AN OVERVIEW OF METHODS AND APPROACHES FOR EVALUATING THE EFFECTIVENESS OF WILDLIFE CROSSING STRUCTURES: EMPHASIZING THE SCIENCE IN APPLIED SCIENCE

Amanda Hardy, Western Transportation Institute, 416 Cobleigh Hall, Montana State University, Bozeman, MT 59717 USA

Anthony P. Clevenger, Western Transportation Institute, 416 Cobleigh Hall, Montana State University, Bozeman, MT 59717 USA and Faculty of Environmental Design, University of Calgary, Calgary, Alberta T2N 1N4 Canada

Marcel Huijser, Western Transportation Institute, 416 Cobleigh Hall, Montana State University, Bozeman, MT 59717 USA

Graham Neale, Garcia and Associates, 7550 Shedhorn Drive, Bozeman, MT 59715

Abstract: Human activities today often cause landscape habitat fragmentation and blockage of wildlife movements across landscapes and ecosystems. North American and European Union initiatives such as the Transportation Equity Act and COST-341 program have heightened the importance of mitigating the negative effects of roads, such as animal-vehicle collisions and barrier effects. Wildlife crossing structures are being incorporated into some road construction and improvement projects in an attempt to reduce negative effects on wildlife populations. Transportation and resource agencies are becoming increasingly accountable and therefore concerned as to whether highway mitigation measures are functional and perform to expected standards. However, there are presently gaps in our knowledge regarding the effectiveness of wildlife crossings structure applications. One reason for the lack of available information is that relatively few mitigation projects implement rigid monitoring programs with sufficient experimental design. Thus, results obtained from most studies remain anecdotal or descriptive at best. With sufficient lead-time, experimental study designs can provide rigorous assessments of highway impacts and wildlife crossing structure performance pre- versus post-construction. Alternative methods of post-construction assessment can be used if time does not permit for data collection during the pre-construction period. We review past and current methods used to evaluate wildlife crossing structures and examine criteria to consider when evaluating wildlife passage effectiveness. We focus on methods to monitor mammals and summarize representative studies published international journals and conference proceedings. We examine pre- and post-mitigation study designs versus evaluations that base effectiveness solely on post-mitigation monitoring. We make suggestions for conducting quality scientific evaluations that will allow transportation agencies to address the question, “Do wildlife crossing structures work?”

Introduction

Highways have direct and indirect effects on wildlife and natural habitats. Animal-vehicle collisions (AVCs) and fragmentation of habitats present safety and ecological concerns that are gaining attention from departments of transportation, resource agencies, and the public. As highway infrastructure is improved or expanded, many stakeholders want to know how to best reduce these negative effects. A variety of approaches to mitigating road impacts on wildlife have been applied in North America, but conclusive information about the effectiveness of these mitigation measures is minimal (Clevenger and Waltho 2000, Evink 2002, Forman et al. 2002).

Wildlife underpasses and overpasses (hereafter referred to as “crossing structures”) in combination with wildlife fencing have received increasing consideration over the last decade as a potential mitigation measure to reduce road effects on wildlife. These measures can result in a safer road by keeping animals off the road and can also reduce the barrier effect of roads as they allow animals to pass safely under or over the road. On a landscape level, crossing structures can help to restore, maintain or increase wildlife connectivity between core areas for a wide variety of species. Incorporating crossing structures into transportation projects also may also facilitate faster environmental regulatory approvals, streamlining the transportation planning process. These potential outcomes will likely vary from one project to another, and there are significant gaps in our understanding of how to best apply crossing structure mitigation. Scientific monitoring approaches can help close these gaps.

When a wildlife crossing structure is installed, there is an opportunity to assess performance and further contribute to this field of applied science in an adaptive management process. However, monitoring of crossing structures is rarely performed or is an after-thought resulting in little or no statistically valid data to rigorously investigate effectiveness of the mitigation measures. It is necessary to *apply science* systematically if we are to learn if our efforts actually do what they are intended to do.

We provide an overview of various considerations for practitioners initially embarking on an evaluation of wildlife crossing structures. We outline steps, methods, and study design issues and summarize options to fit various research questions, budgets, and timelines. Our intent is to encourage transportation agencies to incorporate rigorous evaluations into wildlife crossing structure deployment projects in order to address the inevitable question that follows such installations: “Do these things work?”

