by the use of certain BMPs. If not designed and managed properly, they can provide habitat conditions suitable for the propagation of mosquitoes. This is an issue of prime concern because of the existing and widespread presence of endemic vector-borne diseases (e.g., West Nile virus, eastern equine encephalitis). Statistically, as vector populations increase, so does the risk of disease transmission (Metzger 2003, Metzger et al. 2002).

   In 1998, the California Department of Health Service's Vector-Borne Disease Section, in cooperation with the California Department of Transportation, conducted a two-year study of vector production associated with the 37 operational storm water BMP structures in southern California. The study found that a variety of vector species, particularly mosquitoes, utilize the habitats created by storm water BMP structures throughout the U.S. With easy access, no predators, and constant water levels, mosquitoes can easily propagate within hydrodynamic separators.

7. Liberation of metals and nutrients

   Due to the relatively quiescent conditions inside the separators, there is little oxygen exchange and the material captured within the sump of the device can develop conditions with low dissolved oxygen (DO). During periods of low DO concentrations, metals and nutrients adsorbed to sediments can become desorbed and dissolve into solution (Breault and Granato 2000, Rushton 1998). This means that storms accompanying this process would displace the captured storm water containing these dissolved nutrients and metal ions. Further analysis of this class of BMPs is warranted to characterize their effects on the release of metals and nutrients from captured sediments into the water column.

8. Operation and maintenance considerations

   Regular maintenance is critical to the proper function of storm water BMPS. Hydrodynamic separators pose particular requirements for maintenance. Without regular clean-outs the devices may be prone to the following: accumulated sediment reducing available treatment volume, sediment resuspension during high-flow storm events, and accumulated floating material becoming entrained into the water and ultimately discharged during subsequent storm flows.

   In the SEE Study, MassHighway found that inspection and maintenance of the WQI is much more difficult than with open systems (e.g., detention basins, drainage swales) or even catch basins. Routine inspection and the determination of sediment accumulation were constrained by the limited access and physical size and configuration of the device.

   Physically cleaning the WQI also was difficult and required using personnel to access the device under "confined-space protocol" to ensure effective cleaning of the device. Cleaning and disposal costs are anticipated to be much higher for this type of device than for "open" BMPs.

   The assessment of any particular hydrodynamic separator should include an evaluation of the procedures, cleaning frequencies, and associated costs, as well as the treatment effectiveness, in order to determine if their use is warranted in a particular setting.

Figure 3. Vacuum truck employed during the cleaning operation of a water-quality inlet along the Southeast Expressway in Boston (left) and a maintenance worker pushing sediments to a vacuum hose while exercising "confined-space entry" protocol (right).

Conclusions and Recommendations

The field evaluation of the treatment performance of hydrodynamic separators requires careful planning and appropriate study methodology to secure representative storm water data. Without such data, the results from these studies will lack scientific credibility and/or statistical confidence. Scientifically valid data is essential for the selection and design of BMP technologies and for assessing whether these technologies are capable of meeting regulatory requirements. This paper has presented some primary factors that should be incorporated into the design of a scientifically valid BMP test study.

Based on the findings and experience gained during the Southeast Expressway Study, MassHighway recommends the following for validating the field performance of hydrodynamic separators:

- Collect field data that is both representative of the range of rainfall events and that is applicable to the conditions (e.g., ambient particle-size distributions) under which the separator likely will be installed;
- Sample a sufficient number of storms to obtain statistically significant data and cover the full range of operating conditions to which the device is subject;
- Sample storms sequentially, with complete data acquisition to allow for a mass-balance calculation;
- When sampling, use flow-proportional sampling throughout the duration of each storm event to determine the active-particle removal by the separator (i.e., "hydrostatic" vs. "hydrodynamic" separation) and not bias the results because of "supernatant displacement;"
- Account for antecedent conditions, bypass flows, and resuspension when calculating the SSRE;
- Analyze treatment performance by "Summation of Loads" to characterize long-term overall effectiveness; and
- Include measurements of particle-size distribution in the sampling and analysis program to assess the removal efficiency of TSS (or preferably SSC) as well as that of other contaminants associated with various particle-size fractions.

In light of MassHighway's evaluation of WQIs and on the literature discussed herein, further evaluation—using scientifically sound methods that generate data with high statistical confidence—is necessary to demonstrate the effectiveness of hydrodynamic separators as primary-treatment devices. Although MassHighway has documented the limitations of the WQIs used along the Southeast Expressway (e.g., low overall removal of suspended sediment, particularly fine particles), hydrodynamic separators may be appropriate for pre-treatment and retrofit applications where sand is the target contaminant and where the operator has adequate maintenance capabilities.

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Habitat Restoration Plan and Programmatic Biological Assessment for *Potamilus Capax* (Green 1832) in Arkansas

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Abstract

The fat pocketbook, *Potamilus capax* (*Mollusca: Unionidae*), was designated as "Endangered" in June 1976 by the USFWS in the entire range of the species. The present general distribution of *P. capax* has been reported from the upper Mississippi River on the boarders of Minnesota, Wisconsin, Iowa, Illinois, and Missouri, the Ohio River System on the borders of Indiana, Illinois, and Kentucky, especially its tributary the Wabash River in Indiana and Illinois, the White River of Missouri and Arkansas, and the St. Francis River system in Arkansas. Relocation of freshwater mussels prior to large-scale bridge construction, repair, or replacement has been broadly utilized for conventional management of construction impact. The success of that practice related to long-term viability of relocated specimens, however, has not been fully validated. This research was jointly funded by the Federal Highway Administration (FHWA) and the Arkansas State Highway and Transportation Department (AHTD) in 2003 as an Environmental Streamlining Initiative to provide more information regarding the likelihood of specific impacts to mussels attributed to sediment plumes downstream of highway construction activities. The research proposes to support a programmatic Biological Opinion for *P. capax*, which will provide a protocol for highway projects that may impact the species. Relocation can then be assessed for its ability to minimize loss of endangered freshwater mussel species, and in particular, *P. capax*.

The objectives of this project are: 1) to determine the success of relocation efforts for *P. capax* associated with highway construction projects by investigating survival, movements, mortality, fitness (as indicated by condition factor), and fecundity of relocated and non-relocated adults and sub-adults, 2) to determine the success of propagation efforts resulting from highway construction projects by investigating the survival of juveniles returned to identified habitats and used for population enhancement (recruitment), and 3) to determine relative impacts at highway construction sites to *P. capax* and associated mussel assemblage by comparing pre- and post-construction abundance and composition, sediment deposition downstream of the construction, and individual mussel fitness. Data acquired will be submitted to the Fish and Wildlife Service as documentation of the likelihood of impacts for the programmatic Biological Assessment. These data will be utilized by the Fish and Wildlife Service in crafting the programmatic Biological Opinion.

Initial observations have indicated relocated *P. capax* and *Quadrula quadrula* exhibit very different movement patterns post-relocation. For example, many resident and relocated *P. capax* are capable of moving 10 miles or more over a 12-hour period, while resident and relocated *Q. quadrula* have remained stationary up to four months after relocation. A continuation of this pattern may reveal that species-specific life history characteristics potentially influence movement patterns following relocation. Fatalities have occurred in the resident, relocated, and propagation animals of both species, though time to and cause of fatality are not known.

Highway Crossing Structures for Metropolitan Portland's Wildlife

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Abstract

The protection and restoration of the Portland, Oregon metropolitan region's wildlife biodiversity is an overarching objective of Metro Parks and Greenspaces. Metro, Portland's elected regional government, currently manages 8,000 acres of open space containing 50 mammal species. Included are roughly 50 miles of stream and river frontage as well as wetlands, riparian areas, meadows, forests, and other valuable habitat. Metro, the U.S. Fish and Wildlife Agency, and Portland State University have embarked on a jointly funded project to promote biodiversity by encouraging the use of wildlife-crossing structures to reestablish wildlife-movement corridors within areas currently fragmented by roads.

This team project has three sequential stages. Stages 1 and 2 have been completed. Stage 3 is currently underway:

Stage 1. Examination of the extent of the deer-vehicle conflict problem in the Portland metropolitan region and identification of deer-vehicle accident (DVA) hotspots for potential crossing-structure construction. The black-tailed deer (*Odocoileus hemionus Columbianus*) is the resident subspecies.[1]

Stage 2. Production of a user-friendly manual that can be employed by transportation planners to incorporate wildlife-crossing structures into the region's transportation-planning process.[2]

Stage 3. Development of a model that predicts DVA hotspots to facilitate the intelligent siting and design of future roads in the region. While the literature contains accounts of model development for predicting DVA hotspots for the white-tailed deer (*Odocoileus hemionus*), there appear to be no studies (to date) for predicting DVA hotspots for the black-tailed deer.[3]

In stage 1, we collected a total of 2,200 DVA incidents in Clackamas, Multnomah, and Washington Counties for the period 1987-2002 from road-maintenance department carcass pickup reports, Oregon Department of Transportation (ODOT) wildlife-vehicle accident reports, and wildlife-rehabilitator intake records. Because ODOT does not maintain deer carcass pickup records for state and federal highways, the most complete data available were for county-maintained roads. Incidents were geocoded and mapped. A GIS analysis, using grid cells of 1.00mi^2 and 0.25 mi^2, regressed total DVAs/cell against a suite of landscape characteristics/cell: 1) total new building permits, 2) total miles of streams and rivers, 3) total miles of roads and highways, 4) total forest vegetation, 5) total other vegetation, and 6) total wetland area. DVA hotspots were identified visually.

We determined that DVAs were nonrandomly located along roads and that they began to increase in June and peak in November. No significant correlation was established between DVA density and any of the landscape variables.

Metro is currently pursuing development of crossing structures at several of the sites identified by the data as hot-spots. Students in Portland State University's Master of Urban and Regional Planning program used the results of stage 1 to produce the Metro publication "Wildlife Crossings: Rethinking Road Design to Improve Safety and Reconnect Habitat." This is a comprehensive manual for siting, designing, and funding wildlife-crossing structures in the urban/suburban/rural mix of metropolitan Portland. It is designed for transportation planners and resource agencies and is available to the general public.

In stage 3, a temporal and spatial DVA hotspot model for the black-tailed deer is under development for northwest Clackamas County using additional years of wildlife-vehicle accident reports and carcass-pickup data.

As a result of this study, we recommend that all road-maintenance agencies maintain carcass-pickup records, including carcass-pickup locations identified by GPS, date of retrieval, species, gender, and age class. This information should be consolidated in a regional database to identify wildlife-movement corridors and substantiate the need for wildlife-crossing structures at selected locations.

[1]**Team**: Jennifer Budhabhatti, Metro Parks and Green Spaces; Jo Price, Metro Data Resource Center; Luis Ruedas and Linda Anderson, Portland State University. [2]**Team**: Masters in Urban and Regional Planning students Theresa Carr, Radcliffe Dacanay, Kevin Drake, Charl Everson, Arianne Sperry, and Kerri Sullivan, supervised by professors Connie Ozawa, Deborah Howe, and Steve Johnson of Portland State University; Jennifer Budhabhatti, Metro parks and Green Spaces; and Ted Leybold, Metro Transportation Department. [3]**Team**: Linda Anderson, M.S. candidate, and committee members Keith Hadley, Joseph Poracsky, Heejun Chang, Geography Department; Alan Yeakley, Environmental Sciences and Resources, Portland State University.

Biographical Sketch: Linda Anderson is a M.S. candidate in geography at Portland State University, Portland, Oregon. Her master's thesis, "An Examination of Black-tailed Deer (*Odocoileus hemionus columbianus*) Deer-Vehicle Accident Hotspots in Northwest Clackamas County, Oregon," will be completed in December 2005. Fields of interest include wildlife ecology, biogeography, landscape ecology, and conservation biology. She strongly believes that the conservation of wildlife-movement corridors and habitat should be standard practice in the design of transportation networks.

How to Teach a Mule Deer to Safely Cross an Interstate? Preliminary Results of a Wildlife Mortality Mitigation Strategy on Interstate 15 in Utah, USA

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Abstract

This poster presents the preliminary results of an on-going study in Utah. Previously, high wildlife mortality registered in a 20-mile stretch of Interstate15 south of its confluence with Interstate 70 led to the establishment of a mitigation strategy focused on mule deer. The strategy focused on two major objectives: 1) decrease wildlife-vehicle crashes and 2) maintain and improve landscape permeability that facilitates wildlife movement across the highway. The mitigation put in place involved the construction of exclusion fencing, right-of-way escape ramps, and two underpasses designed primarily for large-mammal passage.

In this study, we assessed the effectiveness of the mitigation measures in reducing mule deer mortality and evaluated the success of the new underpasses in allowing wildlife to cross the road safely. In this poster, we compare the pre- and post-construction levels of road mortality. We also report observed problems with the mitigation structures as well as the solutions we used to solve them. We used remotely sensed cameras to record deer passage through the new underpasses during the Fall 2004 and Spring 2005 migrations and compare results with a 20-year old 'control' structure.

Early results showed a sporadic and lower use of the new underpasses. We suspect that the novel presence of the new crossing structures, coupled with historic learned-behavioral migration patterns, may be responsible for these early results. The number of animals that used the new structures, however, leaves optimistic expectations for increased use in the future. We will test the prediction of increased use during the Fall 2005 and Spring 2006 migrations.

In this poster, we also address the use of bait to encourage passage, and report on the occurrence of startle behavior in response to heavy traffic, suggesting that it may be fruitful to explore the effects of noise and the visual barriers to encourage underpass passage by wildlife.

Biographical Sketches: Silvia Rosa is currently a graduate student at Utah State University working with John Bissonette. Her work aims to assess the effectiveness of a mitigation strategy planned to reduce wildlife mortality in roads and to look at road effects on small-mammal communities in sagebrush habitats.

John Bissonette is leader of the USGS Utah Cooperative Fish and Wildlife Research Unit and professor in the Department of Forest, Range, and Wildlife Sciences at Utah State University. He is currently leading a team of scientists on an NCHRP project funded by the National Academy of Sciences that is investigating the current status of wildlife crossings in North America. Bissonette is the author of four books and is currently working on a fifth book that is exploring the temporal effects of resource timing on animal response. His web sites are: http://www.cnr.usu/faculty/jbissonette/index.htm and http://www.wildlifeandroads.org.

Inferring White-Tailed Deer (*Odocoileus Virginianus*) Population Dynamics From Wildlife Collisions in the City of Ottawa

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Abstract: Concerns associated with growing white-tailed deer (*Odocoileus virginianus*) numbers in Ottawa, Ontario have motivated several studies related to the distribution and ecology of deer in the Ottawa-Carleton region. This project infers deer-population trends from deer-vehicle collisions in Ottawa, Ontario, and considers the influence of traffic volume on estimates of population dynamics from deer-vehicle collision data. Traffic volume and collision data for various road segments across suburban Ottawa were analyzed to answer questions related to the characteristics and spatial distribution of deer collisions and traffic volume in the city.

Deer-vehicle collisions are increasing at a faster rate than traffic volume, suggesting that the deer population is increasing. The distribution of collisions supports the boundaries previously suggested for the location of one deer-herd summer range, but not the other. Deer-collision numbers east and west of the Rideau River, a likely barrier to deer movement, were very similar, even though research and concern related to deer numbers has been concentrated west of the Rideau. More collisions occurred on 400-series highways than on other roads, suggesting that highways are a higher risk for deer collisions than other roads. The number of deer-vehicle collisions is much higher on recently constructed 400-series highways than on older 400-series highways, indicating that new highways represent high-risk areas for collisions.

This research suggests that deer-vehicle collisions could be a very useful data source for inferring deer population dynamics of suburban deer, but it is imperative that significant factors affecting the number and distribution of collisions, such as category of road and traffic volume, are considered during any analyses.

Introduction

White-tailed deer (*Odocoileus virginianus*) in the City of Ottawa have become a substantial source of complaints in recent years (Broadfoot and Voigt 2000). Concern for human and deer safety has escalated in consideration of recent increases in deer-vehicle collisions (NCC draft; Broadfoot and Voigt 2000). Deer browsing has caused much damage to cash crops (Broadfoot and Voigt 2000) and damage to natural vegetation in the Ottawa area may be causing structural changes to ecosystems (Carr and Koh 2002). In response to mounting complaints, the National Capital Commission has established a Deer Management Committee for the purpose of developing a management strategy to address concerns associated with increasing deer abundance (NCC draft). This committee is comprised of staff members from the City of Ottawa, National Capital Commission, Department of National Defense, Ontario Ministry of Natural Resources, Ontario Ministry of Agriculture, and the Ministry of Transportation of Ontario (NCC draft). The strategy is being developed to maintain sustainable deer populations in Ottawa's rural landscape (NCC draft). A large portion of this strategy concerns the Ottawa Greenbelt, which is a large area of public land originally established to control urban sprawl, protect local agriculture, and ensure long-term supply of land for future needs (figure 1) (Palermo 1993).

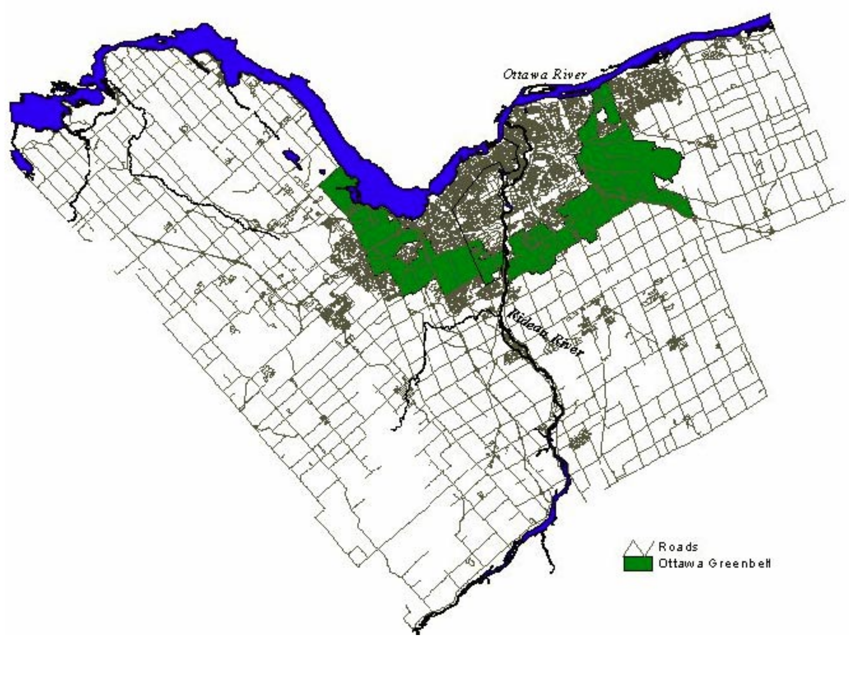

Figure 1. The Rideau River and the Ottawa Greenbelt within the City of Ottawa.

Since it is time consuming and costly to determine exact deer numbers directly, deer-vehicle collision data have been used to estimate population trends in Ottawa over the last decade (Broadfoot and Voigt 2000). Although collision data are not the only indicator available for deer population changes, their accessibility and spatial specificity give them important potential for use in deer monitoring and management. This project infers deer-population trends from deer-vehicle collisions in Ottawa, Ontario, and considers the influence of traffic volume on estimates of population dynamics from deer-vehicle collision data.

An increasing trend in deer-vehicle collision numbers does not necessarily indicate an increasing deer population. Previous studies have shown traffic volume to be an important contributing factor to deer-collision numbers (McCaffey 1973; Allen and McCullough 1976). Therefore, the first question asked in this study is: Is the increasing trend in deer-vehicle collisions in The City of Ottawa due to an increase in the size of the deer population or could it be simply a reflection of an increasing trend in traffic volume? If the deer population in Ottawa is increasing, I expect to see a greater rate of increase of deer-vehicle collisions than traffic volume.

Broadfoot and Voigt (2000) identified three major areas of high deer density in the Ottawa area and delineated the summer- and winter-range boundaries associated with these proposed herds. While winter-range size and extent was determined according to deer-browsing studies, the shapes of summer ranges were inferred from the general movement behavior of Ontario deer and the location of likely barriers to deer movement (Broadfoot and Voigt 2000). Knowledge of deer-herd locations is important in any deer management plan (Porter et al. 2004; Van Deleen et al. 1998; Grund et al. 2002). The second question addressed in this research is: Does the spatial distribution of deer-vehicle collisions corroborate the deer-herd locations proposed by Broadfoot and Voigt (2000)?

The City of Ottawa is bisected by the Rideau River (figure 1), with a typical width of 150 to 200 m, and likely presents a barrier to deer movement. A large portion of the research related to white-tailed deer in the City of Ottawa has been focused to the west of the Rideau River (NCC draft; Broadfoot and Voigt 2000; Campbell 2002; Carr and Koh 2002), while little research has been conducted east of the Rideau River (Carr and Koh 2002). This may be because areas of high deer densities west of the river are located in close proximity to suburban areas, which results in a higher rate of deer-human conflict west of the Rideau. The impression that the deer population is increasing west of the Rideau River has recently led to an extension of the deer-hunting season in this part of the region (OMNR 2003). The third question is: Do deer-vehicle collision trends reflect a larger deer population west of the Rideau River than east of the Rideau?

My two final questions relate to deer behavior with respect to roads. Allen and McCullough (1976) found deer-collision numbers to increase with increasing traffic speed to a maximum of 95 km/h and then to decline dramatically, suggesting that deer may avoid roads with high-speed traffic. To test this I asked: Do 400-series highways experience a lower deer-vehicle collision rate, indicating that deer avoid high-speed traffic?

It is possible that white-tailed deer become accustomed to the location and perceived risk associated with the location, of roads over time. Avoidance of roads by deer has been observed previously (Rost and Bailey 1979); therefore the number of collisions on a road should decrease over time as deer learn to avoid a particular road. The last question asked will be: Do recently constructed 400-series highway segments experience more deer-vehicle collisions than older 400-series highway segments? The results of this question could indicate that deer learn to avoid roads over time.

Materials and Methods

Traffic-volume data

Traffic-volume data for municipal and regional intersections within Ottawa were obtained from the City of Ottawa for the years 1995 to 2004. Traffic counts are conducted by the City of Ottawa between May and August for an unfixed number of hours within a day for various intersections throughout the city. All traffic counts available for segments about the city's perimeter were collected. Traffic counts for a specific intersection were only used in an analysis if they were available in the form of an 8-hour total taken on a weekday and at least five years data were present within the time period considered in each question (table 1). Traffic-volume data were not always available for consecutive years for a road segment, necessitating the interpolation of traffic volume numbers for some years for some segments. This meant that the five years of volume data had to include both the first and last years considered in the specific question in order for traffic-volume values to be interpolated.

Traffic-volume data from the City of Ottawa were converted from a per-intersection basis to a per-segment basis. This was done in one of two ways: a) by combining the values of traffic counts of adjacent intersections for vehicles directed towards a common road segment (figure 2) or b) by combining the subtotals from the same intersection for traffic coming from and heading towards a common road segment (figure 3). Traffic-volume data for provincial and 400-series highways of interest within the City of Ottawa were purchased from Ronen Publishing House, Inc. These included Highway 7, Highway 417 (Queensway), and Highway 416 (Veteran's Memorial Highway). These traffic counts were available per segment ,and covered varying time periods depending on the completion of construction of the highway/highway segment. The values were provided as 24-hour totals and were divided by three so that they could be analyzed with the 8-hour totals provided by the City of Ottawa. Since traffic volume is greatest during the day, these 8-hour totals likely underestimate the 8-hour total daily traffic volume on the highways.

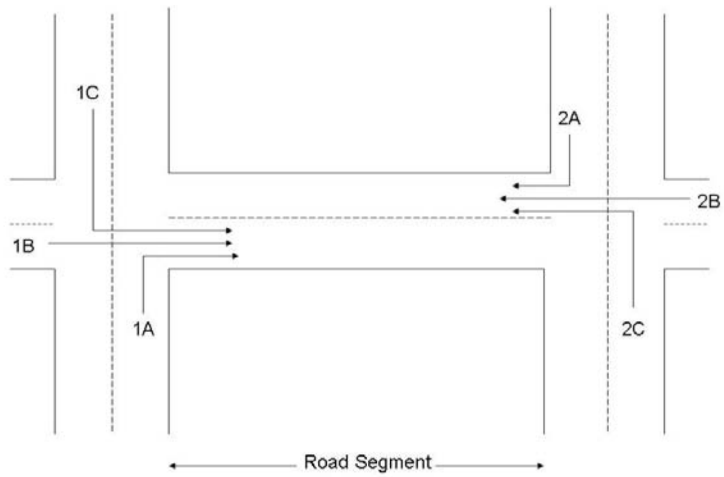

Figure 2. Determining traffic volume of a segment using two adjacent intersections. The total traffic volume for this segment was determined by combining the number of cars in positions 1A, 1B, and 1C with positions 2A, 2B, and 2C.

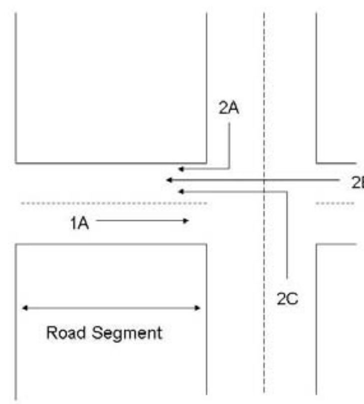

Figure 3. Determining traffic volume of a segment using one intersection. The total traffic volume for this segment was determined by combining the number of cars in position 1A with positions 2A, 2B, and 2C.

Table 1. Response variables and time periods considered in each question

Question	Response Variable	Initial Year	Final Year
1. Is the increasing trend in deer-vehicle collisions in the City of Ottawa due to an increase in the size of the deer population or could it be simply a reflection of an increasing trend in traffic volume?	1) Cars/m/1995 value 2) Collisions/1995 value	1995	2002
2. Does the spatial distribution of deer-vehicle collisions reflect the locations of Ottawa deer-herd summer ranges as defined by Broadfoot and Voigt (2000)?	1) Collisions/car/m in Stony Swamp summer range 2) Collisions/car/m in South March summer range 3) Collisions/car/m outside both ranges	1997	2002
3. Do deer-vehicle collision trends reflect a larger deer population west of the Rideau River than east of the river?	1) Collisions/car/m west of the Rideau River 2) Collisions/car/m east of the Rideau River	1997	2002
4. Do 400-series highways experience fewer deer-vehicle collisions, indicating that deer avoid high-speed traffic?	1) Collisions/car/m on 400-series highways (excluding recently constructed segments) 2) Collisions/car/m on other segments	1997	2002
5. Do recently constructed highway segments experience more deer-vehicle collisions than older segments?	1) Collisions/car/m on 400-series highway segments constructed since 1995 2) Collisions/car/m on older 400-series highway segments	1997	2002

Deer-vehicle collision data
Deer-collision data were collected from the City of Ottawa for the years 1995 to 2003. These data included all deer-vehicle collisions reported to the Ottawa Police during this time period. In my analysis, I only included deer-vehicle collisions that took place between intersections on road segments for which I had traffic-volume data (see previous section). Collisions that took place in an intersection were not included in analyses, as it was impossible to assign them to a specific road segment.

GIS database
All traffic volume and deer-collision data were compiled into a Geographic Information System using ArcView 3.2. Deer-vehicle collision data and traffic-volume data were assigned to the location of the road segment and the year of interest. The length of each provincial, municipal, and regional segment used in the analyses was determined using the ReturnLength function available in ArcView 3.2.

Data Comparison and Statistical Analysis

The set of road segments used in this study were the segments for which traffic-volume data were available. Collision and traffic-volume data were compared in various ways to answer the questions addressed in this study. When deer-vehicle collisions were used as an indicator of relative deer-population size (relative-population index), the response variable was the number of deer-vehicle collisions per car per meter to correct for both traffic volume and segment length. This was also the response variable used to compare collision frequencies of different categories of roads. Rates of increase of traffic volume and deer-vehicle collisions were determined using standardized collision and traffic-volume index values. The collision frequency for a particular area was the number of collisions that year divided by the number of collisions in the first year in the time period, while the traffic-volume index was the traffic volume per meter divided by the traffic volume/m in the first year in the time period.

1. Is the increasing trend in deer-vehicle collisions in the City of Ottawa due to an increase in the size of the deer population or could it be simply a reflection of an increasing trend in traffic volume?
To determine whether collision trends are simply a reflection of traffic-volume trends, rates of change in deer traffic casualties and traffic volume in suburban and rural Ottawa were compared for 1995 to 2002. The traffic-volume index value for each year was determined using the following equation:

$$\Sigma\ (v/l1 \ldots v/li)$$

Where v/l_1 is the 8-hour total traffic volume of a segment divided by its length in meters and i represents the total number of segments in the focus area. The deer-vehicle collision index value for each year was defined as the total number of reported deer collisions during that year within the focus area. The deer-vehicle collision values were standardized to the 1995 index value. The traffic-volume values were standardized to the 1995 traffic-volume value. The standardized collision and traffic-volume values were then plotted against time to compare their trends. If the rate of increase of deer-vehicle collisions is noticeably greater than that of the traffic volume, then the deer population in Ottawa is likely increasing. If not, then the deer-vehicle collision trends could simply be a reflection of growing traffic volume. Some highway segments were excluded from this comparison, as traffic-volume data were not available for Highway 416 and two segments of Highway 417 for the years 1995 and 1996.

2. Does the spatial distribution of deer-vehicle collisions corroborate the deer-herd locations proposed by Broadfoot and Voigt (2000)?
The deer-vehicle collisions within two proposed summer ranges were compared against each other and against segments outside both ranges for the years 1997 to 2002. The South March and Stony Swamp summer ranges were considered in the analysis, but the Hardwood Plains summer range was not included because traffic-volume data were not available for segments in this area. A segment was deemed to be within a summer range if its center was contained within the boundaries proposed by Broadfoot and Voigt (2000). The relative-population indices (collisions/car/m) for the South March and Stony Swamp summer ranges and the relative-population index of segments outside of both summer ranges were plotted against year (1997-2002). For the distribution of collisions to support the summer-range locations, I would expect to see greater population indices within the ranges than without.

Furthermore, the relative-population index of the Stony Swamp summer range should be greater than that of the South March summer range, since Stony Swamp was estimated to contain a higher deer density (Broadfoot and Voigt 2000). T-tests were used to determine if the summer-range population indices were significantly different from each other and from segments outside both ranges. Traffic volume per meter within and outside the summer ranges was also plotted, as was the standardized traffic volume in these areas, for comparison.

3. Do deer-vehicle collision trends reflect a larger deer population west of the Rideau River than east of the river?
To determine if the distribution of deer collisions reflects a greater deer abundance west of the Rideau River, the relative-population index west of the Rideau River and the relative-population index east of the river were plotted against year (1997 to 2002). A t-test was used to determine if the difference in collisions per car per meter on either side of the river was significant. Traffic volume per meter east and west of the Rideau was also plotted for comparison purposes.

Deer-harvest data was available from the Ontario Ministry of Natural Resources for the years 1999 to 2002 for Wildlife Management Units (WMUs) in Ontario. In order to compare deer-harvest trends with deer-vehicle collision trends east and west of the Rideau River, the number of deer harvested in WMU 65 and 64B, located east and west of the river respectively (figure 4), were plotted against year.

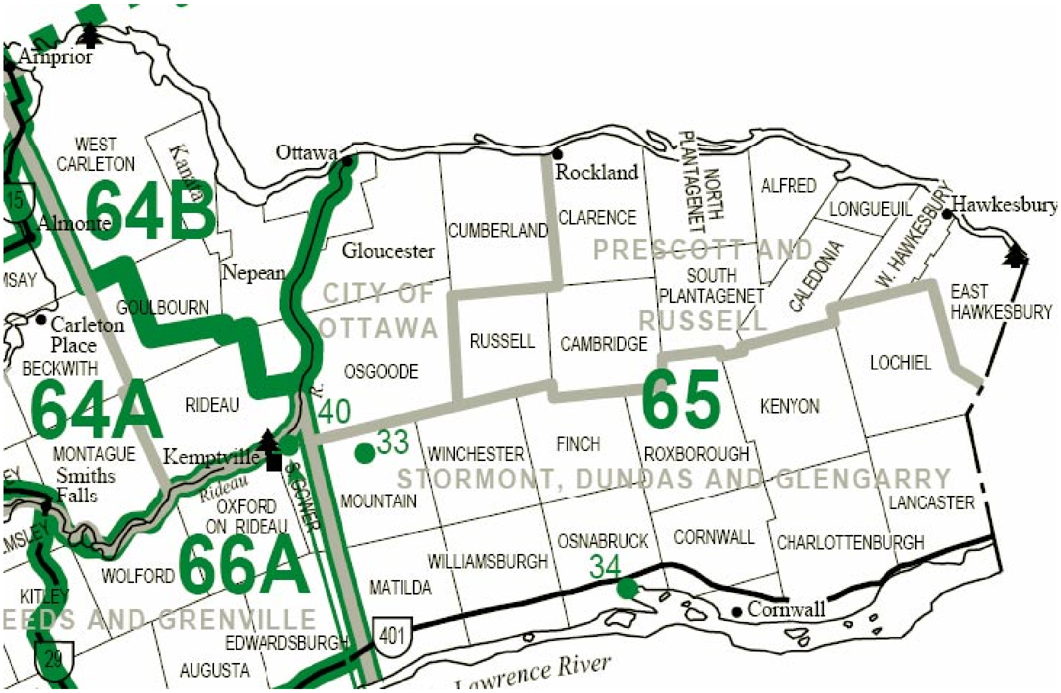

Figure 4. Wildlife Management Units 64B and 65 (OMNR 2003).

4. Do 400-series highways experience fewer deer-vehicle collisions than other segments, indicating that deer avoid high-speed traffic?

The collision frequency (collisions/car/m) on highway segments and the collision frequency for other segment types were plotted against year (1997 to 2002). All segments included were located west of the Rideau River to avoid any discrepancies due to the small sample size east of the river. Recently constructed 400-series highway segments were not included in the comparison so as to avoid their possible influence on the number of collisions/car/m (see question 5). A t-test was used to determine whether the difference in collision frequency for highways and other roads was significant. Traffic volume per meter on highways and other category roads was also plotted for comparison.

5. Do recently constructed 400-series highway segments experience more deer-vehicle collisions than older 400-series highway segments?

The collision frequency for recently constructed 400-series highway segments (since 1995) and for older 400-series highway segments were plotted against year (1997 to 2002). New segments included Highway 416 and the Panmure and March sections of Highway 417. All segments included were located west of the Rideau River. Only highway segments were considered in this analysis to eliminate any differences in collisions due to the speed of traffic or the category of road. A t-test was used to determine whether the collision-frequency index of newer highways was significantly different from that of older highways. Traffic volume per meter on recently constructed highways and older highways was also plotted for comparison.

Results

1. Is the increasing trend in deer-vehicle collisions in the City of Ottawa due to an increase in the size of the deer population or could it be simply a reflection of an increasing trend in traffic volume?

Figure 5 shows the distribution of segments used to compare rates of increase of traffic volume and deer-vehicle collisions in Ottawa. Deer-vehicle collisions are increasing at a greater rate than the traffic volume (figure 6). Therefore, the increasing trend in deer-vehicle collisions is not simply a reflection of an increasing trend in traffic volume.

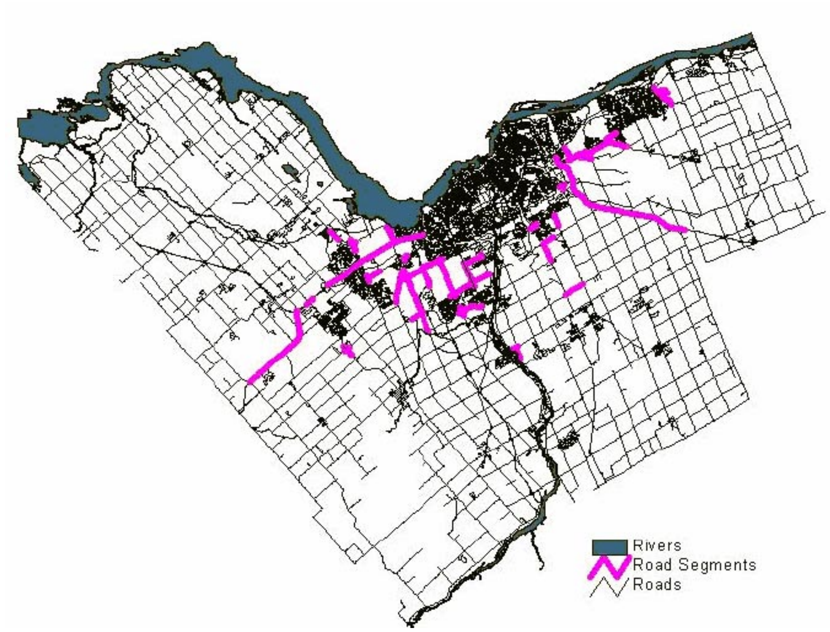

Figure 5. Spatial distribution of road segments included in question 1.

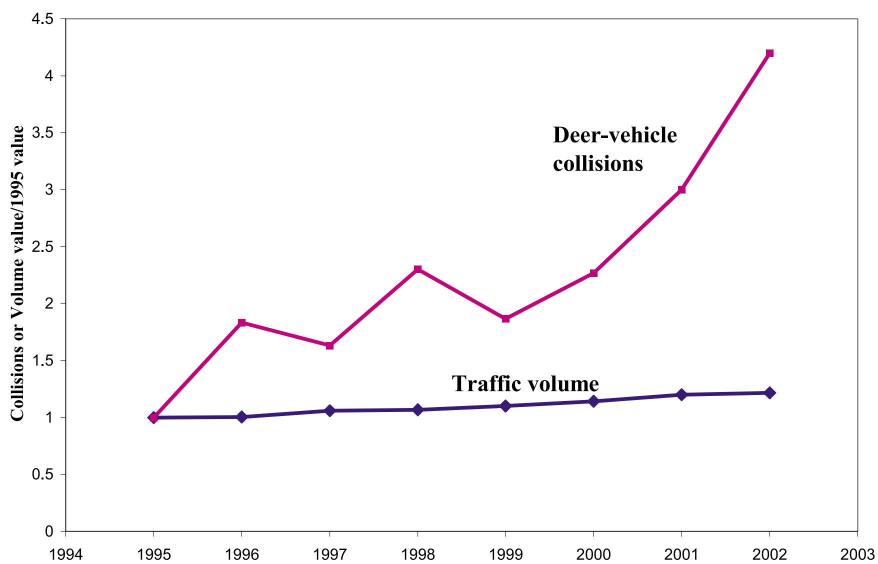

Figure 6. Traffic volume and deer-vehicle collisions from 1995 to 2002, standardized to their 1995 values.

2. Does the spatial distribution of deer-vehicle collisions corroborate the deer-herd locations proposed by Broadfoot and Voigt (2000)?

Figure 7 shows the boundaries of the Stony Swamp and South March summer ranges as identified by Broadfoot and Voigt (2000), as well as the road segments considered to be within and outside of these ranges. Segments within South March returned the largest relative-population index for the entire time period (figure 8), although traffic volume in this area was similar to the Stony Swamp area (figure 9). The relative-population index for the South March range was significantly greater than the relative-population index for segments outside both ranges ($T = 4.84$, $p = 0.01$, $df = 5$) and for the Stony Swamp range ($T = 11.1$, $p < 0.00$, $df = 5$). Collisions/car/m w/car within the Stony Swamp summer range were not significantly different from those outside both ranges ($T = 2.44$, $p = 0.06$, $df = 5$).

The distribution of deer-vehicle collisions supports the boundaries proposed by Broadfoot and Voigt (2000) for the South March summer range, but not the Stony Swamp summer range. The relative-population index for segments outside both ranges is increasing, while the populations within the ranges appear to be stable (figure 10).

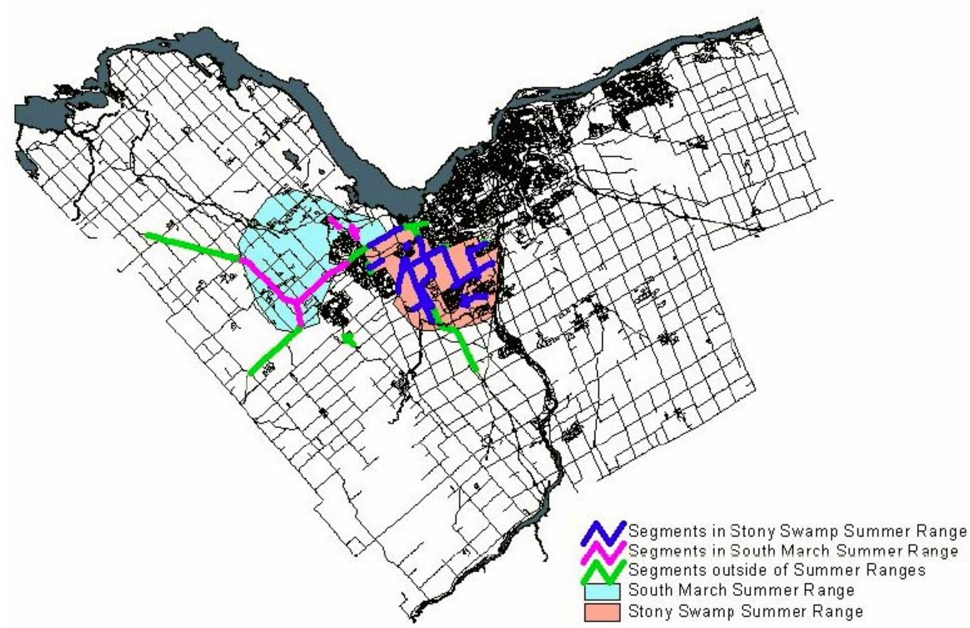

Figure 7. Spatial distribution of road segments included in question 2 and locations of the Stony Swamp and South March Deer Herd summer ranges.

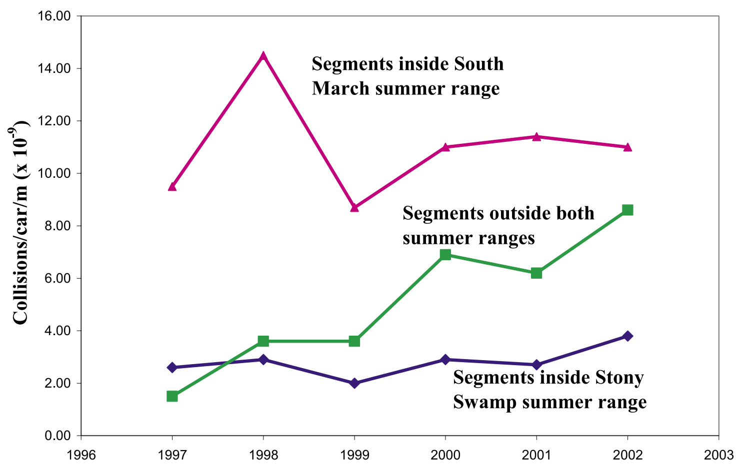

Figure 8. Deer collisions/car/m within the proposed summer ranges of the Stony Swamp and South March deer herds and collisions outside of these ranges.

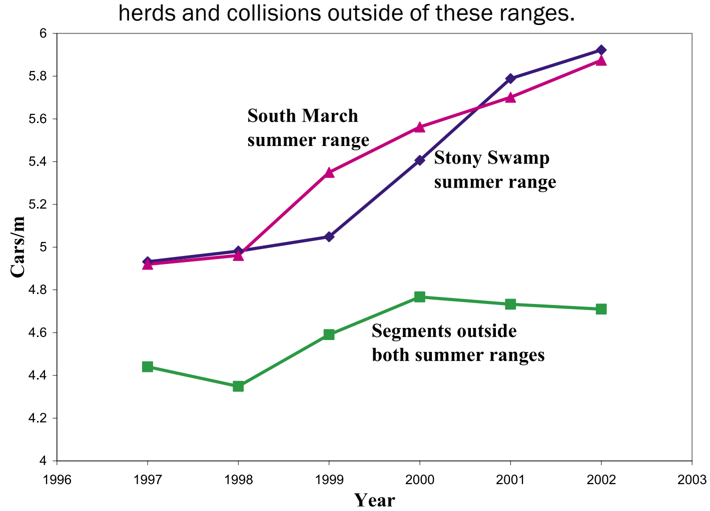

Figure 9. Traffic volume/m (8-hour total) within and outside of the Stony Swamp and South March summer ranges.

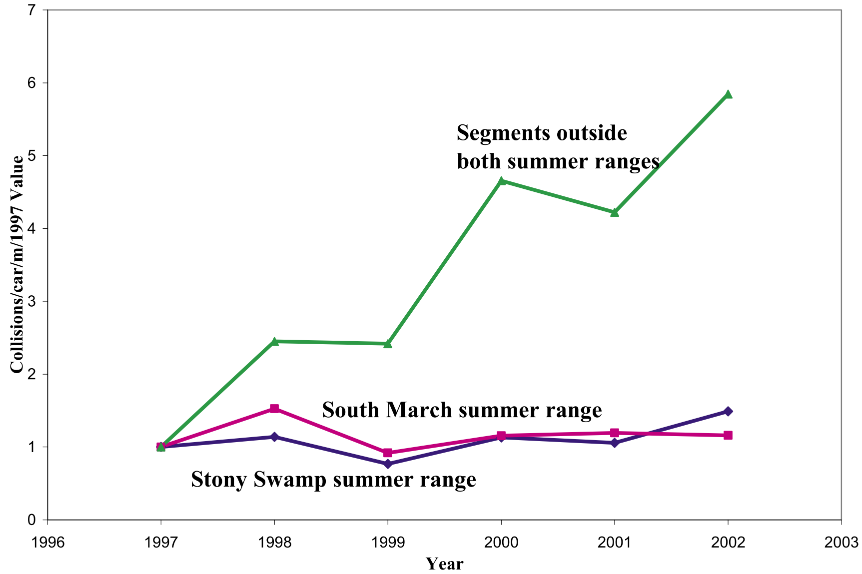

Figure 10. Rate of increase of collisions within and outside the Stony Swamp and South March summer ranges.

