Conservation Value of Wildlife Crossings: Measures of Performance and Research Directions

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Is it sufficient to state that wildlife crossings are functional if animals use them? Novel approaches to measuring function and performance of crossing structures go beyond this simple cognition. They look into the effects on different species and higher taxa and they account for the impact of different locations and landscapes.

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Abstract

In the last ten years, there has been a surge of interest in the ecological effects of roads on landscape ecology and in devising means of reducing road impacts on wildlife populations. The number of wildlife crossings built in North America and worldwide has increased during the last decade and their design and performance as mitigation measures has received considerable attention. In this paper I will discuss current approaches to restoring connectivity across roads with wildlife crossing structures. Once in place, wildlife crossings must be monitored and evaluated to determine their conservation value and ecological performance. I discuss some guiding principles for planning and measuring performance of mitigation crossings for wildlife that consider a range of ecological goals, time-frames, and changes in landscape conditions. Last, cost-effective designs and integrated planning are seen as important areas to make significant advances in designing sustainable transport systems.

Keywords

ecological network, habitat fragmentation, integrated planning, landscape context, mitigation measures, monitoring, road ecology, wildlife crossings

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Over the last decade, federal land management and transportation agencies in North America have become aware of the effects that roads have on wildlife. For an overview of the effects of habitat fragmentation, see Jaeger et al. (2005, in this issue). Despite significant advances in our understanding, the means to adequately mitigate these impacts have been slower in coming (Transportation Research Board 2002). To mitigate habitat fragmentation and reduce the number of animal-vehicle collisions, there is a need to provide transportation agencies with guidance on the use and effectiveness of wildlife crossings. Approximately 200 highway passages have specifically been built for wildlife in North America (Evink 2002), yet most engineers and land managers lack guiding principles for functional designs based on criteria that are relevant to real conservation decisions. Rarely are there monitoring programs planned or budgeted post-construction (Hardy et al. 2003).

In this paper, I discuss the means of restoring landscape connectivity across roads with wildlife crossings, describe general guidelines for monitoring performance, and identify knowledge gaps.

Function and Performance

Habitat patches of similar suitable habitat linked by a corridor are likely to have greater conservation value than isolated fragments of similar size (Diamond 1975). Wildlife crossings are designed to link critical habitats and provide safe movement of animals across busy roads (see figures). Typically they are combined with fencing and together are proven measures to reduce road-related mortality of wildlife and restore movements (Clevenger et al. 2001). The first crossing structure in the United States designed for wildlife was built in northern Florida nearly 50 years ago. Since then, many more have been built in North America and worldwide (McGuire and Morrall 2000, Goosem et al. 2001). The *US Transportation Equity Acts (TEA)* of the last decade have enabled mitigation passages to be part of the early stages of highway project planning (US Department of Transportation 1999).

Until now, the general idea of how well a crossing performs has not gone far beyond the simplest level of scrutiny – if animals use it, then it must be functional. There are many interpretations of what functional wildlife crossings should do. Wildlife crossings and fencing should reduce the impact of roads to a level allowing maintenance or restoration of basic ecological processes and functions within their historic range of variability. Measures that promote movement across road barriers enhance population viability and likelihood of recolonization (Beier and Noss 1998, Van der Grift 2005, in this issue). Even skeptics will agree that most wildlife passages have the potential to enhance population viability (Hanski 1999).

Generalizations about the conservation value of habitat corridors remain elusive because of the species-specific nature of the problem (Beier and Noss 1998). Wildlife crossings tend to be evaluated for focal or target species. However, structures designed for single species may have cascading positive or negative effects on non-target species. If measures for habitat connectivity are to succeed, then it is paramount that a multi-species approach be adopted to evaluate the efficacy of such mitigation on non-target species as well. If the goal of wildlife crossings is to maintain diversity at multiple levels of biological organization (Noss 1990), then evaluating crossing structure efficacy can become quite complex.