Objectives

The goal of this paper is to summarize steps and methods used to evaluate the effectiveness of wildlife crossing structures. Specific objectives of this paper are to:

- Outline steps for conducting quality evaluations of wildlife crossing structures
- Propose levels of ecological and engineering criteria to consider when evaluating wildlife crossing structure effectiveness
- Summarize methods to monitor medium and large mammal use of wildlife crossing structures
- Review elements of rigorous study design approaches
- Support the above objectives with examples that demonstrates successful application of exemplary monitoring and research approaches

We compile this review of information to help practitioners incorporate good science into their evaluations to yield valid and useful results. This review provides practical suggestions and examples for consideration when making initial efforts to conduct an evaluation of mitigation measures. This paper is not a substitute for the literature search that is necessary when beginning a study, but can serve as a stepping-stone to lead one to valuable resources.

Evaluation Planning Steps

There are several steps to consider when planning an evaluation of the effectiveness of wildlife crossing structure installations. Following these steps, one can identify an approach that fits the project, budget, and questions of interest. Basic steps for planning an evaluation are listed below, followed by further discussion of each step:

1. Identify evaluation questions and definitions of effectiveness
2. Identify methods to measure effectiveness
3. Design monitoring program
4. Pilot methods, adjust to meet goals, project budgets
5. Collect data for evaluation
6. Analyze data to determine effectiveness
7. Report results

This is a simplified list of steps in the process; Ratti and Garton (1996) offer a detailed systematic outline of sequential events for conducting scientific research.

Step 1: Identify Evaluation Questions and Definitions of Effectiveness

This step forms the foundation of any evaluation or research project. Identifying clear and concise evaluation questions will serve to guide one through the remaining steps. Once the research questions are identified, they will be tied directly to the project’s objectives, providing specific reasons for the work. To keep on task, it is helpful to continually return to the identified research questions and ask if the direction of the evaluation truly addresses what you set out to accomplish.

There are a number of questions one might consider when setting out to evaluate a wildlife crossing structure installation. Evaluation questions might focus on the following relevant issues:

- Motorist safety and animal-vehicle collisions
- Ecological impacts of mortalities and the “barrier effect” due to roads and traffic:
    - on individual animals
    - on a specific species
    - on populations of animals
    - on ecological communities and biodiversity
    - on ecosystem processes and functional landscape integrity

This list of issues is outlined in an order of increasing complexity. The most basic evaluation of crossing structures will address the first two issues: Do crossing structures reduce animal-vehicle collisions and allow animals to move across roads? It is important to address these two questions together; if we only consider the mitigation’s effect on animal-vehicle collisions, we fail to address the effect that the road and mitigation measures may have on animal movements across on the landscape. If we were only concerned with animal-vehicle collisions, we would install and evaluate wildlife exclusion fencing along roads with no crossing structures. But because the negative effects of habitat fragmentation have been well documented (Forman et al. 2002), we include crossing structures under or over roads in an effort to make the road more "permeable" to wildlife movements. Therefore, this feature of the installation should also be evaluated in terms of animal crossing events.

The more complex research questions included in the above list are important to understanding the long-term and large-scale effectiveness of crossing structures in terms of populations, communities, biodiversity, ecosystem processes, and landscape ecology. There is a need to address how crossing structures affect populations of animals in terms of survivorship, recruitment and dispersal of juveniles, physical condition, short-term and long-term reproductive rates, sex ratios, and genetic exchange. These questions typically require greater time commitment and financial support, as long-term monitoring will be required in addition to co-lateral studies of wildlife populations residing in the transportation corridor. Information of this type takes many years (≥10 yrs) before even beginning to suggest preliminary results (Clevenger et al. 2002, Clevenger and Waltho 2003, Stephens et al. 2003). If crossing structures have not fulfilled their function as habitat connectors and movements are obstructed, individuals and populations become isolated, resulting in reduced breeding opportunities, skewed sex ratios, use of suboptimal habitat and decreased individual fitness, and reduced population survival probability. Effective crossing structures must allow for subadult dispersal out of maternal ranges and areas to be recolonized after long absences or local extinctions (Beier and Noss 1998). Information to verify the above is difficult to obtain and requires long-term studies, especially for long-lived, slow-reproducing species that occur in low population densities, such as grizzly bears (Proctor 2003).