3. Do deer-vehicle collision trends reflect a larger deer population west of the Rideau River than east of the river? The distribution of segments considered in this question is shown in figure 11. The relative-population indices for both sides of the Rideau River are shown in figure 12. The difference in number of collisions/car/m was not significant ($T = 1.25$, $p = 0.27$, $df = 5$). Figure 13 shows traffic volume per meter east and west of the Rideau. A greater number of deer has been harvested east of the Rideau River than west of the river, according to deer-harvest data from WMUs 65 and 64B respectively (figure 14). The rates of increase of number of deer harvested appear similar east and west of the river (figure 14).

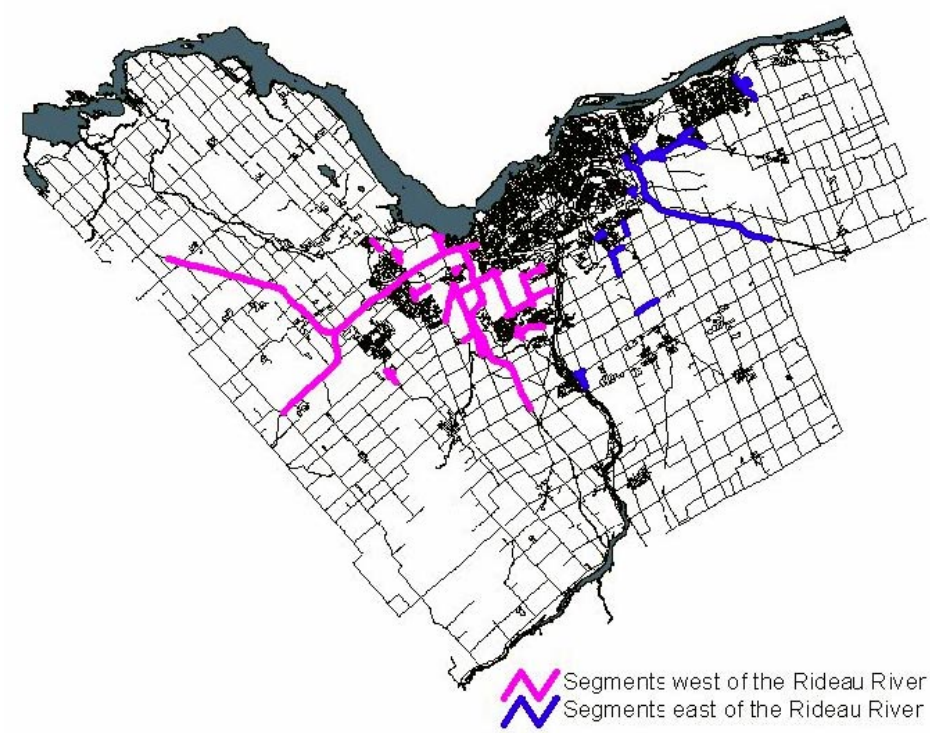

Figure 11. Distribution of segments east and west of the Rideau River.

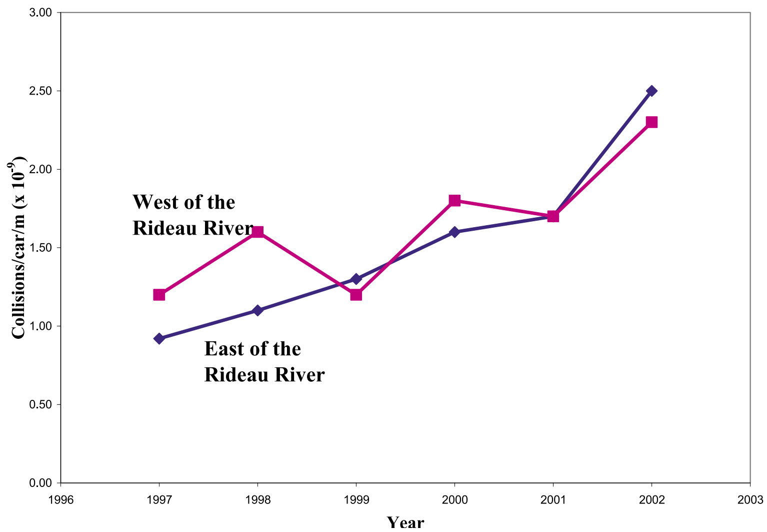

Figure 12. Deer collisions/car/m west and east of the Rideau River.

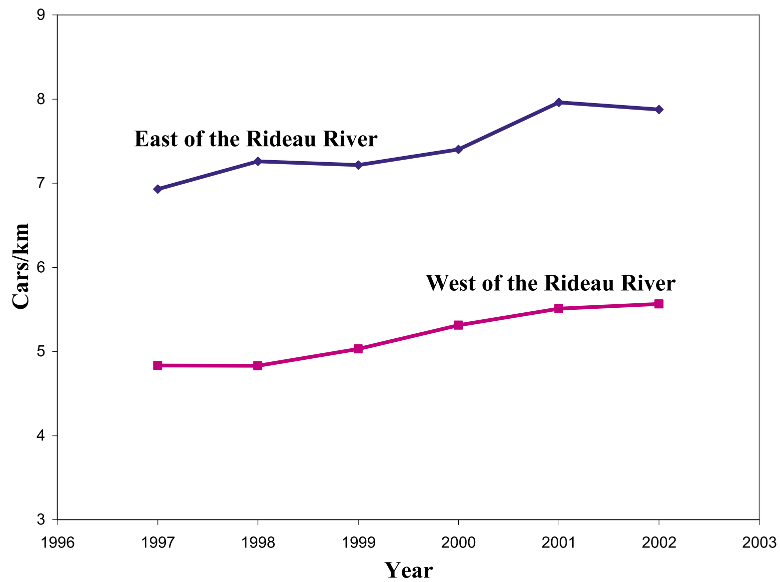

Figure 13. Traffic volume/m (8-hour total) west and east of the Rideau River.

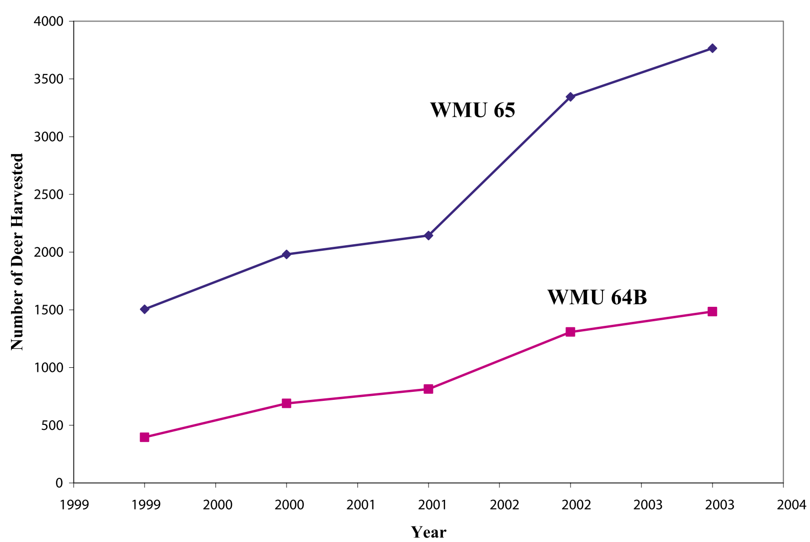

Figure 14. Deer-harvest data from Wildlife Management Units 64A and 65, respectively.

4. Do 400-series highway segments experience fewer deer collisions than other segments, indicating that deer may avoid high-speed segments?

The collision frequencies for 400-series segments and other segments are shown in figure 15. The 400-series highway segments do not experience fewer deer-vehicle collisions/car/m than other segments. Significantly more collisions actually take place on highway segments ($T = 10.3$, $p < 0.00$, $df = 5$). Average traffic volume for highway and other segments is shown in figure 16.

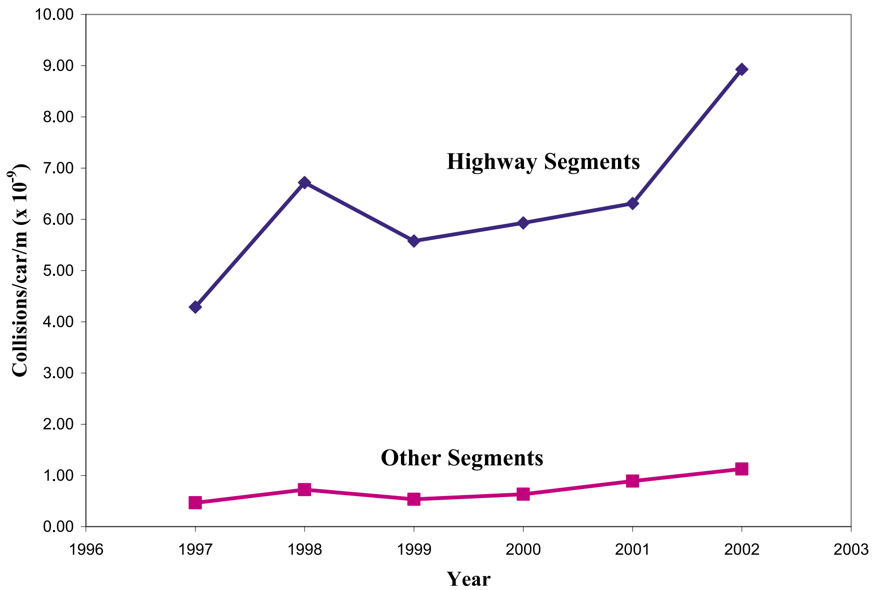

Figure 15. Collisions/car/m on highway and other segments.

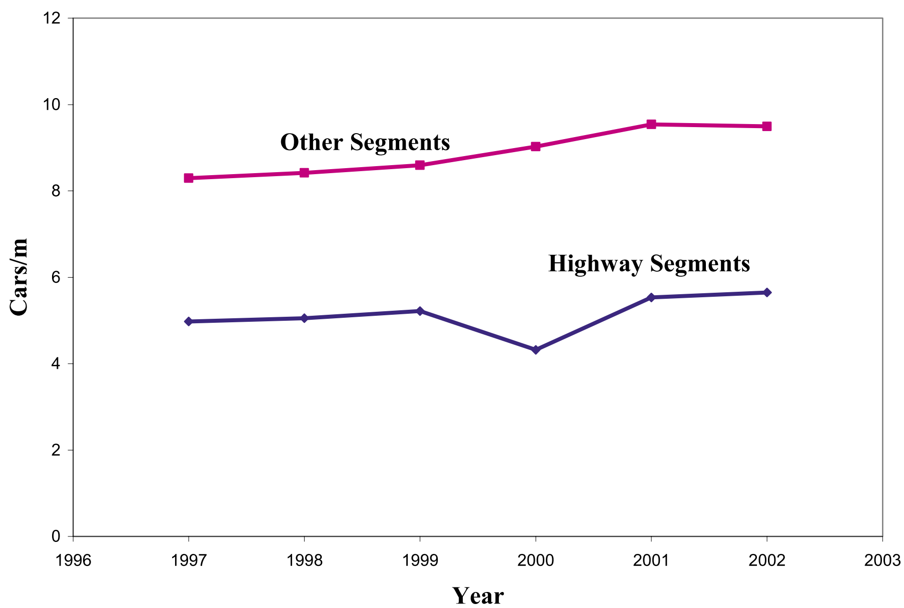

Figure 16. Traffic volume/m (8-hour total) on highway and other segments.

5. Do recently constructed 400-series highway segments experience greater numbers of deer-vehicle collisions than older 400-series highway segments?

Significantly more deer-vehicle collisions/car/m occurred on newer highway segments than older highway segments ($T = 5.31$, $p < 0.00$, $df = 5$) (figure 17). Average traffic volume on newer segments was much lower than on older segments (figure 18).

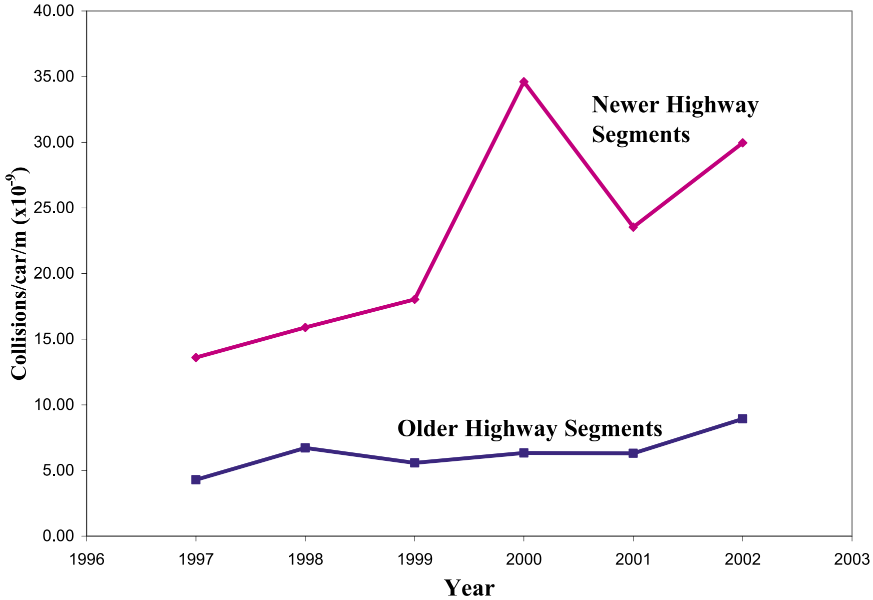

Figure 17. Collisions/car/m on recently constructed (since 1995) and older highway segments.

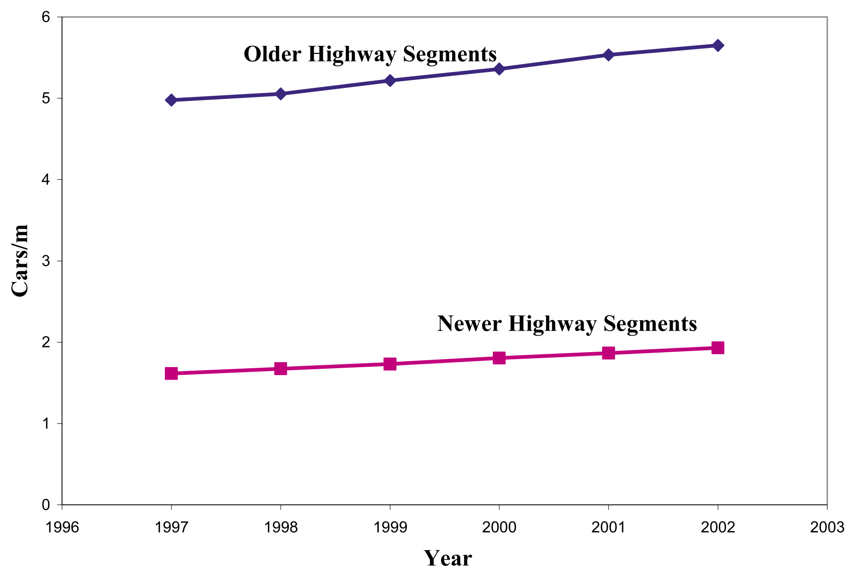

Figure 18. Traffic volume/m (8-hour total) on recently constructed (since 1995) and older highway segments.

Discussion

Deer in the City of Ottawa

The results of this study suggest that the deer population in and around the City of Ottawa is increasing. The rate of increase of deer-vehicle collisions is greater than the rate of increase of traffic volume on the same road segments. In theory, the two most significant factors contributing to numbers of deer-vehicle collisions should be the number of cars and the number of deer on a road segment. If traffic volume was the controlling factor in observed long-term changes of deer collisions in Ottawa, then the rate of increase of collisions should be similar to the rate of increase of cars per meter. Since this was not observed (figure 6), the deer population is likely increasing. A correlation between wildlife collisions and the corresponding species population has not been universally accepted, however. McCaffery (1973) found road kills adjusted for changes in traffic volume provided an acceptable relative-population index for white-tailed deer. Baker et al. (2004) found a significant relationship between fox density and road traffic casualties.

In contrast, in a review of ungulate traffic collisions in Europe, Groot Bruinderink and Hazebroek (1996) concluded that the effects of traffic volume or ungulate population trends on road-casualty numbers are often ambiguous.

A number of factors could have contributed to a rise in numbers of deer in the Ottawa area. Vegetation changes resulting from farmland abandonment and reforestation have led to increased areas of young forests and shrubs, which provide ideal deer habitat (Broadfoot and Voigt 2000). A steady loss of light vegetation (farmland, grasses) to dense vegetation (coniferous and deciduous forest, swampy forest) has taken place from 1955 to 1999 throughout western Ottawa (Campbell 2002), and was likely mirrored east of the Rideau River. Recent mild winters with little snow accumulation may have allowed more deer to survive to the spring (Broadfoot and Voigt 2000). Rural properties do not allow hunting provide reserves for deer, as does the Ottawa Greenbelt (figure 1) (Broadfoot and Voigt 2000).

In the late 1970's, deer numbers were perceived to be low and, consequently, the selective-harvest system implemented by the Ontario Ministry of Natural Resources was initially restricted to allow deer populations to increase (Giles and Findlay 2004). Furthermore, the loss of natural predators in suburban Ottawa (NCC draft) could have contributed to deer-population growth within and around the City of Ottawa.

Figure 12 suggests that the deer population density west and east of the Rideau River is relatively similar. Considering the similar number of collisions/car/m on both sides of the river, it is possible that the Rideau River does not represent a significant population barrier to white-tailed deer in Ottawa. Deer movement across the Rideau River would have important management implications, as deer movement patterns are important to the successful management of white-tailed deer (Van Deelen et al. 1998; Porter et al. 2004; Oyer and Porter 2004; Grund et al. 2002).

The situation surrounding deer in the Ottawa area has been researched in much greater detail west of the Rideau River than east of the river (Broadfoot and Voigt 2000; NCC, draft; Campbell 2002; Carr and Koh 2002). This is likely because deer are in closer proximity to areas of suburban development on the west side of the river and because escalating complaints related to deer have necessitated intervention by the National Capital Commission and the City of Ottawa. Equivalent numbers of adverse deer-human interactions have not occurred on the east side of the river and, consequently, less research has been conducted in this area, even though deer density appears similar.

In addition, the rate of increase in the number of deer harvested on either side of the river appears similar (figure 14). Figure 14 shows a greater number of deer to be harvested in WMU 65 than 64B; this is likely because WMU 65 encompasses a larger area (figure 4). The relationship between proximity to suburban areas and perceived deer-human conflict indicates that human-population density is also an important contributor to problems associated with deer abundance.

Deer herds west of the Rideau River

The spatial distribution of collisions supported the summer-range boundaries of the South March deer herd delineated by Broadfoot and Voigt (2000), but not the Stony Swamp herd (figure 8). The summer-range boundaries were based on general movement trends of Ontario deer, and the location of potential barriers to deer movement within and around Ottawa (Broadfoot and Voigt 2000). The high relative-population index for the South March area is consistent with a greater estimated post-reproduction deer population in the South March summer range (190 deer) compared with the Stony Swamp summer range (100 deer) (Broadfoot and Voigt 2000).

However, Braodfoot and Voigt (2000) estimated that the South March summer range contains 2.7 deer/m^2, while 4 deer/m^2 reside in Stony Swamp, which is not consistent with our results. The relative-population index for Stony Swamp was not significantly greater than that outside both ranges, suggesting that the deer population density of this area may have been estimated incorrectly or that the summer-range boundaries were incorrect. The rapid increase in collisions/car/m in areas outside both summer ranges could indicate a growing deer population outside of the summer ranges or the expansion of current summer ranges. South March and Stony Swamp areas could have reached carrying capacity, while areas outside these ranges may support additional deer.

The carrying capacities of the South March and Stony Swamp summer ranges were determined according to deer-browsing studies and were then correlated with the Ontario Deer Model to estimate actual deer population and density (Broadfoot and Voigt 2000). The disagreement between our estimates and the estimates of Broadfoot and Voigt (2000) suggests that perhaps an actual deer census should be conducted prior to the commencement of any management plans in Western Ottawa that draw on deer abundance and density estimates. It is also possible that deer-vehicle collisions are a poor indicator of the spatial distribution of deer density. The spatial distribution of wildlife collision abundance has been linked previously with wildlife density across a city (Baker et al. 2004) and along a highway (Puglisi et al. 1974), but is not unanimously accepted (Groot Bruinderink and Hazebroek 1996).

Should the boundaries for the summer ranges be incorrect, this could have important management implications for Western Ottawa deer herds. As mentioned previously, knowledge of seasonal movement and migration patterns has been shown to be an important component of the successful management of urban white-tailed deer (Van Deelen et al. 1998; Porter et al. 2004; Oyer and Porter 2004; Grund et al. 2002). Immigration and emigration of deer should not be assumed to be equal in an area considered for localized management, especially when management goals are set to achieve low population densities (Porter et al. 2004). Broadfoot and Voigt (2000) acknowledged in their study of the Western Greenbelt that migration between the Hardwood Plains, Stony Swamp, and South March deer herds is highly likely.

It is important that the extent and seasonality of these migration patterns are well understood before a localized-management plan is implemented, as management programs focused during times of little movement would allow more effective control of population numbers (Grund et al. 2002).

Deer behavior

The results of this study also give important insight as to the behavior of white-tailed deer with respect to roads in an urban environment and risks of certain categories of roads to deer-vehicle collisions. The 400-series highways are shown to experience significantly greater numbers of deer-vehicle collisions, which is consistent with previous findings that accidents increase with increased speed (Allen and McCullough 1976). Allen and McCullough (1976) speculated that slower vehicles had more reaction time to avoid deer, which suggests that if the public is well educated as to high deer-collision sites, slower speeds in these areas should aid in reducing accident numbers. The results of this analysis do not support the hypothesis that deer may avoid high-speed traffic; thus highways represent high-risk collision areas.

The concept that deer may learn to avoid roads over time was not contradicted by our results (figure 18), however there are several other possible explanations for more collisions on recently constructed segments. For example, fewer collisions on older segments could simply reflect a decreased population in that area. Regardless of the cause, the finding that significantly more deer-vehicle collisions occur on newer roads has important implications for road construction in high deer density areas. It is critical that sufficient environmental assessments and ongoing monitoring programs are conducted to identify and mitigate deer-collision risks associated with new roads, especially highways.

In addition, managers and researchers using the spatial analysis of deer-vehicle collisions to determine areas of deer-population density should consider the increased likelihood of collisions on recently constructed roads and highways. For example, the proportion of new highway segments was higher in the Stony Swamp summer range and could have resulted in an overestimation of deer population density due to the increased risk of collisions on the newer segments in this area. The results of questions 4 and 5, that highway segments experience more collisions than other category roads and that recently constructed highway segments experience more collisions than older segments, support previous findings that the category of road is an important factor to be considered in the analysis of wildlife collisions (Baker et al. 2004; Allen and McCullough 1976).

Conclusion

This research suggests that deer-vehicle collisions could be a useful data source for inferring deer-population dynamics of suburban deer. However, factors other than deer numbers that affect deer-vehicle collisions make this data source less reliable as a proxy for deer-population estimates. The ecology of white-tailed deer occupying urban landscapes has received little attention (Grund et al. 2002) and studies of deer-vehicle collisions provide a cost-effective means of addressing research in this area. Collision data could give information about deer numbers and behavior, could be used to study relationships between deer and roads, and to learn local deer population and movement trends, but it is imperative that significant factors affecting the number and distribution of collisions, such as category of road and traffic volume, are considered during any analyses.

Biographical Sketches: Kerri Widenmaier has recently completed the requirements for a B.Sc. in environmental science, minor in biology and looks forward to graduation in November from Carleton University. Her recent fourth-year thesis project focused on inferring population dynamics of white-tailed deer from wildlife collisions within the City of Ottawa under the supervision of Dr. Lenore Fahrig. Taking a break from her studies, she currently holds the position of Assistant Science Advisor in the Science Advice and Biohazard Containment Division of the Canadian Food Inspection Agency. Kerri hopes to continue her education towards a master's degree in the near future.

Lenore Fahrig is professor of biology at Carleton University, Ottawa. Dr. Fahrig studies the effects of landscape structure on wildlife populations. She uses spatial-simulation modeling to formulate predictions and tests those predictions using a wide range of organisms, including plants, insects, amphibians, mammals, and birds. Her current work on road-system ecology includes empirical studies of road impacts on small mammal and amphibian populations and movements, as well as generalized simulation modeling of population responses to road networks. Dr. Fahrig has published over 50 papers in landscape ecology. Many of her recent papers focus on ecological impacts of roads. She is currently a member of the U.S. National Academy of Sciences Committee on Ecological Impacts of Road Density.

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Integrated Training Course for Engineers and Wildlife Biologists

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Abstract

The need for a comprehensive (yet concise) training course on the basics of highway and wildlife interactions has become more apparent as more transportation engineers and wildlife biologists are faced with demands to consider wildlife mortality and connectivity issues and to incorporate wildlife crossing structures in highway projects.

The USDA Forest Service has developed an interagency, interdisciplinary two-day training session that walks engineers and biologists through the basics of habitat connectivity, impacts to wildlife from highways, effective mitigation measures, funding sources, and law and policy related to highway projects. This course, Innovative Approaches to Wildlife and Highway Interactions, has been designed to be taught by a wildlife biologist and a transportation engineer, with a target audience of mixed, mid-level professionals who are planning highway projects of various types.

The course was designed to integrate disciplines so that the challenging situations we face in highway projects can be innovatively solved and networking between agencies and disciplines is facilitated. The course is modular and based on the Wildlife Crossings Toolkit (http://www.wildlifecrossings.info), also developed by the USDA Forest Service, and current scientific works.

Eight sessions across the country have been completed since course development, with participants from eight state DOT's, FHWA, NGO's, state fish and wildlife agencies, FWS, and three federal resource agencies. Departments of transportation and resource agencies are welcome to host training sessions across the country with these training materials and instructors.

Funding for the course development was provided by the Coordinated Transportation Improvement Project fund, an interagency pooled fund.

Biographical Sketch: Sandra L. Jacobson, wildlife biologist/research and management liaison, Pacific Southwest Research Station, Redwood Sciences Laboratory, Arcata, California. Education: B.A. in zoology (1983), Humboldt State University, Arcata, California, and M.S. in natural resources/wildlife (1986), Humboldt State University. Jacobson has served as a wildlife biologist for the USDA Forest Service since 1980, working on three national forests at the district and forest levels in California and Idaho. She has worked for the USDI Fish and Wildlife Service, California Department of Fish and Game, and the USDA Soil Conservation Service. As the district wildlife biologist for the Bonners Ferry Ranger District on the Idaho Panhandle National Forests for 13 years, she managed grizzly bears, woodland caribou, and other threatened or endangered wildlife in an interagency and international setting. Ms. Jacobson is the lead biologist for the Wildlife Crossings Toolkit website. She is a charter member of the Transportation Research Board's Task Force on Ecology and Transportation and a team member for NCHRP 25-27's Evaluating the Effectiveness of Wildlife Crossing Structures. She is a member of the University of California-Davis Road Ecology Center's Scientific Advisory Committee. Currently, Ms. Jacobson is providing project-level technical expertise and training on wildlife and highway issues for several agencies around the country while acting as a research/management liaison at the Pacific Southwest Research Station.

Integrating Transportation and Resource Conservation Planning

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Abstract

The arroyo toad was federally listed as an endangered species in 1994. For the last 10 years, the Cleveland National Forest in southern California has been evaluating and mitigating the effects of roads and road crossings on this species. To date, we have closed five miles of roads within toad habitat and have constructed seven crossings to reduce or eliminate the effect of the crossings on toads.

Prior to this effort, most of the stream crossings in toad habitat were unimproved and vehicles drove directly through the stream. This caused several problems for toads:

1. While crossing the stream, vehicles would often proceed to drive up and down the stream, causing considerable disturbance of the stream bed and increasing turbidity in the stream.
2. Vehicles would often become stuck in the stream or hit a rock while attempting to cross the stream, which could result in spillage of oil or other toxic substances into the stream.
3. Tadpoles present in the stream could be crushed by vehicles driving through the crossing.

Two different types of stream crossings were constructed to separate vehicle traffic from contact with the streams. The first type was an "Arizona" crossing, which is a raised concrete ford with culverts. This type of crossing was constructed with adjacent partially buried k-rail or fencing to ensure that vehicles stayed on the road surface. The second type of crossing was a precast concrete 93 feet span designed to accommodate a 50-year flood and to eliminate vehicles from driving 400 feet up of the stream. Our poster will illustrate these two types of crossings. Since 1999, the Cleveland National Forest has been monitoring Forest roads/road crossings after rainfall events and we have not observed any arroyo toads killed or injured by vehicle traffic.

The Invasive Common Reed (*Phragmites Australis*) Along Roads in Quebec (Canada): A Genetic and Biogeographical Analysis

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Abstract

During the last century, common reed (*Phragmites australis*) colonies expanded in marshes of north-eastern North America. This species is highly problematical because it has a strong impact on plant and animal diversity. In the province of Québec (Canada), the spread of common reed coincided with the expansion of the highway network from 1963 to 1984. We hypothesized that highways contributed to the spread of the common reed by creating dispersal corridors and favorable habitats for the growth of the species. To test this hypothesis, in 2003 we mapped the spatial distribution of common reed colonies along all Québec's highways (2800 km). We also sampled 260 populations to determine whether common reed found along highways is native or exotic. Furthermore, in 2004 we mapped the spatial distribution of colonies along secondary roads in three large areas (485-810 km^2), more specifically in regions where common reed colonies were particularly abundant. Globally, 24% of roadsides were invaded by common reed. Highest common reed densities were registered near the city of Montréal, in the south-western part of the province. In this region, the common reed formed hedges several kilometres long. The roadsides of secondary roads where also highly invaded, which suggests that the entire road network contributed to the spread of common reed. Genetic analyses indicated that 99% of common reed colonies found along highways were exotic (haplotype M from Eurasia). Only three out of 260 colonies were dominated by a North American genotype. The spread of common reed in Québec probably resulted from the introduction of an exotic genotype in the first part of the 20th century. This genotype likely benefited from the expansion of the highway network to establish new colonies in most regions of southern Québec. The maintenance of the highway network (ditch digging, roadside mowing) also probably contributed to the spread of common reed and to the improvement of growth conditions for the species.

Biographical Sketch: Benjamin Lelong is a biologist and received his masters of environmental biosciences degree at Université Aix-Marseille 3 (France), where he studied the allelopathic potential of *Pinus halepensis* in secondary succession on abandoned agricultural land. He is presently a Ph.D. student and his major research interest is biological invasions.

Landscape Ecology in Transportation Planning

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Abstract

There has been a recent emergence of "road ecology" as a science that looks at the overall impacts of roadway systems on ecological communities in general. The evidence indicates that roadway impacts may extend beyond the operating right of way. To date, few projects have incorporated the idea of landscape ecology in the planning process.

The I-90 Snoqualmie Pass East project is breaking new ground in integrating landscape ecology and ecosystem processes into the design of a proposed expansion of the existing highway from four to six lanes for a 15-mile stretch. The project crosses/bisects an area that has been identified as the narrowest band of publicly owned land in the Washington Cascades. To better accommodate the project's identified ecological connectivity need, the project team has focused on sites called "Connectivity Restoration Areas." These areas have the highest likelihood of linking aquatic, riparian, and terrestrial habitat of relatively high quality north and south of the highway.

Although high-visibility wildlife (such as elk and deer) have been the major focus of most connectivity structures, there is a greater need to restore and enhance ecological processes (such as the regulation of hydrologic flows and soil retention) that often drive the ecosystem in general. This is most evident along the I-90 corridor during periods of snow-melt when water is a dominant feature on the landscape. The I-90 corridor contains numerous high-quality wetlands, some of which have been separated hydrologically by the existing highway. In some cases, the highway has created wetland areas by acting as a dike, interfering with natural-surface and subsurface flow paths. Many stream crossings have constriction points that impact the floodplain connectivity and do not allow for channel meander.

Via a collaborative, interdisciplinary process, the Washington State Department of Transportation (WSDOT), South Central Region has developed guidance for recommending a preferred alternative that will integrate the needs of aquatic, riparian, wetland, and terrestrial ecosystems and the needs of the associated organisms into the design of the new highway expansion. This incorporates not only the area adjacent to the highway and within the operating right-of-way, but expands to look at proper functioning of hydrologic processes at a broader scale. WSDOT also incorporated the work of Singleton and Lehmkuhl (2000) that identified areas of animal movement and landscape permeability within the I-90 corridor. The placement of the structures should provide opportunities for movement of organisms between populations and reduce the risks associated with demographic isolation. Increasing the permeability of the highway should also reduce direct mortality of individuals and increase the likelihood of persistence of local and regional populations that may be genetically distinct.

The desired, long-term conditions associated with the highway expansion are a functioning ecosystem with late-successional reserve forests, properly functioning streams, and wetlands that provide additional opportunities for species diversity.

Biographical Sketch: For the past seven years, I have worked as the biology program coordinator at the Washington State Department of Transportation, South Central Region. This position is responsible for compliance with the Endangered Species and Clean Water acts and includes the writing of biological assessments, wetland inventories, and wetland mitigation plans. In addition, I have been a core member of the Mitigation Development Team for the I-90 Snoqualmie Pass East Project, which has been developing strategies for wildlife and hydrological connectivity from a landscape perspective.

Ledges to Nowhere—Structure to Habitat Transitions

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Abstract

The purpose of this poster is to call attention to problems that are being encountered in the design and construction of wildlife crossing structures that significantly undermine their usefulness to wildlife.

The problem
Three roadway projects nearing completion in Florida Department of Transportation (FDOT) District 5 (east central Florida) include modifications to existing bridges and culverts that add ledges for the passage of small wildlife. In all three projects, the ledges ended abruptly at the ends of the structures, with no transition and even significant obstacles between the ledges and the surrounding habitat. Each of the roadway projects was designed independently by a different engineering firm, so the lack of awareness was not limited to one individual designer or firm.

(Expensive) solutions
The design engineers for each project have produced corrected drawings. Modifications are completed or underway, except at one structure, for which the roadway contractor declined to bid on the changes. A second project to correct the problem will be needed.

Recommendations
Small oversights during design and construction can virtually eliminate the usefulness of wildlife passages included in structures. Engineers and biologists should collaborate throughout the design process. Biologists should monitor these accommodations during and after construction.

Biographical Sketch: Stephen Tonjes has a B.S. in zoology from the University of Michigan and a M.S. in oceanography from Oregon State University. He served three years in the U.S. Coast Guard, then taught for a year at Seacamp in the Florida Keys. He worked two years managing the Coast Guard bridge permit program in Juneau, Alaska, and worked a year in the Office of Endangered Species of the U.S. Fish and Wildlife Service in Washington, D.C. Since 1986, he has worked with the Florida DOT District 5 Environmental Management Office writing and reviewing NEPA documents, applying for permits, managing mitigation contracts, coordinating commitment compliance, moving or mitigating for gopher tortoises, assessing trees, moving bats, and doing a few other things.

Monitoring of Wildlife Crossing Structures on Irish National Road Schemes

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Abstract

Ireland is currently undergoing the largest extension to the National road network in recent years. For this reason, the number of crossing structures for wildlife on the Irish National road network has increased markedly within the last few years.

In Ireland, the structures are targeted at protected species whose habitat is directly disturbed by road construction. In general, the target species are otters (*Lutra lutra*) and badgers (*Meles meles*). However, structures have been put in place for red squirrels (*Sciurus vulgaris*); i.e., rope ladders linking trees on opposite sides of a motorway and the first structures for pine martens (*Martes martes*) and bats will be put in place in the coming year. Bat boxes and bird boxes have also been fitted on the tunnel ceilings of oversized arched culverts with mammal ledges.

Underpasses and overpasses (potential green bridges) have been constructed where farms have been bisected by new road schemes. These structures allow for the safe passage of domestic cattle over the road carriageway, but may also be utilized by wildlife, for example, red deer (*Cervus elaphus*) and other smaller wildlife species.

Non-target native species which can utilise these structures are: red deer (*Cervus elaphus*), the indigenous Irish hare (*Lepus timidus hibernicus*), stoat (*Mustela erminea hibernica*), fox (*Vulpes vulpes*), pygmy shrew (*Sorex minutus*) and field or wood mouse (*Apodemus sylvaticus*).

Non-native species which could potentially utilize such structures include: Sika deer (*Cervus nippon*), fallow deer (*Cervus dama*), brown hare (*Lepus europaeus*), rabbit (*Oryctolagus cuniculus*), grey squirrel (*Sciurus carolinensis*), hedgehog (*Erinaceus europaeus*), brown rat (*Rattus norvegicus*), house mouse (*Mus (musculus) domesticus*), bank vole (*Clethrionomys Glareolus*), feral ferret (*Mustela furo*), American mink (*Mustela vison*), and domestic cats and dogs, amongst other introduced species.

This is the first study to examine the effectiveness of crossing structures in Ireland. An initial pilot study monitoring the use of crossing structures on the Watergrasshill By-Pass, County Cork, Ireland, revealed encouraging results as the following species were found to utilize oversized arched culverts with mammal ledges: otter, fox, rabbit, pygmy shrew and wood mouse. Tracking tools utilized include: ink pads, sand beds, and infrared cameras.

The initial pilot study was expanded to monitor crossing structures on a national scale in order to examine: (A) how effective are the culverts at providing passage for the target species? and (B) to what extent are cow under- and overpasses being utilised by wildlife?

More specifically, the study is also currently examining: (1) with what frequency are the various passages being utilized?; (2) what non-target species utilize these passages?; (3) does the design of the fauna pipe (dimensions) affect utilization of the passage? e.g., are shorter pipes or longer pipes or small diameter (600 mm) or large diameter pipes (900 mm) more frequently used?; (4) does the presence of hedgerow planting enhance use of passage structures? (5) what kind of pipes do smaller species have a preference for?

It is intended that the results of the study will provide valuable information which could improve the layout, design, and maintenance of future crossing structures to be put in place on national road schemes in Ireland, and indeed, in other countries.

Monitoring the Recovery of Decommissioned Roads With Citizen Scientists in the Clearwater National Forest, Idaho

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Abstract: Road decommissioning is an increasingly important tool for restoring watersheds on national forest lands. Wildland roads can result in a number of negative impacts leading to decreased terrestrial and aquatic habitat quality. It is believed, therefore, that road decommissioning can have significant positive effects on a watershed—cleaner water, improved fisheries, and restored habitat for terrestrial animals.

However, very little research has been conducted to quantify these benefits. In 1998, the Clearwater National Forest (CNF) and Nez Perce Tribe (NPT) began an intensive road decommissioning program after extensive flooding caused hundreds of landslides in 1995-1996. Since the program's inception, more than 500 miles of roads have been decommissioned. Neither the CNF nor the NPT can sustain the budget and personnel necessary to monitor how effectively these projects are restoring fish and wildlife habitat.

Data collected through a citizen monitoring program will fill this need. Citizen science is a popular and powerful way to monitor the long-term trends and conditions of natural systems while also encouraging a stewardship ethic for the resources being monitored. The information gathered by "citizen scientists" can help land managers make more informed decisions about how best to care for public and private land. We have created the first citizen monitoring program that focuses on the ecological recovery of decommissioned roads. We developed monitoring protocols for citizen scientists, recruited and trained volunteers, and led monitoring trips in the field every weekend during the summer and fall of 2005, engaging, thus far, some 20 volunteers.

As this project is still in progress, all conclusions and findings reported are preliminary. We can, however, make general observations on the efficacy and accuracy of employing citizen scientists to measure ecosystem recovery as a result of road decommissioning. In addition, a second year of funding has been obtained for this project. We anticipate that next year's program will be a success in forwarding our objectives for this project.

Background

The importance of wildland road removal

The effect that roads can have on ecosystems has become an extremely popular area of scientific comment, theory, and research. The presence of roads is associated with the presence of non-native weeds, invasions of non-native animals that are attracted to edge habitat, and other alterations in the structure and function of communities of animals and plants (Trombulak and Frissell 2000). Restoration of watersheds through road removal is an increasingly important tool for land managers, including the U.S. Forest Service. However, very little research has been conducted to quantify the perceived benefits of such restoration. The Forest Service's long-term transportation policy calls for removing up to 25 percent of its existing road system during the next 20-40 years. Wildland roads are a target for restoration because, while they can provide economic and social benefits, they can also degrade the quality of both aquatic (water) and terrestrial (land) habitats (Trombulak and Frissell 2000).

Aquatic Impacts

Removing roads from national forest lands can have a number of beneficial effects. Major beneficial effects include increased infiltration of surface water and reduced surface erosion, which can, in turn, lead to reduced landslide risk and decreased sediment delivery to streams and lakes (Switalski et al. 2004). Road removal and the accompanying decrease in sedimentation can be an important step in protecting aquatic species which need streams nearly free of suspended sediments (for example, most species of salmon and trout). Sediments can harm salmon and trout fisheries through direct mortality, by hindering the development of eggs and larvae, disrupting natural movements and migration, and disrupting fish feeding behavior as a result of reduced visibility (Newcombe and MacDonald 1991).

Terrestrial Impacts

Many species of terrestrial wildlife are influenced by roads as well. Wisdom et al. (2000) reviewed the impacts of forest and range roads on animals and reported that roads and road-associated factors had a negative effect on over 70 percent of the species reviewed. Roads directly or indirectly lead to habitat loss and fragmentation, poaching, over-trapping, snag reduction, down log reduction, negative edge effects, movement barriers, displacement or avoidance, harassment or disturbance at specific use sites, and chronic negative interactions with humans. Additionally, more intact forests (habitat which has not been fragmented by roads) have been shown to provide better habitat for various species of wildlife. We predict that removing wildland roads and restoring habitat to a more intact system will benefit wildlife.

The Clearwater National Forest road removal program

Ecological Conditions in the Clearwater
Idaho's Clearwater National Forest covers nearly two million acres of land in the north-central portion of the state, from the Bitterroot Mountains in the east to the Palouse Prairie in the west. It is the ancestral home of the Nimi'ipuu, or Nez Perce Tribe and forms a nearly contiguous block with the Selway-Bitterroot Wilderness Complex to the south—wild country where old growth cedars, larch, and pine still stand, and where clear, cold water is birthed—much of which flows, eventually, into the Lochsa Wild and Scenic River to the north.

A noted premier whitewater recreation site, the Lochsa River is also home to several protected species of fish, including spring Chinook salmon and steelhead and bull trout—fisheries which supported the Nez Perce when the rivers west of here still ran free, and the draw of which continues to support communities economically who have grown to focus on tourism as a main source of revenue. Additionally, hunting outfitters and guides profit from leading paying visitors to the full complement of native terrestrial wildlife (with the exception of the grizzly bear) which still thrives in the CNF.

On the north side of the Lochsa, however, things are not quite so unspoiled. A legacy of logging over several decades has left the Forest heavily roaded and greatly reduced the quality of much of the habitat on the forest, with more than 4,500 total miles of roads in the forest, some areas have road densities as high as 30 miles of road per square mile. That's higher than in metropolitan areas like New York City. In an area already heavily landslide prone, roads, especially in densities such as these, increase the risk of landslides by interrupting natural water flow patterns and threatening water quality and fish habitat with high influxes of sediment.

The Road Removal Program
In the winter of 1995-96, extensive flooding caused hundreds of landslides, nearly half of which were directly traced to old, abandoned, and overgrown logging roads which had previously been considered stable (McClellan et al. 1997). Similar flooding events had occurred approximately once every 10-15 years, with the number of landslides increasing as the road mileage increased. In 1998, with an influx of cash from emergency federal funding, the CNF partnered with the NPT to begin an ambitious road-decommissioning program in an attempt to restore watershed health and protect the valuable fisheries that still exist in the area (Wildlands CPR 2003). Since the program's inception, more than 500 miles of roads have been decommissioned, hundreds of stream channels have been restored, and planning is underway to restore many more watersheds by decommissioning hundreds more miles of roads. The Clearwater National Forest road-removal program is now one of the largest road-restoration programs in the country.

The goal of ongoing road decommissioning on the CNF is "to reduce watershed impacts by reclaiming roads that are no longer a necessary part of the Forest's transportation system" (USDA FS 2003). The primary objectives are to reduce erosion from road surfaces, reduce the risk of mass failures, restore drainage patterns, stream channels, and site productivity and to protect and restore fish habitat. These habitat improvements should benefit many fish and other aquatic species. Decommissioned roads would presumably create habitat for a variety of terrestrial animals as well. Some wildlife biologists argue that road decommissioning will reduce grizzly bear mortality risk (USFWS 1993) and increase elk-habitat security. Unfortunately, as with many projects that are ambitious but strapped for funding, in-depth monitoring of watershed restoration across the Forest has been somewhat less than adequate, because resources to monitor the effectiveness of this restoration activity are slim. Adding to the complexity of the problem, it will very likely take several years to detect significant changes in watershed health once monitoring has begun and after decommissioning has occurred.

Citizen science is a powerful tool to monitor restoration
The primary goal of ecological restoration (like road decommissioning) is to return ecosystem structure, functions, and processes to natural conditions (Block et al. 2001). It is often assumed that if restoration is "successful," ecological conditions will be favorable for the native plant and animal species. Although this assumption is rarely tested, it should be, and citizen monitoring can play a key role in that testing. Often, project monitoring is not completed by federal, state, or private land managers because of lack of funding. But without that monitoring, the effectiveness of particular restoration techniques is unknown. Without monitoring, restoration techniques cannot improve.

