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Publication Date
2005-08-29

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.