Perhaps the ultimate test of crossing structure function is whether ecosystem processes can be maintained over the long term. Evaluation questions addressing this level of ecological complexity may examine how crossing structures affect habitat use (e.g., how herbivores access foraging areas), habitat quality, and predator access of prey species. Indicators such as these require many years of monitoring to assess how wildlife-crossing structures perform in maintaining natural processes and flows across a fragmented landscape. Long-term monitoring is perhaps the only means of obtaining solid, reliable information on species relationships, ecosystem processes and the functionality of crossing structures for wildlife in facilitating normal life history patterns. The fluxes and changes in human activity and development will typically need to be incorporated into these long-term and large-scale studies (Clevenger and Waltho 2000). Monitoring species' populations and critical resources in relation to human-related elements, in concordance with studies that focus specifically on wildlife use of crossing structures, will provide greater information and novel research results regarding the ecological effectiveness of wildlife crossing structures.

Once the evaluation questions are specified, it is necessary to define effectiveness relative to these questions. According to Mirriam Webster's Collegiate Dictionary (Tenth Edition), "effective" is defined as "producing a decided, decisive, or *desired effect*." The key words here are italicized to emphasize the need to decide what the desired effect will be in order to deem the wildlife crossing structure installation "effective." With the basic evaluation question, "Do crossing structures reduce animal-vehicle collisions and allow animals to cross the road?" we would evaluate if the mitigation results in (1) a reduction in animal-vehicle collisions, and (2) maintaining animal movements across the road. These are broad assertions about overall desired effects, but we suggest defining effectiveness relative to specific *a priori* goals. For example, one could state that crossing structures will be considered effective if monitoring shows (1) a 50 percent reduction in animal-vehicle collisions, and (2) a 25 percent increase in animal movements across the road. A common misconception is that mitigation measures for reducing road mortality must be 100 percent effective. This is not achievable, as motor vehicles, even on the most effectively mitigated roads, will invariably collide with animals; no fence is an absolute barrier at all times. Good goals relate to the research questions, are supported with logical reasoning and applicable literature, and are attainable and measurable. By clearly stating a priori goals that will be referenced to declare whether or not the mitigation was "effective," one can direct any debates about the results of the evaluation back to the thought processes that went into this decision.

Rarely have criteria been used to rigorously evaluate wildlife crossing structure function. One of the problems in developing a set of criteria is mutual agreement. Transportation professionals and resource managers use different terminology and will have to go through some effort in order to understand each other's needs and concerns. Both transportation and ecological issues often are more complex than one would think at first glance. Nevertheless, for future mitigation projects, we recommend that a priori criteria or indicators of mitigation effectiveness be prepared, and agreed upon by all responsible for supervising the measures' implementation and function. These indicators may be designed with some flexibility (or ranking) in terms of goal attainment and target dates, and then be refined and updated if required.

Step 2: Identify Methods to Measure Effectiveness

Selecting appropriate measures of effectiveness will occur concurrently with the next step, developing a study design for the monitoring or research project. It may take some creativity and exploration to find the right combination of methods that measure effectiveness in a workable monitoring effort and study design to conduct an effective evaluation within the time and budget constraints. Digging into relevant literature, preferably sources from peer-reviewed journals, is essential during this phase.

With well-stated evaluation questions, goals, and definitions of effectiveness, it should be fairly easy to identify what will need to be measured to complete the evaluation. Measures of effectiveness quantifiably relate to the goals, definitions of effectiveness, and research questions. If a goal is to reduce animal-vehicle collisions by 50 percent, one needs to measure animal-vehicle collisions in the area of the mitigation, before and after installation of the crossing structures and wildlife fencing. If a goal is to increase black bear movements across the road, then one needs to measure black bear movements relative to the road before and after the mitigation is applied or in treatment and control (mitigated and non-mitigated areas that are as similar as possible in all other respects. Goals related to maintaining ecological processes may require numerous integrated research projects to measure multiple variables, such as predator and prey distributions relative to habitat quality. The key is to know what the determination of effectiveness will be based upon in order to find methods that will measure these specific variables.

We list methods that have been or are being applied in wildlife crossing structure evaluations and review considerations that can help narrow your search for measures of effectiveness that fit the needs and limitations of your project. Actual costs and skills required to employ the techniques depend on the combination of methods, study design and duration, but we list these in an order that generally moves from simple, lower-cost techniques to methods that require more technical skills and funding. We provide examples, when possible, of projects that have used the methods to effectively quantify effects of roads and or mitigation measures on wildlife so the reader can access these published papers for details on how the method was applied and the consequent results.

It is also important to identify, measure, and control for confounding variables that might influence the variable of interest. For example, if there is a statistically significant reduction in animal-vehicle collisions, is it due to an effective mitigation installation, or a decrease in traffic levels, animal populations observed vehicle speeds, or increased barrier effect due to wider roads and higher traffic volumes that often result from reconstruction projects? Population data pre- and post-mitigation is important to control for any changes in wildlife abundance during the study period. We include population trend indexing methods and methods to quantify other co-variates at the end of this section.