Citizen Scientists Fill in the Gaps
Citizen science is a powerful way to monitor the long-term trends and conditions of natural systems while also encouraging a stewardship ethic for the resources being monitored. This method is popular across the United States. According to the U.S. Environmental Protection Agency, in 1998 there were more than 772 citizen monitoring projects across the country (US EPA 1998). Participants in these monitoring projects can become intimately acquainted with the systems they are monitoring and often develop into exceptional advocates for their protection and conservation as a result of that relationship.

One of the most important roles of citizen scientists is to help fill in the blanks that cannot be covered by government or private personnel because of funding constraints. Therefore, these citizen scientists can provide a more complete picture to public-lands managers and decision-makers. Limited resources mean limited time and personnel to carry out essential monitoring projects. The information gathered by citizen scientists through monitoring can provide vital help to land mangers as they make more informed decisions about how best to care for public and private land.

The Clearwater National Forest as a Citizen Science Testing-Ground
The Clearwater National Forest is ideal for developing and implementing a citizen monitoring protocol for several reasons. First, the Forest Service and Nez Perce Tribe have worked in close partnership on this project since 1998, creating a strong cooperative bond that extends beyond the reach of these two entities and into the surrounding communities. Second, the CNF and NPT have developed active education programs to promote road decommissioning in their communities, which has enabled them to significantly reduce the controversy that often accompanies such work. Because several local communities are already relatively supportive, there are local citizens interested in engaging in this volunteer project. Third, the CNF, as the leader in road removal on Forest Service lands, has several hundred miles of roads identified as candidates for decommissioning as funding becomes available. Fourth, the scale of road decommissioning on the Clearwater National Forest affects entire watersheds; consequently, monitoring stream response in these watersheds may yield meaningful data. The Forest Service does not have the budget or personnel to expand their monitoring of stream-habitat conditions and conduct population assessments of fisheries and wildlife. Citizen science has the potential to be an effective, low-cost solution, while also increasing local involvement and support for watershed restoration.

Benefits of Citizen Science on the Clearwater National Forest
Participation in this citizen-science program will result in a number of long-term benefits to local communities. Most importantly, informed local communities will better understand why road decommissioning is a critical component of watershed restoration. Additionally, by investing community time and energy in monitoring, citizen science promotes community stewardship and cooperation. With a greater understanding of watershed restoration, this community will be more supportive of the benefits of watershed protection and sustainable management practices.

In addition to benefiting local communities, this project could act as a model for other programs across the U.S. Extensive road decommissioning efforts are occurring across the western coastal states (Washington State, Oregon, and California). Although some monitoring is occurring in these locations as well, there is no universal protocol to allow comparison and meta-analysis. By implementing a protocol and promoting citizen science programs in other areas of the country, we will increase the amount of data available to analyze the benefits and impacts of road decommissioning—a topic that remains almost completely unstudied.

Objectives
Seeing this need and perceiving a possible solution, the CNF and NPT teamed up with Wildlands CPR and the University of Montana's Environmental Studies program to create a citizen monitoring program which would fulfill several objectives simultaneously. Our specific objectives for this project were twofold: 1) to assist Forest Service and tribal personnel in obtaining vital monitoring data regarding their road decommissioning program in several areas of the forest, and 2) to engage and educate members of the public about the existence of road-decommissioning projects and their benefits and impacts. Each of these objectives was achieved by fulfilling various goals set out at the beginning of the project in a detailed planning process undertaken as a part of the original grant-application procedure.

Methodology

The project was divided into two main components with separate and clearly definable purposes. The first component was to develop monitoring protocols specifically geared toward monitoring decommissioned roads with citizen scientists and plan for their implementation. The second component was to recruit citizen scientists from local communities within and nearby the Clearwater National Forest to carry out the implementation of the aforementioned protocols.

Developing monitoring protocols and ensuring their usefulness
Initially, during the summer and fall of 2004, we assessed existing monitoring protocols and programs and adapted them to create our own unique citizen monitoring program, focused on road decommissioning. The protocols outline aquatic and terrestrial sampling methods (see list 1), including pebble counts, erosion pins, vegetation surveys, measurement of water temperature, collection of macroinvertebrates, and the use of photo points. Wildlife-sampling methods, including remote-sensor cameras and tracking stations designed specifically for use on decommissioned roads, were incorporated into these protocols (see Townsend and Switalski 2004). Simultaneously, we developed a quality-assurance plan to ensure that the data collected would be accurate and useful. We also field tested several of the monitoring protocols during the fall with students from the University of Montana's (UM) Wilderness and Civilization class.

Recruiting Citizen Scientists
The following winter we developed an outreach plan to guide outreach activities in various target communities and groups. This plan helped us identify local citizen leaders and organizations interested in long-term, consistent volunteer opportunities. During the spring of 2005, we actively recruited volunteers via schools, county groups, local businesses, and environmental and conservation organizations from small communities in Idaho such as Kamiah, Kooskia, and Orofino, as well as from larger communities such as Moscow, Lewiston, and Missoula (Montana). Individual recruitment presentations were made at local chapters of Trout Unlimited, as well as at several university and high school classrooms. That spring, we also prepared for the field season by developing an informational data entry and analysis website (online at www.clearwaterroads.com) and citizen comment surveys with the help of the University of Montana's Wilderness Institute. The website allows volunteers to remotely upload data collected in the field to a central database, as well as perform some basic analyses.

Preparing for Citizen Scientists in the Field
Before we brought volunteers into the field, we identified seven monitoring segments on the CNF and set up monitoring equipment in preparation for data collection. Our broad goal was to compare the results of decommissioning across drainage types for a watershed-level assessment. Our sampling design, therefore, included monitoring segments that exist in unroaded (or nearly so) drainages, drainages that have overgrown (un-decommissioned) roads slated, and drainages where a great deal of restoration through decommissioning and culvert removal has occurred. We also monitored an area that will remain roaded. Comparisons between data collected at the watershed level can increase the scale of the overall picture gained from monitoring. We attempted to choose sites in drainages which were as similar to one another as possible, with similar topography and soils composition, and which drained to a similarly-sized creek. Included in our monitoring sites are a roadless area, a decommissioned area, a site slated to be decommissioned, and an area which will remain roaded. Once the monitoring sites, protocol, and data-entry website were all in place, citizen monitoring began.

List 1. Monitoring methods used by citizen scientists:

- Pebble counts
- Macroinvertebrate surveys and temperature measurements
- Vegetation transects
- Erosion pins
- Photo points
- Wildlife surveys (cameras, track stations)

We trained citizen scientists to collect various ecological data using the protocols specifically developed for their use on decommissioned roads. Citizen scientist teams of 2-10 participants were created from communities throughout the Clearwater region, with a goal of creating long-term, self-sustaining volunteer partnerships at these and other study sites.

Results

Our monitoring season began in late June and will continue through mid-October. Through our wildlife-monitoring methods, we have already recorded use of decommissioned roads by black bear, cougar, gray wolf, coyote, fisher, white-tailed and mule deer, elk, moose, squirrels, chipmunks, and voles. We have set up erosion pins and conducted five vegetation surveys. Three pebble counts have been completed in target streams and three macroinvertebrate surveys are planned for the fall. The season will continue through mid-October, when we anticipate snow will prevent access to our study sites, and will begin again after the snow melts in May or June. More than 30 volunteers will participate in this inaugural field season, including members of eight separate environmental organizations, students from four high schools and two universities, and residents of six different communities within two states. The rural nature of the area has been one of the primary challenges to developing a larger citizen science program.

Discussion and Conclusion

Lessons learned
In terms of practical lessons we have learned, there are several things that have been achieved. We have learned that we can capture photos and tracks of wildlife on decommissioned roads using our modified tracking methods. Additionally, we have found that our protocol for collection of data by citizen scientists works. We discovered some technical limitations of the projects, such as the fact that cameras don't work in very cold temperatures. Weather also can limit our access to sites and snow has prevented us from beginning our sampling.

We have also found that it is essential to build a strong foundation for a citizen monitoring program. Ensuring that quality data can be collected over time is a must. Once we developed a protocol, created our online database with the capacity for analysis, we could begin field sampling. The next step was to get the volunteers on the ground and begin collecting high-quality data following the detailed guidelines laid out in our protocols. In our first year of field work with citizen scientists, there have been few observable problems with employing citizen volunteers. Many of the complications of using citizens for field work may have been offset by our development of protocols specifically tailored to use by citizen scientists, thus preventing initial confusion and difficulties in following guidelines.

In terms of getting the word out, we have found that advertising the project opportunities has created a local "buzz" that will continue and we hope help build community support of restoration on the CNF. Above all, the partnerships which were created during the project have been essential to its being carried out successfully—without these partnerships, citizens could never have become engaged.

List 2. Partnerships created during this project are essential to its success, now and in the future. Wildlands CPR has worked closely with the following:

- The Nez Perce Tribe, Clearwater National Forest, and University of Montana helped review the protocol, assisted in deciding priorities for monitoring on the forest, and provided logistical support.
- Conservation & Education groups helped find citizen leaders and recruit volunteers: the Palouse-Clearwater Environmental Institute, the Three Rivers and West Slope Chapters Trout Unlimited, the Native Forest Network, Friends of the Clearwater, the Watershed Education Network, and the Flagship Program.
- Schools helped generate volunteers: Willard Alternative High School, Hellgate High School, Kamiah High School, Clearwater Valley High School, Orofino High School, Lapwai High School, the University of Montana, and the University of Idaho.

Future research needs

Future research should examine the accuracy of data collected by citizen scientists. Also, more work is needed to determine how to make a citizen science program self-sustaining and how to promote citizen involvement in road decommissioning in other regions.

Final thoughts

The potential for good things to come from this project is massive. We anticipate many beneficial effects. As with all projects begun from the ground up, things are bound to move slowly at first, especially in rural areas where communities are often resistant to change and to anything that might be perceived as coming from the outside. However, excellent groundwork has been laid for what will very likely be a successful program as work progresses over the next few years. It is our hope that, if we can prove that this type of monitoring is valuable, other forests with similar road-decommissioning programs will also see the potential and begin to employ citizen scientists. In time, citizen scientists may help national forests all over the country complete essential research on road decommissioning, which will in turn allow forests to make more informed decisions about where restoration should occur and how to accomplish it.

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Biographical Sketch: Katherine Court is a graduate student in the Environmental Studies Program at the University of Montana. She obtained a B.A. in environmental studies from Eckerd College in 2002. Adam Switalski is the science coordinator for Wildlands CPR. Len Broberg is the director of the Environmental Studies Program at the University of Montana. Rebecca Lloyd is a hydrologist with the Nez Perce Tribe of Idaho.

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National Implications of Regional Deer-Vehicle Crash Data Collection, Migration, and Trends

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Abstract

The magnitude and trend of the deer-vehicle crash (DVC) problem in the United States can only be grossly estimated. Data that could be used to define this problem more closely are not consistently collected. However, at least two "national" surveys have attempted to estimate the number of DVCs in the United States and their results critically have been evaluated and presented. The number of fatalities and estimated non-fatal injuries in the United States due to animal-vehicle collisions will also be included.

The inability to properly define the DVC problem in the United States is primarily related to the misunderstandings produced by the collection, estimation, and combination of several data sets (with varying characteristics) that can be used to describe it. During the last four years the DVCIC staff has completed a DVC data collection and management survey and also collected (if available) 10 years of police-reported DVCs, deer-carcass numbers, and deer-population estimates for a five-state region (i.e., Illinois, Iowa, Michigan, Minnesota, and Wisconsin). The survey was primarily completed to document, compare, and/or combine the state-level DVC data collected properly Representatives from the Departments of Transportation and Natural Resources from each state were surveyed and used to collect the data.

The results of the survey, and the analyses and evaluation of the data collected, will be included in this presentation and paper. Summaries of the information gained from the survey and the data collected will be used to recommend activities to improve the current understanding of the DVC problem in the United States.

Biographical Sketch: Professor Knapp is an assistant professor/program director in the Engineering Professional Development Department at the University of Wisconsin and is jointly appointed with the Civil and Environmental Engineering Department. He has over 14 years of experience in the areas of transportation consulting and research. He has experience in the analysis of traffic operations and safety, roadway design, and traffic control. His primary areas of research are the safety and mobility impacts of roadway system characteristics. Prior to joining the University of Wisconsin, Professor Knapp was an assistant professor at Iowa State University and manager of the Traffic and Safety Program at the Center for Transportation Research and Education. He is a registered professional engineer in Iowa, Illinois, Michigan, and Wisconsin.

He has a B.S. in civil and environmental engineering degree from the University of Wisconsin-Madison, a masters of engineering in civil (transportation) from Cornell University, and a Ph.D. in civil engineering from Texas A&M University.

Planning a Sustainable Community: Infrastructure Development and Natural Areas Management

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Abstract: Sarasota County is a Florida gulf-coast community working to alleviate growth and development pressures and provide a balanced community of citizen amenities, economic growth, and a healthy natural environment. To meet this end, county government has been pursuing two main objectives: the acquisition and protection of ecologically significant lands and the minimization of roadway impacts in ecologically valuable areas. In 1992, a committee of citizens was appointed to evaluate the ecological value of undeveloped lands and facilitate a land-acquisition program. Subsequently in 1999, Sarasota voters approved a referendum to fund the Environmentally Sensitive Lands Protection Program (ESLPP). This program has since enabled the acquisition of over 15,000 acres of environmentally sensitive habitat for a total of nearly 105,000 acres of protected land throughout the county. In 2003, the land-acquisition agenda was expanded through the development of the Regional Environmental Mitigation Program, which was designed to facilitate the purchase and restoration of natural lands as compensation for unavoidable environmental impacts associated with county infrastructure projects. Despite protections afforded lands acquired by these land-protection programs, fragmentation continues to threaten ecologically intact landscapes in the county. To address this matter, the Board of County Commissioners initiated an investigation of the habitats and wildlife fragmented by transportation infrastructure. Field-investigation methods have involved reviews of aerial photography with local data overlays (*e.g.* Florida scrub-jay habitat, panther sightings, etc.), evaluation of significant habitats and protected wildlife, use of motion-sensory cameras, creation of animal-track sand pits, and incorporation of mortality surveys. Data collected continue to be used to identify and recommend promising areas for innovative design of infrastructure, land-acquisition priorities, and habitat-restoration measures. As a result of the current initiative, road projects are increasingly scrutinized for alternative alignments, sound ecological improvements, and defragmentation opportunities. Sustainable design is now a bona fide consideration of Sarasota County road-design teams.

Introduction

Population growth and development are threatening the quality of Florida's natural ecosystems and native wildlife. As a government entity, Sarasota County is working to alleviate these pressures and encourage a sustainable community of citizen amenities, economic growth, and a healthy natural environment. To this end, county government has been pursuing two main objectives: the acquisition and protection of ecologically significant lands (Natural Ecological Corridors) and the minimization of roadway impacts in ecologically valuable areas (Artificial Ecological Corridors).

Sarasota County government understands the inherent value of protecting native landscapes. This value is realized through the establishment of two significant land-protection initiatives: the Environmentally Sensitive Lands Protection Program (ESLPP) and the Regional Environmental Mitigation Program (REMP). Ultimately, however, local government is responsible for providing public infrastructure to reduce traffic congestion and ensure evacuation routes from coastal communities, as well as convenient access to interstate highways. Despite protections afforded environmentally sensitive public lands and parks, fragmentation from infrastructure provisions continues to threaten ecologically intact landscapes, inevitably impacting habitat corridors and wildlife populations. Realizing this threat, the Board of County Commissioners (BCC) initiated a countywide investigation of the habitats and wildlife affected by transportation infrastructure. To better evaluate the effects of road projects on these ecological communities, county staff, alongside PBS&J (private) consultants, conducted three ecological evaluations between 2003 and 2005 along future and existing transportation corridors: the Englewood Interstate Connector, Honore Avenue-Pinebrook Road Extension, and Interstate 75.

The purpose of these evaluations was to identify significant ecological features and critical landscape corridors and to discover opportunities for defragmentation of isolated habitats. An equally important aspect was to facilitate improved inter-agency and departmental coordination during the design and permitting stages of road-improvement projects. It was presumed that the identification of important ecological corridors would allow more efficient planning, permitting, and resource-management activities on a landscape scale.

Several county and state road-improvement projects currently in the planning and design stages are situated adjacent to environmentally significant lands (protected and unprotected). Consequently, these projects have precipitated the collection of field data with the hope of identifying critical areas for ecosystem connectivity and to recommend areas for innovative design of future infrastructure, land-acquisition priorities, corridor restoration, and mitigation opportunities.

Land-Acquisition Programs (Natural Corridors)

Environmentally sensitive lands protection program

Initiated in 1992, the Environmentally Sensitive Lands Protection Program (ESLPP) has become one of Sarasota County's most celebrated land-acquisition programs. In 1999, Sarasota voters approved two referenda to help fund ESLPP: one approving an increase in the ad valorem tax and the second to approve bonding. The county also passed Ordinance 99-004, establishing the citizen-appointed Environmentally Sensitive Lands Oversight Committee to facilitate the program and evaluate the ecological value of undeveloped lands. Working with willing-seller property owners, the Nature Conservancy (TNC), the Southwest Florida Water Management District (SWFWMD), and several other state partners, the program has enabled the acquisition of over 16,000 acres of environmentally sensitive habitat for a total of nearly 105,000 acres of protected land throughout the county.

Parcels are nominated for the ESLPP program based on habitat quality, connectivity, habitat and species rarity, water-resource protection, and manageability. The ESLPP program has had great success in acquiring environmentally sensitive lands through obtaining supplemental grant funding and developing partnerships with state agencies, non-profit organizations, and other county divisions and departments. Even with these successes, numerous challenges face the ESLPP program, including competition with developers, an escalating real-estate market, and and management and security costs.

Regional environmental mitigation program

Sarasota County's land acquisition agenda was expanded in 2003 through the development of a Regional Environmental Mitigation Program (REMP). The program was designed to promote ecologically significant mitigation facilities to compensate for unavoidable environmental impacts associated with Sarasota County infrastructure projects. A regional-mitigation perspective represents an environmentally and fiscally responsible approach to mitigating unavoidable environmental impacts. Traditionally, environmental compensation for jurisdictional wetlands, mesic hammocks, and listed wildlife focused on small, ecologically fragmented tracts adjacent to the project impacts. Unfortunately, this dogma often restricted the mitigation projects to areas with limited landscape value at best. The regional approach provides an avenue to fund land acquisition in concert with significant habitat creation, enhancement, restoration, and preservation projects.

REMP benefits from economies of scale in terms of land-acquisition costs. In addition, as the cost of vacant land continues to rise, the purchase of land in anticipation of future needs has already resulted in considerable savings to the county. Furthermore, the mitigation program should derive significant reimbursement funds by selling mitigation and floodplain credit for county infrastructure projects, selling excavated fill, and through mitigation funds derived from the Florida Department of Transportation for local interstate-mitigation needs. Additional savings include consolidations of design, permitting, construction, and maintenance. Finally, planning and building mitigation facilities today, as compensation for impacts anticipated over the next 10 to 20 years, should expedite the permitting and construction of future county-infrastructure projects.

To date, two parcels (totaling 160 acres) have been acquired through this program, based largely on landscape position, location with respect to watershed basin, and regional ecological value. A third mitigation parcel was purchased prior to the establishment of REMP, but has since served as a mitigation facility for the federally threatened Florida Scrub-jay (*Aphelocoma coerulescens*) impacts. Sarasota County exists within four state-recognized watershed basins, two of which comprise significant portions of the county. The currently permitted regional-mitigation parcels exist within the Southern Coastal Watershed Basin, and include Curry Creek Regional Mitigation Site, Fox Creek Regional Mitigation Site, and Lemon Bay Preserve. Acquisition and permitting of additional vacant lands within the Myakka River Watershed Basin are under evaluation at this time. These could serve as future mitigation facilities to offset impacts associated with infrastructure projects occurring within that watershed.

Curry Creek Regional Mitigation Site

The 19.2-acre Curry Creek Regional Mitigation Area, located adjacent to Curry Creek in Venice, Florida, was the county's first permitted regional mitigation facility. At a cost of approximately $500,000, the county acquired the Curry Creek parcel in 1997 to accommodate stormwater. Prior to purchase, this coastal site faced strong development pressure due to an adjacent navigable waterway.

Aerial photography dating to 1948 was used in developing the design for this historically human-altered area, with the final layout designed to mimic site conditions similar to those existing prior to human disturbance. Currently under construction, this project involves conversion of two excavated finger canals into an emergent saltmarsh habitat and the creation of a meandering tidal creek. In addition to the hydrologic restoration of wetland habitats, the Curry Creek effort will result in the preservation, enhancement, and management of native uplands. Once complete, the site will provide a mosaic of habitat types, including mangrove forest, estuarine marsh, tidal creek, hydric flatwoods, oak hammock, and scrubby flatwoods.

The restoration of historical hydrologic conditions at the Curry Creek site will improve both onsite and adjacent offsite aquatic environments, as well as compensate for unavoidable wetland impacts associated with multiple county road projects. The preservation of upland and wetland communities along Curry Creek will also protect a riparian habitat corridor connecting adjacent ESLPP lands, provide a buffer for Curry Creek, and prevent coastal development of the parcel.

Fox Creek Regional Mitigation Site

The Fox Creek Regional Mitigation Site consists of 140 acres of restoration and enhancement opportunities. In 2003, the county purchased this property, originally slated to become a residential development for about $4 million. Once completed, the site will comprise a network of freshwater marshes, forested wetlands, pine flatwoods, wet prairies, estuarine marshes, and scrubby flatwoods. The site will also feature several unique aspects, including large compensation areas for the state-protected Sherman's Fox Squirrel (*Sciurus niger*) as well as the Florida Scrub-jay. The Fox Creek site will derive phased-mitigation credit for unavoidable wetland and wildlife impacts associated with county-infrastructure projects.

Existing aquatic landscape features directly contiguous to the parcel include Fox Creek, Shakett/Salt Creek, and Cow Pen Slough. The utilization of these waterways by wildlife has been documented (see the Honore Avenue-Pinebrook Road Extension ecological evaluation below). Although Interstate 75 creates an impediment to wildlife movement at the eastern border of the Fox Creek site, one of the reasons for acquiring this parcel was to protect a vital piece of the natural linkage between estuarine areas of Shakett Creek to the southwest, and protected lands to the east (Knights Trail Park, Pinelands Reserve, and Myakka River State Park).

Lemon Bay Preserve
As part of a multi-departmental effort, Sarasota County purchased the Lemon Bay Preserve (LBP) in 1998 for $3.9 million. This 165-acre coastal scrub and estuarine parcel is bordered to the west by the intercoastal waterway and connects to a series of conservation easements, private preserves, and ESLPP parcels that together comprise an area primarily focused on affording protection to the Florida Scrub-jay. Currently, LBP supports two scrub-jay families, as well as sporadic transient birds. One family has served as compensation for impacts associated with a county road project and the parcel has received "credit" for one future scrub-jay impact. Land management efforts have included prescribed fires, scrubby flatwoods enhancement, exotic plant control, hydrologic restoration, and coastal upland and wetland plantings.

Infrastructure Development (Artificial Corridors)

Despite the protection afforded ESLPP and REMP lands, fragmentation continues to threaten ecologically intact landscapes in the county. In response to this concern, the Sarasota Board of County Commissioners (BCC) called for evaluations of the habitats and wildlife affected by transportation infrastructure. To address this BCC directive, county staff has been working closely with PBS&J consultants to evaluate local road-improvement projects currently in the planning and design phases. Specifically, three ecological evaluations were initiated in 2003 focusing on three prominent roadway arteries: the Englewood Interstate Connector, the Honore Avenue-Pinebrook Road Extension, and Interstate 75. Through these evaluations, data regarding the effects of existing and future infrastructure alignments on habitat connectivity and wildlife mortality may help identify significant ecological features, critical landscape corridors, and opportunities for defragmentation of isolated habitats.

Ecological evaluations

Englewood Interstate Connector
Design for this hurricane evacuation route began late in 2004. The ecological evaluation was conducted beginning in June 2004 and the final report concluding the study (Kurz et al. 2005a) was completed in July 2005. The ecological evaluation at this site focused on wildlife utilization of all culverts (of varying hydrologic function) along this rapidly developing corridor. Key habitat zones severed by the roadway, but not currently connected by culvert were also monitored. Large tracts of protected public land exist along this roadway (including ESLPP parcels, the Jelk's Preserve, and Myakka State Forest). Ecologically significant private land is also present and was evaluated with respect to quality and connectivity potential. Other ecologically significant features (the Myakka River and Sweetwater Gully) exist along this transportation corridor, and all features, severed or otherwise, were evaluated for defragmentation opportunities.

Honore Avenue–Pinebrook Road Extension
A two-year, ecological evaluation was conducted along this future road corridor as part of the planning process, ultimately to serve as a guide during roadway design. The study, paid for by the Honore Avenue-Pinebrook Road project, involved evaluation of lands and highway projects surrounding the proposed road extension. Surrounding road projects concurrently evaluated included the Central Sarasota Parkway Interchange and Interstate 75. The Honore Avenue-Pinebrook Road is being designed to help alleviate transportation demands currently plaguing the adjacent Interstate 75.

Interstate 75
The widening of Interstate 75 through Sarasota County has prompted county-funded ecological evaluations along two environmentally sensitive segments of this highway: one adjacent to the future Honore Avenue-Pinebrook Road Extension and the second, further south between ESLPP and publicly owned lands. The Interstate 75 upgrade is proposed to accommodate traffic projected through the year 2020. Communications between Sarasota County, the Florida Fish and Wildlife Conservation Commission, the Water Management District, The Nature Conservancy, and the FDOT have ensued as part of the PD&E along this stretch of highway to help establish a coordinated effort.

Evaluation Methods
The three major road-expansion projects mentioned above were chosen for habitat and wildlife evaluations based on their proximity to ecologically important landscape features (e.g. ESLPP and public lands, Myakka River, etc.). For each roadway-expansion project, data were collected from adjacent public lands, drainage easements, and undeveloped lands. Data consisted of historical accounts and aerial photography, on-site field assessments of habitats and wildlife (including field identification of tracks and helicopter over-flights), use of motion-sensory cameras, and

mortality surveys. Field-investigation methods were primarily intended to note the occurrence of certain habitats and wildlife, identify zones of high wildlife mortality, and recognize species-movement patterns across the study areas. The evaluations were also intended to assess the benefits and drawbacks of incorporating artificial-wildlife corridors into roadway-expansion projects. Publicly owned lands, drainage easements, or areas under conservation easement were often given higher priority in terms of recommendations for defragmentation, but private land-development plans and specific infrastructure-project needs (mitigation, stormwater, and floodplain) were also considered.

Historical Accounts and Aerial Photography
Wildlife-species lists for Sarasota County were referenced from the Florida Natural Areas Inventory (FNAI), United States Fish and Wildlife Service (USFWS), and Florida Fish and Wildlife Conservation Commission (FWC) databases (see also Kurz et al., 2005a). Local wildlife data were obtained from Sarasota County Natural Resources' databases. Aerial photographic images augmented by local data overlays (e.g. those for the Florida Scrub Jay and Florida Panther (*Felis concolor coryi*) were referenced during the course of each evaluation. Project Development and Environment (PD&E) studies, conducted as part of each infrastructure project, included threatened and endangered species surveys and wetland- and water-quality evaluations. Data from the PD&E studies were evaluated to help clarify field data-collection efforts associated with each ecological evaluation.

On-Site Field Assessments
Both terrestrial and aerial surveys were conducted to evaluate wildlife use broadly in each study area. Terrestrial surveys were conducted on foot and/or from off-road vehicle and were focused on habitat quality evaluations, identification of restricted corridors (dense exotic vegetation), presence of wildlife tracks, and general evidence of wildlife use. Aerial surveys via helicopter were conducted during the spring and summer of 2003 and 2004, with wildlife (predominantly mammals and birds) and nests quantified and their coordinates recorded during each flight (see also Kurz et al. 2005a).

Motion-Sensory Cameras
Remote cameras (DeerCam and Moultree Feeders cameras) were used to document wildlife utilization of existing culverts and suspected game trails (see also Kurz et al. 2005a). DeerCam 35-mm cameras housed in camouflaged plastic cases and equipped with "passive" infrared/heat sensors were installed at major creek crossings and drainage-conveyance structures. Cameras were carefully mounted on fence posts, tree branches, shrubs, stakes, and concrete pillars, regardless of the limitations the area posed to wildlife movement. Camera locations were modified seasonally based on the success/failure of previous surveys. Wildlife utilization and avoidance was documented at existing span underpasses, wet and dry culverts, and along bisected wetland boundaries. In certain instances, sand pits were installed in conjunction with cameras in areas where capturing wildlife images proved challenging. Each sand pit consisted of a layer of sand placed on a suspected game trail that appeared to be frequently utilized by wildlife.

Mortality Surveys
Road-kill surveys were conducted to evaluate wildlife presence and movement associated with each study area. Due to seasonal changes in wildlife behavior, hydrology, and plant-community composition, surveys were conducted intermittently from summer through autumn in 2003, all year in 2004, and during winter and spring in 2005. Surveys were conducted only sporadically during 2003, while four to seven surveys were conducted during each season in 2004 and 2005. Surveys were conducted by vehicle, driving at 5-10 mph along the roadway shoulders. Safety measures were utilized during data collection to ensure the protection of motorists and field staff. At each road kill site along the survey route, the animal was identified and the coordinate recorded using a hand-held Global Positioning System (GPS) unit. GPS data were organized into a master file in ArcGIS 9.0 (ESRI 2004), enabling statistical comparisons. Digital photographs were also taken of certain representative species (see also Kurz et al. 2005a).

Results and Discussion

Ecological evaluations and data-collection efforts have thus far been only cursory, spanning the last 1-2 years (depending on location). Although largely anecdotal, interpretations of the data collected over the course of these evaluations have started proving valuable for identifying existing impediments to wildlife posed by roadway infrastructure. Subsequent recommendations to road-design teams will likely focus on the realized need for improvements in habitat connectivity and reductions in wildlife mortality. All three roadway evaluations (the Englewood Interstate Connector, the Honore Avenue-Pinebrook Road Extension, and Interstate 75) have provided unique contributions to the combined data.

Englewood Interstate Connector
It is believed that the existing highway corridor extending along River Road and Winchester Boulevard has impacted historic wildlife movements within the Myakka River floodplain. Currently, the Englewood Interstate Connector (EIC) corridor is marked by a number of hydrologic culverts beneath the road; however, the majority of these culverts appear inadequate for wildlife utilization due to restrictions imposed by construction activity, high water, or impenetrable vegetation. Despite the paucity of suitable crossings, wildlife was nonetheless documented utilizing two existing concrete culverts (24" and 36" diameter) within the study area (Kurz et al. 2005a).

Future and existing development has limited the scope of wildlife-amenity recommendations proposed along this corridor. Many properties along the EIC are under private ownership, and a growing number of these parcels are currently under construction or have submitted plans for development approval. Since so much of the area is slated for development, creating linkages to and from these areas may be counterproductive to protecting wildlife (as many local populations would likely be lost to road mortality and/or habitat destruction, Kurz et al. 2005a). Recommendations to the EIC design team for artificial wildlife corridors and advanced land acquisition were prioritized based on a number of factors including proximity to public lands, drainage ways and easements, acquisition potential, and mitigation opportunity.

Two artificial wildlife passages have been proposed as part of the design phase of the road. The first, involving the connection of a conservation easement to the Jelk's Preserve along a forested waterway, proposes a small mammal shelf to allow animal passage during a range of seasonal water fluctuations. Foresman (2004) showed that species prone to use culverts opted to use shelves when water was present. In fact, the same study explained that activity in experimental culverts (with shelves) remained high or even increased when water levels rose, due to consistent use of shelving by wildlife (Foresman 2004). The second artificial wildlife corridor proposes the connection of a different conservation easement to the Jelk's Preserve through a residential development. This second passageway is intended to restore an east-west habitat corridor from the Jelk's Preserve to a series of preserved "residential" habitat corridors west of the interstate highway.

Another effort underway as part of this road project is the advanced acquisition of two parcels naturally contiguous to the Jelk's Preserve. These priority sites were initially identified by the ESLPP due to their connectivity, habitat value, and location along the Myakka River. The parcels are of dual interest to the EIC design team due to mitigation potential for stormwater, wetlands, floodplain and mesic hammock impacts. The county's road-program team anticipates additional value to other road projects "on line" for the future.

Honore Avenue–Pinebrook Road Extension

Several landscape corridors were identified throughout this project area; however, due to the extent of existing and future infrastructure, their suitability for wildlife utilization is currently limited. Historic aquatic landscape features that exist in this area include South Creek, Fox Creek, Cow Pen Slough, and Shakett/Salt Creek. Utilization of these waterways by wildlife was documented during the study, but historic wildlife movement has also likely been altered by infrastructure. Undeveloped lands bordering the area include the Fox Creek REMP, Oscar Scherer State Park, and a Sarasota County buffer parcel. The protection and enhancement of vital habitat linkages between these lands west of Interstate 75 and protected lands east of the Interstate (e.g. Knights Trail Park, Pinelands Reserve, and Myakka River State Park) was an important consideration during this study and will remain a high priority during the design phase of the Honore Avenue-Pinebrook Road Extension. In addition, coordination with FDOT on wildlife improvements along Interstate 75 is anticipated.

Several artificial wildlife corridors have been proposed as part of the Honore Avenue – Pinebrook Road Extension project, although land-ownership obstacles continue to hinder the establishment of finalized locations and make determination of the magnitude of improvement difficult. The focus during the design process will be toward the restoration of historic corridor linkages. This may include continued negotiations with land owners, establishment of conservation easements, removal of restrictive fencing, installation of appropriately placed barrier fencing, upgrades to culverts, incorporation of mammal shelves, creation of earthen bridges, and design of span bridges suitable for unrestricted wildlife movement.

An upgrade to an existing span bridge at Fox Creek was requested by local wildlife agencies as part of the Interstate 75 PD&E study through this area. Additional improvements to this bridge must include the reconfiguration of barrier fencing to direct (rather than prohibit) wildlife movement beneath the roadway and modest management of vegetation. Agreements with adjacent landowners will also be necessary for this passage to reach its full potential, ensuring connection with protected lands east of Interstate 75. Sarasota County has agreed to match all upgrades proposed at Fox Creek by FDOT, as well as at other nearby span bridges. For example, considerable wildlife utilization of the floodplain under the Salt Creek span bridge has been documented, with noticeable reductions in wildlife mortality on the roadway above. The county has proposed a wide span crossing over this creek. Additionally, a dual-purpose earthen bridge is proposed at Cow Pen Slough, a deeply cut, human-altered canal. Finally, barrier fencing at wetland-highway interface zones and culvert upgrades with mammal shelves will be considered at specific locations along the Honore Avenue – Pinebrook Road Extension.

Interstate 75

Ecological evaluations have been conducted along two environmentally sensitive segments of Interstate 75: the segment associated with the Honore Avenue – Pinebrook Road Extension, and a six-mile segment further south which bisects large expanses of publicly-owned lands adjacent to the Myakka River and Deer Prairie Creek. In the southern area, Florida Panther sightings have been documented one mile north of the I-75 corridor on the T. Mabry Carlton Memorial Reserve and on Schewe Ranch, while a Scrub-jay family has been recorded along Deer Prairie Creek, a tributary of the Myakka River. Florida Scrub-jays have also been documented using span bridges beneath the interstate at Fox Creek in the northern study zone.

The Interstate 75 expansion project provides an opportunity to restore crucial habitat connectivity between state-owned and ESLPP lands. Continued infrastructure expansion (I-75 and EIC) and development (North Port) have inadvertently isolated these environmentally sensitive habitats. Failure to take advantage of the I-75 widening to restore connectivity will likely have long-term ecological implications for the success of wildlife populations dependent on movement across this barrier. Large-scale artificial-corridor enhancements will therefore be important to improving habitat connectivity between these otherwise separated areas. In particular, artificial corridors should be designed to accommodate wildlife requiring larger geographic ranges, such as is required by the rare Florida Panther.

Overall

Data collected as part of the three ecological evaluations have provided evidence of a variety of wildlife utilizing areas beneath span bridges, low water hydrologic culverts, and one specifically designed small mammal crossing. Data have also suggested substantial wildlife mortality associated with unsuccessful roadway crossings. Currently, road-design engineers and environmental staff are working together to design artificial wildlife corridors to help allow safe wildlife passage around, under, and through barriers at each of the three road-expansion projects.

Road-kill mortality surveys documented impacts to at least 70 different species of wildlife. These species include white-tail deer (*Odocoileus virginianus*), river otter (*Lutra canadensis*), coyote (*Canis latrans*), flying squirrel (*Glaucomys volans*), American woodcock (*Scolopax minor*), American alligator (*Alligator mississippiensis*), gopher tortoise (*Gopherus polyphemus*), eastern diamondback rattlesnake (*Crotalus adamanteus*), and pig frog (*Rana grylio*). In addition to resident wildlife, migratory species such as the American Robin (*Turdus migratorius*) were significantly impacted as they moved through the area. Although road kill surveys were conducted over the course of two years, the frequency of surveys was not sufficient to evaluate fully the consequences of roadway expansion on local wildlife populations. Often, animal remains were unidentifiable by species, suggesting that additional species (beyond those recorded) were likely affected. The data also do not account for injured wildlife that expired in areas beyond the survey zones, predation by scavengers, removal by collectors, or disintegration caused by weather or traffic. Nonetheless, these data suggest that animal dispersal into habitats separated by roadway barriers is reduced, as documented for small mammals by Oxley et al. (1973).

Wetlands bisected by roadways appeared to affect movement patterns of herpetofauna noticeably. Air temperature also played an important role in the activity levels of many animals, particularly ectotherms (Kurz et al. 2005a). During the course of the surveys, an increase in herpetofauna mortality occurred during summer and fall, with a noticeable increase in frog mortality during October. This may coincide with precipitation events and nesting and breeding behaviors, but such was not specifically examined. Water levels for many of the wetlands in the study area were at or near their seasonal high levels during October of both 2003 and 2004, and thus were situated closer to the highway interface (Kurz et al. 2005b). Although amphibian and reptile mortality was documented, few specific recommendations have thus far been made to accommodate these animals' movements. At this time, culvert materials appropriate for use by these species are being considered and barrier wall-culvert systems and culvert size are being researched for use along the Honore Avenue-Pinebrook Road Extension.

Small mammals were negatively affected annually throughout the evaluated areas. Studies have shown that the effects on small mammals are magnified when highways bisect unique habitats such as wetland communities or forested areas historically serving as wildlife corridors (Foresman 2004). The implications of these findings are quite relevant to our evaluations given the abundance of wetlands, waterways, and forested lands associated with potentially impacted areas throughout Sarasota County. Although higher wildlife mortality was expected at wetland-highway interfaces in our evaluations, differences in mortality between these and more upland areas were not always observed. However, vegetated drainage swales established parallel to highways may artificially inflate the prevalence of persistent wetland-highway interface zones.

A noticeable reduction in mammal mortality was observed in a few key areas. These areas appeared to correspond to span bridges over creek corridors. Six span bridges exist in the evaluated areas, but fencing restrictions and human use may limit exploitation by wildlife. Seasonal fluctuations in water level and artificial and vegetative barriers appeared to influence small mammal use of artificial structures (culverts) negatively, while the size of the structure and the "tunnel effect" appeared to have less of an influence. Small mammals appeared to favor dry or mostly dry culverts. Given the success of capturing motion-sensory camera images at several dry (passable) span bridges, the failure to capture images of wildlife at other crossings suggests that those structures may not be as conducive to wildlife movement (Kurz et al. 2005a). One particular well-used dry culvert (36") was devoid of vegetation (other than sod) and extended beneath four lanes of roadway ("tunnel-effect"), while other unused culverts (>1 m) were often full of water and/or impeded by dense populations of Brazilian Pepper (*Schinus terebenthifolius*) or cattail (*Typha sp.*). Game trails leading to the road surface were often observed bypassing these "unacceptable" culverts.

Summary

Sarasota County continues to strive toward a balance between ecological sustainability and economic growth. The acquisition and protection of ecologically significant lands (Natural Corridors) and the minimization of roadway impacts in eco-geographically valuable areas (Artificial Corridors) have become top priorities of elected officials, planners, road-design, engineers and county environmental staff. Community support for these approaches has also been overwhelming, providing continued momentum toward their success.

The county's land-acquisition programs continue to move ahead. ESLPP has realized great successes over the past year, boasting critical land-acquisition achievements along the Myakka River corridor. The REMP program has employed unique and creative permitting approaches (generating healthy discussions) to pursue fiscally (and ecologically) appropriate land acquisitions with high restoration potential for use in future infrastructure projects.

The three county-initiated ecological evaluations (EIC, Honore Avenue-Pinebrook Road Extension, and Interstate 75) were chosen based on their proximity to ecologically important landscape features and continue to provide road design teams and environmental staff with a better understanding of the environmental challenges posed by development. Unfortunately, creating and improving wildlife corridors and avoiding ecologically valuable lands is often complicated by property ownership, development plans, political lines, and fiscal limitations. Designing a road incorporating every possible artificial-corridor improvement can be cost-prohibitive. Instead, publicly-owned lands, drainage easements, or areas under conservation easement were often given higher priority for defragmentation, but specific infrastructure project needs (mitigation, stormwater, and floodplain) and private land-development plans were also considered.

As long as county ecological evaluations continue to identify priority areas for advanced land acquisition, mitigation, and innovative design of future infrastructure, these programs should continue to move forward in spite of the challenges. This new county initiative has resulted in increased scrutiny of county infrastructure projects through alternative road alignments, sound ecological improvements, and defragmentation proposals. Sustainable design is now a genuine consideration of county road-design teams. It is our hope that Sarasota County can provide a model for sustainable development applicable to other communities across the country.

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Biographical Sketches: Sherri R. Swanson is a project scientist for Sarasota County Natural Systems Management. Her professional responsibilities involve project management and oversight of the county's Regional Mitigation Program, through which she serves as liaison between transportation and natural-resource interest groups. She holds a bachelor of science degree in environmental, soil and water science from the University of Arkansas. Her professional experiences involve permitting and natural resource and wildlife management.

Dr. Ray Kurz is a senior environmental scientist and program manager for PBS&J's West Florida Sciences program based in Sarasota and Tampa. He currently serves as a project manager to several public-agency clients for projects related to transportation improvements, watershed management and restoration, water-quality evaluations, and natural-resource management. He holds a bachelor of science degree in zoology and a master of science in fisheries and aquatic sciences, both from the University of Florida. He earned his Ph.D. in public health, with a focus on environmental health, at the University of South Florida in 1998.

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Quantifying and Mitigating the Barrier Effect of Roads and Traffic on Australian Wildlife

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Abstract

The network of highways, freeways, and other major roads in Australia and around the world continues to expand in length and width as new roads are built and existing roads widened. The effects of roads and traffic on the survival and movement of indigenous wildlife are potentially numerous and profound. Successful mitigation of these effects relies on the detailed definition of the nature and extent of the problem and appropriate analysis of the effectiveness of amelioration.

Habitat loss across large areas of Australia has been so extensive that many landscapes currently support less than 5 to 10% of indigenous vegetation. Ironically, much of the remaining vegetation occurs adjacent to existing roads or in unused road reserves. Consequently, new roads will dissect these vegetation remnants, potentially disrupting the movement of animals along these linear corridors. Similarly, the widening of existing roads will typically result in the removal of valuable habitat for wildlife.

In our study, we investigated the effect of a new road on the movement and ecology of the Squirrel Glider *Petaurus norfolcensis* in southeastern Australia. The squirrel glider is an endangered species restricted to forest and woodland in eastern Australia. Its primary form of movement is by gliding between trees. We radio-tracked nine individuals for a two-month period in the vicinity of a new dual-carriageway freeway and an existing single-carriageway highway. A total of 488 radio-tracking fixes revealed that animals were resident adjacent to both roads and that the rate of road crossing varied by sex and road width. Females were never observed to cross the dual carriageway, while a single male was located on opposite sides at a ratio of 1:0.4. Both females and males crossed the single carriageway regularly. Two of the nine gliders disappeared during the study.

The results of this study are being used to design a major collaborative research project that aims to more fully quantify the negative effects of roads and traffic on Australian wildlife. At present, there is a poor understanding of the ecological effects of roads and traffic in Australian ecosystems and on Australian wildlife. In particular, we are focusing on the population-level effects in order to determine the extent that population viability has been reduced. A range of taxa with different levels of vulnerability are being studied, including arboreal marsupials, ground-dwelling mammals, geckoes, and invertebrates. We will incorporate studies of movement patterns with genetic techniques and meta-population-viability analyses to elucidate effects at the population level. The project will then test the effectiveness of various mitigation measures by determining the extent to which population viability has been improved.

Biographical Sketch: Dr. Rodney van der Ree is the ecologist at the Australian Research Centre for Urban Ecology (ARCUE). He obtained his Ph.D. in 2000 from Deakin University, where he studied the impacts of habitat fragmentation on arboreal marsupials in northeastern Victoria. He used the principles of landscape ecology to investigate the response of fauna to a landscape where the habitat was arranged as a network of linear strips along roads and streams. Rodney now brings this knowledge and skill to ARCUE to investigate the response of mammals to urbanization. Rodney will be investigating the distribution and abundance of mammals within the greater Melbourne area, with a focus on the rate of species decline, their habitat requirements, and survival prospects.

The Return of the Eastern Racer to Vermont; Successful Conservation Through Proactive Project Development and Interagency Collaboration

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Abstract: During fieldwork for the Vermont Reptile and Amphibian Atlas Project, a population of Eastern Racers (*Coluber constrictor*) was found utilizing a parcel of state land managed by the Vermont Agency of Transportation (VTrans) in southeastern Vermont along Interstate 91. This species was thought to have been extirpated from Vermont for nearly 20 years. Until 2003, the last positively identified Racer in Vermont was a road-killed specimen in Putney in 1985. But the recent discovery along I-91, resulting in the species being listed as State Threatened in Vermont, proves that a few hardy individuals are making their way back to the northern fringes of their geographic range. To date, a minimum of eight individuals have been identified in Vermont, and researchers feel that this is a very encouraging sign that the Racer is making a comeback in Vermont.