Measuring Wildlife Crossing Performance

Even today few studies have rigorously evaluated the efficacy of mitigation passage structures (Romin and Bissonette 1996). Most studies have simply described the number of species using crossings and frequency of use (Foster and Humphrey 1995). Others have identified factors that facilitate passage by wildlife (Rodríguez et al. 1996) and only few have actually measured performance of mitigation in meeting design goals (Woods 1990). I am not aware of any studies that have empirically addressed whether wildlife crossings enhance the population viability of species impacted by roads.

Small sampling windows, typical of one- or two-year monitoring programs, generally fail to take into account that adaptation periods can take several years – depending on the species as they experience, learn and adjust their behaviour to the wildlife crossings (Opdam 1997, Clevenger et al. 2002). Lately, more rigorous study designs include a pre-construction versus post-construction comparison of animal movements across highways or using a before-after-control-impact (BACI) study design (Van Manen et al. 2001).

Assignment testing is a novel genetically based approach to testing primarily barrier effects (e.g. by highways), but also could be used to test whether mitigation measures are aiding animal movement and connectivity (Luikart and England 1999). By measuring movement or dispersal rate of animals between populations or across the landscape, assignment tests can yield information on the impact of barriers on animal movements (Proctor 2003). Repetition at intervals can show if the barrier effect is decreasing or increasing over time (e.g. pre- versus post-mitigation). Hardy et al. (2003) provide a review of methods used to evaluate wildlife crossings.

Measuring the Conservation Value

Some preliminary guidelines have been developed to monitor the function of wildlife crossings and assess their conservation value (see Forman et al. 2003, figure 6.8). The criteria used to measure function or conservation value, however, will depend on the intended purpose of the crossing(s) and the biological or taxonomic level of organization of concern. Goals can range from simple, single species to more complex ecological processes and functions.

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TABLE: Indicators to monitor the conservation value of wildlife crossing systems. Ecosystem complexity increases from top to bottom.

ecosystem function achieved	level of biological organization targeted [a]	level of connectivity [b]	cost and duration of research required [c]
movement within populations and genetic interchange	genetic	genetic	low cost – short-term
ensure that the biological requirements of finding food, cover and mates are met	species-population	demographic	moderate-to-high cost – long-term
dispersal from maternal ranges and recolonization after long absences	species-population	functional	moderate-to-high cost – long-term
populations to move in response to environmental changes and natural disasters	ecosystem-community	functional	high cost – long-term
long-term maintenance of metapopulations, community stability, and ecosystem processes	ecosystem-community	functional	high cost – long-term

a See Noss 1990.

b Genetic: predominantly adult male movement across road barriers; demographic: genetic connectivity with confirmed adult female movement across road barriers; functional: genetic and demographic connectivity with confirmed dispersal of young females that survive and reproduce.

c Based on studies of large mammals; cost and duration will largely be dependent upon area requirements, population densities, and reproductive rates.

I suggest using a hierarchical approach to identify specific, measurable indicators to monitor the performance, function, and conservation value of wildlife crossing systems (see table). Crossings that function as habitat or landscape connectors should allow for essential ecosystem functions as listed in the table. The hierarchy concept suggests that biological diversity be monitored at multiple levels of organization and at multiple spatial and temporal scales (Noss 1990). However, no single component is essential, and different levels of resolution will be appropriate for different mitigation assessment questions.

Levels of Biological Organization

Genetic Level

Both inbreeding and genetic drift are countered by movement between populations – and therefore when connectivity is guaranteed (Hanski 1999). It has been suggested that once connectivity is restored, it takes relatively little exchange between populations to maintain genetic diversity (Vucetich and Waite 2001). However, a scientific understanding of how much connectivity is necessary and what imposes a barrier to connectivity is difficult to attain. Connectivity can be achieved several ways that translate to varying levels of population viability: genetic, demographic and functional connectivity (see table). Predominantly male movement across potential road barriers would suggest that genetic connectivity is being maintained, but demographic connectivity may be fractured if female movement is limited. Functional connectivity can be achieved, however, if females were able to move freely and disperse across road barriers; particularly dispersing young females that eventually survive and reproduce. Future research focusing on employing new methods such as DNA-based techniques and satellite technology may answer some of the connectivity questions raised (see Manel et al. 2003).