Road-kill or vehicle collision data. The simplest and most straightforward method to assess mitigation effectiveness is that of road mortality. The costs and technical skills required for collecting road-kill or vehicle collision data can be quite low. There are sampling considerations to take into account (discussed in the next section), and variables to control (e.g., traffic levels, animal population levels), but overall, this variable is the easiest to quantify for before-after comparisons (Clevenger et al. 2002).

A statistically significant reduction in the number of road-kills pre-mitigation compared to post-mitigation indicates some level of effectiveness (final declaration of effectiveness should relate back to specifically stated *a priori* goals). If the research question is focused on public safety, measuring motor vehicle accidents (motorist injuries and mortalities) before and after mitigation measures may be more appropriate. If the goal of the mitigation is to sustain viable populations or meta-populations of a particular species of interest, it will be important to measure road-related mortality for that species. In addition, population density and the magnitude of other mortality sources for the focal species needs to be quantified as these ultimately influence a population's ability to persist over the long term (Ferreras et al. 2001, Vucetich and Waite 2001, Boyce et al. 2002).

Snow tracking, tracking beds, tracking plates. Mammal tracks can be used to document presence and movements relative to roads and mitigation measures, and, potentially, population trends (Beier and Cunningham 1996, Clevenger et al. 2002). Track data alone cannot identify absolute total numbers of different animals or distinguish between specific individuals passing through the structure, but they can be a measure of relative population density (Huijser and Bergers 2000) and relative movement rates. The method detects an animal at a fixed location by identifying tracks left after crossing a track bed or surface of soft media. For large mammals, a 2-meter-wide swath with silty or sandy soil, gypsum, or marble dust is checked for tracks and raked smooth on a regular basis. Small mammal passages are monitored using track plates with both ends of the plate "sooted" (using a torch to apply soot to a non-flammable, smooth surface) and the middle of the plate with paper (contact paper is preferable) to pick up the traversing animal's sooty footprints. When snow is present, tracks can be identified and individual animals can be tracked for longer distances (Singleton and Lehmkuhl 1999). There are numerous resources that outline tracking techniques and track identification guides for North American mammals (O.J. Murie 1974, Halfpenny and Biesiot 1986, Forrest 1988, Rezendez 1999, Stall 1989, Zielinski and Kucera 1995).

Inside culverts and crossing structures, tracking material and tracks are typically protected from wind and rain and provide fairly reliable data when checked and raked smooth on a regular basis. Track beds are often used to monitor animal passage inside crossing structures (Yanes et al. 1995, Rodriguez et al. 1996, Rosell et al. 1997, Clevenger and Waltho 2000). Track beds inside structures simply capture crossing events from sets of distinguishable species or suites of species.

Several studies have used the existing substrate alongside the highway, as described by Barnum (2001) in the southern Rocky Mountains. Scheick and Jones (1999) and van Manen et al. (2001) prepared existing media on timber and farm roads and a power line right-of-way near the highway to monitor wildlife movements relative to road projects. When using track beds that are not sheltered from the weather, the error introduced due to tracks disappearing needs to be acknowledged, and, if possible, measured.

Depending on whether tracking media is available on-site, this technique is relatively low cost and low tech, though reading and interpreting tracks requires a fair amount of skill. If attempting to document behavior through tracks, differences in interpretation between observers may introduce an "observer effect" that can add variability to the data.

Camera and video monitoring. Motion and heat-activated cameras capture images of animals, providing presence and occurrence data, similar to tracking occurrences (Kucera and Barrett 1993). One potential advantage of cameras over tracking is that individuals may be identified if they have unique markings or tags that can be seen in the images. Video monitoring also allows one to study animal behavior, including possible failed crossing attempts. Because animals are often more active during low-light periods, flashes are necessary for standard still-film cameras, and infra-red film may also work in low-light conditions. With typical triggering ranges from about 10-20m from the camera, remotely triggered cameras can be set up to capture images of animals moving along a trail or can be set up in arrays to sample larger areas. Costs vary and depending on the duration of the study; remotely triggered digital cameras may be more cost efficient than traditional film technology in the long run and video technologies vary widely.

Anecdotal information and observational data. Anecdotal information from scattered observations of animals and their movements can be used as supplemental data (Chruszcz et al. 2003), though these data must be treated differently than data that have been formally sampled. Beier and Noss (1998) discuss the value of observations of dispersing animals when assessing the efficacy corridors.