Introduction

The discovery site has been scheduled for reconstruction as a truck weigh station. This puts the snakes' habitat on a collision course with the bulldozers. Taking a proactive approach to this potentially contentious situation, VTrans has been working closely with the Vermont Department of Fish and Wildlife (VDF&W) and the Vermont Department of Forest and Parks to develop an advance habitat-mitigation plan for these snakes.

All stakeholders involved feel that the collaborative approach taken here is an example of how multiple state agencies can work together as partners to protect the needs of a State Threatened Species while keeping an important transportation project on schedule.

The following objectives were set by VTrans and VDF&W:

- Identify common goals for VTrans and VDF&W.
- Formalize an agreement between state agencies to work collaboratively.
- Monitor snakes to determine habitat functions of VTrans site and population size.
- Develop a plan to replace habitat impacted by the VTrans project.
- Continue to manage and maintain the VTrans site without harming snakes.
- Create new habitat to compensate for habitat taken for re-development project.

Eastern Racer Description

The Eastern Racer is a very charismatic, strikingly attractive, and sleek creature. It is a large, strong, and active snake, well known for its feisty disposition and surprising speed. The smooth black scales of adult Racers are somewhat iridescent and can have a bluish tint. Juveniles have a pronounced dorsal pattern on a grayish or brownish background. The Eastern Racer is not venomous, but will almost always try to defend itself vigorously by biting and thrashing if handled. Given the choice, a Racer, almost without exception, will flee when confronted by a perceived threat or remain still if it thinks it is hidden. Racers have been known to charge toward humans when they feel threatened. However, sometimes a run for known cover can be misinterpreted as a charge if the observer is between the snake and its intended destination. Racers rely heavily on their vision for hunting and defense and will hold their head up several inches off the ground to facilitate their view (Harding 1996).

Methods

VTrans hired a herpetologist to guide the Agency through the process of considering the habitat needs of a State Threatened Species while planning and designing this transportation project. To meet the needs of the project and the needs of the VDF&W, the following steps were undertaken:

- A study funded by VTrans and FHWA has been undertaken to determine the function and importance of the habitat at the re-development site.
- Two large adult Racers were captured and implanted with radio transmitters so that their movements could be monitored on a weekly basis (during their active season) for two years.
- Passive integrated transponders have been implanted into all known Racers from this population.
- Open and frequent communication, as well as regular meetings between VTrans and VDF&W, are essential components of this joint effort.

Results

Since the initial discovery of this population of Racers, VTrans has continued to maintain an aggressive schedule for the re-development of this site. VTrans and VDF&W agree that both the project schedule and the welfare of this population of snakes are important. Both agencies anticipate that the proactive effort put into the habitat issues will keep this project on schedule and ensure that the habitat needs of the snake are met before, during, and after construction of the new truck weigh station. The accomplishments are encouraging.

- An interagency Memorandum of Understanding (MOU) was developed between VTrans and VDF&W to outline an advance mitigation plan and detail VTrans' responsibilities while re-developing the project site.
- Mowing and maintenance protocol has been adopted by the VTrans District 2 Maintenance staff to protect the safety of the Racers during scheduled maintenance activities.
- Mapping of habitat mitigation area has begun.
- In addition to answering some very pragmatic questions related to the development of the VTrans weigh station project, the study of this small group of snakes is providing new information on the behavior and habitat needs of Eastern Racers.

Biographical Sketches: Chris Slesar is an environmental specialist at the Vermont Agency of Transportation. He has an M.A. in environmental studies from Antioch University Seattle.

Jim Andrews is a research herpetologist at Middlebury College. He serves as chair of the Vermont Reptile and Amphibian Scientific Advisory Group and is coordinator of the Vermont Reptile and Amphibian Atlas.

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Riparian Restoration and Wetland Creation at Solano Community College

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Abstract: The California Department of Transportation (Caltrans) conducted mitigation work to establish and protect native wetland and riparian habitat on approximately 0.5 hectare (1.3 acres) adjacent to Dan Wilson Creek. Dan Wilson Creek is located in the Solano Community College property just off of Suisun Valley Road in Fairfield, California. This work mitigates for impacts to 0.07 hectare (0.17 acre) of wetland habitat and 0.05 hectare (0.13 acre) of riparian habitat resulting from the Solano Interstate Route 80 Widening Project located between Interstate 680 and State Route 12 East. Caltrans began construction on the I-80 Widening Project in the fall of 2003. Mitigation work coincided with the widening of Interstate 80 over Dan Wilson Creek that occurred during the summer of 2004.

Approximately 0.16 hectare (0.40 acre) of the land contoured, graded, and planted at the mitigation site will provide riparian habitat and 0.20 hectare (0.50 acre) will provide wetland habitat after the five-year monitoring period to meet the mitigation goals established by Caltrans, the California Department of Fish and Game, and the U.S. Army Corps of Engineers.

Caltrans biologists obtained a photographic record of the mitigation site in June 2004 before it was graded and contoured. These biologists will obtain photographic records of the same location(s) annually during the five-year monitoring period to monitor the progress of the mitigation project.

Caltrans biologists will conduct spring and summer plant surveys to detect early and late-season species and will map the extent of the vegetation cover using a Global Positioning System (GPS). Caltrans biologists will use a minimum of 20 vegetation sample plots, each measuring 3 x 3 meters (10 x 10 feet), to estimate plant coverage and dominance and will collect information on wildlife observed at the mitigation site on an opportunistic basis.

The majority of plants installed at the mitigation site have been successful as of June 2005. Approximately 90% of the plants installed in the upland and upland-riparian zones of the mitigation site showed signs of growth. Approximately 488 (91%) of the 535 planted arroyo willows were found in the mitigation area, with 313 (64%) of the counted willows showing signs of growth. Some of the installed wetland plants, including common tule (*Scirpus acutus* var. *occidentalis*), have established and spread throughout the wetland zone.

Animal species identified by Caltrans biologists in the area before the mitigation work began were again observed in the area after the work. Some of the aquatic species have migrated into the newly developed wetland from Dan Wilson Creek. The number of bird species observed in the area increased after the mitigation work. Birds commonly observed in freshwater pond habitats are using the wetland.

Introduction

Caltrans conducted mitigation work to establish and protect native wetland and riparian habitat on approximately 0.5 hectare (1.3 acres) adjacent to Dan Wilson Creek (figure 1). Dan Wilson Creek is located in the Solano Community College (College) property just off of Suisun Valley Road in Fairfield and eventually drains into Suisun Marsh and Grizzly Bay. This work mitigates for impacts to 0.07 hectare (0.17 acre) of wetland habitat and 0.05 hectare (0.13 acre) of riparian habitat resulting from the Solano Interstate Route 80 (I-80) Widening Project located between Interstate 680 (I-680) and State Route 12 East (figure 1). Caltrans began construction on the I-80 Widening Project in the fall of 2003. Mitigation work coincided with the widening of the I-80 bridge over Dan Wilson Creek that occurred during the summer of 2004.

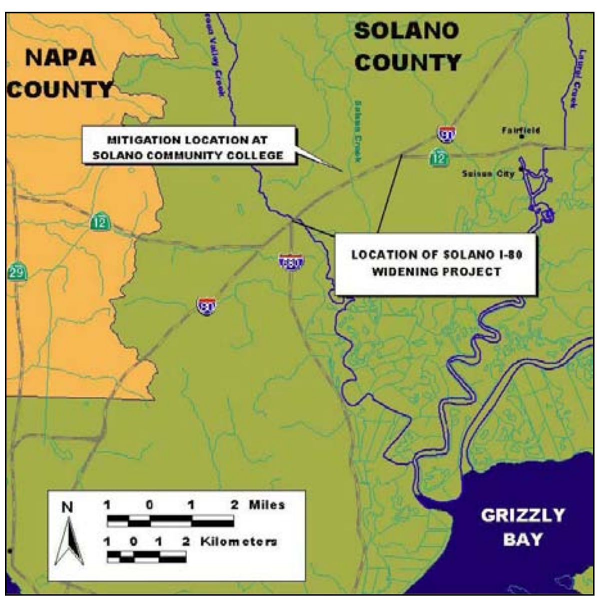

Figure 1. Project Location Map. Location of the Solano I-80 Widening Project and mitigation site at Solano Community College.

The goal of the mitigation project is to convert a flood-control channel with marginal riparian habitat into a high-quality riparian corridor and seasonal-wetland area. This project serves as in-kind mitigation for impacts to riparian and seasonal wetland habitat that occurred as a result of the I-80 Widening Project. The mitigation area is located on and adjacent to Dan Wilson Creek at the eastern end of Solano Community College and bounded by a paved road and the college's athletic facilities (figure 2).

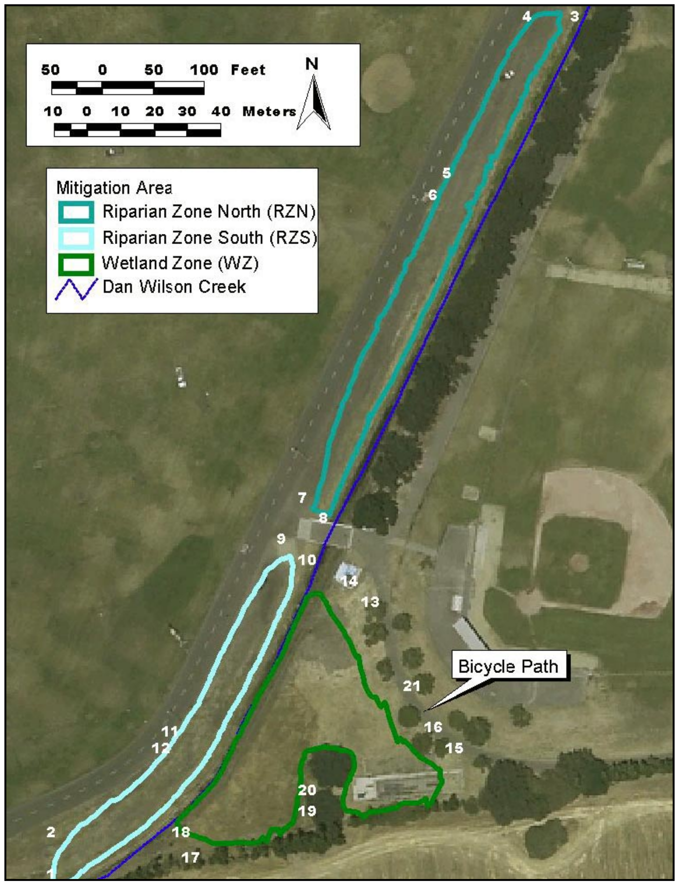

Figure 2. Aerial map of Solano Community College. The aerial image shows the areas where mitigation work has occurred (Riparian Zone South, Riparian Zone North, and Mitigation Zone). The numbers in white represent approximate points in each section where ground photos were taken. Photo courtesy of Caltrans Digital Highway Inventory Photography Program. Copyright 2003, Department of Transportation.

The successful project will result in a high-quality riparian corridor and seasonal-wetland area. Success is primarily dependent on establishment of the planted riparian and hydrophytic vegetation. Success criteria will include long-term channel morphological stability without extreme changes in the flow regime of the creek, adequate hydrology of the wetland from the adjacent creek, and establishment of a self-sustaining wetland and riparian corridor.

Objectives

The objective of this study is to monitor the Solano Community College mitigation site over the span of five years. Biologists will monitor the plants at randomly sampled quadrats to determine plant success and will collect data on wildlife usage of the site on an opportunistic basis.

The California Department of Fish and Game (CDFG) and U.S. Army Corps of Engineers (USACE) are concerned with the success of the mitigation plantings and plant establishment in the created wetland and riparian corridor. They expect approximately 0.16 hectare (0.40 acre) of the land contoured, graded, and planted at the mitigation site to provide riparian habitat, and 0.20 hectare (0.50 acre) to provide wetland habitat after the five-year monitoring period. They also expect a 70% success rate for all plantings in both areas after five years. Other parameters that Caltrans may assess during the monitoring period include hydrology, sedimentation, and water quality. Caltrans will conduct these surveys in the area approximately four times per year.

Methods

The mitigation work began during the summer of 2004 (between June 15 and October 15). Caltrans graded and contoured the site. A landscape contractor (American Civil Constructors) planted the site with the native riparian and wetland plant species during the summer and fall of 2004. Before installing plants in the mitigation area, the landscape contractor hydroseeded the area with a native seed mix of legume species (including Spanish clover (*Lotus purshianus*), sky lupine (*Lupinus nanus*), and arroyo lupine (*Lupinus succulentus*) and non-legume species (including meadow barley (*Hordeum brachyantherum*), three week's fescue (*Vulpia microstachys*), California brome (*Bromus carinatus*), molate red fescue (*Festuca rubra*), California poppy (*Eschscholzia californica*), purple needlegrass (*Nassella pulchra*), and creeping wildrye (*Leymus triticoides*) to prevent erosion of the graded and contoured slopes.

Caltrans biologists will conduct spring and summer plant surveys to detect early and late-season species and will map the extent of the vegetation cover using a GPS. Annual reports submitted to CDFG and USACE will include the initial number of planted species in the riparian areas (riparian zone south (RZS) and riparian zone north (RZN)) and an estimate of how many of those plantings survived each year. Caltrans biologists will survey a minimum of nine random vegetation sample plots measuring approximately 3 x 3 meters (10 x 10 feet) in each riparian and wetland zone to estimate plant coverage and dominance.

Analysis

A grid with 3 x 3 meter (10 x 10 feet)-quadrats was placed over an aerial photo of the site to obtain the sample plots. The riparian zones were subdivided into three zones each. The wetland zone (WZ) was subdivided into four zones to provide an equal representation across the different elevations. The upper zone contains mostly upland plants, the middle zone represents a transition between upland and riparian (streamside) plants, the lower zone of the riparian zone contains riparian vegetation, and the wetland zone contains wetland (hydrophytic or aquatic) plants. The weir separating the wetland zone from Dan Wilson Creek contains both wetland plants and riparian vegetation. Caltrans biologists randomly selected a minimum of two quadrats from each subdivision prior to the first plant surveys.

Caltrans biologists will monitor these quadrats for the percent cover change of vegetation over the five-year monitoring period. During the first three years of monitoring, known as the plant-establishment period (PEP), the landscape contractor will monitor all of the plantings and will replace dead or dying plants. CDFG and USACE success criteria for the mitigation site are 90% plant survival after the PEP, 80% plant survival after year four, and 70% plant survival after year five.

Results

During the pre-mitigation and post-mitigation surveys, Caltrans biologists surveyed the dominant plants within the three mitigation areas (RZS, RZN, and WZ) as well as wildlife in or near the mitigation areas. Caltrans biologists obtained photographic records of each mitigation area at specific points (figure 2). Figures 3, 4, and 5 are representative of the photographic records taken at the site. Caltrans biologists delineated the three mitigation areas using GPS for later determination of plant coverage after the PEP.

Caltrans Biologists Michael Galloway, Hal Durio, David Amme, Karen Taylor, and Tami Schane conducted post-mitigation surveys of the project area between July 27, 2004, and February 14, 2005. Caltrans Biologists Michael Galloway, Hal Durio, and Tami Schane conducted post-mitigation plant surveys of the project area on May 12 and May 24, 2005.

Riparian zone south

Caltrans left an unplanted area measuring approximately 0.01 hectare (0.02 acre) at the southern end of the RZS to allow the Solano County Water Agency access to Dan Wilson Creek for flood-control maintenance activities. The landscape contractor planted the remaining 0.11 hectare (0.28 acre) with native vegetation (figure 3). The RZS was subdivided into three zones representing a native upland area at the upper elevations, an upland/riparian transition zone at the middle elevations, and a riparian zone adjacent to Dan Wilson Creek (table 1). The upper third of RZS was planted with native upland species, the middle third consists of an upland/riparian transition zone, and the lower third of the RZS adjacent to Dan Wilson Creek was planted with arroyo willow (*Salix lasiolepis*).

Point 1

Point 9

Point 11

Figure 3. Riparian Zone South. Photos taken before mitigation work on the left (June 9, 2004) and after mitigation work on the right (June 10, 2005).

Table 1. Final plant list for the Solano Community College Mitigation Site

Scientific Name	Common Name	Quantity	Installation Period	Location Installed[1]
Aesculus californica	California buckeye	277	August 2004	Upland, Upland/Riparian
Alnus rhombifolia	White alder	169	August 2004	Upland/ Riparian
Artemesia douglasiana	Mugwort	337	November 2004	Upland/ Riparian
Baccharis pilularis	Coyote bush	289	August 2004	Upland
Baccharis salicifolia	Mule fat	337	August 2004	Upland/ Riparian
Cercis occidentalis	California redbud	75	August 2004	Upland
Cyperus eragrostis var. eragrostis	Common nut grass	199	August 2004	Wetland
Eleocharis macrostachya	Spike rush	249	August 2004	Wetland
Fraxinus latifolia	Oregon ash	241	August 2004	Upland
Heteromeles arbutifolia	Toyon	289	August 2004	Upland
Juncus balticus	Baltic rush	100	August 2004	Wetland
Juncus phaeocephalus	Brownhead rush	134	August 2004	Wetland
Juncus xiphioides	Iris-leaved rush	100	August 2004	Wetland
Platanus racemosa	California sycamore	108	August 2004	Upland/ Riparian
Populus fremontii	Fremont poplar	84	August 2004	Upland/ Riparian
Quercus agrifolia	Coast live oak	145	August 2004	Upland
Quercus lobata	Valley oak	9	August 2004	Upland
Rhamnus californica	California coffeeberry	211	August 2004	Upland/ Riparian
Salix lasiolepis	Arroyo willow	535	September 2004	Riparian, Wetland
Scirpus acutus var. occidentalis	Common tule	169	August 2004	Wetland
Scripus americana	Three-square bulrush	6	September 2004	Wetland
Symphoricarpos albus laevigatus	Creeping snowberry	675	August 2004	Upland/ Riparian

During the plant surveys, the biologists conducted random plant sampling of the upland and upland/riparian transition zones of RZS. Approximately 60 plants were observed in the sampled areas. Of the plants, 54 (90%) showed budding, leafing, or other signs of growth. One of the six plants that did not show any signs of growth was identified as a California sycamore (*Platanus racemosa*).

Caltrans biologists counted 150 arroyo willow in the riparian zone of RZS. Approximately 56 (37%) of the arroyo willow in the area showed budding, leafing, or other signs of growth.

Riparian zone north

The landscape contractor planted approximately 0.15 hectare (0.38 acre) of the RZN similarly to the RZS (figure 4). The RZN was also subdivided into three zones representing a native upland area at the upper elevations, an upland/riparian transition zone at the middle elevations, and a riparian zone adjacent to Dan Wilson Creek (table 1).

During the plant surveys, the biologists conducted random plant sampling of the upland and upland/riparian transition zones of RZN. Approximately 83 plants were observed in the sampled areas. Of the plants, 75 (90%) showed budding, leafing, or other signs of growth. Three of the eight plants that did not show any signs of growth were identified as toyon (*Heteromeles arbutifolia*).

Caltrans biologists counted 190 arroyo willow in the riparian zone of RZN. Approximately 155 (82%) of the arroyo willow in the area showed budding, leafing, or other signs of growth.

Point 3

Point 6

Point 8

Figure 4. Riparian Zone North. Photos taken before mitigation work on the left (June 9, 2004) and after mitigation work on the right (June 10, 2005).

Wetland zone

Caltrans was not able to plant approximately 0.11 hectare (0.28 acre) of the WZ at the lowest elevations. This area ponded immediately following contour excavation because the groundwater table was shallower than expected (figure 5). Caltrans anticipates that the wetland vegetation planted at lower elevations will spread into the unplanted, ponded area. The landscape contractor planted the upper and middle elevations of the remaining 0.13 hectare (0.32 acre) of the WZ similarly to the riparian zones, with an upland area along the upper elevations and an upland/riparian transition zone along the middle elevations. The landscape contractor also planted the lower elevations of the WZ with hydrophytic plants (table 1). The landscape contractor planted the weir that separates Dan Wilson Creek from the WZ with these hydrophytic species at the lower elevations and arroyo willow at the higher elevations.

During the plant surveys, Caltrans biologists conducted random plant sampling of the upland and upland/riparian transition zones of the WZ. Approximately 108 plants were observed in the sampled areas. Of the plants, 98 (91%) showed budding, leafing, or other signs of growth. Two of the 10 plants that did not show any signs of growth were identified as toyon.

Caltrans biologists counted 148 arroyo willow in the riparian zone of the WZ. Approximately 102 (69%) of the arroyo willow in the area showed budding, leafing, or other signs of growth.

The planted wetland vegetation is competing with species recruiting into the ponded area of the WZ. Water bent (*Agrostis viridis*), perennial rye grass (*Lolium perenne*), cattail (*Typha* sp.), and hairy willow herb (*Epilobium ciliatum*) have recruited from the creek and established in the ponded area of the WZ. Percentage cover of the planted wetland vegetation in the sampled quadrats varies from 0% to 80%. The most dominant planted-wetland species are common tule (*Scirpus acutus* var. *occidentalis*), common nut grass (*Cyperus eragrostis* var. *eragrostis*), brownhead rush (*Juncus phaeocephalus*), and iris-leaf rush (*Juncus xiphioides*).

Point 14

Point 16

Point 18

Figure 5. Wetland Zone. Photos taken before mitigation work on the left (June 9, 2004) and after mitigation work on the right (June 10, 2005).

Biologists recorded wildlife observed at the mitigation site on an opportunistic basis. Table 2 lists the wildlife species observed at the mitigation site after the site had been graded and contoured (July 27, 2004).

Table 2. Wildlife observed at the Solano Community College Mitigation Project after the grading and contouring Work on July 27, 2004

Scientific Name	Common Name	Date First Observed	Zone Observed
Birds			
Agelaius phoeniceus	Red-winged blackbird	October 7, 2004*	DWC
Anas platyrhynchos	Mallard	February 14, 2005	WZ
Buteo jamaicensis	Red-tailed hawk	February 14, 2005	WZ
Buteo lineatus	Red-shouldered hawk	December 14, 2004	WZ
Ceryle alcyon	Belted kingfisher	September 8, 2004*	WZ
Charadrius vociferus	Killdeer	July 27, 2004	WZ
Corvus corax	Common raven	November 9, 2004*	RZN
Egretta thula	Snowy egret	October 7, 2004	WZ
Gallinago gallinago	Common snipe	November 9, 2004	WZ
Mergus serrator	Red-breasted merganser	January 11, 2005	WZ
Sayornis nigricans	Black phoebe	November 9, 2004	WZ
Tachycineta bicolor	Tree swallow	May 24, 2005	WZ
Tringa flavipes	Lesser yellowlegs	September 8, 2004	WZ
Zonotrichia atricapilla	Golden-crowned sparrow	January 11, 2005*	WZ
Invertebrates			
Damselfly sp.	Damselflies	July 27, 2004*	WZ
Odonata Order	Dragonflies	July 27, 2004*	WZ
Procambarus sp.	Crayfish	September 30, 2004	WZ
Amphibians			
Hyla regilla	Pacific treefrogs	February 14, 2005	WZ
Rana catesbeiana	Bullfrogs	September 23, 2004*	WZ, DWC
Fish			
Gambusia affinis	Mosquitofish	July 27, 2004*	WZ, DWC
Reptiles			
Sceloporus occidentalis	Western fence lizards	July 27, 2004*	DWC
Mammals			
Ondatra zibethicus	Muskrat	December 14, 2004	WZ

An asterisk (*) indicates animal species observed at the mitigation site before and after the grading and contouring work.

The Napa-Solano Mosquito Abatement District provides annual stocks of mosquitofish (*Gambusia affinis*) to Dan Wilson Creek at Solano Community College to control mosquitoes in the area. Caltrans Biologist Michael Galloway contacted the Napa-Solano Mosquito Abatement District to request that they place mosquitofish into the WZ as well. During grading and contouring of the site, it appeared that additional mosquitofish had been placed into Dan Wilson Creek and the WZ.

Conclusions

Approximately 0.16 hectare (0.4 acre) of the land contoured, graded, and planted at the mitigation site will provide riparian habitat, and 0.20 hectare (0.5 acre) will provide wetland habitat after the five-year monitoring period to meet the mitigation goals established by Caltrans, the California Department of Fish and Game, and the U.S. Army Corps of Engineers.

During the three-year plant-establishment period (PEP), the landscape contractor will maintain all plants that are installed at the mitigation site by replacing any dead or dying plants before the end of the PEP. The majority of plants that were installed in the upland and upland-riparian zones of the mitigation site were successful after one year, with approximately 90% of the plants showing signs of growth. The unsuccessful plants that could be identified were either California sycamore or toyon. The landscape contractor will determine whether the same species of plant will be used as a replacement or if the dead or dying plants should be replaced with another plant in the planting table. The land-scape contractor will replace the dead or dying plants in fall 2005.

Caltrans biologists found 488 (91%) of the 535 arroyo willows installed by the landscape contractor in the mitigation area, with 313 (64%) of the counted willows showing signs of growth. The southern end of the site has the highest concentration of unsuccessful willow plantings. This may be indicative of the lack of shading or wind protection at the southern end of the mitigation area, which may lead to a drying-out of the willows, a difference in the soils, a difference in the elevation of the willow plantings, or the method of installation. The Caltrans biologists and the landscape contractor will further monitor the growth of the willows in the area to determine if additional willows need to be planted at a later time.

The majority of wetland plants in the mitigation site are successful. Some plants, including common tule, have established and spread throughout the wetland zone. Some existing plants identified near the mitigation site, such as cattail, have recruited into the WZ. The success of the plants installed in the wetland combined with the recruitment of hydrophytic plants into the WZ defines this area as a wetland. The landscape contractor will determine whether the plants that have recruited into the area should be removed to maintain plant diversity of the area.

Animal species identified by Caltrans biologists in the area before the mitigation work began were again observed in the area after the work. Most of the animals found in Dan Wilson Creek are either exotic species or, in the case of mosquitofish, were placed into the creek as a vector-control measure. Caltrans biologists identified many of these species in the WZ after Caltrans finished the grading and contouring of the area. Some of these species have migrated from Dan Wilson Creek into the newly developed WZ.

The number of bird species observed in the area increased after the mitigation work. Birds commonly observed in freshwater pond habitats, including the common snipe (*Gallinago gallinago*), snowy egret (*Egretta thula*), black phoebe (*Sayornis nigricans*), killdeer (*Charadrius vociferus*), and lesser yellowlegs (*Tringa favipes*), are using the WZ.

Acknowledgments: This project would not have been possible without the assistance and the land provided by the Solano Community College. We would like to thank everyone involved at the college for all of their help. We would also like to thank the Solano County Water Agency for their input on the restoration work. We would especially like to thank all the field biologists at Caltrans who helped gather data for this study. Thanks to Fred Botti, retired California Department of Fish and Game biologist, who suggested this site at the college as a possible restoration area. This project is dedicated to the memory of Kirby McClellan, Caltrans biologist, who did most of the biological work on the Solano Interstate Route 80 Widening Project and was responsible for getting the ball rolling on this mitigation project.

Biographical Sketches: Michael Galloway is currently employed as a biologist for Caltrans. He graduated from San Francisco State University in 2001 with an M.A. degree in marine biology. His master's thesis focused on Pacific harbor seal (*Phoca vitulina richardii*) haul-out behavior at a haul-out site in the San Francisco Bay. He is currently monitoring several Caltrans restoration projects in the San Francisco Bay area, including this project, and the Triangle Marsh Restoration Project in Corte Madera, California.

Chuck Morton is a district branch chief for the California Department of Transportation in the Oakland office. His area of responsibility encompasses Marin, Sonoma, Napa, Solano, and Contra Costa Counties and includes over 700 miles of roadway. He holds a B.S. in biology and marine science and a M.S. in environmental planning.

ROAD ECOLOGY OF THE NORTHERN DIAMONDBACK TERRAPIN, *MALACLEMYS TERRAPIN TERRAPIN*

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Abstract: Diamondback terrapin populations along the East Coast have suffered due to a number of factors since the early 1900's. Overexploitation from commercial harvesting, drowning in fishing gear, and loss of habitat has had a negative impact on the terrapin (Roosenburg 1991). Terrapins in several areas, specifically in New Jersey, are now threatened by an additional source of mortality, road mortality (Wood and Herlands 1997, Hoden and Able 2003), which could cause further declines in the abundance of this species.

Road mortality and ecology of the northern diamondback terrapin, *Malaclemys terrapin terrapin*, in the Jacques Cousteau National Estuarine Research Reserve was examined and compared to traffic patterns during the nesting seasons (May-July) of 2004 and 2005. Traffic-measuring devices were stationed on sections of Great Bay Boulevard (GBB), an access road through salt-marsh habitat to obtain traffic-volume estimates. A total of 1201 terrapins were observed on the road with 104 road mortalities (8.66%). In 2004, a significantly greater proportion of road kills was found in the section of the road with the highest traffic volume.

However, we did not see this same pattern in 2005 as road mortalities across the sections were fairly evenly distributed. There was a positive correlation between road kills and increasing traffic volume throughout the day observed in 2004. Three hundred terrapins were tagged with passive-integrated transponder (PIT) tags over the course of the study. The tagging portion of this study indicated that some females may have been returning more than once in the season to lay multiple clutches along the roadside and demonstrated nest-site philopatry by returning to the area where they were initially tagged.

The information gathered suggests that terrapins are attracted to the roadside as it meets the requirements for a suitable nesting habitat. Future mitigation, such as drift fencing and increased patrolling of the roads, is needed to help reduce road mortalities. Fencing will be proposed to be installed in the areas of greatest road mortality and of greatest nesting activity along Great Bay Boulevard for 2006.

Introduction

Road mortality is becoming a significant problem for the northern diamondback terrapin, *Malaclemys terrapin terrapin*. Since terrapins are a "Species of Special Concern" in New Jersey (N.J. Department of Environmental Protection, Division of Fish and Wildlife, N.J. Endangered and Non-Game Species Program website 2005), understanding the impact of road mortality is critical (Forman et al. 2003). Great Bay Boulevard (GBB), an 8.1-km paved access road running through fairly pristine salt-marsh habitat in the Jacques Cousteau National Estuarine Research Reserve (JCNERR), is the site of many deaths each summer. Since suitable nesting habitat exists along the side of the boulevard, adult female terrapins are at risk from collisions with vehicles. Accordingly, this detailed survey was conducted to evaluate the relationship between traffic, road occurrence, and road mortality along this road for 2004/2005.

The field work was conducted at Rutgers University Marine Field Station, Institute for Marine and Coastal Sciences, Tuckerton, New Jersey.

Methodology

Surveys of Great Bay Boulevard in the JCNERR were conducted during the terrapin-nesting season from May-July of 2004/2005. Transect sections were chosen based on bridges that divide the road and cross over the subtidal marsh creeks (figures 1 and 2). Approximately five-six days per week, eight to 10 surveys were completed each day for a total of 299 samples in 2004 and 272 samples in 2005.

TRAX I Plus Traffic Counters/Classifiers (Jamar Technologies Inc.) were stationed in the middle of the six transect sections of the road to measure traffic patterns.

GPS data points were recorded for all terrapins and plotted on aerial images using ArcView GIS to obtain distances to nearest major and extension creeks and bridges. Comparisons of road mortality between sections and were tested using Pearson Chi-Square Analysis. Spearman's Rank Order Correlation was used to test mortality rate and mean traffic volume during the hours of the day. Three hundred terrapins were tagged with 2 x 12-mm passive-integrated transponder (PIT) tags (Biomark Inc).

Figure 1. Map of the Jacques Cousteau National Estuarine Research Reserve in New Jersey, where Great Bay Boulevard is located.

Figure 2. Aerial image of Great Bay Boulevard with defined transect sections within the Great Bay Wildlife Management Area of the Jacques Cousteau National Estuarine Research Reserve.

Results

- Numerous terrapins were observed each nesting season (N, 2004 = 601 and N, 2005 = 600) with peaks of nesting along the road around the lunar phases.
- Road mortality in 2004 was found to be significantly greater ($p < 0.001$) in section 6 and exhibited the highest traffic volume. In 2005, no differences were found between sections, except that section 2 had significantly less mortality ($p < 0.005$) (table 1).
- Most road-killed terrapins in section six were killed near creeks and bridges that intersect Great Bay Boulevard (table 2, figure 3).
- Road-mortality rates correlated positively with average traffic volume by hour in 2004 during our survey times of 0900-1600 ($p < 0.03$).
- Sixty five of 300 (21.67%) tagged terrapins were recaptured. One female crossed GBB a minimum of 5 times in the 2004 season.
- Some demonstrated possible multiple clutching and nest-site philopatry within and among years.

Table 1. Summary results of terrapin occurrences, mortalities, and average traffic volume (vehicles/day) by transect section on Great Bay Boulevard during the nesting seasons of 2004 and 2005

Transect Section	Live (2004)	Dead (2004)	Mean Traffic Volume (2004)	Live (2005)	Dead (2005)	Mean Traffic Volume (2005)
1	57	2 (3.39%)	233.70	83	4 (4.60%)	250.38
2	101	9 (8.18%)	262.71	96	**1 (1.03%)***	337.71
3	189	13 (6.44%)	363.36[a]	153	20 (11.56%)	621.39
4	84	8 (8.70%)	363.36[a]	91	13 (12.5%)	707.22
5	91	10 (9.90%)	464.00	84	7 (7.69%)	749.41
6	25	**11 (30.56%)****	936.00	42	6 (12.5%)	905.97
Total	547	53 (8.83%)		549	51 (8.5%)	

** *($P < 0.001$, $x^2 = 22.44$, df = 1)*
* *($P < 0.005$, $x^2 = 8.299$, df = 1)*
[a]*Estimated traffic volumes.*

Table 2. Summary results of terrapin road mortalities in relation to nearest creeks and a bridge along transect section 6 of Great Bay Boulevard

	Mean	Range	N
Straight-line distance (m) to nearest creek (major or extension) from:			
2004 road mortalities[a]	69.87	14.74-334.89	11
2005 road mortalities[b]	93.42	10.57-283.31	6
Straight-line distance (within 150 m) to nearest bridge from:			
2004 road mortalities[a]	130.25	93.36-148.87	6 (54.5%)
2005 road mortalities[b]	141.05	132.97-149.13	2 (33.33%)
[a]*Data from GPS telephone pole locations.* [b]*Data from GPS actual locations.*			

Figure 3: Aerial image of transect section 6 of Great Bay Boulevard 2004 (circles) and 2005 (plus signs) road mortalities. It appears some terrapins are being killed closer to the bridge and where the extensions of the creeks meet the road.

Discussion

Our findings are similar to past studies proposing that there are greater road mortalities of herpetofauna where there is greater traffic volume. Snakes have been observed to be more vulnerable to road mortality as traffic peaks during certain time periods (Rosen and Lowe 1994). A correlation has been shown between the number of mortalities and the number of vehicles on a road (Bernardino Jr. and Dalrymple 1992). It has been calculated that, for amphibians, the probability of being killed increases with greater traffic volume (Hels and Buchwald 2001). Fahrig et al. (1995) also suggested that the proportion of dead frogs and toads increased with traffic intensity, while the number of live animals surrounding the roadway decreased.

This study, which has provided us with new information regarding areas of greatest nesting and highest mortality rates, will assist in determining mitigation strategies. A project to install drift fences to reduce terrapin mortality along Great Bay Boulevard has been proposed for the 2006 breeding season.

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Biographical Sketch: Stephanie Szerlag received her B.S. in biology, marine option at Millersville University of Pennsylvania in 2001. She is currently a M.S. in biology graduate student at Saint Joseph's University and plans to defend her thesis in December 2005. This document serves as background material and as partial preparation of her thesis manuscript.

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Road Watch in the Pass: Using Citizen Science to Identify Wildlife Crossing Locations Along Highway 3 in the Crowsnest Pass of Southwestern Alberta

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Abstract

The municipality of Crowsnest Pass is situated in a rare east-west corridor bisecting the Rocky Mountains in Southwestern Alberta and Southeastern British Columbia. Highway 3, which runs the length of the Pass, is a major transportation route supporting over 13,000 vehicles per day. Wildlife mortality, due to collisions with vehicles, has been identified as a major human-safety and wildlife-conservation issue on this stretch of highway with approximately 109 large mammal deaths per year. Another immediate threat to wildlife populations in the region is the proposed expansion and realignment of Highway 3. The expanded highway footprint and increased traffic will likely affect wildlife use in the area. It is therefore important that decision makers acquire information on where wildlife are most likely to cross the road to ensure effective mitigation measures. Currently, information pertaining to wildlife movement in the Pass is limited.

Road Watch in the Pass is an innovative, community-based research project that engages local citizenry in reporting wildlife observations along Highway 3 through the Crowsnest Pass in southwestern Alberta, Canada. Through the use of a Web-based GIS, interested citizens can participate in data collection that will be instrumental to decision makers in reducing wildlife-vehicle collisions and for developing mitigation measures for highway expansion. Road Watch was designed to test and profile the use of local knowledge and volunteer data collection in the Crowsnest Pass by providing land managers and the community with valuable baseline information related to wildlife highway crossings. The goals of the project are to collect, analyze, and communicate information highlighting crossing locations of wildlife along the highway based on local knowledge and observations, as well as to engage the citizenry of the pass in local issues relating to wildlife movement and safety.

The project was launched in November 2004 after considerable communication with decision makers in the Pass and the hiring of a local project coordinator. There are currently 51 active participants using the website and interactive mapping tool. The 51 participants have recorded over 581 large mammal sightings. These results are provided to the community on a regular basis through the local media, project website, and email messages. Although the project is still new in inception, preliminary results indicate that the community is successfully engaged with an average of five new volunteers joining Road Watch each month. Each volunteer has contributed an average of 12 observations, with 59 percent of the participants submitting observations on more than one occasion. The number of individual observations ranges from one to 167. Participants have recorded the full compliment of large mammals that occur in the pass, including: 243 mule deer (*Odocoileus hemionus*), 106 big horn sheep (*Ovis canadensis*), 66 white-tailed deer (*Odocoileus virginianus*), 64 unidentified deer species (*Odocoileus* spp.), 35 elk (*Cervus elaphus*), 30 moose (*Alces alces*), 11 coyotes (*Canis latrans*), seven black bears (*Ursus americanus*), three wolves (*Canis lupus*), three mountain goats (*Oreamnos americanus*), three grizzly bears (*Ursus arctos horribilis*) and two cougars (*Puma concolor*), with the exception of wolverine (*Gulo gulo*) and lynx (*Lynx canadensis*).

Road Watch observations provide a valuable supplement to mortality data and have the potential to greatly enhance the existing information base. For example, the percentages of species observations from Road Watch correlate to the recorded levels of wildlife mortality, with mule deer as the highest recorded species from both data sources. From preliminary comparisons of these two data sources, we have identified zones with high Road Watch observations corresponding with low mortality records. This may indicate that there are areas where wildlife are successfully crossing, which has important implications for highway mitigation.

Road Watch is an innovative initiative that will generate a unique dataset resulting from a comparative anlysis of knowledge sources. Preliminary results demonstrate that this approach increases the knowledge base by providing new emerging knowledge that would not have been explicit from a single source. This initiative also provides the opportunity for the Crowsnest Pass community to actively engage in an important wildlife-conservation issue. This information will be important to citizens in the community and local decisionmakers in relation to human safety and wildlife conservation around Highway 3.

The Role of Transportation Corridors in Plant Migration in and Around an Arid Urban Area: Phoenix, Arizona

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Abstract

While the potential importance of corridors has been acknowledged for both native and non-native species, little is known about how corridors actually function in developed and fragmented landscapes. Transportation corridors, such as roads and freeways, provide fairly consistent habitat conditions traversing nearly all man-made developments, including cropland, suburbs, reserves, and cities, and connect them with undeveloped areas. The combination of the particular conditions along road and freeway verges and the characteristics of the plants that reach these corridors will ultimately determine which species, native or not, will be able to move within cities and developed areas, as well as to and from cities and surrounding undeveloped areas.

This study will advance ecological understanding of the plant species that are able to move through existing corridors in arid and semi-arid urban areas. Urban areas, including freeway corridors, are intensively managed. This study will consider human management and urban development as integral and natural parts of the ecosystem under study. Understanding the similarities and differences in traits that affect movement of plant species along corridors will provide evidence as to whether native and non-native or functional groupings of species actually move differently in corridors. It will contribute to the literature on assessing the potential for particular plant species to invade new areas. Linking local plant processes to the larger landscape scale of movement between cities and undeveloped areas will have important implications for conservation planning in both environments.

Twenty sites were selected along the four major freeways in the cardinal directions around the Phoenix Metropolitan Area. Beginning in March 2004, vegetation surveys have been performed seasonally at each site. In addition, seed-bank samples and bulk-soil samples were collected at each site. The seed-bank samples are germinating in the greenhouse to determine the seed-bank composition; analysis of physical soil characteristics and available and total levels of soil nutrients (nitrogen and phosphorus) is nearly complete.

Initial soil-chemistry results show that levels of plant-extractable nitrate are significantly increased in the surface soil located directly adjacent to the asphalt (ANOVA using log surface soil concentration; $F = 5.556$, $P = 0.005$). There were also significant differences between sites located adjacent to different land uses, with the sites located in the more densely developed city areas having higher nitrate levels than those at the edges of developed areas. The urban residential sites had the highest levels, followed by croplands, then lower density “fringe” development, and desert sites had the lowest levels of extractable nitrate (ANOVA using log surface soil concentration, $F = 123.67$, $P < 0.001$; Fisher’s multiple comparison, all combos $P < 0.001$).

The plant community composition and seed-bank composition at these sites will be compared with nutrient levels to determine whether similar patterns emerge. It is likely that in the typically nitrogen-limited Sonoran Desert, the addition of nitrogen as a result of exhaust from combustion engines is significantly impacting which plant species are most likely to grow along the roadsides. This raises the question of whether heavily traveled roadsides in naturally nutrient-limited ecosystems should be considered as potential vegetation reserves, since intense maintenance would likely be needed to maintain a native community. Perhaps these areas are best landscaped with species unlikely to move along the highway corridors, whether native or not.

The results of this research will advance ecological understanding in several ways. I will elucidate the suite of plant traits that allow effective dispersal in fragmented landscapes with well-defined corridors, clarifying whether these corridors favor plants with particular traits, rather than native or non-native species. This study will increase understanding of the connection between urban and extra-urban environments and will have important implications for conservation planning in both types of environments. Finally, this research specifically incorporates humans into ecological theory, including human management and urban development as an integral and natural part of the ecosystem under study.

The project results will also be useful to highway and road managers, particularly in arid areas. The results will illuminate potential management techniques that will enhance or prevent plant migration along transportation corridors, as well as providing information on how management of transportation verges for objectives other than plant dispersal is likely to affect plant community composition.

Software for Pocket PC to Collect Road-Kill Data

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Abstract

Animal-vehicle collisions are an important issue in North America. Accidents are numerous and result in human injuries and fatalities, property damage, and the death or injury of the animals concerned. Some animal species may be affected at the population level and face increased risk of local or regional extinction due to the high number of road-kills and other negative effects of roads and traffic. Systematically collected road-kill data can help quantify the magnitude of this problem and potential changes in road-kill occurrences and "hot spots" over time. Such data allows for prioritization and focusing of mitigation efforts to avoid or reduce collisions.

However, not all DOT's or DOT districts record animal-vehicle collisions and the DOT's that do record road-kill data often use different methods. A national standard and tool for the recording of animal-vehicle collisions would not only stimulate DOT's and other organizations to collect animal-vehicle collision data, but would also allow for more effective analyses and use of the data.

The Western Transportation Institute at Montana State University (WTI-MSU) has developed software that allows for easy, standardized, and spatially precise collection of animal-vehicle collision data. The software runs on a Pocket PC that is linked to a Global Positioning System (GPS). The software distinguishes between "monitoring" and "incidental observation" modes and tracks the route of the observer. Road-kill data, including species name as well as optional parameters such as the sex of the animal, are stored in a separate file that can be uploaded to a PC and imported into standard spreadsheet or mapping software. Recording road-kill observations with this tool eliminates manual data entry and transcription.

Beyond the basic data-collection software, we anticipate developing data-management and analysis software that will allow for easy merging and analyses of data from numerous sources, including cluster analyses, and linking to other spatial data in a Geographic Information System (GIS). This has the potential to allow for much faster and better feedback to plan and prioritize for mitigation to address human-safety or conservation concerns.

Once mitigation measures have been put in place, the tools and procedures described above allow for proper evaluation of these measures. We expect that the tools and procedures will ultimately result in fewer animal-vehicle collisions, less work for road maintenance crews, and a reduction in the transportation and disposal costs of the carcasses.
A CD-ROM that demonstrates the software is available on request. Please contact WTI-MSU if you have further questions or if your organization is interested in helping us with the testing and further development of this tool and procedures.

Spatial Patterns of Road Kills: A Case Study in Southern Portugal

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Abstract: Roads promote high levels of animal-vehicle collisions and have one of the most visible man-made impacts on wildlife. In Portugal, SW Europe, very few ecological studies have focused on the impacts from roads on vertebrates. Knowledge of the main factors driving the emergence of hotspots of vertebrate mortality is still scarce.

A segment of a main road 26-km long was sampled by car at an average speed of 20 km/h every two weeks for two years (54 surveys) between 1995 and 1997, collecting all road-killed specimens found. We defined road sections with high collision rates, or vertebrate-mortality hotspots (VMH), by detecting clusters of animal collision locations. The analysis was conducted by comparing the spatial pattern of road kills with that expected in a random situation. In such a condition, the likelihood of collisions for each road section would show a Poisson distribution. Differences of explanatory variables between hotspots and low-mortality sections were evaluated with the Mann-Whitney U-test. Also, a direct-gradient analysis (Canonical Correspondence Analysis (CCA)) was executed with the mortality rates of the 24 most-killed species and the explanatory variables considered.