Species-Population Level

Effective mitigation should allow animals to travel, migrate and meet their life requisites (Bennett 1999). If crossings do not provide this service (when compared to control areas), there will likely be differences in relative population abundance (lowered), population structure (skewed sex- and age-ratios), migratory patterns (obstructed or filtered), and a suite of demographic processes (decreased natality, recruitment, survivorship, and increased mortality). Animal physiology (nutrition, stress) might also be affected in situations with suboptimal mitigation (Wasser et al. 1997).

If crossings fail to facilitate normal movement patterns, metapopulation dynamics might be altered, affecting genetic structure of populations in the area (see chapter *Genetic Level* above). Crossings should help maintain true populations or metapopulations by facilitating dispersal and recolonization after local extinctions. Last, effective crossings should allow populations to shift distributions if affected by landscape stressors, such as natural disasters and environmental change.

Demonstrating that species are affected at the population level will require a substantial time and funding commitment, particularly if focused on wide-ranging, elusive large carnivores. Long-

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Both photos display wildlife crossings on the Trans-Canada Highway in the Banff-Bow Valley, Canadian Rocky Mountains. 16 meter wide open span wildlife underpass, built in 2004.

Metal culvert underpass, four meters in diameter and built in 1983.

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term monitoring will be required in addition to co-lateral studies of wildlife populations residing in the transportation corridor. Large mammals will not be suitable focal species of study because of their demographic characteristics and sample size limitations. Studies could be designed to monitor animal movements in paired treatment and control areas pre- and post-construction, a type of BACI experiment (Underwood 1997). However, randomization and replication of experimental units is difficult with studies of this type, and there are many controlling or confounding factors to contend with even in a replicated study.

DNA profiling of individuals using wildlife crossings is a promising technique that could be carried out in a relatively short period of two to three years (Foran et al. 1997). Hair-sampling at wildlife crossings would provide not only information on the number of individuals using them, but also key demographic parameters needed for population viability analysis (sex- and age-class, genetic relatedness, dispersal, seasonality of use, behavioural traits). Modelling population viability by linking GIS-generated landscape data with species demographic data can aid to evaluate the role of crossing mitigation in stabilizing and maintaining animal populations (Larson et al. 2004, Frank et al. 2005, in this issue, Van der Grift 2005, in this issue).

Community-Ecosystem Level

Perhaps the ultimate test of wildlife crossing function is whether communities and ecosystem processes can be maintained over the long term, e.g. herbivores being able to access foraging areas; predators accessing prey species; sustaining plant-animal interactions including seed dispersal and pollen movement (see table). This might be interpreted as a litmus test to indicate whether ecological processes have been maintained and not impaired by substandard mitigation. Studies have shown that roads are capable of altering ecosystem functions. The effects of roads on hydrology have been the focus of many studies. Changes in hydrology affect ecosystem processes such as primary productivity, decomposition, nutrient cycling, and disturbance regimes, e.g. flooding frequency and intensity (Swanson et al. 1988).

The fragmentation effects of roads can strongly influence the distribution and land use patterns of wide-ranging and migratory wildlife (Noss et al. 1996, Berger 2004). Research should be conducted to critically examine if roads effectively impede access to foraging areas or key prey species, which might result in cascading effects to other trophic levels (Berger et al. 2001). At this level of organization, wildlife crossings should contribute to the long-term maintenance of metapopulations, by allowing for dispersal and other movements necessary to sustain viable populations. Wildlife communities should be stable, and ecosystem processes maintained or restored. Indicators such as these will require continuous monitoring to assess how wildlife crossings perform in maintaining natural processes and flows across a fragmented landscape.

Mitigation Planning

When planning, designing and evaluating wildlife crossings, it is important to remember that every mitigation scheme is different, and it is difficult to extrapolate results or expectations across political boundaries or landscapes. Each mitigation scheme has their own set of faunal components, connectivity concerns and land management priorities. Mitigation schemes may be vastly different between adjacent watersheds. These landscape-specific

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issues need to be taken into consideration during the planning process and will play a large role in devising guidelines for effective measures.