Radio-monitoring animal movements. Radio telemetry studies can produce comparative data on animal movements relative to roads and wildlife fencing and crossing structures (Chruszcz et al. 2003). Depending on the species and battery life of the radio-telemetry equipment, individuals can be followed before and after the installation. This enables researchers to detect changes in movement patterns relative to the "new landscape" that the wildlife fencing and crossing structures create (Dodd et al. 2003).

There are numerous issues to weigh when considering using radio-telemetry methods. Samuel and Fuller (1996) review general radio telemetry methodology considerations. Permits and approvals often must be obtained to deploy radio collars or tags, because it involves capturing, immobilizing and handling animals. Experienced biologists with considerable technical skills are needed to accomplish this task. Once subjects are tagged or collared, monitoring of VHF radio transmitters requires field technicians to repeatedly locate and triangulate azimuths to estimate the collared animals' location. Locating animals with VHF collars aerially demands a skilled pilot that specializes in wildlife radio-telemetry location flying techniques. Animals fitted with collars that use Global Positioning System (GPS) technology are automatically located by multiple satellite triangulations on a pre-programmed schedule. These GPS location data are downloadable from a data platform or may be stored on the collar itself, which will (hopefully) be retrieved via VHF signal detection after the collar is released from the animal, either by falling off when the collar disintegrates or when a mechanism releases the collar at a pre-programmed time. Cost of radio-telemetry methods is moderate to high, depending on the technology used, with GPS collars sitting at the more expensive, high-tech end of the spectrum.

DNA assignment testing. This approach focuses on obtaining hair roots on barbed wire sampling stations as a source of DNA to identify individual animals with microsatellite markers. These data can detect genetic discontinuities at different spatial scales and correlate these with environmental features, such as man-made barriers, including highways (Gerlach and Muslolf 2000, Conrey and Mills 2001, Proctor 2003, Thompson 2003) and can identify where individual animals have been and test whether mitigation measures are aiding animal movements, dispersal rates and connectivity between populations (Luikart and England 1999, Wills and Vaughan 2001, Waser and Strobeck 1999). The application of such techniques at intervals can help one understand if movement of animals across a potential barrier (e.g., a highway) is decreasing or increasing over time (e.g., pre- vs. post-mitigation). Field skills and material costs required for this method are usually low while the lab skills required are high, along with cost, but this novel technique can address questions related to mitigation effects on population genetics, as well as potential consequences for population demography (Proctor 2003), key issues in long-term conservation of specific species.

Fecal stress measures. Fecal stress measures can be used to quantify non-observable physiological responses via non-invasive sampling techniques. Stress measures can be correlated to an animal's proximity to roads and traffic levels over time (Wasser et al. 1997, Creel et al. 2002). This could consist of comparing fecal stress measures from wildlife (i.e., one or two focal species) in areas adjacent to a highway with planned mitigation and areas far from the highway to test for differences in stress. Once mitigation measures are in place, and animals have been given time to adapt to them, a subsequent analysis can examine whether the crossing structures affect animal stress levels in a positive way, if we are evaluating whether crossing structures provide a less stressful environment than areas of highway without crossing structures. Similar to the DNA technique, skills and cost are high for this technique, with field work and lab work, but this novel technique can address questions related to mitigation effects.

Controlling other variables. Numerous other variables can affect an interpretation of effectiveness if the variable of interest is analyzed without controlling these potential influences. It will be necessary to identify these potential influences and ways to measure these in order to include these factors quantitatively in the analyses.

Annual or seasonal population trends are important to quantify and control for when evaluating the effect of mitigation measures on wildlife. Surveys of tracks, pellets, hair, mark/recapture or mark/resight methods, and point sightings or call-counts can effectively determine presence/absence, relative abundance, and distributions of various species. Each technique has unique considerations; Lancia et al. (1996) provides a thorough review about estimating numbers of animals in a population.

Habitat may be a driving factor that influences animal movements. Categorical determinations of habitat may be collected at points or areas in the field. Geographic Information Systems (GIS) can provide electronic spatial estimates of habitat types and satellite imagery can be applied as well, though these types of "remote" techniques require higher skill levels, special computer software, and specific approaches to incorporate into an analyses.

Human activities need to be quantified and controlled for in analyses. Traffic levels and speeds can influence animal movements, as can proximity to recreational activities, and developments (Smith 1999, Clevenger and Waltho 2000, Clevenger and Waltho in press). Human activities can be indexed by using road and building densities, which can be obtained from GIS data layers or distance from a point of interest to nearest side road or building can be measured in the field.