A total of 2421 vertebrate road-killed specimens were collected, which corresponded to nearly 46 specimens per 0.5 km per year. Eighty non-domestic species were recorded. Several sections were defined as VMH, both for all observations and for each vertebrate class. Results suggested that some road sections should receive particular mitigation actions given that mortality hotspots may arise, particularly sections where montado is the dominant habitat and where stream and other water courses run nearby and parallel to the road.

Introduction

One major human agent of habitat fragmentation is the ever-increasing and expanding road network worldwide (Forman et al. 2002) that can be harmful to various faunal groups such as invertebrates (e.g., Haskell 2001), amphibians (e.g., Carr and Fahrig 2001), reptiles (e.g., Gibbs and Shriver 2002), birds (e.g., Kuitunen et al. 1998) or mammals (e.g., Philcox et al. 1999). Roads and traffic can act as barriers which may make animal movements difficult and reduce population connectivity. By diminishing the gene flow and disrupting sink-source population dynamics, roads may increase inbreeding and loss of genetic diversity (Ferreras 2001). Resultant isolation might lead to higher local population extinction risks due to stochastic effects (van der Zande et al. 1980; Saunders et al. 1991; Fahrig and Merriam 1994; Cooper and Walters 2002).

Roads also promote high levels of animal-vehicle collisions, which is particularly significant for larger species with wider home ranges as carnivores. These collisions are one of the most visible road impacts on wildlife (e.g.: Hodson 1960; Oxley et al. 1974; Fahrig et al. 1995; Philcox et al. 1999; Gibbs and Shriver 2002; Taylor and Goldingay 2004).

In Portugal, SW Europe, very few ecological studies have focused on the impacts of roads on vertebrate populations. Knowledge of the main factors driving to the emergence of hotspots of vertebrate mortality is still scarce. This study refers to a two-year roadkill survey on a main road (IP2) located in southern Portugal (figure 1).

Study Area

The study was conducted in Portalegre District, between the cities of Portalegre and Monforte cities near the Natural Park of S.Mamede (NPSM) (figure 1). This region is in the center of the Iberian Peninsula, generally dominated by smooth areas, except on the natural park where mountain topography reaching 1024 meters a.s.l. The climate is mediterranean, although the NPSM is considered to be an Atlantic Biogeographic island in the middle of a mediterranean region. This biogeographic crossroad enables the coexistence within the same area of several species from both biogeographic regions.

Road vicinity is dominated by characteristic mediterranean agro-forestry areas; cork and holm oak tree stands (*Quercus suber* and *Q. rotundifolia*), hereafter referred as “montado;” open land as pastures, meadows, or extensive agriculture (cereal, fodder); and olive groves (figure 2). This IP2 section has a moderate traffic intensity of about 5000 vehicles day -1.

Methods

Sampling

A segment of the IP2 road (26-km long) was sampled by car at an average speed of 20 km/h every two weeks for two years (54 surveys) between 1995 and 1997. All vertebrates found killed on the pavement were collected and identified to species level *in loco*, whenever possible, or by analysis of skin, scales, feather or hairs, depending on the taxonomic group, in the laboratory.

It should be emphasized that the number of casualties found was most probably biased due to several constraints, namely carrion foraging from other animals, climatic conditions, and physical characteristics of roads, which can mislead correct counting and detection of corpses on roads (see Erritzoe et al. 2003, pers. observ.). Thus, records should be regarded as an underestimation of real carnage occurring on the road. Furthermore, non-daily surveys prevent the detection of all small-bodied animals like amphibians, passerines, or small mammals, since their corpses often remain between one and three days on the traffic lane (António Mira, unpublished data).

Explanatory variables
For each 0.5-km road section, we created a 500-meter-radius buffer, with its center on the section's middle point. Land cover was assessed for these buffers through orthofoto map analysis, with corrections from field work observations. Five classes of land cover were considered: montado (MNT), open areas (OPEN), olive groves (OLIVE), fruit tree groves and horticultures (FRUIT), and urban areas (URBAN) (figure 2).

On each buffer, we also considered the length of streams present inside each buffer (STREAM_L) and the distance of the middle point section to nearest stream (STREAM_D). The number of culverts (CULVERT) and houses (HOUSE) present on each 0.5 km road section were as well considered. All the information was processed with ArcView 3.2 (ESRITM, Redlands, California).

$$p(x) = \frac{\lambda^x}{x!\,e^\lambda}$$

We considered that a section was a potential vertebrate-mortality hotspot when its probability summation exceeded the 90 percent threshold, that is $\Sigma\, p(x)>90\%$.

Data analysis
Differences of explanatory variables between hotspots and low-mortality sections were evaluated with the Mann-Whitney U-test (Zar 1999). This analysis was performed for all observations, for anurans and caudata orders (amphibians), and for the vertebrate classes reptiles, birds, and mammals (domestic cat and dog were excluded from analyses).

For multivariate analysis, we used canonical ordination techniques. A direct gradient analysis (Canonical Correspondence Analysis (CCA)) was executed with the mortality rates of the most 24 killed species (species with above 15 casualties, table 1) and the explanatory variables considered, with downweight of rare species and detrending by segments options (Jongman et al. 1995), using CANOCO for Windows version 4.5 (ter Braak and Šmilauer 2002).

We selected the variables MNT, OLIVE, OPEN, FRUIT, CULVERT, STREAM_L, and STREAM_D. This option was chosen in order to achieve a compromise between obtaining the maximum percentage of variance explained and the significance of both eigenvalues and correlations of species-explanatory variables with the axis. The significance of species-environment correlation was tested by the Monte Carlo test (499 permutations). Ordination axes were interpreted using the intraset correlations that allow inference on the relative importance of each variable for predicting community composition (ter Braak 1986).

Results

A total of 2421 vertebrate road-killed specimens were collected, which corresponded to about 46 specimens per 0.5 km per year. At the species level, 2128 individuals were identified. Eighty non-domestic species were recorded (table 1).

Casualties among vertebrate classes were significantly different (chi-test, $X^2 = 1630$, df = 3; $p<0.001$), being higher for amphibians (n = 1362), followed by birds (n = 681), mammals (n = 225), and reptiles (n = 153).

Several sections were defined as vertebrate-mortality hotspots (VMH), both for all observations and for each vertebrate class (figure 3). VMH clusters seemed to be mainly aggregated at the first half of the studied road segment.

Regarding amphibians, hotspots of anuran mortality occurred mainly in the proximity of streams ($U = 203.5$, n1 = 35, n2 = 18; $p<0.05$), and in sections with a lower number of culverts ($U = 159.0$, n1 = 35, n2 = 18; $p<0.01$). For caudata, a high number of killed specimens were detected in sections with a low number of houses near the road ($U = 214.0$, n1 = 37, n2 = 16; $p<0.05$).

Concerning reptiles, road sections with high mortality also had a lower number of culverts ($U = 192.5$, n1 = 37, n2 = 16; $p<0.05$). Stream proximity was also significant, because the hotspots of mortality were closer to stream lines than to other sections ($U = 203.5$, n1 = 37, n2 = 16; $p = 0.073$).

Higher bird mortality occurred in road sections near watercourses ($U = 145.0$, n1 = 39, n2 = 14; $p<0.01$), with houses in close proximity of the road ($U = 153.5$, n1 = 39, n2 = 14; $p<0.01$), and with a lower cover of montado ($U = 153.0$, n1 = 39, n2 = 14; $p<0.05$).

Concerning environmental variables, there were no significant differences between road sections with high and low mortality of mammals.

The direct-gradient analysis (CCA) results are shown in figure 4. The eigenvalues were 0.153 in the first axis and 0.063 in the second. The Monte Carlo test was significant for both the first canonical axis (F = 6.099, P<001) and all canonical axes (F = 1.933, P<001). The first two axes explained 74.2% of data variability. First axis reflects mainly the effects of fruit-tree groves and horticulture (FRUIT), which are related to anthropogenic presence, and the montado cover density (MNT). The second axis reflects the proximity and length of watercourses near the road (STREAM_P and STREAM_L).

On the CCA plot, we observed that most species are positioned on the left side, suggesting that higher mortality rates occurred in sections dominated by montado. Exceptions to this are the cases of *Passer domesticus* (PD) or *Sylvia atricapilla* (SyA), species that are related to anthropogenic environments and are shown close to the FRUIT variable. Fruit-tree groves and small horticulture are typically located near small urban areas in mediterranean landscapes (as is the case near Portalegre). Anuran mortality seemed to have occurred on sections close to watercourses. Also noteworthy is that the position of several small species (such as the amphibians *Bufo bufo* (BB), and *Bufo calamita* (BC), the reptile *Natrix maura* (NM), and the small mammal *Apodemus sylvaticus* (AS) suggests that higher mortality levels occurred on sections with a lower number of culverts.

Discussion

Mortality rates on the Portuguese road presented in this study support the ideas that further road expansion should consider impacts on animal populations and that mitigation measures must be taken account on the existing road network. Furthermore, considering that the Iberian Peninsula is included in a global-biodiversity hotspot, namely the Mediterranean Basin (Myers et al. 2000), and that most species are in one way or another threatened by anthropogenic actions such as road expansion (de Vries et al. 2002), high-priority actions should be implemented so that on Iberian roads can provide a more permeable road system to animal movement. This is more relevant for the studied road given its location, which is near the border of an important Portuguese protected area, Serra de S. Mamede Natural Park (figure 1). This area is located in a biogeographic crossroad combining Mediterranean and Atlantic climatic characteristics, which provides multiple habitat patches allowing high species diversity and richness. Probably this is reflected in the highest number of road-killed species and specimens being found on the first kilometers. As suggested by Spector (2002), biogeographic crossroads appear to be areas of high conservation priority and opportunity in both the short and long term and require increased attention in the process of setting conservation priorities.

Results suggest that some road sections should receive particular mitigation actions given that mortality hotspots may arise. This is particularly true in sections where montado is the dominant habitat and where stream and other watercourses run nearby and parallel to the road. Also, the presence of culverts may diminish the collision risk, providing alternative paths for road crossings. This way, as previous authors described (e.g., Yanes et al. 1995; Rodríguez et al. 1996; Cain et al. 2003; Mata et al. 2005), the implementation of several of these or other similar structures, with different sizes and configurations, should be of primary concern.

Presently, an ongoing project using the same methodology is taking place on the same segment of road with the purpose of evaluating and comparing the vertebrate mortality rates and their spatial patterns 10 years after.

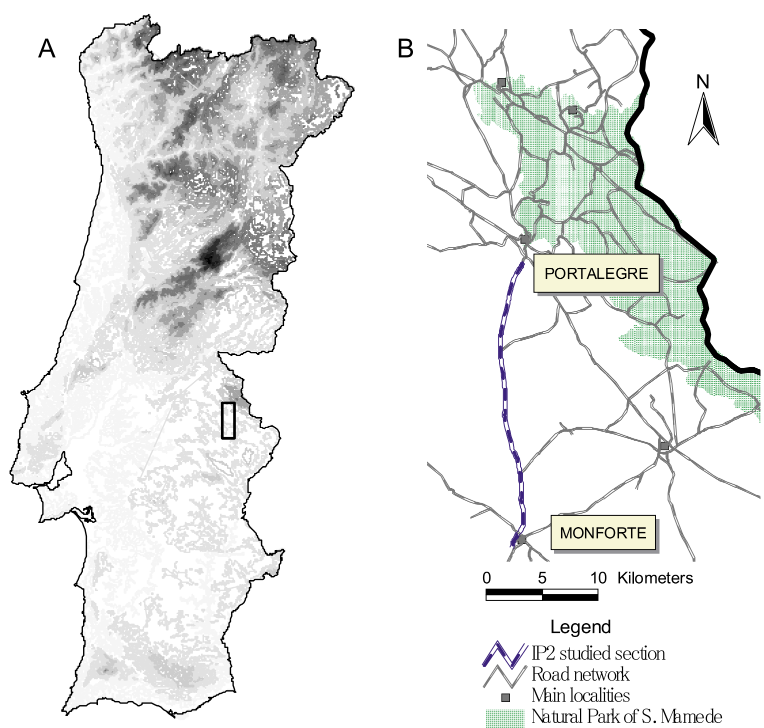

Figure 1. Location of studied IP2 road section (A) and map of study area (B).

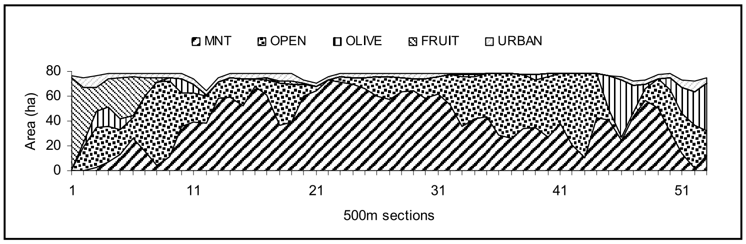

Figure 2. Land cover (main classes) within each 500-meter-radius buffer (near 79 ha) along the studied road.

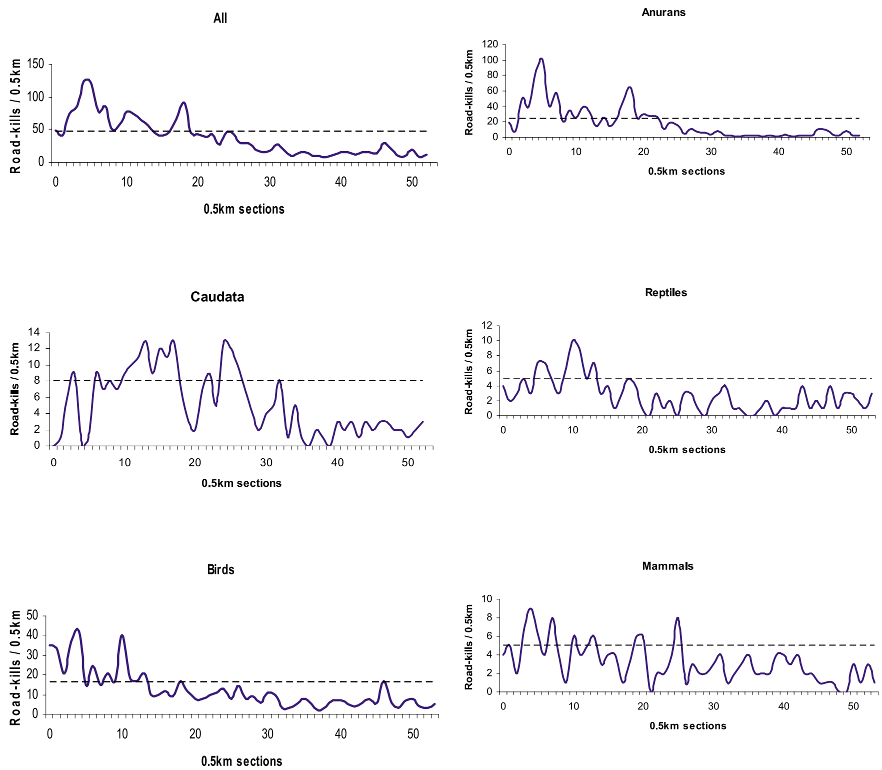

Figure 3. Road mortality along 0.5-km road sections. The dashed line sets the threshold for the definition of vertebrate mortality hotspots (Malo et al. 2004): 46 individuals for all observations, 24 for anurans, eight for caudata, five for reptiles, 17 for birds, and five for mammals.

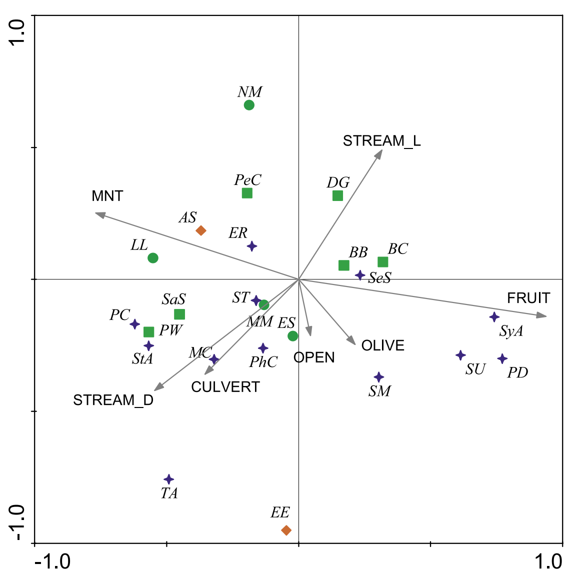

Figure 4. CCA ordination plots of the 24 most killed species (squares are amphibians, circles are reptiles, stars are birds, and diamonds are mammals), with explanatory variables. See text for variables' names. Longer vector lines represent stronger "intraset correlations" (ter Braak 1986). See text for variables' names and methods.

Species: Amphibians - BB, Bufo bufo; BC, Bufo calamita; DG, Discoglossus galganoi; PeC, Pelobates cultripes; PW, Pleurodeles waltl; SaS, Salamandra salamandra; Reptiles - ES, Elaphe scalaris; LL, Lacerta lepida; MM, Malpolon monspessulanus; NM, Natrix maura; Birds - ER, Erithacus rubecula; MC, Miliaria calandra; PC, Parus caeruleus; PD, Passer domesticus; PhC, Phylloscopus collybita; SeS, Serinus serinus; SM, Sylvia melanocephala; ST, Saxicola torquata, StA, Strix aluco; SU, Sylvia undata; SyA, Sylvia atricapilla; TA, Tyto alba; Mammals - AS, Apodemus sylvaticus; EE, Erinaceus europaeus.

Table 1. Species identified during field work (54 surveys on a 26 kilometer road section); Portuguese red book status (RBS); and number of specimens (N). Species are sorted, within each class, by decreasing number of casualties.

Species	RBS	N
Amphibians		
Bufo calamita	LC	456
Pelobates cultripes	LC	319
Bufo bufo	LC	177
Salamandra salamandra	LC	157
Pleurodeles waltl	LC	106
Discoglossus galganoi	NT	17
Triturus marmoratus	LC	11
Hyla meridionalis	LC	6
Rana perezi	LC	5
Alytes cisternasii	LC	2
Pelodytes sp.	NE	1
Reptiles		
Elaphe scalaris	LC	46
Malpolon monspessulanus	LC	28
Lacerta lepida	LC	21
Natrix maura	LC	16
Mauremys leprosa	LC	12
Psammodromus algirus	NT	9
Coluber hippocrepis	LC	7
Coronella girondica	LC	1
Natrix natrix	LC	1
Birds		
Passer domesticus	LC	80
Miliaria calandra	LC	45
Saxicola torquata	LC	41
Sylvia atricapilla	LC	37
Phylloscopus collybita	LC	33
Sylvia melanocephala	LC	33
Serinus serinus	LC	32
Erithacus rubecula	LC	31
Tyto alba	LC	27
Sylvia undata	LC	26
Parus caeruleus	LC	24
Strix aluco	LC	20
Carduelis carduelis	LC	15
Lanius senator	NT	14
Hirundo daurica	LC	11
Athene noctua	LC	8
Cisticola juncidis	LC	8
Turdus merula	LC	6
Fringilla coelebs	LC	5
Parus major	LC	4
Carduelis chloris	LC	3
Lanius meridionalis	LC	3
Phylloscopus trochilus	LC	3
Alectoris rufa	LC	2
Carduelis cannabina	LC	2
Elanus caeruleus	NT	2
Ficedula hypoleuca	LC	2
Troglodytes troglodytes	LC	2
Turdus philomelos	NT	2
Alcedo atthis	LC	1
Bubulcus ibis	LC	1
Carduelis spinus	LC	1
Ciconia ciconia	LC	1
Falco tinnunculus	LC	1
Galerida cristata	LC	1
Motacilla alba	LC	1
Muscicapa striata	NT	1
Passer hispaniolensis	LC	1
Petronia petronia	LC	1
Phoenicurus ochruros	LC	1
Pica pica	LC	1
Mammals		
Apodemus sylvaticus	LC	37
Erinaceus europaeus	LC	19
Oryctolagus cuniculus	NT	12
Lepus granatensis	LC	11
Vulpes vulpes	LC	10
Mus spretus	LC	9
Pipistrellus kuhli	LC	7
Crocidura russula	LC	6
Genetta genetta	LC	5
Meles meles	LC	5
Pipistrellus pipistrellus	LC	5
Mustela putorius	DD	4
Microtus cabrerae	VU	3
Microtus duodecimcostatus	LC	3
Herpestes ichneumon	LC	2
Rattus norvegicus	LC	2
Talpa occidentalis	LC	2
Martes foina	LC	1
Rhinolophus ferrumequinum	VU	1

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Studies of Fish Passage Through Culverts in Montana

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Abstract: Road crossings that utilize culverts on fish-bearing streams can impede fish passage in several ways. The most common impediments include large outlet drops, insufficient water depths, and excessive velocity. High velocities can act as passage barriers, especially for fish that migrate during high-flow periods of the year such as westslope cutthroat trout and Yellowstone cutthroat trout. We performed a basin-wide culvert study to investigate fish passage across a large basin in Montana. A second study (in progress) focused on the velocity component of fish passage.

Our basin-wide culvert study was performed in the Clearwater River drainage near Seeley Lake, Montana. Fish species included westslope cutthroat trout, brook trout, brown trout, and bull trout. We studied 46 culverts over a range of culvert types and characteristics. We used a tiered approach to assess fish passage: analysis with FishXing, upstream and downstream population sampling, and direct-passage assessment. Results from the FishXing model from analysis of all 46 culverts indicate 76 to 85 percent are barriers at low flow, depending on the selection of minimum water depth. The upstream and downstream population-sampling analysis of a subset of 21 culverts indicated little or no significant difference in population characteristics (upstream characteristics compared to downstream characteristics). The direct-passage analysis of a subset of 12 culverts indicated no passage restriction at four culverts, some degree of passage restriction at seven culverts, and no passage at one. Our direct-passage study results may suggest more passage is occurring at low flows than the other methods suggest.

The basin-wide study did not address passage issues during high flows. We have embarked on a second study (in progress) to assess this high flow passage with field sites at Mulherin creek, located near the north boundary of Yellowstone National Park. The site is an important spawning tributary for Yellowstone cutthroat trout and rainbow trout. We are using a combination of field studies and computational fluid dynamic (CFD) modeling to assess high-velocity fish passage over a range of flows. Field studies include fish monitoring and detailed velocity mapping using a traditional 1-D current meter and a 3-D acoustic Doppler velocimeter (ADV). We have chosen to monitor direct assessment of fish passage using Passive Integrated Transponder (PIT) tags in individual fish and fixed antennas placed at five culverts and throughout the system. Preliminary results indicate that inlet-velocity patterns can persist through the culvert barrel. Fish movement observations show use of the low-velocity region for passage even at high flows (average barrel velocities at the outlet up to 2.2 m/s) with passage restricted at times, even though areas of lower velocities exist.

Introduction

Over the years, much research has been done to evaluate the effect that culverts in fish-bearing streams may have on fish populations. The primary physical factors that impede fish passage are fairly well documented and include outlet drop, excessive velocity, and insufficient water depth (Baker and Votapka 1990; Votapka 1991; Fitch 1995; Stein and Tillinger 1996). Some important biological considerations include fish species, size of fish, condition of fish, life history requirements, and movement timing (MacPhee and Watts 1976; Baker and Votapka 1990; Bell 1991; Stein and Tillinger 1996). More recent research has shown the importance of providing passage for not only adult salmonids, but also juvenile salmonids. Kahler and Quinn (1998) performed a literature review to assess movement of juvenile and adult salmonids and concluded that movement was common among all species, age classes, and seasons.

Determining the barrier status of a culvert can pose some interesting challenges because of the dynamic nature of the setting, both from a physical and biological standpoint. Past research methods can be split into direct and indirect methods of assessing fish passage at culverts. Direct methods typically use some sort of fish-marking technique followed by observations of fish movements through culverts over a period of time and comparison to hydraulic conditions such as water velocity and depth (Belford and Gould 1989; Fitch 1995; Warren and Pardew 1998). Indirect methods include using comparisons of upstream and downstream fish population characteristics and/or hydraulic modeling (Riley 2003).

This paper focuses primarily on a basin-wide culvert study designed to assess fish passage across a large basin in Montana. In the basin-wide study, we used a tiered approach with three separate methods: 1-D hydraulic modeling, upstream and downstream fish population sampling and habitat assessment; and direct passage using a mark-recapture technique. Information about the study area, methods, and results are presented in the body of this paper. An introduction to the companion study in progress is included in Appendix A. The companion study is designed to investigate the velocity component of fish passage, with specific goals of comparing fish movement timing to detailed culvert-hydraulic conditions.

Study Area

The Clearwater River flows in a southerly direction to its confluence with the Blackfoot River, with the Swan Mountains to the east and the Mission Mountains to the west. Streams in the basin that have culverts are generally first or second order, medium to high gradient, with primarily cobble substrate. No culvert crossings are located on the main stem of the Clearwater River; however, there are two man-made barriers on the main stem above Seeley Lake and a third in the lower portion of the drainage. Figure 1 shows the location of the study drainage within Montana and the study culverts.

Only the portion of the Clearwater River drainage upstream of and flowing into Seeley Lake was included in this study. The studied drainage area is 370 km^2. The drainage is heavily forested with a combination of coniferous and deciduous trees. Past and present land-use activities have resulted in a fairly complex network of roads with culvert crossings primarily on the smaller tributaries to the Clearwater River. Land ownership is a mixture of national forest land, state land, and private land.

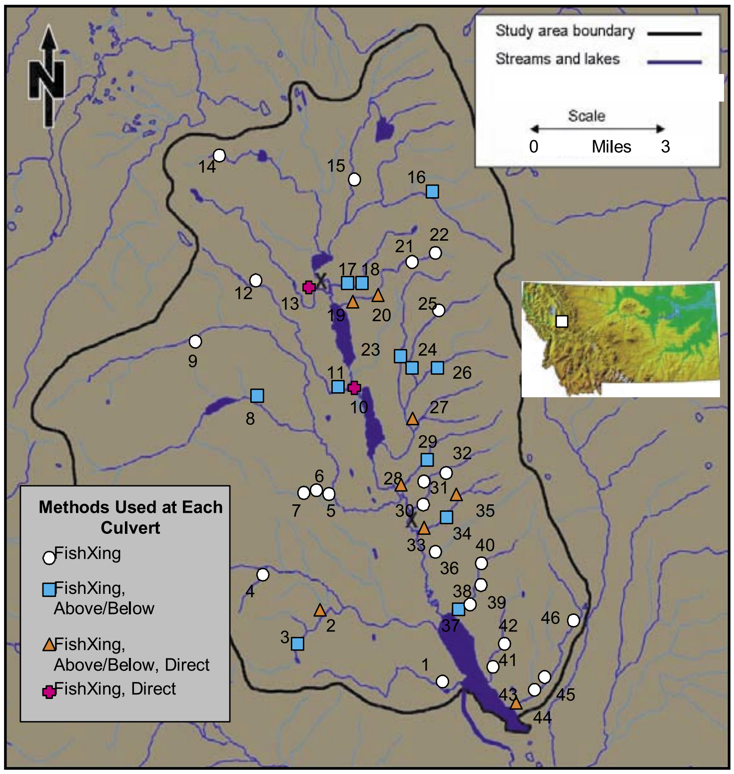

Figure 1. Map of Clearwater River drainage with locations of study culverts and methods used at each.

We specifically included all the trout detected in the basin in the study: westslope cutthroat trout (*Oncorhynchus clarki lewisi*), bull trout (*Salvelinus confluentus*), brook trout (*Salvelinus fontinalis*), and brown trout (*Salmo trutta*). Westslope cutthroat trout are a species of special concern in Montana (Carlson 2003) and bull trout are listed as endangered under the Endangered Species Act (Federal Register, June 10, 1998). Other species that we encountered during the study include slimy sculpin (*Cottus cognatus*) and brook stickleback (*Culaea inconstans*).

Methods

We used the FishXing model to assess passage concerns at all 46 crossings. At a subset of 21 culverts, we compared samples of upstream and downstream fish populations and riparian habitat characteristics. At another subset of 12 culverts, we used a mark-recapture-based protocol to directly observe fish passage through the culverts, as compared to passage through a control reach of a natural channel.

First, we identified and visited all culvert sites within the drainage and reduced the total number of study crossings to 46 by eliminating crossings we felt had little to no fisheries value based on the following criteria: (1) dry or intermittent as observed at the site; (2) discharge of less than 60 L/min; (3) sustained stream slope greater than 15 percent as measured on a 1:24,000 scale topographic map; or (4) no fish presence as determined by electrofishing.

Field data were collected from June through October 2002 and from July to October 2003. Field data collected at all 46 sites followed the protocol developed for passage assessment using the FishXing model (Clarkin et al. 2003) with some additional data collection. We surveyed the geometry of the culvert and the stream channel both upstream and downstream of the culvert using a total station. Key features surveyed include culvert slope, tailwater cross section, outlet drop, maximum pool depth, depth at jump location (estimated as the depth at 6 inches downstream of the culvert outlet invert), and upstream and downstream gradient. We collected substrate samples to determine the roughness characteristics of the channel and classified substrate into size ranges from silt to boulder, with identification of the dominant particle size.

FishXing is public-domain software that utilizes 1-D hydraulic calculations to estimate water depth and velocities in culverts and compares known fish swimming abilities to the modeled hydraulics. The software then assigns a passage status to the culvert. If a culvert is identified as a barrier, a code identifying the type of barrier is included as part of the output. Potential barrier codes include: excessive velocity (water velocity in the culvert exceeds swimming ability of the fish), insufficient depth (water depth in culvert less than designated minimum water depth), and leap (excessive leap height at outlet) (FishXing 1999). We analyzed all culvert sites with FishXing and separated the analysis into two categories: juvenile trout (rainbow trout with a length of 60 mm) and adult trout (cutthroat trout with a length of 150 mm). The size of the analysis fish was based on fish data collected during the upstream and downstream fish population-sampling events. The analysis discharge was measured at each site as part of the physical data collection. Discharge was measured in the stream channel near the culvert site using a Pygmy flow meter following a modified version of the USGS 0.6 depth method. The modeled discharge is comparable to base flow. We did assess higher flows at each crossing with FishXing; however, we didn't include them in this paper because the other methods were performed at base flow only.

We sampled fish upstream and downstream of 21 culverts to assess the degree to which culverts may have influenced fish species abundance, size structure (median length), and presence. Single-pass electrofishing in an upstream direction with a Smith-Root Model 15-D backpack electrofisher was used. Two samples were collected at each crossing: approximately 100 meters directly upstream and downstream of the culvert. All species captured were anesthetized, identified by species, and measured to the fork length.

The relative abundance of individual species was compared between upstream and downstream samples. A substantial difference in relative abundance indicates a twofold difference in the number of fish, with a minimum of five fish in the smaller sample. If one sample had less than five fish, the sample size was considered too small. Differences in median fish size between the upstream and downstream samples were assessed using a two-tailed Mann-Whitney test. We also pooled all trout by species upstream and downstream of the culvert sites and assessed the pooled differences using the same statistical method. Statistical results were significant if the p-value was ≤ 0.05.

Habitat characteristics such as wetted width, average depth, and maximum depth were measured in the upstream and downstream reaches following R1/R4 protocol (Overton et al. 1997) to evaluate the possibility that differences in relative abundance or median fish size might be attributable to differences in habitat characteristics. Mann-Whitney tests were used to assess differences in upstream and downstream habitat variables.

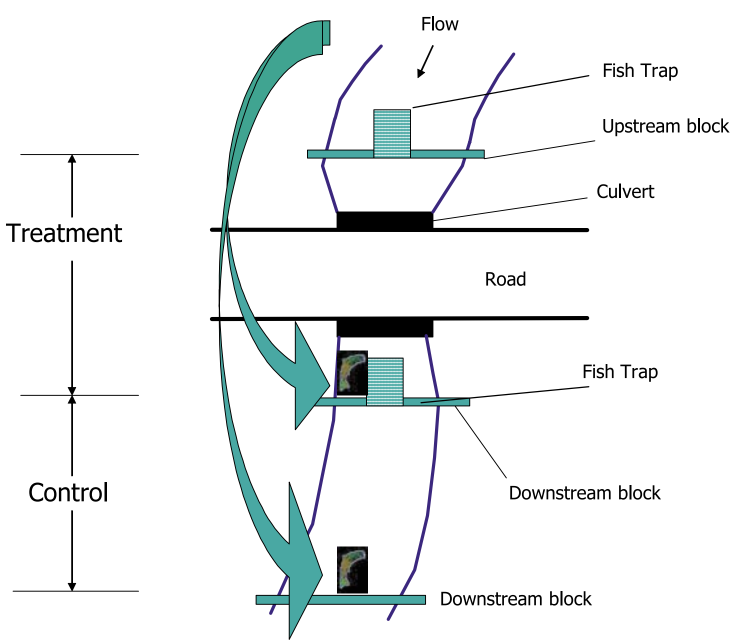

Figure 2. Diagram showing the experimental design for the direct-passage studies.

We used a mark-recapture scheme to directly assess fish passage at 12 culverts (figure 2). We divided the site into a treatment reach that included the culvert and a control reach in the natural channel. The area of the treatment reach, not including the culvert, was measured and used to determine the area for the control. The control reach was always located downstream of the treatment reach. Prior to initiating the experiment, we removed fish from both reaches by electrofishing. We then collected a sample of 40 to 50 fish well upstream of the experimental reach and separated them into two equal groups based on size and species. We placed wire mesh in the stream to block the experimental reaches at the upstream and downstream ends with a fish trap placed at the upstream end of each reach. We clipped the left pelvic fin of all control fish and the right pelvic fin of all treatment fish for re-identification. The fish were set free in the stream at the bottom of each reach. During each successive day for three days following the release, we collected discharge, inlet and outlet depths, and inlet and outlet velocities and recorded the number of marked and unmarked fish captured in each trap.

Several comparisons were made to analyze the direct-passage data. Figure 3 shows how we calculated the passage rate and passage indicator. We then used both simple and multiple linear regression to evaluate the effect of physical characteristics including culvert slope, outlet drop, culvert length, water depth, change in slope (between upstream channel slope and culvert slope), and constriction ratio on the passage indicator. The constriction ratio was calculated as the ratio of the culvert width to the average bankfull width. Mann-Whitney tests were used to assess whether the recaptured fish in the treatment had similar lengths to the recaptured fish in the control.

$$\text{Passage Rate} = \frac{\text{\# of fish recaptured}}{\text{\# of fish marked}} = \text{Pc or Pt} \qquad \text{Passage Indicator} = \frac{\text{Pt - Pc}}{\text{Pt + Pc}} = \text{PI}$$

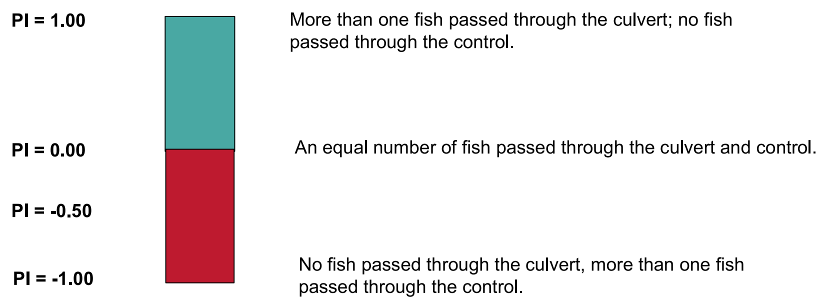

Figure 3. Diagram showing how the passage rate and passage indicator were calculated for each direct-passage study.

Results

Physical characteristics of the 46 culvert sites are listed in table 1. Culvert slopes ranged from an adverse slope of -0.9 to 16.6 percent with a mean of 4.3 percent. Outlet drops ranged from 0 cm to 64.3 cm with a mean of 11.6 cm. Culvert lengths ranged from 3.8 m to 28.6 m with a mean of 12.3 m. Constriction ratios ranged from 0.34 to 1.33 with a mean of 0.75. The study streams average bankfull widths ranged from 0.91 m to 4.54 m with a mean of 2 m.

FishXing identified 35 of the 46 culvert sites as barriers at low flow for adult fish. Figure 4 summarizes the type of barrier designation (insufficient depth, excessive leap, or water velocity). All 35 of the barrier culverts were identified as having insufficient water depth. It should be noted that some culverts were designated as having multiple types of barriers, insufficient depth, and excessive leap for instance. Six of the 11 culverts that were not identified as water-depth barriers simulate natural channel conditions. Therefore, these sites were considered passable at low flow. These sites were analyzed with FishXing by changing the settings to indicate the culvert was embedded and increasing the roughness to a value equivalent to the substrate size in the culvert. FishXing protocol recommends caution when analyzing culverts with substrate bottoms as the physics of 1-D hydraulics cannot account for irregular flow patterns that will exist as water moves over the irregular substrate surface. These irregularities provide reduced velocities and micro-eddies that the fish, especially juvenile fish, can utilize to pass. It is interesting to note that FishXing identified five of the six pipes with natural channel beds as barriers to adults because of insufficient water depth.

Table 1. Physical characteristics of all 46 culvert sites studied

Site	Continuous Substrate	Length (m)	Slope (%)	Outlet Drop Height (cm)	Constriction Ratio
1	N	9.4	1.5	12.2	1.15
2	N	10.7	3.4	6.1	0.55
3	N	10.9	2.0	0.0	1.33
4	N	12.6	7.1	6.1	0.56
5	N	12.5	3.3	53.3	0.37
6	N	16.9	16.6	2.1	0.34
7	N	9.9	10.6	14.3	0.56
8	N	9.4	2.1	3.0	0.86
9	N	11.2	6.0	36.6	0.59
10	N	12.4	0.9	9.1	0.70
11	N	10.5	1.3	0.0	0.48
12	N	8.6	2.9	49.4	0.66
13	N	10.9	3.9	15.2	0.45
14	N	11.2	2.1	30.5	0.44
15	Y	12.5	5.5	0.0	1.16
16	Y	12.1	0.8	0.0	0.89
17	N	26.4	1.3	0.0	1.11
18	N	9.3	4.9	0.0	0.92
19	N	28.6	2.4	0.0	0.89
20	N	11.8	4.4	0.0	1.20
21	N	7.6	1.1	18.3	0.62
22	N	9.5	5.6	5.5	0.66
23	Y	11.8	1.6	0.0	0.84
24	N	13.0	4.8	0.0	0.71
25	N	8.7	6.7	3.0	0.53
26	N	12.1	9.2	6.1	0.67
27	N	11.8	7.6	24.4	0.52
28	N	12.7	4.9	0.0	1.00
29	N	13.7	9.9	27.4	0.70
30	N	10.0	3.2	61.0	1.18
31	N	9.9	1.5	18.9	0.78
32	N	6.2	1.0	0.0	0.70
33	N	12.4	7.4	64.3	0.48
34	N	14.3	10.6	30.8	0.52
35	N	13.0	5.0	21.3	0.78
36	N	11.0	3.2	0.0	1.17
37	Y	8.1	-0.3	0.0	0.96
38	Y	14.6	5.7	0.0	0.86
39	Y	21.3	1.3	0.0	0.67
40	N	12.4	12.2	4.6	0.64
41	N	22.1	2.4	0.0	1.08
42	N	12.4	6.1	4.9	1.28
43	N	9.8	0.8	3.7	0.62
44	N	13.8	2.7	3.7	0.67
45	N	3.7	1.1	0.0	0.36
46	N	11.1	-0.9	0.0	0.77

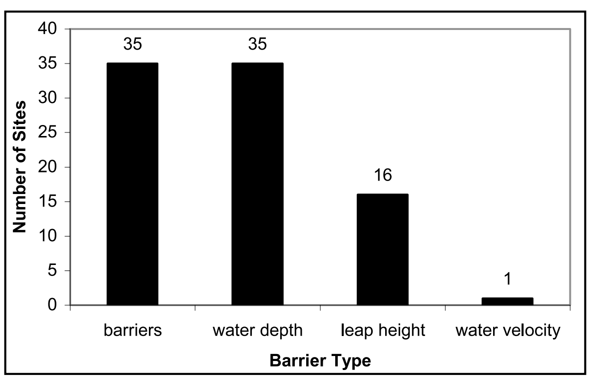

Figure 4. Barrier determinations for low flow adult fish analyses by FishXing. We used a minimum water depth of 3 cm for low flow based on size of adult fish, observed water depths in natural channels and conditions fish moved through without impedance as observed during direct passage experiments.

FishXing results indicate 35 of 46 culvert sites were barriers at low flow for juvenile fish. Figure 5 summarizes the barrier designation for these culverts. More velocity barriers were designated for juvenile fish compared to adult fish because smaller fish have weaker swimming abilities. FishXing identified two of the six pipes having a natural channel bed as barriers because of insufficient water depth. As before, we considered these crossings to be passable at low flow because they had met the natural channel-simulation criteria.

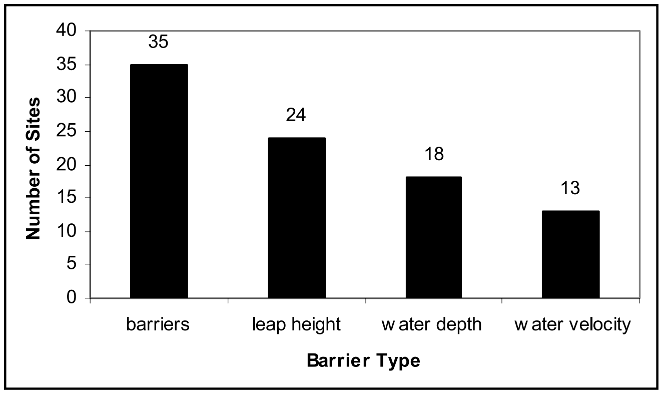

Figure 5. Bar chart showing the barrier determination for low flow, juvenile analyses by FishXing.

While sampling fish upstream and downstream of 21 culverts, we cataloged a total of 989 fish. Figure 6 presents the number of fish by species sampled downstream of all culverts. Figure 7 presents the number of fish by species sampled upstream of the culverts. Appendix B includes a table with numbers of fish by species captured upstream and downstream of the culverts. Brook trout ranged in length from 34 mm to 176 mm with a median length of 83 mm. Westslope cutthroat trout ranged in length from 26 mm to 203 mm with a median length of 89 mm. Bull trout ranged in length from 81 mm to 218 mm with a median length of 108 mm. Brown trout ranged in length from 110 mm to 142 mm with a median length of 127 mm.

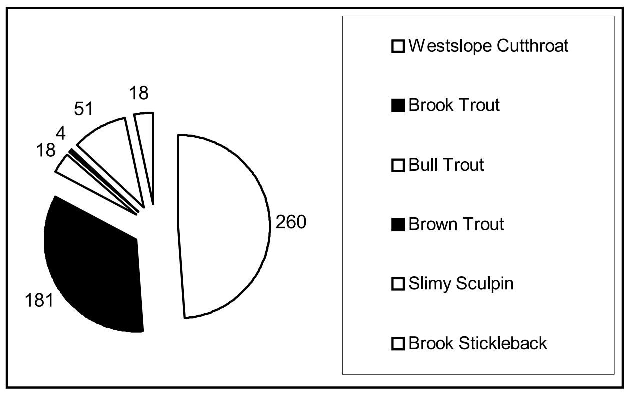

Figure 6. Number of fish by species collected downstream of culvert sites.

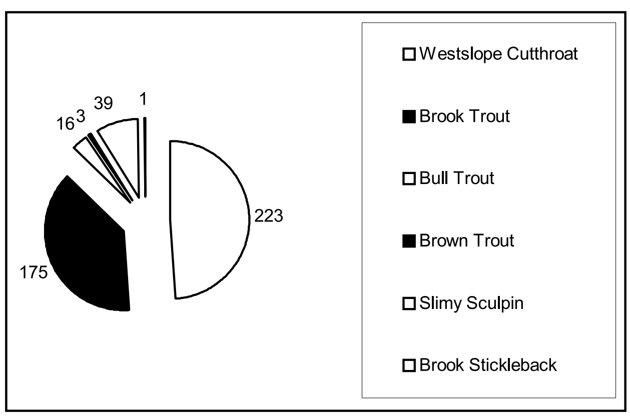

Figure 7. Number of fish by species collected upstream of culvert sites.

We compared the number and size of fish cataloged above the culvert to fish cataloged below the culvert at each site by trout species and for all trout combined. While there were occasional differences in count or size by species, there was no evidence to suggest that any species should be considered or examined separately from trout in general with respect to count or size in the upstream/downstream sampling. When considering all trout, there was only one site that had twice as many or more trout downstream of the culvert than upstream. On the average, there were 1.17 times as many trout detected downstream of the culvert than upstream. Two sites had significantly larger fish on one side of the culvert than the other. One site had larger fish downstream of the culvert, one site had larger fish upstream of the culvert, and the remaining 19 sites had similar-sized fish on either side of the culvert (Mann-Whitney, 95 percent confidence interval). Three of the 21 sites had different habitat designation on each side of the culvert.

The results of the direct passage trials were analyzed by species and for all trout at each culvert. Again, there was no evidence to maintain species differentiation, so the results we present here are for all trout combined. Overall, 172 of 283 fish were recaptured in the control (61 percent) and 101 of 283 fish were recaptured in the treatment reaches (36 percent). The average size of all fish recaptured in the control was 103 mm, compared to an average size of all fish recaptured in the treatment of 107 mm.

The direct-passage results are summarized in figures 8 and 9. Four of the sites had PI values greater than 0.00, indicating more fish moved through the treatment (culvert) than control (natural channel). Seven sites had PI values between 0.00 and -0.85, indicating more fish moved through the control than the treatment, but that fish did move through both sections, indicating that the culvert was not a total barrier to fish passage. One site had a PI value of -1.00, indicating no fish moved through the treatment and that fish did move through the control.