Our research has shown that species respond differently to wildlife crossing structure designs and adjacent landscape features, therefore mitigation planning in a multiple-species ecosystem will not be a simple task (Clevenger and Waltho 2000, Clevenger and Waltho 2005). No individual crossing structure design fits all (see figures). Further, the crossings will only be as effective as the land and resource management strategies around them. For crossings to fulfill their function, mitigation strategies need to be contemplated at two levels. At the local level, impacts from development and human activity near crossing structures will decrease habitat quality and likely disturb animal movements, particularly predators (Rodríguez et al. 1996, Clevenger and Waltho 2000). Similarly, large-scale habitat disturbance could impede or obstruct movements towards the structures, preventing animals from using them entirely, thus rendering them ineffective. Mitigating highways for wildlife is a long-term process that will last for many decades and affect individuals and populations alike (Opdam 1997). Thus, mitigation strategies developed around land-use planning should not terminate with the construction process, but need to be proactive at both scales to ensure that crossings remain functional over time.

An important point to remember in the planning process is that wildlife crossings will be permanently imbedded in the landscape, but the ecological processes going on around them are dynamic. The physical structure of a crossing will remain in place for the next 50 years or more. However, wildlife populations will undoubtedly vary geographically and fluctuate in number during this time. For crossings to be effective over the long term, they will have to be able to accommodate the fluctuations in species, their demographics, variances in animal behaviour, while maintaining viable populations around them.

An Emerging Science

Research on the impact of road systems on wildlife and remedial actions to counter these effects is an emerging science. Basic information exists, but alongside these valuable kernels of information, gaps in our knowledge of planning and designing functional wildlife crossings remain.

Guiding Principles

The level of wildlife crossing use varies between species, higher taxa, locations and landscapes, and the reasons why are unclear (Transportation Research Board 2002). Recommended minimum dimensions have been suggested for some ungulate species (Foster and Humphrey 1995, Ballon 1985), but the needs of wide-ranging, fragmentation-sensitive species are vague (Forman et al. 2003). Human activity and traffic noise can significantly influence passage use (Clevenger and Waltho 2000, Clevenger and Waltho 2005). Other studies have inferred that the location of a crossing, particularly in relation to habitat quality, might be the most important feature (Foster and Humphrey 1995, Rodríguez et al. 1996). It will be essential to determine how long to monitor post-construction in order to accurately evaluate wildlife crossing function and species use patterns. Biological and physical elements play an important role in crossing use. Some research suggests that predator use of crossings may influence how prey species use passages. Last, numerous methods of identifying wildlife crossing placement have appeared, yet a critical review is needed with respect to scale, accuracy of data input, reliability or validity testing of model, advantages, limitations, means of improving process, recommended future applications.

Cost-Effectiveness

Wildlife crossings are expensive. Generally, cost benefits rather than ecological benefits strongly influence crossing design. Previous design plans are typically passed on to new projects, as are estimated costs (adjusted for inflation), without any consideration for breaking old templates and creating new, innovative, cost-effective wildlife crossing structure designs and concepts. There is an urgent need for research and development into novel crossing designs that meet all the necessary technical and ecological requirements (legal transportation standards and biological criteria), but are less costly than current crossing structure designs.

Vision for the Future

The goal for preserving animal populations should be part of a management framework designed to restore or maintain ecosystem processes and functions. Transportation agencies have recognized that early stakeholder involvement and identification of issues and areas of concern is essential if their projects are to be environmentally sustainable. Recent developments in large-scale, GIS-based information for transportation planning and mapping of priority habitat areas are providing an opportunity to coordinate ecological and transportation networks at multiple scales.

The marrying of transportation and ecological network planning makes good ecological sense. Integrating these plans would help ensure that habitat conservation and connectivity concerns appear at the beginning of the planning process and guide transportation and land management actions. Looking at the broader picture instead of reacting to a specific project is certainly a novel approach for transportation practitioners. Mapping ecological and transportation corridors will help better understand stakeholder concerns, prioritize agency objectives, and incorporate landscape patterns and processes in the planning and construction process. An effort of this type would greatly enhance interagency collaboration while working toward a common goal – sustainable surface transportation.

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