Weather variables and stochastic events such as floods, forest fires, and severe winters may affect the variables of interest. Depending on the scale that one might want to control for, weather data may be collected in the field using special data loggers or regional data may obtained from National Climatic Data Center (NCDC 2003).

Step 3: Designing the Monitoring Program

Studies that offer statistically significant results do not happen by chance. Thorough planning well in advance of initiating data collection is needed to maximize the chance that one will really be able to answer the research questions. Depending on the research questions, focal animal(s) and definitions of effectiveness, sampling schemes need careful consideration with regard to methods, spatial scale, duration of study, sample size, variability, the magnitude of change one is attempting to quantify, and the analytical tools that may be applied to achieve statistical relevance.

Methods and sampling design will affect the type of data collected and how it can be analyzed. As one sifts through general study design approaches, it is also necessary to identify what statistical tools can be used with the data collected. The analytical approach chosen will have specific ways it can be interpreted and limitations to the interpretations. It is important to know if the final interpretations can be applied to the definitions of effectiveness. As the methods, sampling design, and analytical tools affect these outcomes, it may be necessary to readjust the definitions of effectiveness. Consult with a statistician to ensure sampling schemes and methods will yield data that can be analyzed and interpreted so that the results relate back to the research questions and definitions of effectiveness.

Good scientific experimental design will have replicates of treatments and controls, will randomly sample the “population” or conditions of interest, and can be replicated. These goals are easily attainable in a laboratory setting where the environment can be manipulated and controlled. Ecological experiments are more challenging to conduct because there are so many different variables that cannot be controlled. But whenever possible, incorporating treatments, controls, replicates, randomization, and repeatability into research or monitoring sampling design will improve confidence that the results seen are not due to chance and that similar results would emerge if the study were repeated. Basic tenets of experimental design for wildlife studies are extensively discussed by Ratti and Garton (1996).

The ideal evaluation of wildlife crossing performance will sample the measures of effectiveness before and after the installation of the mitigation (pre- and post-mitigation). Once a project has committed to installing crossing structures for wildlife, there typically will be two to five years before the construction begins. Planning and initiation of the pre-mitigation data collection should begin as soon as possible to maximize the sampling effort over time. Long-term monitoring captures more data and variability that better allows patterns to be seen amongst “noise.” Small sampling windows of only one or two years can lead to results that may be skewed from what is actually occurring, misleading managers to short sighted conclusions (Clevenger et al. 2002). Sampling the inherently changing conditions (e.g., high animal movement periods such as breeding season, fluctuating seasonal traffic levels, weather conditions) over time will allow better control for the confounding variables that can influence the measures of effectiveness. The design and budget will ultimately dictate how long sampling occurs, but maximizing the period of monitoring will improve the certainty of the results.

In addition to the ideal pre- and post-mitigation comparison study design, incorporating spatial comparisons between mitigated and unmititated areas that are otherwise similar will further improve the rigor of the study. Before-After, Control-Impact (BACI) designed experiments are being used to evaluate the effects of a road that will be expanded (Van Manen et al. 2001). However, randomization and replication of experimental units is difficult with studies of this type, and there are also many controlling or confounding factors to contend with even in a replicated study (Underwood 1994). Pre-mitigation data must be comparable to post-mitigation data. Differences between the pre- and post-mitigation conditions should be considered when analyzing the data from these two time periods.

If pre-construction data on animal movements are not available, then post-construction study of animal movement behavior is an option. Data on roadkill and animal use of crossing structures can be combined with other wildlife studies to reveal mitigation effects on the studied species. Some post-construction studies are mentioned below.

Null movement models can be developed post-construction to test the effect of roads on animal movement by comparing observed road crossings with expected crossings (see McKelvey et al. 1999, Serrouya 1998, Dyer et al. 2002, Whittington 2002). In theory, the expected crossings should represent a situation where movement patterns are unobstructed by the landscape features being assessed, such as roads. Null movement models test the effect of roads on animal movement by comparing observed road crossings (empirical data) with expected crossings (hypothetical data) simulated for the same individual.

A null model is generated for each individual and includes a sequence of expected movements completely contained within the animal’s home range. The number of movements and the distances between successive points are the same as in the empirical data, but the points are placed at random locations, and movements are in random directions within the home range. The length of movement chosen is in the same order as the observed movements. A road-crossing index is calculated for each home range by dividing the proportion of total movements crossing roads by the total number of movements in the home range. We calculate observed and expected frequencies of road crossings using a GIS. If there is no statistical difference between the two frequencies, then movement patterns are unaffected by roads, i.e., crossing structures are functional.