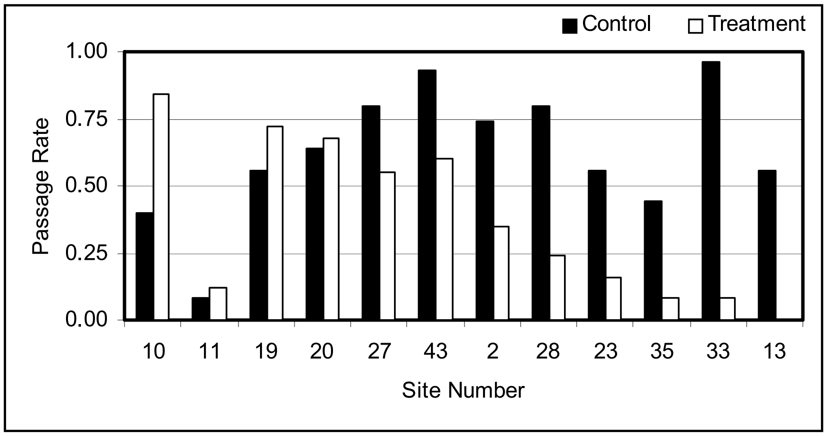

Figure 8. Passage rate for control and treatment by site number.

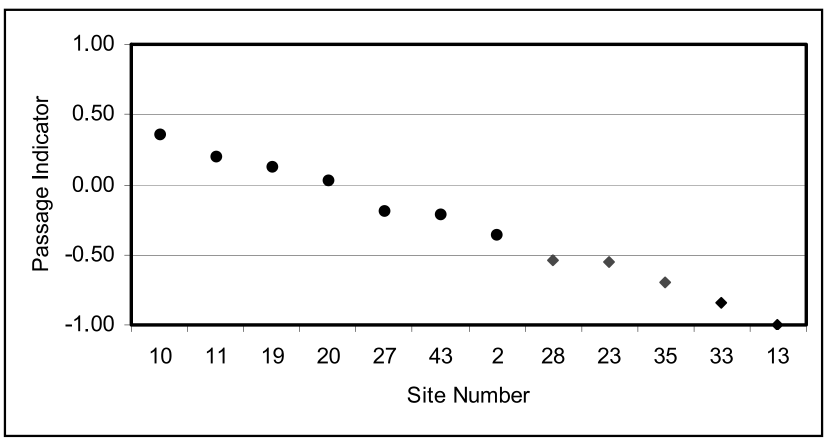

Figure 9. Passage indicator by site number.

Both simple linear regression and multiple linear regression were used to evaluate the effect of physical characteristics (slope, outlet drop, culvert length, water depth, change in slope, and constriction ratio) on the passage indicator. There were no significant relationships found at the 95 percent confidence level. The most significant relationship was found between the passage indicator and outlet height ($p = 0.095$). Figure 10 shows a plot of the passage indicator and outlet-drop height with the regression line ($R^2 = 0.2538$).

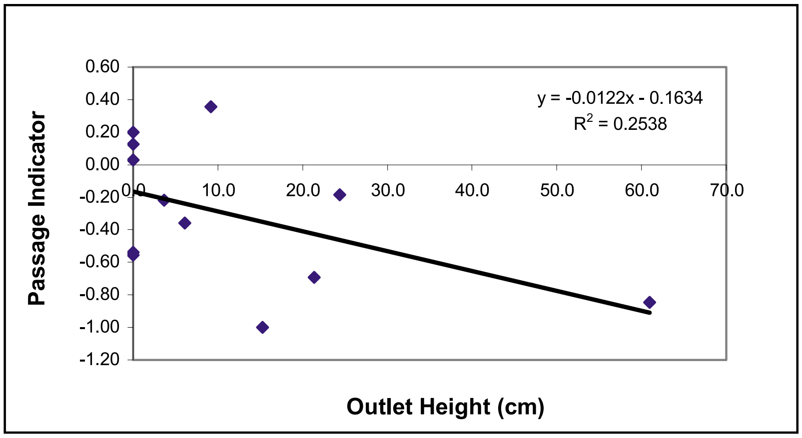

Figure 10. Relationship between passage indicator and outlet drop for all 12 direct passage sites ($p = 0.095$).

Discussion

Table 2 presents a comparison of the FishXing results and the direct passage results. Some physical data from each culvert is also included for comparison. One of the more interesting findings of this study is that, depending on the method used, different conclusions regarding the barrier status of a culvert may be reached.

Table 2. Comparison of FishXing results, direct passage results, and physical data. B = barrier, P = passable, l = excessive leap at outlet; d = insufficient water depth; v = water velocity exceeds swimming ability of fish; eb = water velocity in culvert causes fish to be exhausted at burst speed

	FishXing Results		Direct Passage Results	Physical Data				
Site Identification	Adult	Juvenile	Passage Indicator	Slope (%)	Outlet Drop (cm)	Substrate (yes/no)	Length (m)	Constriction Ratio
2	B(d)	B(l)	-0.36	3.4	6.1	no	10.7	0.55
10	B(d)	B(l)	0.35	0.9	9.1	no	12.4	0.70
11	B(d)	P	0.20	1.3	0.0	no	10.5	0.48
13	B(l,d,eb)	B(l,v)	-1.00	3.9	15.2	no	10.9	0.45
19	B(d)	B(d)	0.13	2.4	0.0	no	28.6	0.89
20	B(d)	B(v)	0.03	4.4	0.0	no	11.8	1.20
23	P	P	-0.56	1.6	0.0	yes	11.8	0.84
27	B(l,d)	B(l)	-0.19	7.6	24.4	no	11.8	0.52
28	B(d)	B(d)	-0.54	4.9	0.0	no	12.7	1.00
33	B(l,d)	B(l,d)	-0.85	7.4	64.3	no	12.4	0.48
35	B(l,d)	B(l,v)	-0.69	5	21.3	no	13.0	0.78
43	B(d)	B(l,d,eb)	-0.22	0.8	3.7	no	9.8	0.62

For example, site 10 had a passage indicator of 0.35, but was identified by FishXing as a barrier to both adult and juvenile fish. On the other hand, site 23 had a passage indicator of -0.56, but was identified as passable to both adult and juvenile fish by FishXing. The direct passage results do indicate that fish moved through culverts at low flow; however, these results also show that culverts are limiting the movement in some pipes (seven of 12 studies) and (in one case) the culvert may be a total barrier (site 13), though further study at higher flows would need to be done to gain confidence in identifying this culvert as a total barrier.

Varying the minimum water depth from 3 cm to 9 cm did not have a large effect on the number of barriers identified for adult fish by FishXing. With the minimum depth set at 9 cm, 39 of 46 culverts were deemed a barrier, compared to using a minimum depth of 3 cm, which resulted in 35 of 46 culverts identified as barriers. An accurate representation of the setting (both from a physical and biological standpoint) of the culvert crossing is very important when utilizing an indirect approach such as FishXing. For example, utilizing a minimum water depth of 3 cm may seem ridiculous at first glance. When you consider that many streams had depths in riffles of only 3 cm, the size of the adult fish in the study basin (median length for adult cutthroat was 87 mm), and the direct passage studies show adult fish passing unimpeded through 3 cm of water the use of this shallow of a minimum depth may be appropriate for the setting.

A study recently completed in Alaska designed to assess a culvert barrier-assessment protocol that includes use of the FishXing software identified the need to represent the hydraulics and hydrology of the setting accurately; otherwise, a conservative bias can be added to the passage status of a culvert (Karle 2005). As an example from this study, the researcher found that accurate calibration of the FishXing software using field-measured water depths corresponding to a measured flow rate improved the accuracy of the model. The uncalibrated model identified the culvert as a barrier for the entire period of analysis, which covered 1510 days. The calibrated model reduced the number of days the culvert was deemed a barrier to 173 days.

The data from the upstream and downstream sampling does not provide much information with regards to the barrier status of the culverts in this study. In almost all cases, the fish count, size, and habitat indicators were similar on either side of the culvert. This does not mean the culvert is passable or impassable as these fish could have been above the crossing prior to installation of the culvert and there may be sufficient habitat to sustain a population above the crossing, or the culverts may be partial barriers that allow fish movement at some flows. Other studies have found more success using comparison of fish characteristics upstream and downstream of culverts as a means of assessing culvert barriers (Riley 2003). In the case of the Riley studies, many of the fish were anadromous salmonids and the life-history requirements of these fish are very different than those in the Clearwater drainage. The different life-history requirements of anadromous salmonids, such as the relatively small amount of time they spend in freshwater compared to resident species, may account for the success in using this method to assess passage. The upstream/downstream population characteristics method may have proven more useful in our study for assessing barrier status if it were performed during periods of the year when fish were migrating to spawning locations.

This study is limited by the fact that no field tests were performed during high-flow periods of the year. The primary reason this was not done is the difficulty presented by collecting representative samples of fish during the high water periods of the year in this area, and to a lesser extent the difficulty in accessing some sites during the runoff season. The highest flows of the year in this drainage are typically related to spring snowmelt runoff which occurs in May or June. The companion study discussed in Appendix A is designed to investigate fish-passage issues at a range of flows, including spring runoff.

Conclusions

We found that some culverts limited passage in the drainage even during low flow and, in at least one case, the culvert seemed to act as a low-flow total barrier. However, we also found that more passage is occurring than might have been previously thought. FishXing results compared to the direct passage results indicate that the program can be a conservative estimator of fish passage at culverts during low flow. This finding points to the need for better representation of the hydraulics in the culvert, with emphasis on the distribution of velocities and linking the stream to the culvert. It also points to the need for more study of fish swimming abilities, especially with regards to leaping behavior. For example, fish may have utilized the upwelling currents in the plunge pool to surmount fairly high leap heights, a behavior not unlike that observed by Stuart (1962).

In general, the upstream and downstream population sampling was not very useful for identifying the barrier status of a culvert. It would be interesting to run several upstream and downstream studies at the same culvert over a range of flows to investigate temporal patterns in the abundance, size structure, and fish compositions.

Care must be taken when applying only one technique to assess the barrier status of a culvert. If FishXing identifies a culvert as passable, we found it to likely be passable, so no further study is warranted. If FishXing identifies a culvert as a barrier, further study utilizing a more-intensive field investigation may be warranted to refine the barrier status.

As a final point, it is very important to accurately represent the setting, both physically and biologically, when analyzing culverts with any method.

Acknowledgments: Many people have supported these culvert studies. We'd like to give special thanks to Ladd Knotek, Pat Byorth, and Scott Opitz of Montana Fish, Wildlife, and Parks; Shane Hendrickson of the Lolo National Forest; the Plum Creek Timber Company; the Royal Teton Ranch; Mark Story of the Gallatin National Forest; Al Zale; Michelle Livesey; Lisa Andes; Jeannette Romig; Steve Searles; and Darren Baune. In addition, studies in progress are being performed by three graduate students at MSU: Andy Solcz, Jesse Patton (Mulherin Creek), and Leo Rosenthal (Warm Water Passage).

Biographical Sketch: Matt Blank received a B.S. in geological engineering from the University of Wisconsin-Madison in 1994 and a M.S. in civil engineering from Montana State University in 2002. He is presently a Ph.D. candidate in civil engineering at Montana State University specializing in hydraulics, hydrology, and fish passage. After receiving his B.S., he spent several years doing environmental consulting work based out of Anchorage, Alaska. He specialized in contaminated site assessment and remediation, groundwater-quality studies, and site characterization. His current research interests involve fish passage, hydraulic modeling, and analysis of aquatic impacts of roads and road-maintenance activities.

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Appendix A. Studies in Progress

Study location

We selected Mulherin creek located near Gardiner, Montana as the study drainage for the velocity study (figure 1A). Mulherin creek is a tributary of the Yellowstone river. It is a fairly high gradient stream, with an average gradient from the headwaters to the mouth of 11.6 percent, and gradients of 2 to 5 percent through the study reach. Large substrate, primarily cobble and boulder, dominates the drainage, with some bedrock control in the vicinity of the study reach. The stream has base flows around 0.3 cms with a flow of 2.7 cms as measured in June 1983 (USGS 1986). Average bank full width is approximately 6 m. The stream has low sinuosity through most of the study reach.

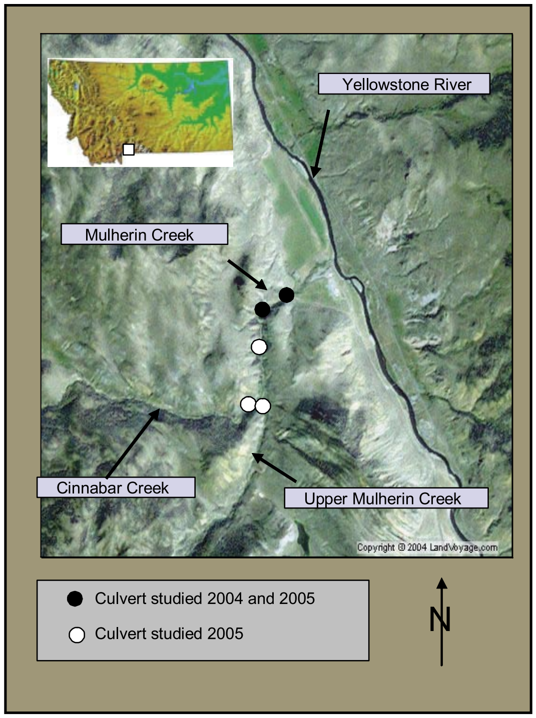

Figure 1A. Map of Mulherin Creek drainage with locations of study culverts.

There are a series of five culverts in the lower drainage, with three on the main stem of the creek and two directly above the confluence of Upper Mulherin Creek and Cinnabar Creek. These culverts present a nice range of physical characteristics and passage conditions. Table 1A summarizes key physical information for the culverts. Only culvert 1 and 2 were studied in 2004, with the other three culverts added to the study in 2005.

Mulherin creek has resident and migratory trout species, including rainbow trout (*Oncorhynchus mykiss*), Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*), and brown trout (*Salmo trutta*) . Yellowstone cutthroat trout are a species of special concern in Montana (Carlson 2003). Mulherin creek is a major spawning tributary for trout living in the Yellowstone river.

Table 1A. Summary of physical characteristics of culverts in the velocity study

Culvert ID	Shape	Width (m)	Height (m)	Diameter (m)	Length (m)	Internal Structure	Slope (%)	Outlet Drop (cm)	Constriction Ratio
Culvert 1	box	3.7	2.0	-	11.4	none	2.0	48.8	0.57
Culvert 2	box	3.7	1.8	-	9.6	concrete baffles	0.8	47.9	0.57
Culvert 3	box	3.7	1.8	-	9.7	concrete baffles with substrate	1	18.3	0.56
Culvert 4	circular	-	-	2.1	9.1	none	1.1	46..6	0.44
Culvert 5	circular	-	-	1.8 to 2.1 (pipe changes diameter)	10.9	none.	6.6	54.9	0.44

Figure 2A. The outlet of culvert 1, a box pipe (l), and the outlet of culvert 4 (r).

Methods

Stage-discharge relationships for Lower Mulherin Creek, Upper Mulherin Creek, and Cinnabar Creek were developed using stilling wells with Trutrack data recorders. A minimum of 10 discharge measurements following the USGS 0.6 method near each gauge location were collected at various points in the hydrograph for establishment of the stage-discharge relationship. Power regression was used to fit an equation of flow as a function of stage. Water temperature was collected using the TruTrack data recorder.

Inlet and outlet depths in the culverts were measured at various flows. Depths were collected from a series of staff gauges installed in all four corners of culvert 1 and culvert 2. Depths were measured using a graduated rod at culverts 3, 4, and 5.

Velocity data were collected as sets in culvert 1 and culvert 2 with the aid of a trolley system. Figure 3A shows the Acoustic Doppler Velocimeter (ADV) collecting data in culvert 2. The trolley system allows for an absolute minimum of flow disturbance as the instrument is the only object to penetrate the flow field. These sets comprised combinations of inlet-velocity profiles and plan-view profiles. Velocity measurements were collected using both a pygmy current meter and an ADV. The pygmy current meter was set to collect average velocities at 30-second averaging periods. The ADV was set to sample at 25 Hz for a minimum of 1 minute. The ADV collects velocities in three directions: x, y, and z. The high frequency of the ADV allows for some estimation of point turbulence. The density of point-velocity measurements varied according to the dynamics of the flow in the culverts. During periods of fluctuating flow, as experienced on the rising and falling limbs of the spring runoff hydrograph, data sets were collected in less than 6 hours. Late in the summer, when flows were more stable, data sets were collected over a period of time that ranged up to two days. A typical inlet-velocity profile would include data collected at every 15-cm horizontal and 3-cm vertical. Plan-view velocity data sets were typically collected at a height of 6 cm above the culvert bed, with horizontal spacing of 15 cm and longitudinal spacing of 1.5 m.

Figure 3A. ADV harness in culvert 2 inlet region.

Idaho weirs with fish traps were used to collect fish. During 2004, alphanumeric visual implant (VI) tags were implanted in fish. Three sets of weirs and traps were used: one near the mouth of the stream, one below the culvert, and one above the culvert. Traps upstream of the initial marking location were used to recapture fish to assess their movement timing. Traps were checked daily at a minimum from early May to mid-July. This method was not very efficient for recapturing fish. Additional funding became available between 2004 and 2005; therefore, we switched the fish-monitoring method to PIT tagging with antennae.

During the 2005 field season, PIT tags were implanted in fish as they migrated from the Yellowstone river. An Idaho weir with a fish trap was used initially to capture the fish. Antennae readers were placed at each of the five culvert crossings, with a minimum of one antennae at the culvert outlet and a second antennae at the culvert inlet. This configuration will allow us to identify the exact time a fish attempted to pass a culvert, the number of attempts, the time it took to swim through the culvert, and the number of attempts to pass successfully. The movement-timing data will be compared to detailed velocity maps prepared from a combination of field-data collection and computer modeling.

Preliminary results from 2004

An inlet velocity profile collected with the ADV on August 8, 2004 at culvert 1 is shown in figure 4A. The figure shows the x-, y-, and z-components of velocity at points in a cross section located at the upstream inlet of culvert 1. Figure 4A also shows the turbulent kinetic energy (TKE) at that cross section. Figure 5A shows a plan view of velocity contours collected August 9, 2004 in culvert 1.

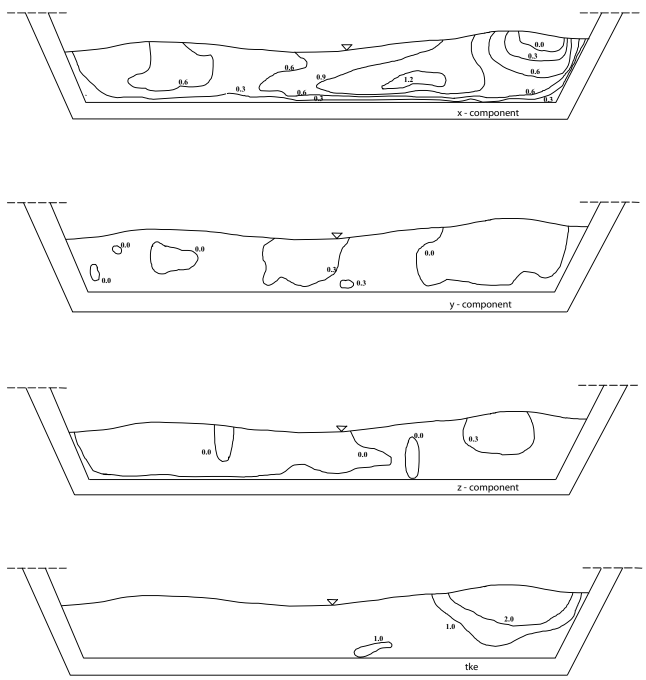

Figure 4A. x-, y-, and z-velocity components and tke contours at inlet of culvert 1 collected on August 8, 2004. Discharge during measurement averaged 0.85 m/s. Velocity contours are in m/s. Note: Only bottom portion of culvert is shown; dashed lines on sides are breaks.

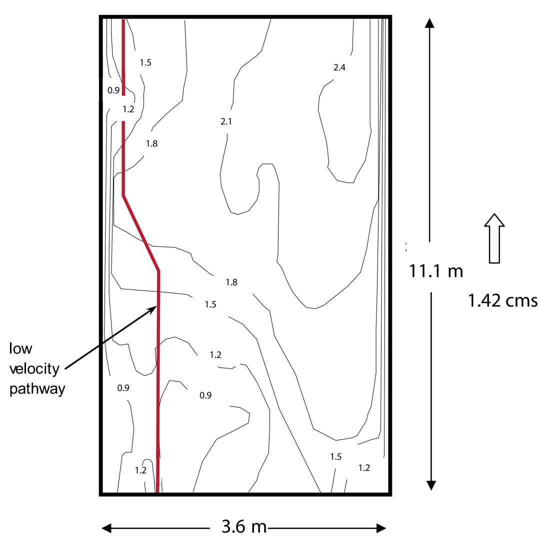

Figure 5A. August 9, 2004 plan view of x-velocity in culvert 1 collected with Pygmy meter. Velocity contours are in m/s. Measurements collected at 6 cm above the culvert bed.

The plan-view data show the development of a low-velocity region along the left wall of the culvert. This low-velocity region is created by the skew of the culvert with the natural stream alignment and roughness elements, consisting of boulders and a log just upstream of the culvert inlet. Fish-movement observations verified use of the low-velocity region for passage through this culvert even at high flows (average barrel velocities at the outlet up to 2.2 m/s), with passage restricted at times, even though areas of lower velocities exist.

A total of 390 fish were captured and cataloged during the course of the 2004 fish collection portion of the project. The predominant species collected was Yellowstone cutthroat trout, at a total of 339. Figure 6A compares the average daily flow observed during the period from May 1 to August 31, 2004 against the number of YCT captured. The fish were observed to enter in mass during the falling limb of the hydrograph when water temperatures consistently reached 12° C during the afternoon hours.

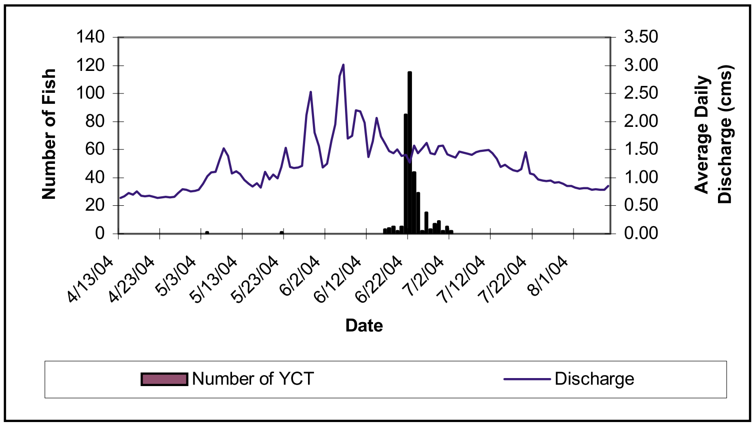

Figure 6A. Average daily flow compared to number of YCT captured, summer 2004.

A total of 91 leaping attempts were observed between June 16 and July 6, 2004 at culvert 1. Of these, 34 were successful in leaping into the culvert barrel and 18 were successful in passing through the culvert. Figure 7A presents a summary of the leaping observations. The fish behavior in the outlet pool was similar to observations made at waterfalls in England (Stuart 1962). Often, a fish was observed breaking the surface with just its head at the plunge of the free overfall, as if it were visually assessing the size of the leap. Leap attempts seemed to intensify over time. The first leap often was unsuccessful because the fish did not leap high enough to clear the free overfall. Subsequent leaps were higher and stronger. Once inside the culvert barrel, fish typically swam upstream and towards the left side of the culvert, using the lower velocity zones mentioned earlier.

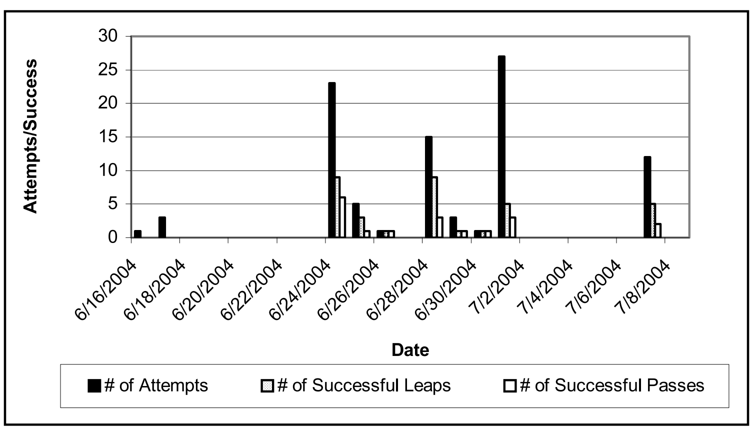

Figure 7A. Summary of leaping observations at culvert 1, 2004 field season.

Work in progress
A 3-D computer model is under development for simulating velocity patterns in the culverts studied at Mulherin Creek. The velocity maps shown above are used for model calibration and validation. The measured and modeled velocity data (1-D and 3-D) will be compared to fish movement data from the trapping and PIT tagging experiments. In addition, we plan to use the modeling to explore how far inlet-velocity patterns created by stream geometry will propagate through a culvert before they become muted by the culvert geometry.

Appendix B. Summary table of Upstream/Downstream Sampling in Clearwater drainage

Ct = cutthroat trout, Bk = brook trout, Bl = bull trout, Br = brown trout, Ss = slimy sculpin, Bs = brook stickleback

Site Number	Species	Number Downstream	Number Upstream
2	Ct	17	21
	Ss	30	7
	Bl	0	1
	Bk	0	2
3	Ct	6	9
8	Ct	1	0
	Bk	19	21
11	Ct	5	4
	Bk	36	38
16	Ct	1	2
	Bl	10	12
17	Ct	13	14
	Bk	12	10
	Bs	14	1
18	Ct	26	20
	Bk	12	5
19	Ct	27	26
	Bk	0	4
20	Ct	27	31
	Bk	0	1
23	Ct	3	0
	Bk	32	32
24	Ct	20	12
26	Ct	15	4
27	Ct	26	18
	Bk	6	4
28	Ct	9	9
	Bk	10	2
29	Ct	8	6
30	Ct	13	13
	Bl	7	1
	Bk	6	25
	Br	4	0
31	Ct	13	13
	Bl	1	2
	Bk	25	9
	Br	0	3
35	Ct	26	14
	Bk	11	5
37	Ct	4	7
43	Bk	12	17
	Ct	0	1
	Ss	21	32
	Bs	4	0

Thinking Outside the Marketplace: A Biologically Based Approach to Reducing Deer-Vehicle Collisions

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Abstract: Deer-vehicle collisions are a major concern throughout much of the World, accounting for human injury and death, damage to vehicles, and immeasurable waste of deer as a wildlife resource. Throughout the planning of our research project, we reviewed the primary literature to identify strategies with the most potential to reduce deer-vehicle collisions. Our review is available online as an annotated bibliography at: http://www.forestry.uga.edu/h/research/wildlife/devices/GADOTLiteratureReview.pdf.

Our findings indicated that most states in the U.S. have attempted to minimize deer-vehicle collisions through a variety of techniques. However, most studies have not empirically examined the efficacy of such techniques and many deer-deterrent devices were not designed with an understanding of the sensory capabilities of deer. Many previous studies also were isolated in scope or were inadequately replicated to afford statistical validity. Hence, the questions regarding efficacy of many deer deterrent devices remain largely unanswered and there still exists a need for research on mitigation strategies based on the sensory abilities of deer.

Until these research results become available, management efforts to minimize deer-vehicle collisions should focus on (1) implementing proper deer-herd management programs; (2) controlling roadside vegetation to minimize its attraction to deer and maximize visibility for motorists; (3) increasing motorist awareness of the danger associated with deer-vehicle collisions; (4) thoroughly monitoring deer-vehicle collision rates; and (5) encouraging communication and cooperation among governments, wildlife researchers, highway managers, motorists, and others involved in the issue of deer-vehicle collisions. We are conducting a research project designed to provide a more thorough understanding of the physiological processes driving white-tailed deer (*Odocoileus virginianus*) roadway behavior. Our ultimate goals are to use this knowledge to develop improved strategies designed to reduce deer-vehicle collisions.

Introduction and Critical Literature Review

Citations and a brief summary of all literature related to deer-vehicle collision reduction strategies that we reviewed are available online as an annotated bibliography at: http://www.forestry.uga.edu/h/research/wildlife/devices/GADOTLiteratureReview.pdf.

After our review of the literature, several prominent themes were evident: (1) Of the mitigation technologies previously studied, fencing of adequate height combined with the proper wildlife-crossing structures was the most effective method for reducing deer-vehicle collisions while providing a semi-permeable road/landscape interface. (2) Areas in need of improvement on an international level included: monitoring of deer-vehicle collision rates; scientifically rigorous evaluation of reduction strategies; and communication and cooperation among governments, wildlife researchers, highway managers, motorists, and others involved in the issue of deer-vehicle collisions.

To develop solutions aimed at reducing the occurrence of deer-vehicle collisions, we must enhance our understanding of the factors that result in hazardous encounters between deer and motorists. This requires a unique cooperative effort among disciplines to design, implement successfully, and refine mitigation techniques. Ultimately, we should possess a collection of strategies that were developed with consideration for the specific behavioral and physiological traits of deer and motorists alike.

Fences and wildlife-crossing structures

Roadside fencing was arguably the most-studied device implemented to reduce the incidence of deer-vehicle collisions. Most research indicated that fences were not an absolute barrier to deer and only served to reduce the number of animals entering the roadway. Conventional wire fencing must be at least 2.4 m high to limit the ability of deer to jump over it. Alternative low-in-height fence designs, such as solid-barrier fencing and non-traditional configurations of electric fencing, may provide a less-expensive fencing option to exclude deer from roadways and other areas. Construction of fencing is prohibitively expensive for many applications and regular maintenance is both costly and necessary for effectiveness. Gaps created by weather events, humans, and animals are quickly exploited by deer, and may create "hotspots" for deer-vehicle collisions when deer enter the roadway corridor and are unable to locate an escape point. Although fencing is not a complete barrier to deer, its presence may severely limit the natural movements and gene flow of deer populations and other wildlife. Fencing coupled with a variety of underpasses, overpasses, road-level crosswalks, one-way gates, and other strategies were tested to allow animals to cross roadways at controlled areas along fenced highways. Crossing structures were most successful when used where traditional migratory routes of mule deer, elk, and other migratory species intersect highways. An intimate understanding of the proper physical design, location, and integration into the habitat of crossing structures at a particular location is necessary to encourage utilization by the targeted wildlife species.

Wildlife-warning reflectors

Studies of wildlife-warning reflectors have been based on a diversity of testing methods and various levels of scientific validity, which ultimately have resulted in a limited understanding of reflector efficacy. Most reflector evaluations were based on counts of deer-vehicle collisions within test sections either pre- and post-installation of reflectors; when reflectors were covered versus uncovered; or within reflectorized sections as compared to adjacent control sections. Such methods failed to consider changes in deer densities, seasonal movements, or traffic patterns. Further, studies evaluating reflector effectiveness have been hampered by small sample sizes that limited statistical inferences on efficacy. Little is known about how deer react to reflector activation or if individual animals become habituated to the devices over time. Studies that used counts of deer carcasses along roadways to assess reflector effectiveness rarely used data quality controls such as video surveillance of test sections or driver surveys to account for deer-vehicle collisions that resulted in injured deer wandering from the roadside. Beyond differences in experimental design, comparison of results among different reflector studies was confounded further by the variety of reflector models tested and the distinct spectral properties of those devices.

Motorist-warning devices

Active and passive driver-warning devices were largely ineffective at reducing vehicle speeds and deer-vehicle collisions. Drivers ignored the common “deer crossing” sign, perhaps because of its overuse. Reduced vehicle speed was the most common method used for assessing warning-device effectiveness, even though this response was not the primary desired effect of warning drivers about site-specific dangers associated with wildlife crossings. No studies to date assessed driver alertness or other changes in driver behavior relative to warning devices through surveys directed at motorists actually exposed to such strategies. The effectiveness of recently developed active-warning systems, which only alert drivers when animals are present near the roadway, was unclear despite the high cost of such devices. Research indicating that non-redundant command-type messages impact driver behavior more than notification-style messages, which suggests that educating drivers during periods when they are most likely to encounter roadway dangers (i.e., during the fall and spring when deer-vehicle collisions are most common) may be most effective. Such techniques should be evaluated through direct communication with drivers.

Alternative mitigation strategies

No “alternative strategy” proved effective in reducing vehicle collisions with white-tailed deer. Intercept feeding for migratory mule deer (*Odocoileus hemionus*) proved marginally effective. However, successful adaptation of this technique to white-tailed deer in the eastern U.S. is unlikely. Other alternative approaches included variations of highway lighting and even placing imitations of deer with raised tails along roadways. Although not successful in reducing deer-vehicle collisions, such approaches provided evidence that deer-vehicle collision-reduction research may require a departure from typical study designs.

Time and location of deer-vehicle collisions

Most research indicated that peaks in deer-vehicle collision rates occurred late in the evening, at night, and in the early morning on a diurnal basis, and seasonally in the spring and fall. Modern analyses of deer-vehicle collision sites typically involved Global Information Systems (GIS) technology combined with regression modeling to identify areas likely to experience an elevated deer-vehicle collision rate. GIS modeling also was used to select areas for implementation of mitigation strategies based on landscape and economic feasibility, along with many other criteria.

Human dimensions associated with deer-vehicle collisions

The general public greatly values deer as a public resource. Surveys showed, however, that public opinion about deer management and deer-vehicle collision mitigation was affected significantly by human perception of personal risk and cost of implementation. Human-dimensions researchers suggested that professionals involved with wildlife management and roadway management should combine public risk-assessment data with biological data to make decisions about alternative management strategies.

Deer hearing

Information on white-tailed deer hearing abilities and their response to sound-frightening devices was limited. Previous research on deer hearing was preliminary in nature and investigations of the efficacy of sound deterrents employed along roadways were of poor experimental design. Several studies indicated that deer likely have hearing abilities similar to humans, thus suggesting that “ultrasonic” sound-deterrent devices would be ineffective for deer.

Deer vision

Electrophysical examination and behavioral research established that white-tailed deer are capable of limited color vision. During the day, deer likely can discriminate in the color range of blue to yellow-green, and at night in the blue to blue-green color range. Little else is known about how white-tailed deer visually perceive the world. Information on deer visual acuity and depth perception was lacking.

Conclusions and recommendations

Although many aspects of deer biology were well studied, we lack a basic understanding of the anatomy and physiology related to the hearing and visual capabilities of deer, information which may prove integral to the invention of economically effective strategies to minimize deer-vehicle collisions. Furthermore, our knowledge of deer behavior relative to roads is inadequate. Limiting our evaluations of deer-vehicle collision-mitigation devices to comparisons of deer road-kill statistics, for example, tells little about the complex interaction of deer and motorist behavioral traits that leads to collisions. When conducting future tests, we should make detailed observations of deer behavior relative to the implementation of mitigation techniques and, when possible, also document motorist awareness and response to the strategies. Such data may be used to improve strategies during the design and planning stages, rather than as a basis for critique after mitigation strategies are widely instituted or enter the manufacturing process.

At present, fences of the appropriate height may be the most effective method to exclude deer from roads. However, transportation and wildlife managers have an ethical responsibility to consider the potential ecological impacts of fencing on animal populations. Traditional fence designs may severely limit gene flow among populations separated by fenced roads. Fencing also may restrict wildlife access to resources critical to their survival. Crossing structures within fenced roadway corridors may provide partial habitat connectivity for some wildlife species and were most successful when used where traditional migratory routes of mule deer, elk (*Cervus elaphus*), and other migratory species intersected highways. However, white-tailed deer generally do not make mass seasonal migrations and are more likely to cross roads within their home ranges on a daily basis. Over a single kilometer, a roadway may be intersected many times by the home ranges of different white-tailed deer in an area. Previous reports rated wildlife-crossing structures as cost prohibitive for most applications. Considering the road-crossing behavior of white-tailed deer and the cost of wildlife-crossing structure installation, reliance on fencing to prevent deer-vehicle accidents likely is not a feasible option.

Currently there is no simple, low-cost solution for reducing the incidence of deer-vehicle collisions. Like fencing, other devices, including wildlife warning reflectors and motorist warning systems, were used where deer regularly cross roads. Only instituting collision-reduction techniques at select areas or "hotspots" will not guard against non-habitual deer road crossings, which typically occur during the peak seasons for deer-vehicle collisions (breeding and fawning). To guard against these collisions and to provide the most effective system for minimizing deer-vehicle collisions, we have three general conclusions and recommendations:

1. Vehicle-mounted deer warning systems may have the best potential for minimizing deer-vehicle collisions; however, to date none of these systems has been designed in accordance with the senses of deer. Therefore, future research and development of vehicle-mounted deer warning systems must be based on detailed knowledge of deer vision, hearing, and behavior.
2. Every year, motorist awareness of the danger of deer-vehicle collisions can decline over time. Therefore, agencies should develop and routinely implement education programs and/or highway warnings to enhance motorist awareness prior to and during the seasons of greatest danger for deer-vehicle collisions (breeding and fawning).
3. Deer overabundance can increase the potential for deer-vehicle collisions. Therefore, agencies and municipalities should implement proper deer-herd management programs designed to control deer abundance.

Our Research Project

Project objectives

Based on our review of the literature, we designed our research project to accomplish the following objectives:

1. Investigate the visual physiology of white-tailed deer to determine their visual acuity, their ability to discern patterns and shapes, and to gain new insight on deer color and night vision.
2. Investigate the auditory physiology of white-tailed deer to determine the range of their hearing capabilities.
3. Determine roadway behavior of deer and test the effect of wildlife-warning reflectors and auditory deterrents in altering deer roadway behavior.
4. Use new information on deer senses and roadway behavior to improve on existing technologies and develop new strategies to reduce the incidence of deer-vehicle collisions.

Deer vision

We are utilizing a combination of laboratory techniques and behavioral testing to determine white-tailed deer visual capabilities, which were not documented previously. We are training captive-raised deer through discrimination learning to select positive visual targets in a range of spatial frequency gratings, patterns, and shapes. We are calculating visual-acuity scores based on the spatial grating of the highest frequency that the animal is able to discern. Likewise, we will reduce the size of shapes and increase the complexity of patterns to determine those which are most reliably perceived by our trained deer. We are using immunohistochemistry to label rod and cone photoreceptor cells fluorescently and staining to visualize ganglion cells in the deer retina. We are developing spatial-density maps of cells across the retina to provide better understanding of light-signal processing by the deer visual system. Using our estimates of ganglion-cell densities, we also will be able to infer deer visual-acuity limits.

Deer hearing

We are conducting auditory brainstem response testing to estimate deer-hearing capabilities. While sedated, we expose their hearing system to a range of frequencies from 250 Hz to 30,000 Hz at intensities up to 90 dB. We will analyze auditory electrical potentials evoked from the deer's brainstem to estimate the lowest threshold at which the deer's hearing system can detect sounds throughout the range of tested frequencies. Our preliminary results on 13 deer indicate that deer hearing is less sensitive than that of humans at lower frequencies. At moderate to high frequencies, deer hearing appears to be more sensitive than human hearing and may extend to at least 30,000 Hz. We are performing subsequent trials to determine the behavioral response of deer to auditory cues.

Behavioral field experiments

Our research approach to evaluate the effectiveness of deer-vehicle collision reduction techniques will consider roadway behavior of deer relative to such techniques. This experimental design differs from most other studies of similar purpose, which traditionally have used counts of deer carcasses along test sections of road. We will use a forward-looking infrared camera to monitor deer behaviors at night when negative deer-vehicle interactions are most likely to occur. We will assess deer-behavioral responses to normal vehicle traffic as compared to deer responses to vehicles when reduction techniques are activated. Our experiments will determine the effectiveness of reduction techniques currently available and will provide basic information on deer roadway behavior, which is integral to the development of effective and economically feasible strategies to minimize deer-vehicle collisions.

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Tidal Marsh Restoration at Triangle Marsh, Marin County

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Abstract: The California Department of Transportation (Caltrans) provided funding to help restore and enhance 0.48 hectare (ha) (1.19 acre (a)) of tidal marsh, 0.56 ha (1.39 a) of native wetland and upland habitat, and improve public access at Triangle Marsh in Corte Madera, Marin County, California. This restoration work mitigates for impacts to 0.015 ha (0.038 a) of wetland/tidal marsh habitat resulting from the Highway 101 widening at nearby Corte Madera Creek. The goals of this restoration are to increase the habitat for marsh-dependent species such as the California clapper rail and the salt marsh harvest mouse and to provide wildlife-viewing opportunities for the public while maintaining a suitable buffer from the restored tidal marsh.

In 2000, the Marin Audubon Society (MAS) purchased the 13 ha (31 a) Triangle Marsh, which is located along Paradise Drive in Corte Madera adjacent to San Francisco Bay. Triangle Marsh is a remnant of a larger area of historical marsh of the Marin Baylands. At some unidentified time within the past 100 years, a portion of Triangle Marsh was filled, creating large upland areas with pockets of wetlands where differential settling of fill material occurred.

This restoration occurred within three areas of the site: the eastern, middle, and western. Upland areas were excavated to tidal marsh elevations. An upland berm was constructed along the boundary between the marsh and Paradise Drive to provide a physical barrier between the public pathway and the middle restoration site. In the larger eastern section, this berm has more gradual slopes on its northern (restored marsh) side to provide wetland-upland transitional refugia habitat. The existing levee in the western section was lowered to provide additional transitional refugia habitat. Grading and contouring of the site began in January 2004 and was completed by January 2005. MAS began planting the upland areas with native species after the grading was completed.

Caltrans biologists obtained pre-restoration information on plants and wildlife and took photographic records of the Triangle Marsh in January 2004 before the site was graded and contoured. Caltrans biologists will take photographic records in the same locations annually during the five-year monitoring period to document the restoration progress. Caltrans biologists will conduct spring and summer plant surveys to detect early and late-seasonal species and will map the extent of the vegetation cover using a Global Positioning System (GPS). Surveys will include a minimum of 20 vegetation sample plots, each measuring 3 x 3 meters (m) (10 x 10 feet (ft)), to estimate plant coverage and dominance in the tidal marsh and upland areas. Caltrans biologists will measure wildlife usage of Triangle Marsh on an opportunistic basis.

During the June 2005 monitoring, biologists observed pickleweed, marsh gumplant, and California cordgrass naturally recruiting into the margins of the graded and contoured tidal marsh sections. At the end of the five-year monitoring period, Caltrans expects that the restored areas will have at least 70% coverage of native species typical of local tidal marsh habitats and native wetland and upland areas.

Introduction

The California Department of Transportation (Caltrans) provided mitigation for widening work on Highway 101 that resulted in 0.015 ha (0.038 a) of impacts to wetland/tidal marsh habitat at Corte Madera Creek, in the City of Larkspur, Marin County, California (figure 1).

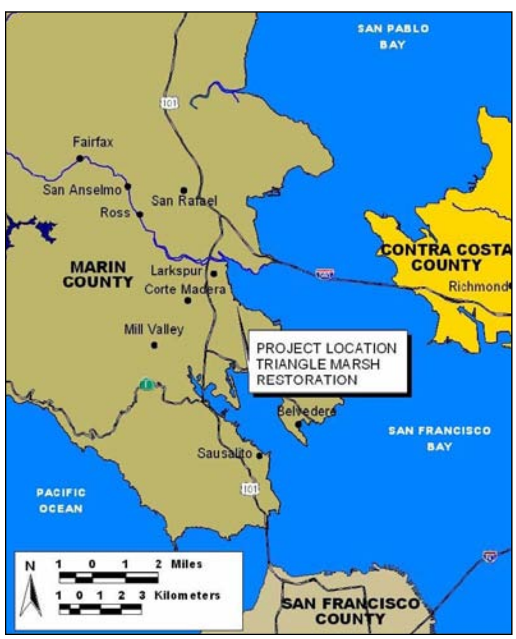

Figure 1. Project location.

Caltrans provided funding and assistance to the Marin Audubon Society (MAS) with monitoring work for the restoration of 0.48 ha (1.19 a) of tidal marsh habitat (figure 2). The restoration occurred within three areas of the site: the eastern and middle portions of the site along Paradise Drive and the levee along the western property boundary. Upland areas were excavated to tidal-marsh elevation while existing tidal marsh and transitional high marsh atop manmade land (fill) were left undisturbed. An upland berm was constructed along the boundary between the marsh and Paradise Drive to provide a physical barrier between the public and the middle site. In the larger, eastern restoration area, this berm has more gradual slopes on its northern (restored marsh) side to provide wetland-upland transitional refuge habitat. The existing western berm was lowered to provide additional transitional refuge habitat. An estimated 8,158 cubic meters (m^3) (10,670 cubic yards (cy) of soil was excavated, 1,869 m^3 (2,445 cy) were used on site for berm construction, and 6,289 m^3 (8,225 cy) were removed for off-site disposal.