Like radio-telemetry-derived data, null movement models can be developed using snow-tracking data. Powell (1994) used a simple univariate test of observed fisher movements in snow against expected movements to determine fisher habitat selection. Species’ relationship to roads, or species habitat selection at different scales, can be tested using Powell’s method.

Up until now, most highway research and assessments of mitigation effectiveness have been focused at the individual level. It will be critical to ultimately know how landscape fragmentation by roads and the measures designed to reduce fragmentation affect the viability of populations or their expected chances of long-term persistence.

Viability of a species is often expressed with variables such as risk of decline, chance of recovery, or expected time to extinction. Population viability analysis is a group of methods for predicting such measures as extinction risk based on species-specific data. These methods often include models that simulate the dynamics of a population or a metapopulation. Natural populations are almost always spatially structured; however, most conservation models ignore this structure. The processes of dispersal and local extinction can be major determinants of population viability. New computer simulation programs, such as RAMAS/GIS, are designed to cope with spatial complexity, such as habitat patchiness, by interfacing population structure with habitat maps imported from a GIS so that spatial structure can be identified (Boyce 1996).

Population viability studies of this type can be designed to determine whether highway mitigation (fencing and wildlife crossing structures) results in maintaining viable wildlife populations. Demographic data from the mammal population(s) of concern are necessary for this application and will increase the realism and the reliability of the models generated. Analyses of this type, linking GIS-generated landscape data with demographic data, also are well suited for identifying key habitats or areas (e.g., security areas for female grizzly bears). Further, models can be used to detect weak points in model input data and make recommendations for further fieldwork.

Step 4: Pilot and Adjust to Meet Goals and Project Budget

It is rare that a person "hits the nail on the head" when initiating data collection. Inevitably, aspects of the project will not perform as expected. It is realistic to incorporate some time to pilot and adjust the methods, schedules, and budgets. During the pilot study, keep asking, "Do these methods measure the variables that will determine effectiveness?" Examine the data collection techniques in terms of standardization and sustainability. Can the method and field personnel continually and consistently measure the same variable over the length of the study while minimizing the "observer effect" that can introduce confounding variability into the data? Consider how extreme heat, wind, cold, rain and snow may affect equipment and readjust the budget if you believe there may be a need for replacements. Adjust data collection sheets so they are as simple as possible for the job, both for data collection and for data entry. Keep track of time to accomplish data collection and data entry, and costs of equipment and personnel. Adjust your budgets and schedules so that the project does not run out of funding before obtaining results. These adjustments will take time but will pay off if they are addressed early on in the project.

Look at how much data are being acquired and the variability of that data—is there a need to increase the sampling effort to ensure your analysis can detect the differences you set out to detect if a change occurs? Or can you decrease sampling effort and extend your budget? Power analysis is an analytical tool that can help you address those questions. Without sufficient sample size, one will not be able to detect the effect that the project has set out to detect to relate to the pre-defined determination of effectiveness. With too large a sample, you may be using valuable resources inefficiently. Either way, implementing a study with too little or too much power does not spend time and resources economically. Knowing the magnitude of the effect that one hopes to detect (if the effect occurs) and the variance of data collected either from the pilot study or from another similar study, one can run a power analysis to determine the minimum sample size required to detect a difference between pre- and post-mitigation periods or treatment (mitigated) and control (unmitigated) areas.

Step 5: Collect Data for Evaluation

After planning, piloting and adjusting the methods and study design to fit the project, it is time to collect the field data that will be used to analyze the performance of the crossing structure. Consistency and standardization in the data collection is paramount here. If possible, to maintaining the same field personnel throughout the study this is preferred, as it will reduce the observer-introduced variability (and it will be easier on the project manager in terms of training new personnel).

It is advisable to enter data into an electronic database as soon as possible. First, it reduces the chance of losing the data if they are in two locations (a filed hard copy and an electronic file that is backed up or archived). Second, if there are questions about the data, the observer is likely to have a more accurate memory of the situation in question. As data are entered, they should be checked on a regular basis for inconsistencies that may indicate a data entry error that can be fixed by looking at the original datasheet.

Many researchers are using computers to log data directly in the field. Personal digital assistants (PDAs) and computer tablets are tools that can eliminate the need for paper data collection sheets and data entry. If using these high-tech tools, it is important to religiously download the data to a backed-up hard drive or server to prevent the possibility of losing data if the system crashes.