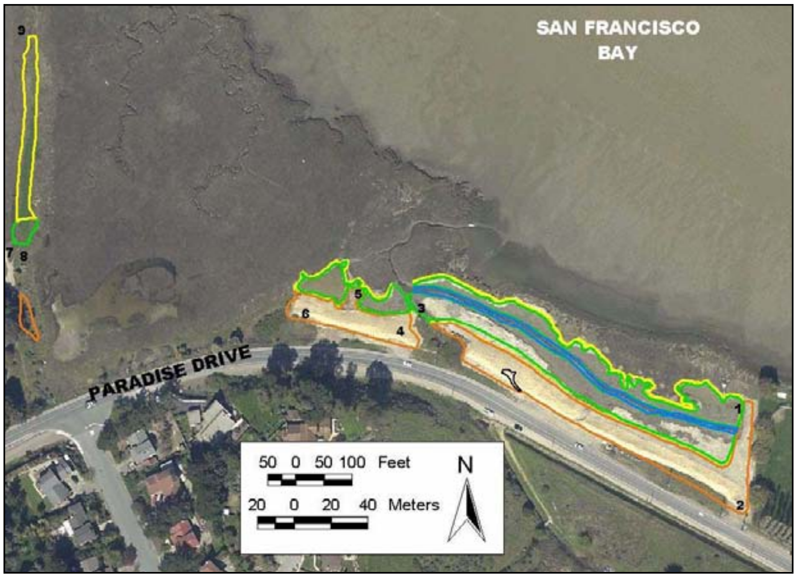

Figure 2. Aerial map of Triangle Marsh.

The topographic features were delineated using GPS after grading and contouring of the site (February 3, 2005). Future tidal-marsh areas (green outline), wetland-upland transition areas (yellow outline), and upland areas planted with native vegetation (orange outline) are shown. A channel was excavated at the eastern section (blue) to allow tidal inundation. Public viewing and access is shown in black. Numbers represent points where ground photos were taken (January 9, 2004 and January 13, 2005).

Functions and values of habitat to be created

The Triangle Marsh Mitigation Project will result in high-quality tidal marsh. Success is primarily dependent on establishment of the planted native marsh vegetation. Success criteria will include adequate hydrology of the marsh area after excavation and establishment of a self-sustaining tidal marsh.

The fundamental goals of this project are to enhance shorebird and waterfowl habitats and associated tidal marsh wildlife and plant communities. This restoration plan seeks to meet four specific ecological goals for tidal marsh and their associated wetland-upland transition areas.

California Clapper Rail

One goal of this plan is to increase habitat suitable for use by the federally endangered California clapper rail (*Rallus longirostris obsoletus*). Clapper rails utilize tidal marshes in the San Francisco Estuary. Individuals of this species have been observed at the site (Barbara Salzman pers. comm.), although no survey has been performed to determine the extent or breeding success of their populations.

Appropriate habitat for the California clapper rail includes tidal marsh with a predominance of pickleweed-vegetated (*Salicornia virginica*) marsh plains and cordgrass-vegetated (*Spartina* sp.) lower marsh, as well as access to other high marsh plants. Other habitat requirements for clapper rail establishment are marsh area, relative distance between the site and other marshes, size of buffer between marsh and upland, and low human disturbance.

Salt Marsh Harvest Mouse

Another goal of this plan is to increase habitat suitable for use and occupation by the federally endangered salt marsh harvest mouse (*Reithrodontomys raviventris*). The salt marsh harvest mouse (SMHM) can be found in salt marshes around San Francisco, San Pablo, and Suisun Bays. Populations of SMHM are present in salt marshes near the site, such as Corte Madera Ecological Reserve, and may already be present at Triangle Marsh. SMHM habitat requirements are the pickleweed and peripheral halophyte zone in mid-to upper marsh areas.

Other Plant and Wildlife Resources
The third ecological goal of this plan is to provide habitats suitable for use and occupation by tidal marsh and wetland-upland transition dependent plant and wildlife species.

Wetland/Upland Transitional Refuge
The fourth ecological goal of this plan is to provide wetland-upland transitional habitats along the margins of restored tidal marsh. This transitional zone consists of gently sloping topography across which microhabitats can establish provides refuge from extreme high-tide events, as well as tall native cover vegetation such as marsh gumplant (*Grindelia stricta*) and salt marsh baccharis (*Baccharis douglasii*) for predator avoidance.

Mitigation Site

Location and size of mitigation area
The Triangle Marsh property is 13 ha (31 a) and is bounded by Paradise Drive on the south, San Francisco Bay on the north, the Marin Country Day School on the east, and a narrow band of tidal marsh and the Mariner's Cove housing subdivision on the west. It lies immediately north of the Ring Mountain Nature Preserve, separated by Paradise Drive. The Corte Madera Ecological Reserve lies northwest of Triangle Marsh, separated by the housing subdivision.

Existing site features at Triangle Marsh include tidal marsh and tidal pannes on the western and central portions of the site, upland fill in the southeastern portion of the site adjacent to Paradise Drive and a remnant berm along the western site boundary. Central San Francisco Bay lies on the northern boundary, which includes intertidal mudflats and shallow open water. San Clemente Creek empties into the Bay a short distance west of the site.

Implementation Plan

Rationale for expecting mitigation success
Collection and analysis of data in this area by MAS combined with the fact that historically, all of Triangle Marsh was a part of a larger tidal marshland in the Marin Baylands, led to the determination that additional tidal marshland can be created at this site. This rationale was determined by analysis of tidal datum, storm water flow, soils, current ecosystem types, and existing vegetation within the Triangle Marsh area.

Vegetation planting will be limited to species that occupy the margins of the tidal marsh and may not necessarily colonize rapidly, including marsh gumplant, alkali heath (*Frankenia salina*), and jaumea (*Jaumea carnosa*). Planting will also include native species in the wetland-upland transition area and will include salt marsh baccharis.

Public access for this project aims to balance the needs of wildlife protection with opportunity for wildlife-sensitive viewing opportunities. The berm constructed parallel to Paradise Drive has a crest elevation 0.9 m (3 ft) above the roadway and is intended to discourage public entry into the restored marsh while maintaining viewing corridors for pedestrians, bicyclists, and motorists. Signs will be installed discouraging public entry and a small fence may be considered.

Along the eastern section of the new berm, a point-access location is also provided. This point access will consist of a 6 m (20 ft) diameter semicircle earthen platform located atop the eastern berm. The access will be reached via an earthen path up the berm slope. No additional improvements or interpretive signs for this access are planned as part of this project. This access point will allow open views to the existing and restored marsh and beyond to San Francisco Bay.

Construction occurred in upland areas and avoided areas dominated by pickleweed and other native marsh vegetation that may potentially provide habitat for the salt marsh harvest mouse. Clapper rails have been observed on the site in previous surveys, although locations were not documented. Therefore, it is inferred that clapper rails could be present at any location on the site. Cooper Crane and Rigging, contractors for MAS, began grading and contouring the site in January 2004. To avoid potential impacts to the California clapper rail, the contractor did not resume grading and contouring of the site until September 2004. Grading and contouring work was completed in January 2005 and MAS began planting the upland areas with native plant species.

Monitoring Plan

Monitoring methods
Caltrans biologists will take photographic records of the same locations annually during the five-year monitoring period to monitor the progress of the restoration work (figure 2). Figures 3, 4, and 5 are representative of the photographic records taken at the site.

Caltrans biologists will conduct plant sampling in the spring and summer to detect early and late-seasonal species. This plant monitoring includes measuring the trend analysis for vegetation at the restoration areas (eastern section, middle section, and western section). Caltrans biologists will map the extent of the vegetation cover using a Global Positioning System (GPS). Annual reports submitted to MAS, California Department of Fish and Game, U.S. Army Corps of Engineers, San Francisco Bay Conservation and Development Commission, and the California Regional Water Quality Control Board will include the initial extent of vegetation coverage in the area, the types of species in the area, and an estimation of the dominant types of vegetation present. The annual report will document the percentage of change in plant coverage from the previous year. Caltrans biologists will use a minimum of nine random vegetation sample plots to estimate plant coverage and dominance in each zone.

To obtain the sample plots, a grid with 3 x 3 m (10 x 10 ft) quadrats was placed over an aerial photo of the site. Each section was divided into three zones to provide an equal representation from different elevations. The upper zone contains mostly upland plants installed by MAS, the middle zone represents a transition between upland and tidal zones, and the lower zone represents the tidal marsh. Caltrans biologists will randomly choose a minimum of one quadrat from each zone to monitor percent cover change of vegetation from year to year. The objective is to conduct a random sampling of approximately 10% of the project area.

Caltrans biologists will record wildlife usage of Triangle Marsh when they are observed during field surveys.

At the end of the five-year monitoring period in 2009, Caltrans expects that the restored areas will have at least 70% coverage of native species typical of tidal marsh habitats and native wetland and upland areas.

Results

Post-restoration survey

Caltrans biologists Michael Galloway, Hal Durio, Tami Schane, and Chuck Morton conducted post-restoration surveys of Triangle Marsh on January 13, 2005, and June 7, 2005. Dominant plants and wildlife within the three restoration areas (eastern, middle, and western sections) were surveyed. The biologists photographed each restoration area at the same points where pre-restoration photographs were taken (figure 2). Figures 3, 4, and 5 are representative of the photographic records taken at the site. Caltrans biologists delineated the plant coverage of each of the three restoration areas by GPS to determine success of natural recruitment. Table 1 is a listing of the vegetation observed on June 7, 2005, for the eastern, middle, and western sections of the site.

Eastern section

Because the January 13, 2005, survey occurred shortly after the grading and contouring of the site was completed, not many plants were observed growing in the eastern section (figure 3). The upland berm of the eastern section was sparsely planted with California sagebrush (*Artemesia californica*), marsh gumplant, coyote brush (*Baccharis pilularis*), toyon (*Heteromeles arbutifolia*), and coast live oak (*Quercus agrifolia*). Pickleweed, marsh gumplant, and California cordgrass (*Spartina foliosa*) were growing at the margins of the eastern section adjacent to the tidal marsh.

Caltrans biologists observed least sandpipers (*Calidris minutilla*) and killdeer (*Charadrius vociferus*) in the excavated areas of the eastern section. Caltrans biologists also observed American crows (*Corvus brachyrhynchos*) and a turkey vulture (*Cathartes aura*) flying near the project area. Deer tracks (*Odocoiles hemionus*) and droppings and raccoon (*Procyon lotor*) tracks were observed throughout the eastern section.

A second plant survey was conducted on June 7, 2005, after MAS completed the installation of upland native plants. During this survey, Caltrans biologists determined plant coverage in quadrats sampled randomly in the eastern section.

Plant coverage in the randomly sampled plots in the tidal zone ranged from 0% to 51% with native marsh plants such as pickleweed, spearscale (*Atriplex triangularis*), and saltgrass (*Distichlis spicata*) recruiting from the adjacent tidal marsh into the restoration area (Table 1). Plant coverage in the randomly sampled plots in the wetland-upland transition zone ranged from 31% to 100%, showing much more recruitment into these areas of tidal marsh plants, especially those directly adjacent to the tidal zone while those areas directly adjacent to the upland zone showed a recruitment of non-native plant species such as birdfoot trefoil (*Lotus corniculatus*) and perennial rye grass (*Lolium perenne*).

Plant coverage in the randomly sampled plots in the upland zone ranged from 35% to 70%. The majority of plants establishing in the upland area consists of non-native plants such as birdfoot trefoil, perennial rye grass, and rabbit's foot grass (*Polypogon monspeliensis*). Plants installed by MAS were found in 8 (73%) of the 11 random upland quadrat samples. The coverage of installed plants ranged from 2% to 15% of the sampled areas and consisted of California sagebrush, coyote brush, blue-eyed grass (*Sisyrinchium bellum*), creeping wildrye (*Leymus triticoides*), meadow barley (*Hordeum brachyantherum*), and bee plant (*Scrophulairia californica*). Table 1 lists the plants observed in the sampled quadrats of the eastern section.

Point 1

Point 2

Point 3

Figure 3. Eastern restoration section.

Photos taken before restoration work (January 9, 2004) are shown on the left. Photos taken after grading and contouring of the site (January 13, 2005) are shown on the right.

Table 1. Post-Restoration Plants Observed at Triangle Marsh (June 7, 2005)

Scientific name	Common name	Habitat-community	Section[1]	Zone[2]
Anagallis arvensis	Scarlet pimpernel	Non-native upland plant	E,M	U, W-U
Artemesia californica[3]	California sagebrush	Native upland shrub	E	U
Atriplex triangularis	Spearscale	Native marsh plant	E,M	TM, U, W-U
Avena barbata	Slender wild oats	Non-native upland grass	E,M,W	W-U
Baccharis pilularis[3,4]	Coyote brush	Native upland shrub	E,M	U
Bromus diandrus	Ripgut grass	Non-native upland grass	M	U
Cotula coronopifolia	Brass buttons	Non-native marsh plant	E	TM, U, W-U
Cuscuta sp.	Dodder	Native marsh plant	E,M	W-U
Distichlis spicata[4]	Salt grass	Native marsh plant	E,M,W	TM, W-U
Eryngium sp.	Coyote thistle	Native plant	E	W-U
Frankenia salina	Alkali heath	Native marsh plant	E	W-U
Grindelia stricta[3,4]	Marsh gumplant	Native marsh plant	E	W-U
Hordeum brachyantherum[3]	Meadow barley	Native upland grass	E,M,W	U
Jaumea carnosa[3]	Jaumea	Native marsh plant	M	U
Leymus triticoides[3]	Creeping wildrye	Native upland grass	E,M,W	U
Lolium perenne	Perennial rye grass	Non-native upland grass	E,M,W	U, W-U
Lotus corniculatus[4]	Birdfoot deerweed	Non-native upland plant	E,M	U, W-U
Melilotus officinalis	Yellow sweetclover	Non-native upland plant	E,M,W	U
Parapholis incurva	Sickle grass	Non-native marsh plant	E	U
Phalaris aquatica[4]	Harding grass	Non-native wetland grass	E	W-U
Plantago lanceolata	English plantain	Non-native upland plant	M	U, W-U
Polypogon monspeliensis	Rabbit's foot grass	Non-native wetland grass	E,M	U, W-U
Salicornia virginica[4]	Pickleweed	Native marsh plant	E,M,W	TM, W-U
Salsola soda[5]	Alkali Russian thistle	Non-native marsh plant	E,M	TM, W-U
Scrophulairia californica[3]	Bee plant	Native upland plant	E	U
Spartina foliosa	California cordgrass	Native marsh plant	M	TM, W-U
Sisyrinchium bellum[3]	Blue-eyed grass	Native upland grass	E	U
Triticum aestivum	Wheat	Non-native upland grass	E	U

1. E = Eastern, M = Middle, W = Western.
2. TM=Tidal Marsh, W-U=Wetland-Upland Transition Area, U=Upland.
3. Plants installed by the Marin Audubon Society.
4. Plants observed in the area during the pre-construction period (January 9, 2004).
5. *Salsola soda* was manually removed from site where feasible.

Middle section
The middle section, like the eastern section, did not have many plants growing in the area as of the January 13, 2005, survey because this section was recently graded and contoured (figure 4). The upper berm of the middle section was also sparsely planted with toyon, coyote brush, marsh gumplant, California sagebrush, and bee plant.
Caltrans biologists observed kildeer and deer tracks in the middle section.

A second plant survey was conducted on June 7, 2005, after MAS completed the installation of upland native plants. During this survey, Caltrans biologists determined plant coverage in quadrats sampled randomly in the middle section.

Plant coverage in the randomly sampled plots in the tidal zone ranged from 10% to 30%, with native marsh plants such as pickleweed, spearscale, marsh gumplant, and saltgrass recruiting from the adjacent tidal marsh into the restoration area. Plant coverage in the randomly sampled plots in the wetland-upland transition zone range from 35% to 55%, showing much more recruitment into these areas of tidal marsh plants, especially those directly adjacent to the tidal zone while those areas directly adjacent to the upland zone showed recruitment of non-native plant species, such as perennial rye grass and yellow sweetclover (*Melilotus officinalis*). Plant coverage in the randomly sampled plots in the upland zone ranged from 36% to 70%. The majority of plants establishing in the upland area consist of non-native plants such as yellow sweetclover, perennial rye grass, and rabbit's foot grass. Plants installed by MAS were found in three (75%) of the four random upland quadrat samples. The coverage of installed plants ranged from 0% to 7% of the sampled areas and consists of coyote brush, creeping wildrye, meadow barley, and jaumea. Table 1 lists the plants observed in the sampled quadrats of the middle section.


Point 4


Point 5


Point 6

Figure 4. Middle restoration section.

Photos taken before restoration work (January 9, 2004) are shown on the left. Photos taken after grading and contouring of the site (January 13, 2005) are shown on the right.

Western section
The western section was also recently graded and contoured down to marsh elevations (figure 5). Pickleweed and marsh gumplant were growing at the margins of the western section adjacent to the tidal marsh on the January 13, 2005, survey. As natural recruitment of the area is expected to occur, the western section was not planted.

Caltrans biologists observed a dead deer, a turkey vulture, and kildeer near the western section. Caltrans biologists identified a California red-sided garter snake (*Thamnophis sirtalis infernalis*) at the edge of the western section in the pickleweed.

A second plant survey was conducted on June 7, 2005, after MAS completed the installation of upland native plants. During this survey, Caltrans biologists determined plant coverage in quadrats sampled randomly in the western section.

The tidal zone in the western section was completely submerged during the survey and no plant coverage in this area was observed. Plant coverage in the randomly sampled plots in the wetland-upland transition zone ranged from 24% to 55%, showing recruitment into these areas of tidal marsh plants such as pickleweed and saltgrass from the adjacent tidal zone. Plant coverage in the randomly sampled plot in the upland zone was 95%, consisting mostly of non-native plants such as yellow sweetclover, perennial rye grass, and slender wild oats (*Avena barbata*). MAS planted creeping wildrye in this area and it was found in 10% of the sampled area. Table 1 lists the plants observed in the sampled quadrats of the western section.

Point 7

Point 8

Point 9

Figure 5. Western restoration section.

Photos taken before restoration work (January 9, 2004) are shown on the left. Photos taken after grading and contouring of the site (January 13, 2005) are shown on the right.

Conclusions

At the eastern section, Caltrans expects that 0.412 ha (1.019 a) of the 0.781 ha (1.929 a) area of land that was contoured and graded will become tidal marsh habitat, 0.084 ha (0.207 a) will become wetland-upland transition areas and 0.285 ha (0.704 a) will become upland habitat after five years.

The quadrats sampled in the tidal marsh of the eastern section show an average of 3% total plant coverage. Because biologists conducted a plant survey of the area only five months after the area was recontoured, this survey does not adequately represent annual plant growth in the area. Plant surveys scheduled for January 2006 will provide a better estimate of annual plant growth in the tidal-marsh area.

The quadrats sampled in the upland-wetland transition areas of the eastern section show an average of 80% total plant coverage. The transition areas directly adjacent to the marsh show recruitment of native marsh plants. Approximately half of the transition area directly adjacent to the upland berm shows recruitment of non-native plant species. MAS will determine whether to control the spread of non-native upland plant materials that have established in the area.

The quadrats sampled in the upland areas of the eastern section show an average of 54% total plant coverage, but only 13% of total plant coverage is represented by plants installed by MAS. MAS will determine whether to install more native plants or to implement weeding methods to control the spread of non-native upland plant materials that have established in the area.

At the middle section, Caltrans expects that 0.057 ha (0.141 a) of the 0.182 ha (0.451 a) area of land that was contoured and graded will become tidal marsh habitat, 0.021 ha (0.053 a) will become wetland-upland transition areas and 0.104 ha (0.257 a) will become upland habitat after five years.

The quadrats sampled in the tidal marsh of the middle section show an average of 21% total plant coverage. The tidal area in the middle section may have more plant coverage than the eastern section because of differences in tidal inundation, differences of elevation of the sampled areas, or differences in how the quadrats were sampled. Plant surveys scheduled for January 2006 will provide a better estimate of annual plant growth in the tidal-marsh area.
The quadrats sampled in the upland-wetland transition areas of the middle section show an average of 46% total plant coverage. The transition areas directly adjacent to the marsh show recruitment of native marsh plants. Approximately 21% of the transition area directly adjacent to the upland berm show recruitment of non-native plant species. MAS will determine whether to control the spread of non-native upland plant materials that have established in the area.

The quadrats sampled in the upland areas of the middle section show an average of 54% total plant coverage, but only 4% of total plant coverage is represented by plants installed by MAS. MAS will determine whether to install more native plants or to implement weeding methods to control the spread of non-native upland plant materials that have established in the area.

At the western section, Caltrans expects that 0.014 ha (0.034 a) of the 0.081 ha (0.200 a) area of the levee that was contoured and graded will become tidal marsh habitat and 0.067 ha (0.166 a) will become wetland-upland transition areas after five years.

The quadrat sampled in the tidal marsh of the western section did not show any plant coverage. This area is constantly submerged, which may inhibit plant growth or prevent plants in the area from being identified. Future plant surveys may identify plants growing in this area.

The quadrats sampled in the upland-wetland transition areas of the western section show an average of 39% total plant coverage. Because this transition area is located directly adjacent to the marsh, it shows recruitment of a high percentage of native marsh plants.

The quadrat sampled in the upland area of the western section show approximately 95% total plant coverage, but only 10% of total plant coverage is represented by plants installed by MAS. MAS will determine whether to install more native plants or implement weeding methods to control the spread of non-native upland plant materials that have established in the area.

Acknowledgments: The authors would like to thank Barbara Salzman of the Marin Audubon Society for her assistance in the development of this site. We would also like to thank Fred Botti, California Department of Fish and Game (retired) for his thoughts and suggestions on the mitigation opportunities within the Highway 101 corridor.

Biographical Sketches: Chuck Morton is a district branch chief for the California Department of Transportation in the Oakland office. His area of responsibility encompasses Marin, Sonoma, Napa, Solano, and Contra Costa Counties and includes over 700 miles of roadway. He holds a B.S. in biology and marine science and a M.S. in environmental planning.

Michael Galloway is currently employed as a biologist for Caltrans. He graduated from San Francisco State University in 2001 with an M.A. degree in marine biology. His master's thesis focused on Pacific harbor seal (*Phoca vitulina richardii*) haul-out behavior at a haul-out site in the San Francisco Bay. He is currently monitoring several Caltrans restoration projects in the San Francisco Bay area, including this project, and the Triangle Marsh Restoration Project in Corte Madera, California.

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Use and Selection of Highway Bridges by Rafinesque's Big-Eared Bats in South Carolina

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Abstract

Rafinesque's big-eared bats (*Corynorhinus rafinesquii*) occur throughout the South and into some Midwestern states. However, they are rare throughout their range and are considered to be a species of special concern in every state in which they occur. Previous studies have documented the use of bridges by Rafinesque's big-eared bats in Louisiana, Mississippi, and North Carolina, but information on bridge use across the range is lacking. Furthermore, two of the three studies on bridge use were conducted in national forests. Thus, our objective was to determine the use and selection of bridges as day roosts by Rafinesque's big-eared bats on all public roads in South Carolina.

We surveyed 1,129 bridges within all 46 counties from May to August 2002. During the summer of 2003, we monitored 236 bridges in previously occupied areas of the state one to five times to evaluate bridge-roost fidelity. Colonies (including maternal groups) and solitary big-eared bats were found beneath 38 bridges in 2002 and 55 bridges in 2003. Occupancy in both years was strongly influenced by bridge size ($P < 0.001$) and construction type ($P < 0.001$); bats selected large, concrete-girder bridges and avoided flat-bottomed, slab bridges. Rafinesque's big-eared bats occupied bridges in the Upper and Lower Coastal Plain, but were absent from bridges in the Piedmont and Blue Ridge Mountains. Big-eared bats demonstrated a high degree of roost fidelity (65.9 percent). We also found that checking bridges three times at two-week intervals ensured the detection of bats, but checking more than three times did not increase detection probabilities.

The high degree of fidelity and use by maternal groups suggest that highway bridges are important roosting sites for Rafinesque's big-eared bats in the South Carolina Coastal Plain. Our results also suggest that if repair or maintenance work is planned for girder bridges during the summer, they should be inspected three times over a four to six week period. Because other studies have shown that Rafinesque's big-eared bats rarely use bridges during winter, delaying work on occupied bridges until that time will aid in the conservation of this rare species.

Biographical Sketch: Frances Bennett completed an honor's degree in biology from the University of Saskatchewan in 1999, after which she worked as a field biologist for three years in eastern Canada for provincial and federal agencies and Acadia University. She attended Clemson University to complete a master's degree in environmental/wildlife toxicology from 2002-2004, where she conducted a statewide survey for Rafinesque's big-eared bats in South Carolina and also carried out an assessment of metal exposure in these bats. Ms. Bennett attends the University of Cincinnati, where she plans to continue her research into the effects of environmental contaminants on insectivorous bats.

Using Remote-Sensing Cameras and Track Surveys to Assess Wildlife Movement Through a Probable Wildlife Linkage Bisected by Two Major Highways

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Abstract

The Arizona Department of Transportation, Natural Resources Management Section (NRMS), and Sky Island Alliance, a non-profit conservation organization, are collaborating on a project utilizing a combination of motion-sensing cameras and track surveys to assess wildlife activity and movement between the Dragoon and Whetstone Mountains in southeastern Arizona. The study investigates the distribution of wildlife across the landscape as it relates to wildlife utilization of different crossing structures on two major highways.

Through its Wildlife Monitoring Program, Sky Island Alliance identifies at-risk landscape-level wildlife corridors within the region and conducts long-term monitoring and data collection within those corridors. Sky Island Alliance is particularly concerned with the movement of four large, wide-ranging mammals: *Ursus americanus* (black bear), *Puma concolor* (mountain lion), *Pantera onca* (jaguar), and *Canis lupus baileyi* (Mexican gray wolf). Top predators were chosen based on their large spatial requirements and reliance on wildlife corridors connecting the region's mountain ranges. In the Sky Island region, the importance of wildlife corridors is magnified due to the numerous, relatively small mountain ranges separated by valleys varying from 16 to 40 km in width. In addition, data are collected on two smaller species: *Lynx rufus* (bobcat), *Nasua narica* (coati). The region between the Whetstone and the Dragoon Mountains was identified as containing possible critical wildlife-movement routes threatened by the increase of habitat fragmentation in the form of road expansion, subdivision of private land, and loss of open space. The area is bordered on the west by the Whetstone Mountains and on the east by the Dragoon Mountains. The San Pedro River, flowing northward out of Mexico, as well as two high-speed four-lane highways, bisects the study area. These three features, one natural and two human-made, are possible deterrents to wildlife movement across the valley.

Wildlife activity is monitored by conducting "track surveys" along pre-established transects. Tracking volunteers, trained by Sky Island Alliance, search for and document incidences of wildlife sign such as tracks, scat, scratches, scrapes, or kill sites. Occurrence of wildlife sign indicates the presence of that species on the transect. Volunteers record species, type of sign, UTM map coordinates for the location of sign and direction of travel (if applicable). Sign from any of the six species of concern are photo documented. Other species are noted, but not assigned data points or UTM coordinates. Sky Island Alliance has been conducting track surreys in the Dragoon/Whetstone corridor since 2001, concentrating efforts in the area east of State Route (SR) 80 and west of the Dragoon Mountains.

Tracking transects are located in four major drainages: Stronghold Canyon and Slavin Wash (which converge before crossing under SR 80) and Smith and Clifford Washes (which converge east of SR 80). Information gathered from tracking surveys is plotted on a map using the ArcView Geographic Information System to determine the location and distribution of wildlife activity. In addition to the tracking transects, Tucson NRMS recently installed remote cameras under two bridges and three culverts along a 10-km stretch of SR 80 in direct relation to the tracking transects. This section, which is located south of the town of St. David, has been identified as having high levels of wildlife activity and roadkill incidence. Tucson NRMS facilitates film replacement and camera maintenance and the management of collected photographic data.

To date, trackers have documented two focal species–bobcat and mountain lion–on all transects within the project area. In addition, Tucson NRMS personnel documented mountain lion tracks outside one of the culvert sites. Sky Island Alliance verified the species identification. Inspection of the first round of remote-camera photographs reveal travel through the culverts and bridges by deer, javelina, cattle, and domestic dog, as well as humans on horseback, ATVs, or foot. To further test the feasibility of using remote cameras under highways, NRMS has installed four cameras along SR90. Future research will expand tracking surveys throughout the Dragoon/Whetstone corridor, specifically in relation to the camera sites on SR 90. Using tracking data in combination with data from the remote cameras, NRMS biologists and Sky Island Alliance will examine characteristics of wildlife corridors in relation to major roadways, in addition to evaluating wildlife use of different crossing structures and how roadway dynamics influence wildlife movement.

What is "Natural?" Lessons Learned in Applying Context Sensitive Design to Stream Restoration And Mitigation Project Development

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Abstract

Instream projects—whether for habitat enhancement, culvert and bridge replacements, mitigation for fisheries or aquatic habitat impacts, or bank protection—often occur in altered streams in altered watersheds. For this paper, we will use the term "enhancement" to include all forms of "restoration" and "rehabilitation." Infrastructure typically interrupts watershed geomorphic processes and places constraints from both physical and legal liability viewpoints. Stakeholders can bring constraints in the form of biased perceptions and interests. Raw materials that may have been historically available for habitat-forming features are likely greatly reduced or even wholly unavailable to the stream, especially lower in the watershed. As a result, these natural materials can be unavailable to sustain or construct enhancement projects, or conversely, may be available to excess. While we often recognize that watersheds are altered, we frequently do not apply that information in the context of individual project development and implementation. As a result, inappropriate project design results from a lack of consideration of the entire project context (both project and watershed scale) and from circumventing a detailed constraints analysis early in the process.

Practitioners often try to improve instream and riparian habitats with the goal of restoring "natural" functions without recognizing the larger context of the existing altered conditions in the watershed. This nearly ubiquitous state of alteration requires us to recognize that the altered state of urban, and even many wildland streams, is unlikely to support historic habitat functions without structural intervention. Elements that formed instream habitat in the undisturbed stream may not work or may require adaptation in the new urban or disturbed environment. If "natural" defines the undisturbed stream, the obvious question is how "non-natural" do our design options need to be in the new urban or disturbed environment?

Our interdisciplinary design team and project management approach mirrors most of what defines the Context Sensitive Design (CSD) approach. We find that CSD applies a balanced approach in order to maximize natural, self-sustaining, low-maintenance elements that provide more long-term habitat functions, while still realizing the immediate creation or enhancement of missing habitats to provide needed functions to keep imperiled species viable. We share a common goal to create successful, natural, and self-sustaining stream-enhancement project designs that contribute to species and ecosystem recovery. This approach is usually more acceptable to the regulatory and environmental community. We are able to apply the reliability and stability of engineered features that may best provide short-term habitat functions, while larger-scale natural processes are allowed to re-establish.

We have identified a list of project and watershed elements that define project context as it relates to CSD and stream enhancement projects. Project context goes beyond site-specific or watershed condition assessment to include:

- Regulatory drivers, expectations and requirements
- Temporal constraints and goals, (short-term and long-term functions and processes)
- Physical/spatial constraints and goals, including landowners and infrastructure
- Liability considerations
- Cost
- The scope and scale of multi-level planning processes and stakeholder involvement.

We will compare the risks and benefits of different project approaches (CSD versus traditional) relative to ecological processes and professional liability. We will discuss natural vs. engineered/non-natural adaptations and new components in terms of:

- Long-term vs. short-term habitat functions and processes
- Symptoms vs. root problems
- Techniques/methods/materials
- Perceptions of stakeholders applied to all of the above

We will present project case studies in the Lower Columbia and Willamette River basins in Washington State and Oregon. Some interesting differences will be noted that resulted from both applying CSD early on, versus applying CSD late in the design process. These projects will illustrate ways to identify and define the watershed and project

context, prioritize structural and non-structural project elements, and develop and choose from a toolbox that includes the maximum range of methods, techniques, materials, and approaches. We will address pre- and post-project monitoring as a critical (but often overlooked and underfunded) element in the successful adaptive management of dynamic resources. Finally, we will reaffirm the message that CSD has great applicability in the future development and prioritization of stream- and river-enhancement projects to improve the success of species and ecosystem recovery on a large scale.

Wildlife Crossings Toolkit

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Abstract

Many highways wind their way through excellent wildlife habitat. Florida's highways slice through rare black bear habitat. Alaska struggles with moose-vehicle collisions. Grizzly bears in the northern Rockies are killed on highways or avoid crossing them, limiting them to smaller areas.

Solutions are available, but the information is widely scattered. The Wildlife Crossings Toolkit gathers information in one location on proven solutions and lessons learned.

Who can use the toolkit?
Professional wildlife biologists, engineers, and transportation planners can use the toolkit to work together to create innovative solutions for wildlife-friendly highways and railways.

Features:

1. Case Histories
    - Fully searchable database of case histories
    - Highlights projects from around the world
    - Provides examples of solutions used in planning or retrofitting to prevent highway-caused impacts to wildlife
    - Demonstrates collaboration of engineers and biologists
    - Includes sections on alternative approaches and suggested modifications
    - Includes engineered drawings and photos
2. Resources
    - Summary articles by experts on wildlife habitat connectivity, highway impacts, and solutions
    - Extensive illustrated glossary to facilitate a common lexicon between engineers and biologists
    - Links to other pertinent resources including ICOET proceedings and international information
3. Training and Workshops

The USDA Forest Service has developed associated training sessions to complement the information in the Wildlife Crossings Toolkit.

Biographical Sketch: Sandra L. Jacobson, wildlife biologist/research and management liaison, Pacific Southwest Research Station, Redwood Sciences Laboratory, Arcata, California. Education: B.A. in zoology (1983), Humboldt State University, Arcata, California; M.S. in natural resources/wildlife (1986), Humboldt State University. Jacobson has served as a wildlife biologist for the USDA Forest Service since 1980, working on three national forests at the district and forest levels in California and Idaho. She has worked for the USDI Fish and Wildlife Service, California Department of Fish and Game, and the USDA Soil Conservation Service. As the district wildlife biologist for the Bonners Ferry Ranger District on the Idaho Panhandle National Forests for 13 years, she managed grizzly bears, woodland caribou, and other threatened or endangered wildlife in an interagency and international setting. Ms. Jacobson is the lead biologist for the Wildlife Crossings Toolkit website. She is a charter member of the Transportation Research Board's Task Force on Ecology and Transportation and a team member for NCHRP 25-27's Evaluating the Effectiveness of Wildlife Crossing Structures. She is a member of the University of California-Davis Road Ecology Center's Scientific Advisory Committee. Currently, Ms. Jacobson is providing project-level technical expertise and training on wildlife and highway issues for several agencies around the country while acting as a research/management liaison at the Pacific Southwest Research Station.

Wildlife Hot Spots Along Highways in Northwestern Oregon

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Abstract: Determining locations where wildlife movement and highway operation conflict is an essential first step in making highways safer for motorists and animals. Using an expert-opinion approach, we identified 86 conflict areas (hot spots) for wildlife along state-maintained roads in the Oregon Department of Transportation's Region 1. Of the 757 miles of highway analyzed, 22% were identified as wildlife hot spots by expert teams, suggesting that the scope of this problem is substantial. Most of these hot spots were locations with frequent deer-vehicle collisions, although some were crossing locations for deer and elk that did not have frequent animal-vehicle collisions. Some hot spots were identified for non-focal species, including northwestern pond turtle, western painted turtle, coyote, bobcat, black bear, and beaver. Hot spots generally were associated with topographic features that directed animals towards highways, the presence of habitat adjacent to highways, or food resources that attracted animals. Six hot spots were considered high priority. The expert-opinion approach employed for this analysis was effective in rapidly assessing many miles of state-maintained highway for the presence of wildlife hot spots and may prove useful in addressing conflicts between wildlife and highways in other locales or on a statewide basis. Not all of the hot spots warrant mitigation, although we suggest that the areas identified in this analysis be examined more carefully during development of projects that may affect wildlife passage.

Introduction

Nearly all human communities in North America are connected via roads. The movement of goods and people allowed by this unprecedented connectivity is fundamental, both economically and socially, to our society. However, while connecting human communities, the modern road network has fragmented the natural environment, leaving animal populations isolated from one another and thus at greater risk of extinction from genetic (Keller and Largiader 2003) or demographic factors (Lande 1988). Animal-vehicle collisions are one of the primary causes of fragmentation, because dispersing individuals that attempt to cross roads suffer elevated rates of mortality due to collisions with motor vehicles (e.g., Lode 2000). Animal-vehicle collisions thus can affect population viability both directly through increased mortality rates and indirectly through the demographic and genetic effects of population fragmentation.

The human costs of animal-vehicle collisions are also substantial, especially when involving large animals such as deer (*Odocoileus* spp.) and elk (*Cervus elaphus*). For example, Conover et al. (1995) estimated that 1.5 million collisions between motor vehicles and deer occur annually in the United States, killing 211 people, resulting in 29,000 human injuries, and causing $1 billion in property damage annually. When insurance costs, lost productivity due to human injury, and value of the animal killed are accounted for, the annual economic cost of collisions between deer and motor vehicles likely exceeds $2 billion (Danielson and Hubbard 1998). As populations of deer in North America continue to swell, the number of collisions and associated costs will continue to rise. In the United States, white-tailed deer (for example) numbered approximately 500,000 in 1900 and climbed to over 20,000,000 in 1996 (Hughes et al. 1996).

Numerous methods exist for allowing safe passage of animals across highways, ranging from relatively inexpensive efforts to modify the behavior of motorists (e.g., warning signs) or animals (e.g., reflective lights, repellents, or intercept feeding) to expensive construction of new infrastructure (e.g., wildlife overpasses or underpasses). However, the success of these measures is strongly influenced by their placement (Clevenger and Waltho 2000, Gloyne and Clevenger 2001, Ng et al. 2004), and thus any effort to maintain safe passage for wildlife and reduce animal-vehicle collisions must first identify the location of problem areas, or hot spots. In addition, the high cost of many passage solutions requires that efforts be prioritized to produce maximum returns on any investment in mitigation. Developing a comprehensive and efficient strategy for addressing the environmental, economic, and social costs of animal-vehicle collisions therefore must be predicated on an understanding of where conflicts between wildlife and highway operation are most severe.

Here, we detail the application of a rapid-assessment process (Ruediger and Lloyd 2003) that can be used to identify potential hot spots quickly for wildlife along highways. Our study area was a portion of the state of Oregon that includes mountainous, agricultural, and highly urbanized landscapes. We chose the study area as a test case to determine the value of the rapid-assessment process for conducting statewide analyses of potential hot spots. Throughout Oregon, collisions between wildlife (especially deer and elk) and motor vehicles have been identified as a significant problem in Oregon (ODFW 2003a, b). However, efforts to address the problem are hampered by a lack of information, most notably the location of areas where wildlife-vehicle collisions are most frequent and wildlife passage most limited. To address this information gap, we conducted a study to identify and prioritize wildlife hot spots along state-maintained highways within Region 1 of the Oregon Department of Transportation (ODOT). We focused on mule deer (*O. hemionus hemionus*), black-tailed deer (*O. hemionus columbianus*), and elk (*Cervus elaphus*) because of public concern for these species and because they pose the greatest risk to motorists when involved in collisions with motor vehicles. We also collected ancillary data about additional species.

Methods

Wildlife hot spots are generally identified using data on the distribution of animal-vehicle collisions (Malo et al. 2004), predictive models of wildlife habitat (Clevenger et al. 2002), or by expert opinion (Clevenger et al. 2002, Ruediger and Lloyd 2003). We chose to use an expert-opinion approach because the data necessary for empirical modeling of wildlife hot spots is lacking for our study area and because expert opinion is faster and generally produces results equivalent to those obtained via empirical modeling (Clevenger et al. 2002, Ruediger and Lloyd 2003).

The study area consisted of the state-managed highway system within northwest Oregon (ODOT Region 1, including the counties of Multnomah, Washington, Clackamas, Columbia, and Hood River, as well as portions of Clatsop County and Tillamook County), including state routes, U. S. highways, and interstate highways. Prior to assembling expert teams, we split the study area into eight subregions, based approximately on the boundaries of maintenance units. Expert teams, comprised of local ODOT maintenance workers, local and regional biologists, and others with knowledge of local conditions, were then established for each subregion. In establishing these teams, we attempted to ensure that each was composed of members with detailed, site-specific information about the location of animal-vehicle collisions (e.g., staff of ODOT Maintenance) as well as members with broader-scale perspectives about the movements and habitat requirements of the focal species (e.g., wildlife biologists from Oregon Department of Fish and Wildlife (ODFW) and the U. S. Forest Service (USFS).

Expert teams were provided with GIS-based, paper maps of the subregion that presented information on topography, land ownership, location of streams and other waters, location of parks and open space, location of highways, and highway mileposts. To help team members accurately identify potential hot spots, expert teams were also provided with interactive, computer-projected GIS maps that included all of the layers provided on the paper maps as well as high-resolution (2-feet pixels), color-infrared digital photography of the entire study area. When a potential hot spot was identified, the team member provided a rationale for identifying the area as a hot spot. The hot spot was only recorded if the expert team reached unanimous consensus.

To ensure accurate representation of hot spots, each was mapped directly into a GIS database once the expert team had reached consensus. This allowed all team members to verify that the location was accurately described. Each hot spot was assigned a record number based on subregion and sequential identification number (e.g., the first hot spot identified in Subregion 8 was identified as 08-01). The following information was collected about each hot spot identified:

1. Basis for nomination.
2. Description of location, including highway mile markers and distinguishing topographic features.
3. Presence of any existing features that facilitate or encourage animal movement across the road.
4. Other species that may use this area as a road crossing.
5. Future threats to the value of the area as a wildlife crossing.
6. Priority to ODOT.

The priority of each hot spot was based on the judgment of the expert team. In general, expert teams considered areas with an unusually high frequency of animal-vehicle collisions, documented or suspected crossings by sensitive or rare species, or deer and elk migratory routes. Medium-priority hot spots generally had lower rates of animal-vehicle collisions than high-priority hot spots or, in several cases, had no documented animal-vehicle collisions but were used frequently as a crossing location for wildlife. Low-priority hot spots typically had only scattered reports of animal use. We visited all of the hot spots identified as high priority by the expert teams, all of the hot spots used as road crossings by rare or sensitive species, and a randomly selected subset of the medium-priority hot spots to document site conditions, establish a photographic record of site conditions, and verify the information received.

Results

Overall

The total length of highways considered in this analysis was 757 miles (Table 1). Of the total highway miles considered, 170 miles, or 22%, were identified as wildlife hot spots. The expert teams identified 86 hot spots in Region 1. Most of these (44) were identified based on frequent deer-vehicle collisions. Elk crossings (10) and areas where both frequent elk crossings and frequent deer-vehicle collisions occurred (15) were also commonly noted by expert teams. Elk-vehicle collisions were not identified as a problem at any hot spot, and only one area was identified as a deer crossing without frequent deer-vehicle collisions. The remaining 17 hot spots identified included 15 areas noted for frequent collisions between motor vehicles and non-focal species (for example, coyote (*Canis latrans*), beaver (*Castor canadensis*), and northwestern pond turtle (*Emys marmorata marmorata*), two areas without frequent animal-vehicle collisions that were used as crossings by non-focal species, and one area with existing underpasses (cattle crossings) that might be used by wildlife.

The size of hot spots varied considerably. Most were greater than one mile long. The mean length of a hot spot was 2.3 miles (Table 1). However, the mean length was biased upwards by the inclusion of several extraordinarily long hot spots (e.g., a 15.5-miles long hot spot along I-84 in Subregion 5). The average median length of hot spots in each subregion was 1.7 miles. Median hot-spot length tended to be greater in the eastern portion of the study area, including the foothills of the Cascade Range (Subregions 7 and 8), Mount Hood and the Hood River drainage (Subregion 6), and the Columbia River Gorge (Subregion 5).

The number of hot spots identified in each subregion did not correspond with the total length of state-maintained highway in each subregion. Western subregions, especially those in the Coast Range (Subregions 1 and 2), had more hot spots identified than did eastern subregions (Subregions 6-8). Rural subregions tended to have longer hot spots and a greater percentage of highway miles in hot spots. For example, the two most urbanized subregions, Portland-Sylvan and Portland-Flanders, had only 10% and 16% of highway miles in hot spots, with an average length of 1.3 miles and 1.9 miles, respectively. In contrast, hot spots in the more rural Clatskanie, Cascade Locks, and Government Camp subregions accounted for more than 30% of total highway miles, and the average length of hot spots was greater (averaging 3 miles). Suburban subregions, such as Sandy and Estacada, were intermediate both in the percentage of highway miles in hotspots and the average length of hot spots.

Table 1. Summary statistics for wildlife hot spots identified along state-maintained highways in Region 1 of the Oregon Department of Transportation

Subregion name (Subregion number)	Total miles of highway analyzed	Percentage of miles in hot spots[1]	Number of hot spots identified	Average length of hot spots (miles)	Median length of hot spots (miles)	Range of hot-spot lengths (miles)
Clatskanie (1)	91	36	18	1.8	0.75	0.2 – 11
Manning (2)	98	16	17	0.9	0.9	0.4 – 1.4
Portland-Sylvan (3)	161	10	12	1.3	1	0.3 – 1.3
Portland-Flanders (4)	142	16	11	1.9	1.5	0.5 – 6
Cascade Locks (5)	74	39	7	4	2.5	1 – 15.5
Government Camp (6)	82	33	9	3.1	3	0.3 – 7
Sandy (7)	38	29	4	2.5	2.1	1 – 5
Estacada (8)	72	23	8	2.6	1.6	0.1 – 7
Total	757	22	86	2.3	1.7	0.1-15.5

[1] Calculated as total length of highway/total length of hot spots.

Subregional summary

Of the 86 hot spots identified by the expert teams, six were considered high priority. Three high-priority hot spots occurred in the Portland-Sylvan subregion (Subregion 3), which includes the western side of the greater Portland metropolitan area. Two of these were segments of State Highway 217 in which amphibians, small mammals, and birds are frequently killed while attempting to cross the highway; the third was on U. S. Highway 26 and was noted for collisions between motor vehicles and deer, waterfowl, and raptors. A high-priority hot spot was identified on State Highway 213, near Milk Creek in the northern Willamette Valley (Subregion 4), based on the frequency of collisions between deer and motor vehicles. In the Cascade Locks subregion (Subregion 5), a high-priority hot spot for several species, including deer, elk, beaver, and several reptiles and amphibians, was identified along Interstate 84 in the Columbia River Gorge. Roadkilled animals are common in this hot spot, which is associated with an extensive wetland complex near Multnomah Falls. The sixth high-priority hot spot was located on State Highway 35 (Government Camp, Subregion 6) where the highway bisects an important migration corridor for deer and elk.

Many of the hot spots in the coastal mountains (Subregions 1 and 2) included moderately long stretches of highway, reflecting the fairly continuous forest cover adjacent to the highways in these subregions. Many hot spots in Subregions 1 and 2 appeared to be connected with ephemeral features of the landscape, such as aging clearcuts that provide foraging opportunities for deer and elk, although the expert teams also identified several hot spots that were influenced by topographic features. No high-priority hot spots were identified in these subregions. Indeed, the most significant hot spots in the coastal mountains of northwest Oregon appear to lie outside the western boundaries of the study area on the west slope of the Coast Range, where larger elk populations exist (D. Nuzum, ODFW, pers. comm.).

The two urban subregions (subregions 3 and 4) contained slightly lower proportions of hot spots than the more rural or mountainous subregions (all others) and also had hot spots that were significantly shorter in length than other subregions (Table 1). Many of the hot spots identified in Subregions 3 and 4 were associated with wetland features and were identified based on the frequency of collisions between motor vehicles and some combination of deer, small mammals, and waterfowl. Hot spots for deer were also associated with areas of remnant open space or other suitable, disturbed environments, such as golf courses and plant nurseries. Elk hot spots were uncommon in these subregions, mainly due to the lack of large blocks of suitable habitat.

Two high-priority hot spots occurred in the City of Beaverton, one of which was located near an area of open space along State Highway 217 (Site 03-04 and 03-05). Both sites are flanked by wetlands and pockets of natural habitat in an otherwise developed area. Good habitat, including wetlands and a golf course adjacent to the highway, exists for migratory birds and small mammals. However, the area immediately adjacent to the highway in both sites is heavily developed. Beaver, nutria (*Myocastor coypus*), raccoon (*Procyon lotor*), and birds are frequently killed in collisions with motor vehicles. The jersey barrier that runs through this section likely represents a significant barrier to most species that attempt to cross and may increase the risk of collision for animals that attempt to cross over the roadway.

Not all hot spots were associated with animal-vehicle collisions. For example, a hot spot was identified near a wetland complex because northwestern pond turtles and western painted turtles (*Chrysemys pictus*), both listed as Sensitive-Critical by ODFW, are thought to cross in this section. The site is located adjacent to the Burlington Bottoms Wildlife Area, just northwest of Portland (Site 03-08). It was ranked as a medium-priority site because the expert team had no information on whether roadkill was occurring at this hot spot. However, no culverts exist to allow animals to cross beneath the roadway, and thus any movement across the highway requires crossing four lanes of traffic. In addition, railroad tracks lie parallel and adjacent to the roadway on both sides, although several small culverts and a bridge allow passage beneath the railroad tracks. Collisions between ducks and motor vehicles are known to occur at this hot spot.

One hot spot in the northern Cascade Mountains, in the Government Camp Subregion (Site 06-07), was singled out by the expert teams as the most important in the study because it encompasses a section of road that crosses an area used during migration by deer and elk. Although expert teams were asked only to prioritize hot spots within their respective subregion, expert team members who contributed to multiple subregions agreed that this hot spot was the most significant in Region 1. The highway in this hot spot, which is three miles long, is curvy and clear zones are limited, resulting in frequent deer-vehicle collisions. Although this hot spot includes a significant elk-migration route, elk-vehicle collisions are rare at present. The only mitigation measure employed within this hot spot is a deer-crossing sign near the turnoff to Cooper Spur Ski Area. The functionality of this hot spot may be threatened by the proposed expansion of Cooper Spur Ski Area, which would significantly increase traffic through this hot spot.

Discussion

Region 1 wildlife hot spots

Collisions between animals and motor vehicles are a significant problem in Oregon. Of the 757 highway miles analyzed in this study, approximately 22% were included in hot spots identified by the expert teams. The extent of these conflict areas suggests that allowing wildlife to move safely across Oregon's highways will yield substantial economic and environmental benefits. In particular, reducing the risk of collisions between motor vehicles and animals will mean fewer human injuries and fatalities, less money spent on vehicle repair and insurance costs, and reduced mortality in wildlife populations.

In addition, allowing safe passage for wildlife will also ensure that animals have access to all necessary habitats and resources and that connectivity among different populations is maintained. The necessary first step towards this goal is to identify those areas where conflicts between wildlife movement and highway operation are most severe. The results of the analysis presented here provide this information for Region 1 of ODOT.

Although deer-vehicle collisions were the basis of most of the identified hot spots, expert team members also identified crossing areas used by deer and elk in which collisions are not an issue, as well as hot spots used by a variety of other species, including black bear (*Ursus americanus*), bobcat (*Felis rufus*), river otter (*Lutra canadensis*), beaver, small mammals, birds, red-legged frogs (*Rana aurora aurora*), northwestern pond turtles, and western painted turtles. Hot spots generally resulted from one of three factors: topography that directed animals towards the road, suitable habitat in close proximity to the road, or food resources that attracted animals. Understanding the nature of hot spots is important, as it will influence the likelihood that animals continue to use the area in a similar fashion in future years. For example, hot spots resulting from topography or hot spots that include historical migration routes are likely to remain hot spots indefinitely.

In contrast, hot spots for deer that exist due to attractive foraging opportunities created by timber harvest may receive less use as the forest ages and food availability declines. Hot spots that are associated with ephemeral resources are unlikely to remain stable through time, and thus may be a relatively low priority when considering mitigation. Considering how forest practices may influence animal movement is especially important in the western parts of Region 1, where much of the land adjacent to state-maintained highways is subject to timber harvest.

The frequency, size, and extent of hot spots varied among subregions. Variation in the length and extent of hot spots likely reflects differences in the amount and configuration of habitat available in each subregion. In the urban subregions, the amount of available habitat is low and tends to be highly fragmented, and animals are concentrated into remaining islands of habitat. Hot spots generally occurred wherever roads bisected remnant habitat patches, thus producing the observed pattern of many short, distinctive hot spots in the urban subregions. With more available habitat and fewer artificial edges to focus movement, animals in the rural subregions may be less likely to encounter the highway at discrete locations, leading to longer hot spots that account for a greater percentage of total highway miles.

Regional differences in the size and frequency of hot spots may also be related to corresponding variation in the behavior and life history of the focal species. For example, black-tailed deer and elk from the Coast Range and the west slope of the Cascade Range either do not migrate at all or undertake much shorter seasonal migrations than mule deer and elk from the east side of the Cascade Range, where deep snow accumulations and cold temperatures often drive significant seasonal migrations (Verts and Carraway 1998). When roads intersect traditional migration routes, which tend to follow well-defined and narrow corridors, short and discrete hot spots with frequent animal-vehicle collisions are likely to result.

In contrast, west of the Cascade Range hot spots probably reflect the proximity of habitat to roads and the local population density of the focal species. In these areas, the animal-vehicle collisions that help define hot spots may reflect the movement of individual animals within a home range, rather than large-scale migratory movements, and the resultant hot spots may be longer and less pronounced. This may be especially true in areas where roads bisect large blocks of habitat that support locally dense populations of the focal species.

Differences among subregions may also be due to the differences in the perceptions of members of expert teams. For example, maintenance crews in some subregions maintain written records of the location of many animal-vehicle collisions, allowing crews to provide more precise information about potential hot spots. In contrast, in subregions where maintenance crews did not record data on animal-vehicle collisions, expert team members were forced to rely on recollection and, in many cases, to approximate the location of hot spots. Thus, hot spots may appear to be longer in certain subregions simply because written records of animal-vehicle locations were not available.

In addition, because we did not establish strict criteria for identifying hot spots and instead relied on the best judgment of the expert teams, some variation may occur among subregions because perceptions of what constitutes a hot spot varied among expert team members. We attempted to minimize this bias by giving examples of what conditions might constitute a hot spot (e.g., unusually high rate of animal-vehicle collisions or frequent observations of animals crossing), but ultimately the opinion of the assembled experts dictated the identification of hot spots.

Efficacy of the approach

Despite the necessarily subjective nature of expert-opinion approaches, the approach outlined here proved a useful template for broader application throughout the state. Because the expert-opinion approach to identifying hot spots relies on existing information, it is far less expensive and time consuming than conducting field studies of animal movement. Few transportation projects operate on sufficiently long timelines to allow the multiple years of data collection and analysis necessary to achieve robust results. Habitat modeling can be used to predict hot spots along highways (e.g., Clevenger et al. 2002), but in most cases the detailed data necessary to build predictive models are lacking, as was the case for this study. For example, the landscape-level information available to predict the distribution of the focal species would have ruled out the presence of hot spots within the Portland metropolitan area, as urban areas are considered non-habitat. However, Portland does support urban-dwelling wildlife, including black-tailed deer, and animal-vehicle collisions are an important local issue.

The expert-opinion approach is also valuable because it draws on the vast, yet largely untapped, pool of local knowledge regarding wildlife and their movements. Although relying on local experts introduces an element of subjectivity, local ecological knowledge is used widely to address resource management issues, especially in remote and undeveloped areas where baseline empirical information is lacking (e.g., Mallory et al. 2003). The study area for this analysis is neither remote nor undeveloped, but baseline information on the location of wildlife hot spots is generally unavailable, both within the study area and throughout the state. Because this approach defines the scope and extent of the conflict between wildlife movement and highway operation, it may be especially useful as a first step in developing a comprehensive strategy for addressing wildlife movement along highways statewide.

One drawback of this approach is that it is difficult to apply to smaller species (such as amphibians and reptiles) that may experience high rates of roadkill but that are rarely observed by maintenance staff or other highway users. More detailed follow-up studies, including field surveys and habitat modeling, may be useful in refining information about the use of hot spots by these species. In addition, because the expert-opinion approach relies largely on observations of roadkilled animals, it does not identify sections of highway in which animals are prevented from crossing but in which animal-vehicle collisions are rare. This may be especially problematic when considering species that exhibit road-avoidance behaviors, including elk (Lyon 1979).

Recommendations for Future Study

The hot spots identified in this analysis should not be considered a definitive list of areas where wildlife crossings are a concern, nor are the results appropriate as the basis for mitigation planning. Rather, the results presented here should help to focus future research and provide guidance during the scoping and planning phases of transportation projects. Research should be directed at the hot spots identified as high priority by the expert teams to better quantify existing conditions at each location. Collecting additional data on animal-vehicle collisions and conducting surveys to determine which species are using these hot spots, and with what frequency, will help in determining whether any mitigation efforts are needed, and if so, what form mitigation should take.

Although the priority hot spots should be the focus of additional work, all of the hot spots identified in this analysis should be considered during project development. Early scoping during project development has been identified as the most effective way to address wildlife hot spots. To facilitate this, the hot spots identified in this study will be added to the other environmental-data sources that are evaluated during project scoping for Region 1. Early identification of these potential conflict areas within a project site may allow the opportunity to budget for further evaluation of hot spots. Although specific mitigation measures will not be known until further analyses have been conducted, costs can be estimated for conceptual-mitigation strategies based on basic project and site information, such as type of hot spot, animals involved, adjacent land use (existing and foreseen future), and type of proposed project (pavement preservation vs. bridge rehabilitation, for example). In addition to project development and construction budgets, other avenues of funding further research and construction of mitigation measures are available, including Federal Highway Administration (FHWA) enhancement grants, wildlife agency grants, or possibly safety or maintenance funds.

Possible mitigation strategies include structural approaches, such as adding fencing or building dedicated wildlife overpasses or underpasses (reviewed in Evink 2002). For those hot spots associated with bridges, mitigation opportunities might include relatively minor modifications to the existing structure, such as adding a bench for wildlife passage on the fill slopes beneath the bridge. Changes to the management of roadside vegetation may also be useful, especially because many of the hot spots identified in this study appear to be related to the presence of food and cover adjacent to the road. Eliminating habitat features that attract deer and elk to the roadside has proven effective in other areas (Rea 2003). Intercept feeding, in which attractive food sources are created that draw animals away from the road, may also help to reduce the frequency of collisions at hot spots (Wood and Wolfe 1988). In general, reflectors, repellents, and warning signs are of little value in reducing animal-vehicle collisions, especially on high-volume highways (Romin and Dalton 1992, Reeve and Anderson 1993, Gordon et al. 2004).

Finally, developing a standardized system for recording and collecting data on the location and nature of animal-vehicle collisions would prove invaluable in addressing wildlife passage problems on major highways. Roadkill or animal-injury records are important data for the development of empirical models that could be used to refine the results of expert-opinion analyses. Currently, the decision to collect data about the location of animal-vehicle collisions and the species involved is left at the discretion of each ODOT maintenance district. The degree to which collision data are collected varies greatly. In some cases, no data are collected at all. Although expert opinion is useful in conducting rapid assessments for potential hot spots, it cannot be used to quantify the severity of a problem in any particular hot spot (e.g., the frequency of animal-vehicle collisions), and thus cannot be used as baseline information for evaluating the effects of mitigation. Implementing a standardized, agency-wide system for collecting data on animal-vehicle collisions will be useful in justifying any investments made in mitigation. Expert opinion is a useful tool for rapidly assessing a highway system, but empirical data, if properly collected, are more reliable and also allow for fully parameterized cost-benefit analyses.

Biographical Sketches: John Lloyd is a biologist with Mason, Bruce & Girard, Inc. He received a Ph.D. in wildlife biology from the University of Montana in 2003, after which he worked as a post-doctoral associate on the USDA Forest Service Highway 93 Wildlife and Fish Habitat Linkage Analysis project. In addition to road ecology, John has expertise in avian ecology, statistics and experimental design, and wildlife-habitat relationships.

Melinda Trask is a biologist in Region 1 of Oregon Department of Transportation and has been with ODOT for over 5 years. Her undergraduate degree was in environmental biology with an emphasis in wildlife ecology from California Polytechnic State University. Ms. Trask has a master of science degree from Oregon State University in rangeland resources and a master of science degree from Washington State University in environmental planning. Her main duty at ODOT is to help the agency maintain compliance with federal and state endangered-species acts. In addition to preparing biological assessments and conducting monitoring on a variety of projects, Ms. Trask coordinates and manages peregrine falcons for many ODOT bridges and has developed a region-wide system for tracking wildlife roadkill.

Alexis Casey is a biologist with Mason, Bruce & Girard, Inc. She has a bachelor of science degree in resource management with an emphasis in forest resources from the University of California Berkeley (2002). In addition to her work on wildlife crossings in Oregon, she has experience with forest management and rare plant studies in California, Oregon, and Washington. She is currently working on a variety of projects to assess the anticipated impacts of development activities on ESA-listed wildlife, fish, and plant species.

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Final Program

Sunday, August 28, 2005

2:00-6:00 **Conference Registration and Check-In — North Foyer**

Speaker Ready Room Opens — Boardroom

3:00-6:00 **Exhibitor Check-In / Set-Up — Terrazza Ballroom**

4:00-6:00 **ICOET 2005 Steering Committee Meeting — Las Palmas**

Monday, August 29, 2005

7:00-8:30 **Continental Breakfast — Foyer**

8:30-9:15 **Conference Welcome and Opening Remarks — International Ballroom (Riviera thru St. Tropez)**

Moderator: Leroy Irwin, Conference Chair

Welcome from CTE (James Martin, Associate Director, CTE, NC State University)

Welcome from the University of California at Davis, Road Ecology Center (Daniel Sperling, Director, Institute of Transportation Studies, and Co-Author, *Road Ecology: Science and Solutions*)

Welcome from Caltrans-District 11, San Diego (Charles "Muggs" Stoll, District Division Chief, Environmental, Caltrans)

Caltrans: On the Road to Environmental Stewardship! (Jay Norvell, Environmental Division Chief, Caltrans)

9:15-10:00 **Session 1: Update on Federal and International Activities — International Ballroom (Riviera thru St. Tropez)**

Moderator: Paul Garrett, FHWA Headquarters, USA

Update on the Activities of the Infra Eco Network of Europe (Hans Bekker, Ministry of Transport and Water Management, The Netherlands)

Results of the August 2005 INTECOL/ESA Conference in Montreal (Jochen Jaeger, Swiss Federal Institute of Technology, Switzerland)

SAFETEA-LU Overview (Mary Gray, FHWA Headquarters, USA)

Stewardship on the Horizon: Integrated Planning in the 21st Century (Patricia White, Defenders of Wildlife, USA)

10:00-10:30 **Break — Foyer**

10:30-12:00 **Session 2: Cross-Cutting Session: ICOET 2005 Sneak Preview — International Ballroom (Riviera thru St. Tropez)**

Environmental Retrofit for Highways: Making Habitat a Priority (Paul Wagner, Washington State DOT, USA)

Science-Based Approach to Adaptive Management of the Trans-Canada Highway Corridor in the Canadian Rocky Mountain Parks (Tony Clevenger, Western Transportation Institute, USA)

Maine's Beginning with Habitat Program and Transportation Partnership (Barbara Charry, Maine Audubon, USA)

Wildlife Tunnels and Fauna Bridges in Poland: Past, Present, and Future (Jadwiga Brodziewska, Suwalki, Poland)

Species Conservation Banking: A New Business-Friendly Option for Protecting Endangered Species (Jessica Fox, EPRI Solutions, Inc., USA)

12:00-1:30 **Lunch (on own)**

1:30-3:00 **CONCURRENT SESSIONS 3A and 3B**

Session 3A: Integrating Transportation and Resource Conservation Planning: Conservation Banking — International Ballroom (Riviera thru St. Tropez)

Moderator: Sandy Jacobson, USDA Forest Service, USA

On the Road to Conservation Planning: State Conservation Strategies and Applications for Transportation Planning (Patricia White, Defenders of Wildlife, USA)

Integrating Transportation with Regional Conservation Planning (John DiGregoria, US Fish and Wildlife Service, USA)

Oregon DOT's Habitat Value Approach to Compensatory Mitigation Debit/Credit Calculations (William Warncke, Oregon DOT, USA; presenting for Bill Ryan)

SANDAG's TransNet Environmental Mitigation Program (Janet Fairbanks, San Diego Association of Governments, USA)

Session 3B: Transportation Corridor Vegetation Management — International Ballroom (San Marino)

Moderator: Bonnie Harper-Lore, FHWA Headquarters, USA

Mitigation for Dormice and their Ancient Woodland Habitat Alongside a Motorway Corridor (Warren Cresswell, Cresswell Associates, United Kingdom)

Response of Acacia Species to Soil Disturbance by Roadworks in Southern New South Wales (Peter Spooner, Charles Sturt University, Australia)

High Altitude Revegetation Experiments on the Beartooth Plateau (Liz Payson, ERO Resources Corporation, USA)

3:00-3:30 **Break — Foyer**

3:30-5:00 **CONCURRENT SESSIONS 4A and 4B**

Session 4A: Aquatic and Marine Ecosystems — International Ballroom (Riviera thru St. Tropez)

Moderator: Paul Wagner, Washington State DOT, USA

Culvert Test Bed: Fish Passage Research Facility (Walter Pearson, Battelle PNNL, USA; presenting for Chris May)

Restoration of Aquatic Habitat and Fish Passage Degraded by Widening of Indian Highway 58 in Garhwal Himalaya (Ramesh Sharma, Garhwal University, India)

Engineered Logjams, An Alternative Bank Protection Method for US 101 Along the Hoh River, Washington (Carl Ward, Washington State DOT, USA)

Role of Geomorphic River Reach Assessments in Developing Environmentally Beneficial Highway Protection Measures (Jennifer Black Goldsmith, Herrera Environmental Consultants, USA)

Session 4B: Context Sensitive Solutions: Integrating Community Values with Conservation Objectives — International Ballroom (San Marino)

Moderator: Amanda Hardy, Western Transportation Institute, Montana State University, USA

Integrating Community Values and Fostering Interagency Collaboration Through Outreach with Interactive GIS Models (Michael McCoy, University of California at Davis, USA)

Quick Fixes: Working Together to Address Herpetile Road Mortality in New York State (Debra Nelson, New York State DOT, USA)

Bayview Avenue Extension, Richmond Hill, Ontario. Habitat Creation and Wildlife Crossings in a Contentious Environmental Setting: A Case Study (Geoffrey Gartshore, Ecoplans Limited, Canada)

6:00-8:00 **Exhibits Open — Terrazza Ballroom**

International Welcome Reception — Foyer
(Sponsored by HDR Engineering, Inc., Sensor Technologies and Systems, Inc., and URS Corporation)

Tuesday, August 30, 2005

7:00-8:30 **Continental Breakfast — Foyer**

Business Meeting of the TRB Task Force on Ecology and Transportation — Portofino

8:30-10:00 **CONCURRENT SESSIONS 5A and 5B**

Session 5A: Acoustics Ecology: Aquatics Issues — International Ballroom (Riviera thru Monte Carlo)

Moderator: Mary Gray, FHWA Headquarters, USA

How Did We Get Into This Mess? (Deborah McKee, Caltrans, USA)

What Do We Know About Pile Driving and Fish? (Arthur Popper, Center for Comparative and Evolutionary Biology of Hearing, University of Maryland, USA)

Barotrauma Injury of Physostomous and Physoclistous Fish by Non-Explosive Sound and Pressure Cycling (Thomas Carlson, Battelle-Pacific Northwest National Laboratory, USA)

Assessing the Impact of Pile Driving on Fish (A.D. Hawkins, Loughine Ltd., United Kingdom)

Session 5B: Wildlife Impacts and Conservation Solutions: Herpetofauna — International Ballroom (St. Tropez)

Moderator: James Martin, CTE, North Carolina State University, USA

Amphibian Road Kill: A Global Perspective (Miklós Puky, Hungarian Danube Research Station of the Institute of Ecology and Botany, Hungary)

Effects of Road Mortality on a Population of Painted Turtles in Montana and the Potential to Minimize These Effects with Barrier Fencing (Kathy Griffin, University of Montana, USA)

Factors Influencing the Road Mortality of Snakes on the Upper Snake River Plain, Idaho (Denim Jochimsen, Idaho State University, USA)

How Do Highways Influence Snake Movement? Behavioral Responses to Roads and Vehicles (Kimberly Andrews, University of Georgia, USA)

10:00-10:30 **Break — Foyer**

10:30-12:00 **CONCURRENT SESSIONS 6A and 6B**

Session 6A: Acoustics Ecology: Wildlife Impacts of Roadway Noise — International Ballroom (Riviera thru Monte Carlo)
(Sponsored by UC-Davis Road Ecology Center)

Moderator: Alison Berry, UC-Davis Road Ecology Center, USA

Evaluating and Minimizing the Effects of Pile Driving on the Marbled Murrelet (Brachyramphus marmoratus), A Threatened Seabird (Emily Teachout, US Fish and Wildlife Service, USA)

Impacts of Road Noise on Birds (Robert Dooling, University of Maryland, USA)

Synthesis of Noise Effects on Wildlife (Paul Kaseloo, Virginia State University, USA)

Bioacoustic Profiles: Evaluating Potential Masking of Wildlife Vocal Communication by Highway Noise (Edward West, Jones and Stokes, USA)

Session 6B: Wildlife Impacts and Conservation Solutions: Large Mammals — International Ballroom (St. Tropez)

Moderator: Susan Hagood, Humane Society of the United States, USA

Modeling Highway Impacts Related to Grizzly Bear Core Habitat and Connectivity Habitat in the Greater Yellowstone Ecosystem Using a Two-Scale Approach (Lance Craighead, Craighead Environmental Research Institute, USA)

Evaluation of Principal Roadkill Areas for Florida Black Bear (Stephanie Simek, Florida Fish and Wildlife Conservation Commission, USA)

Effects of Highways on Elk Habitat in the Western United States and Proposed Mitigation Approaches (Bill Ruediger, Western Consulting Resources, USA)

Monitoring Effects of Highway Traffic on Wild Reindeer by Satellite (Bjørn Iuell, Norwegian Public Roads Administration, Norway)

12:00-1:30 **Lunch (on own)**

1:30-5:00 **Poster Session — Mediterranean Ballroom (Las Palmas thru Portofino)**

Studies of Fish Passage Through Culverts in Montana (Matt Blank, Montana State University, USA)

A Critical Look at Innovative Storm Water BMPs (Henry Barbaro, Massachusetts Highway Department, USA)

Tidal Marsh Restoration at Triangle Marsh (Chuck Morton, Caltrans-District 4, USA)

Riparian Restoration and Wetland Creation at Solano Community College (Michael Galloway, Caltrans, USA)

What Is "Natural?" Lessons Learned in Applying Context Sensitive Design to Stream Restoration and Mitigation Project Development (Kelley Jorgensen, URS Corporation, USA)

Engineered Logjam Technology: A Self-Mitigating Means for Protecting Transportation Infrastructure and Enhancing Riverine Habitat (Tim Abbe, Herrera Environmental Consultants, Inc., USA)

Managing Environmental Compliance for ODOT's OTIA III State Bridge Delivery Program: Many Regulations – One Framework (Jason Neil, Oregon Bridge Delivery Partners, USA)

California Innovation with Highway Noise and Bird Issues (Robert James, Caltrans, USA)

Bird Protection Walls: An Innovative Way to Prevent Bird Strikes? (Csaba Varga, Birdlife Hungary, Hungary)

Assessing Functional Landscape Connectivity for Songbirds in an Urban Environment (Marie Tremblay, University of Alberta, Canada)

The Effects of Roads on Birds: a North American Review (John Lloyd, Mason, Bruce & Girard Inc., USA)

Combining Transportation Improvements and Wildlife Connectivity on Freeway Rebuild in Washington's Cascade Mountains (Charlie Raines, I-90 Wildlife Bridges Coalition, USA)

Planning a Sustainable Community: Natural Areas Management and Infrastructure Development (Sherri Neff-Swanson, Sarasota County Government, USA)

Colorado Wildlife on the Move: A Wildly Successful Road Ecology Awareness Campaign (Monique DiGiorgio, Executive Director, Southern Rockies Ecosystem Project, USA)

The Role of Transportation Corridors in Plant Migration in and Around an Arid Urban Area: Phoenix, Arizona (Kristin Gade, Arizona State University)

The Invasive Common Reed (Phragmites australis) Along Roads in Québec (Canada) : A Genetic and Biogeographical Analysis (Lelong Benjamin, Centre de Recherche en Aménagement et Développement, Canada)

Road Ecology of the Northern Diamondback Terrapin, Malaclemys terrapin terrapin (Stephanie Szerlag, Saint Joseph's University, USA)

The Return of the Eastern Racer to Vermont; Advance Habitat Mitigation Through Collaboration (Chris Slesar, Vermont Agency of Transportation, USA)

Road Crossings and Arroyo Toad (Steve Eastwood, Engineer, Cleveland National Forest, USA)

Impacts of Standard Drop Inlet/Catch Basin Drain Structures on Amphibians and Small Mammals in Western Washington (Michael MacDonald, Washington State Department of Transportation, USA)

Wildlife Tunnels and Fauna Bridges in Poland: Past, Present, and Future (Jadwiga Brodziewska, Suwalki, Poland)

Software for Pocket PC to Collect Road-Kill Data (Marcel Huijser, Western Transportation Institute - Montana State University, USA)

Wildlife Crossings Toolkit: A Comprehensive Online Source of Information on Wildlife and Highways (Sandra Jacobsen, USDA Forest Service, USA)

1:30-3:00 **Session 7B: Streamlining in Washington State — International Ballroom (Riviera thru Monte Carlo)**

Moderator: Debra Nelson, New York State DOT, USA

Transportation Permit Efficiency and Accountability Committee (Barbara Aberle, Washington State DOT, USA)

Use of a Multi-Agency Permitting Team (Christina Martinez, Washington State DOT, USA)

Web-Based Permitting in Washington (Scott Boettcher, Washington State Department of Ecology, USA)

WSDOT Programmatic Permit Program (Marion Carey, Washington State DOT, USA)

3:00-3:30 **Break — Foyer**

3:30-5:00 **Session 8B: Context Sensitive Solutions: Integrating Community Values with Conservation Objectives — International Ballroom (Riviera thru Monte Carlo)**

Moderator: Bill Ruediger (Retired), USDA Forest Service, USA

Improving Mobility for Wildlife and People: Transportation Planning for Habitat Connectivity in Washington State (Paul Wagner, Washington State DOT, USA)

Connecting Values, Process and Project Design: Twinning the Trans-Canada Highway in Banff National Park of Canada (Terry McGuire, Parks Canada, Canada)

Environmental Imperatives and the Engineering Interface: How to Make Hard Decisions (Martin Jalkotzy, Golder Associates, Ltd., Canada)

Case Study in Context Sensitive Design in Transportation Planning (Kenneth Deats, McCormick Taylor, Inc., USA)

6:00-10:00 **Integrating California's Transportation Planning and Wildlife Conservation Strategy: Workshop and Dinner Meeting — Portofino (By Invitation Only)**
(Sponsored by Defenders of Wildlife)

Defenders of Wildlife host a by-invitation-only dinner workshop to discuss the integration of California's wildlife conservation strategy and transportation planning process. For more information, contact Trisha White at twhite@defenders.org.

Wednesday, August 31, 2005

7:00-8:00 **Coffee/Muffin To-Go Station — Foyer**
Pick up box lunches for field trips
Board buses

8:00-5:00 **FIELD TRIPS: Organized and hosted by Caltrans**

Transportation Challenges in Coastal San Diego County
(Field Trip Option #1)

This trip begins with a stop at the South Bay Unit of the San Diego National Wildlife Refuge.
With 90-100% of submerged lands, inter-tidal mudflats, and salt marshes eliminated in the north and central San Diego Bay, the South San Diego Bay refuge, dedicated in 1999, will preserve and restore the remaining wetlands, mudflats, and eel grass beds to help ensure the survival of the bay's thousands of migrating and resident shorebirds and waterfowl. The bay supports numerous endangered and threatened species of plants and animals and is a vital link to other wildlife areas. All of the refuges in the San Diego Refuge Complex have been designated "Globally Important Bird Areas" by the American Bird Conservancy; the South San Diego Bay Refuge was recently designated as a Western Hemisphere Shorebird Reserve site.

The tour proceeds north along the Silver Strand, a narrow neck of land that connects the mainland to Coronado "Island" and separates San Diego Bay from the Pacific Ocean. From Coronado, the tour heads across the Bay on the Coronado Bridge, and then up the coast on I-5. This leg of the trip explores the challenges and opportunities for collaboration and stewardship on the 26-mile-long North Coast Corridor Project, and includes a picnic lunch on the beach.

Heading east, participants visit the Pilgrim Creek Mitigation Bank, which is managed by Caltrans. Returning south on I-15, participants see the effects and restoration challenges posed by the devastating 2003-04 wildfires, which were followed by the torrential rains of 2004-05.

Transportation Challenges in Inland San Diego County
(Field Trip Option #2)

This trip focuses on environmental challenges and opportunities addressed by recent transportation and mitigation projects in inland San Diego County. The tour begins in southern San Diego County with a review of two projects near the international border. This leg of the tour includes some large vernal pool mitigation sites, as well as review of design features and mitigation measures to facilitate wildlife movement in the Otay Mesa area.

The tour then heads north on SR-94, where participants see the effects and restoration challenges posed by the devastating 2003-04 wildfires. The next stop is the Rancho Jamul Ecological Reserve, operated by the California Department of Fish and Game. This site is an important component of the Multiple Species Conservation Program (MSCP) multi-habitat preserve system in southwestern San Diego County, supporting large areas of coastal sage scrub, annual grasslands and riparian habitat. The Reserve is adjacent to the Otay-Sweetwater Unit of the San Diego National Wildlife Refuge.

After a picnic lunch and tour at the Reserve, the tour heads north and east to view wetlands mitigation sites along SR-56, as well as bridges over wildlife corridors.

6:00-9:00 Mission Bay Beach Barbecue — South Poolside

<u>Thursday, September 1, 2005</u>

7:00-8:30 Continental Breakfast — Foyer

8:30-10:00 CONCURRENT SESSIONS 9A, 9B and 9C

Session 9A: Streamlining, Stewardship, and Sustainability — International Ballroom (Sorrento)

Moderator: Tom Linkous, Chair, TRB Task Force on Ecology and Transportation / Ohio Department of Natural Resources, USA

Species Conservation in Idaho: Going Beyond the Endangered Species Act (Brent Inghram, FHWA-Idaho Division, USA)

Temporal Loss of Wetlands as Justification for Higher Mitigation Ratios (Paul Garrett, FHWA Headquarters, USA)

Managing Environmental Compliance for Oregon Department of Transportation's OTIA III State Bridge Delivery Program: Many Regulations – One Framework (Zak Toledo, Oregon Bridge Delivery Partners, USA)

Addressing the "Scenic" in the Wild and Scenic River Act (Michael Hughes, RESOLVE, USA) withdrawn

Oregon Department of Transportation's OTIA III Bridge Program: 400 Bridges – One Biological Opinion (Michael Bonoff, Mason, Bruce, & Girard, Inc., USA)

Session 9B: Wildlife Crossings: Planning, Selection, Placement, and Monitoring for Effectiveness — International Ballroom (San Marino)

Moderator: Chris Servheen, U.S. Fish and Wildlife Service, University of Montana, USA

Wildlife Crossings in North America: The State of the Science and Practice (Patricia Cramer, Utah State University, USA)

How Many Days to Monitor a Wildlife Passage? Species Detection Patterns and the Estimation of Vertebrate Fauna Using Crossing Structures in a Motorway (Juan Malo, Universidad Autonoma de Madrid, Spain)

The Design, Installation and Monitoring of Safe Crossing Points for Bats on a New Highway Scheme In Wales (Stephanie Wray, Cresswell Associates, United Kingdom)

Highway Underpass Use by Large Mammals in Virginia and Factors Influencing their Effectiveness (Bridget Donaldson, Virginia Transportation Research Council, USA)

Session 9C: Animal-Vehicle Collision Prevention and Reduction — International Ballroom (Capri)

Moderator: Sandy Jacobson, USDA Forest Service, USA

Upgrading a 144km Section of Highway in Prime Moose Habitat : Where, Why and How to Reduce Moose-Vehicle Collisions (Yves Leblanc, Tecsult, Inc., Canada)

Evaluation of Highway Modifications in Reducing Key Deer Mortality Along the US 1 Corridor (Anthony Braden, Texas A&M University, USA)

What Features of the Landscape and Highway Influence Ungulate Vehicle Collisions in the Watersheds of the Central Canadian Rocky Mountains? A Fine-Scale Perspective (Kari Gunson, Parks Canada, Canada)

A Probabilistic Approach to Estimating Road Lethality (John Waller, National Park Service, USA)

10:00-10:30 **Break — Foyer**

10:30-12:00 **CONCURRENT SESSIONS 10A, 10B and 10C**

Session 10A: Integrating Transportation and Resource Conservation Planning: Conservation Planning — International Ballroom (Sorrento)

Moderator: Trisha White, Defenders of Wildlife, USA

The Missing Linkages Project: Restoring Wildland Connectivity to Southern California (Wayne Spencer, Conservation Biology Institute, USA)

Linking Colorado's Landscapes (Julia Kintsch, Southern Rockies Ecosystem Project, USA)

Incorporating Results from the Prioritized "Ecological Hotspots" Model into the Efficient Transportation Decision Making (ETDM) Process in Florida (Daniel Smith, University of Central Florida, USA)

The Swiss Defragmentation Programm (Marguerite Trocmé, Swiss Agency for the Environment, Switzerland)

Session 10B: Wildlife Impacts and Conservation Solutions: Small Mammals — International Ballroom (San Marino)

Moderator: Stephanie Stoermer, FHWA-California Division, USA

Addressing Habitat Fragmentation Impacts from Construction of a New Highway (Marion Carey, Washington State DOT, USA)

Modeling the Effect of Roads and other Disturbances on Wildlife Populations in the Peri-Urban Environment to Facilitate Long-Term Viability (Daniel Ramp, University of New South Wales, Australia)

Walking at Height (Hans Bekker, Ministry of Transport, The Netherlands)

Effectiveness of Rope Bridge Overpasses and Faunal Underpasses in Providing Connectivity for Rainforest Fauna (Miriam Goosem, Rainforest CRC, Australia)

Session 10C: Animal-Vehicle Collision Prevention and Reduction — International Ballroom (Capri)

Moderator: Chris Servheen, U.S. Fish and Wildlife Service, University of Montana, USA

OPTIFLUX : A Tool for Measuring Wild Animal Population Fluxes for the Optimization of Road Infrastructures (Philippe Thievent, SCETAUROUTE - Groupe EGIS, France)

Use of Video Surveillance to Assess Wildlife Behavior and Use of Wildlife Underpasses in Arizona (Jeffrey Gagnon, Arizona Game and Fish Department, USA)

Effects of Gender on Spatial and Temporal Patterns of Deer-Vehicle Collisions (Laura Daugherty, Juniata College, USA)

Reliability of the Animal Detection System Along HWY 191 in Yellowstone National Park, MT (Marcel Huijser, WTI-Montana State University, USA)

Use of GPS Telemetry to Assess Elk Highway Permeability and Compare Highway Crossing and Elk-Vehicle Collision Patterns (Norris Dodd, Arizona Game and Fish Department, USA)

12:00-1:30 **Keynote Luncheon — International Ballroom (Riviera thru St. Tropez)**
(Sponsored by Electrobraid Fence, Inc., and the MRUTC Deer-Vehicle Crash Information Clearinghouse and Sand County Foundation)

Facilitator: Sheila Mone, Caltrans, USA

Featured Speaker: Dr. Bruce Leeson, Senior Environmental Assessment Scientist, Parks Canada - Western Service Centre (Calgary)

Topic: "Beauty and the Beast - Human Dimensions in Ecology and Transportation"

Dr. Bruce Leeson will describe the lessons learned in thirty years of planning and building a highway for people and wildlife in Banff National Park, where the human factors of this undertaking posed far greater challenges than either the ecological science or engineering elements.

1:30-5:00 **Poster Session — Mediterranean Ballroom (Las Palmas thru Portofino)**

The Aftermath of Hurricane Ivan – Reconstructing Roadways While Recovering Species (Mary Mittiga, U.S. Fish and Wildlife Service, USA)

Arizona Wildlife Linkages (Siobhan Nordhaugen, ADOT Natural Resources Management Section, USA)

Integrated Training Course for Engineers and Wildlife Biologists (Sandra Jacobson, Wildlife Biologist, USDA Forest Service, USA)

Use and Selection of Highway Bridges by Rafinesque's Big-Eared Bats in South Carolina (Frances Bennett, Institute of Environmental Toxicology, USA)

Inferring White-Tailed Deer Population Trends from Wildlife Collisions in the City Of Ottawa, Ontario (Kerri Widenmaier, Canada)

Highway Crossing Structures for Metropolitan Portland's Wildlife (Linda Anderson, Portland State University, USA)

How to Teach a Mule Deer to Safely Cross an Interstate? Preliminary Results of a Wildlife Mortality Mitigation Strategy on Interstate 15 in Utah, USA (Silvia Rosa, USGS Utah Coop. Fish and Wildlife Research Unit, Utah State University, USA)

Spatial Patterns of Road Kills: A Case Study in Southern Portugal (Fernando Ascensão, Universidade de Évora, Portugal)

Ledges to Nowhere - Structure to Habitat Transitions (Stephen Tonjes, Florida Department of Transportation, USA)

Controlling White-Tailed Deer Intrusions with Electric Fence and Mat (Thomas Seamans, USDA/APHIS/Wildlife Services/NWRC-Ohio Field Station, USA)

A Decision Tool for Mitigating Roads for Wildlife: The NCHRP 25-27 Project (John Bissonette, USGS Utah Cooperative Fish and Wildlife Research Unit, Utah State University, USA)

Thinking Outside the Marketplace: A Biologically Based Approach to Reducing Deer-Vehicle Collisions (Gino J. D'Angelo, University of Georgia, USA)

Quantifying and Mitigating the Barrier Effect of Roads and Traffic on Australian Wildlife (Jody Taylor and Silvana Cesarini, Australian Research Centre for Urban Ecology, Australia)

Using Remote Sensing Cameras and Track Surveys to Assess Wildlife Movement Through a Probable Wildlife Linkage Bisected by Two Major Highways (Janice Przybyl, Wildlife Monitoring Program Coordinator, Sky Island Alliance, USA)

Citizen Science and Wildlife Crossing Locations Along Highway 3 in the Crowsnest Pass of Southwestern Alberta (Tracy Lee, Research Associate, Miistakis Institute, Canada)

National Implications of Regional Deer-Vehicle Crash Data Collection, Management, and Trends (Keith Knapp, University of Wisconsin – Madison, USA)

Citizen Monitoring of Decommissioned Roads in the Clearwater National Forest (Katherine Court, Graduate Student, University of Montana, USA)

Landscape Ecology in Transportation Planning (Patricia McQueary, Washington State DOT-SCR, USA)

Habitat Restoration Plan and Programmatic Biological Assessment for Potamilus capax (Green 1832) in Arkansas (Alan Christian, Environmental Sciences Program, Arkansas State University, USA)

Monitoring of Wildife Crossing Structures on Irish National Road Schemes (Lisa M. J. Dolan, University College Cork, Ireland)

Wildlife Hotspots Along Highways in Northwestern Oregon (Melinda Trask, Oregon Department of Transportation, USA)

I-90 Snoqualmie Pass East Project: Linking Communities in the Natural and Built Environment (Jason Smith and Randall Giles, Washington State Department of Transportation, USA)

1:30-3:00 **Session 11B: Integrating Transportation and Resource Conservation Planning: Landscapes & Road Networks — International Ballroom (San Marino)**

Moderator: Joe Burns, U.S. Fish and Wildlife Service, USA

Corridor Analysis for Transportation and Environmental Planning via Land Cover Mapping and Species Distribution Modeling (Michael McCoy, University of California at Davis, USA)

Does the Configuration of Road Networks Influence the Degree to which Roads Affect Wildlife Populations? (Jochen Jaeger, Swiss Federal Institute of Technology, Switzerland)

Integrating Traffic, Network Location, and Surrounding Habitat to Create a Connected Landscape (Richard T.T. Forman, Harvard University, USA)

The Ecologically Ideal Road Density for Small Islands: The Case of Kinmen, Taiwan (Shyh-Chyang Lin, National Kinmen Institute of Technology, Taiwan)

3:00-3:30 **Break — Foyer**

3:30-5:00 **Session 12B: Wildlife Crossings: Planning, Selection, Placement, and Monitoring for Effectiveness — International Ballroom (San Marino)**

Moderator: Vicki Sharpe, Florida DOT, USA

How Far into a Forest Does the Effect of a Road Extend? Defining Road Edge Effect in Temperate Australia (Zoe Pocock, Victoria, Australia)

Ecological Impacts of SR 200 on the Ross Prairie Ecosystem (Daniel Smith, University of Central Florida, USA)

Railroad Crossing Structures for Spotted Turtles (Steven Pelletier, Woodlot Alternatives, Inc., USA)

Spotted Turtle Use of a Culvert under Relocated Route 44 in Carver, Massachusetts (Kevin Walsh, Vanasse Hangen Brustlin, Inc., USA; presenting for Delia Kaye)

Friday, September 2, 2005

7:00-8:30 **Continental Breakfast — Foyer**

8:30-10:00 **CONCURRENT SESSIONS 13A and 13B**

Session 13A: Integrating Transportation and Resource Conservation Planning: Science and Partnerships — International Ballroom (Sorrento thru Capri)

Moderator: Hans Bekker, Ministry of Transport, The Netherlands

A GIS-Based Identification of Potentially Significant Wildlife Linkage Habitats Associated with Roads in Vermont (Kevin Viani, Vermont Fish and Wildlife Department, USA)

Connecting Transportation and Wildlife Habitat Linkages Through Partnerships, Planning and Science Near Los Angeles, California (Ray Sauvajot, National Park Service, USA)

Sierraville (California) Highway 89 Stewardship Team: Ahead of the Curve (Sandra Jacobson, USDA Forest Service, USA)

Washington State DOT Highway Maintenance: Environmental Compliance for Protected Terrestrial Species (Tracie Caslin, Washington State DOT, USA)

Session 13B: Wildlife Ecology and High Speed Rail — International Ballroom (Riviera) (Sponsored by Defenders of Wildlife)

Moderator: Cynthia Wilkerson, Defenders of Wildlife, USA

This session presents general ecological impacts of High Speed Rail, with a focus on both postive elements and drawbacks. An overview of the California High Speed Rail Proposal is presented and several perspectives on this proposal explores various implications. The session culminates with a moderated panel discussion, including the audience, regarding the California proposal.

Presenters include:

Bill Gallagher, Rail Operations Consultant, Palm Springs, CA, USA

Dick Cameron, Senior Conservation Planner, The Nature Conservancy, San Francisco, CA, USA

Kristeen Penrod, Executive Director, South Coast Wildlands Project, Idyllwild, CA, USA

10:00-10:30 **Break — Foyer**

10:30-11:30 **Session 14: Research and Resources: What's Coming Up? — International Ballroom (Sorrento thru Capri)**

Facilitator: Alison Berry, UC-Davis Road Ecology Center, USA

Federal Resource Guide. Eco-Logical: An Ecosystems Approach to Infrastructure Projects (Tom Pettigrew, USDA Forest Service, USA)

National Academy of Sciences Report. Assessing and Managing the Ecological Impacts of Paved Roads (Paul Wagner, Washington State DOT, USA)

National Highway Institute Course. Stream Impacts and Restoration (Paul Garrett, FHWA Headquarters, USA)

11:30-12:00 **Session 15: Conference Wrap-Up, Session Highlights -- International Ballroom (Sorrento thru Capri)**

Facilitator: Leroy Irwin, Conference Chair

12:00 noon **ICOET 2005 Adjourns**

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