Step 6: Analyze Data to Determine Effectiveness
When there are enough data entered to begin analyses, it is important to "clean" the database, looking again for errors and missing data that can be fixed. When this is complete, save the database as a "master" file and use "working" files for manipulating the data. Find a system to document the process used to analyze the data.

If not fluent with statistics, be sure to consult with a statistician to make sure the correct analyses and processes were used and that the interpretations are correct. General approaches to statistical analysis are detailed by Bart and Notz (1996) and Sokal and Rohlf (1995). There are many different software packages ranging in cost that can run a variety of statistical tests. It should be relatively straightforward to input the clean database and run the analyses, as long as the analytical tools were identified when the study design was established. The literature search conducted early on in the planning process will help identify valid statistical applications for consideration.

Step 7: Report Results
The final step in the scientific process is to report on the study and its results. Sponsors, stakeholders, other transportation agencies, and road ecology researchers will be interested in the outcomes. The most useful reporting is publishing in peer-reviewed journals that can be accessed by the widest audience.

Writing style and formatting will depend on the audience, sponsors or journal, but essentially reporting consists of, at a minimum, an introduction, study area description, methods, results and discussion. Each section is important, but perhaps the most important piece is the discussion, where the results are interpreted relative to the *a priori* definition of effectiveness. It is critical that the discussion of the results acknowledges its limitations. Clevenger et al. (2002) review examples of potential misinterpretations that can result from not accounting for other factors.

Conclusions
In conclusion, we offer suggestions to improve evaluation studies. Long-term, pre- and post-mitigation studies with controls and treatments in replicates are best. Clear statements of the research questions and definitions of effectiveness *a priori* will help with the process of finding the "right fit" when considering the many approaches, methods, study designs and analytical tools available for evaluating the effectiveness of crossing structures. No matter the magnitude of the research questions, it is important to make sure the study design will yield adequate sample sizes that will provide conclusive results.

The availability of adequate funding is one of the primary limiting factors to conducting rigorous evaluations. The different initiatives, environmental regulations, magnitude of the installation, target species, maintenance issues, budgets, and stakeholder attitudes toward the project can influence the decision to conduct a performance evaluation. Because of the importance of monitoring, especially when endangered species might be affected by the mitigation measures, we encourage agencies to find ways to tie research funding to the construction to ensure that monitoring is not overlooked. If an evaluation is funded, it will be most valuable if it is conducted as rigorously as possible to maximize the benefit of the investment. Collaborations such as pooled fund studies and research agreements or consortiums between agencies and universities can extend the funding for more efficient, integrated projects. Graduate research opportunities are excellent investments that result in well-scrutinized projects. Creative funding requires planning and careful thought to fit the unique characteristics of each project. Good science will produce results that can help transportation agencies avoid installing ineffective crossing structures in the future. Research is relatively cheap when one thinks of it in those terms.

We emphasize (re-emphasize) the value of conducting rigorous evaluations that address *a priori* definitions of effectiveness at multiple ecological scales. Evaluating mitigation measures using solid scientific techniques can eventually reveal general trends among studies structures. Statistically conclusive results will build the foundation for transportation professionals and the scientific community to *apply science* to deploy effective wildlife crossings.

Biographical Sketches: Amanda Hardy is a wildlife research ecologist with the Western Transportation Institute (WTI) at Montana State University (Bozeman, Montana). Amanda's current research focus at WTI includes the evaluation of wildlife crossing structures on US 93, Evaro to Polson, and evaluating wildlife fencing and Intelligent Transportation System approaches to mitigating impacts on wildlife along I-90 in the Bozeman Pass area. Amanda obtained her B.Sc. in biology—fish and wildlife management in 1997, and her M.Sc. in ecology—fish and wildlife management, in 2001, both from Montana State University. She is an active member of the Transportation Research Board's (TRB) Animal Vehicle Collision Sub-Committee and the TRB Taskforce on Ecology and Transportation. She also served on the 2003 International Conference on Ecology and Transportation planning committee.

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. Tony 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.

Marcel Huijser is a research ecologist with the Western Transportation Institute (WTI) at Montana State University (Bozeman, Montana). Marcel's current research focus at WTI includes the evaluation of animal-detection driver-warning systems and the study design and the pre-construction data collection for the US 93 wildlife crossing structures. Marcel received his Ph.D. in road ecology from Wageningen University in The Netherlands in 2000. He is involved in the Transportation Research Board's (TRB) Animal Vehicle Collision Sub-Committee and the TRB Taskforce on Ecology and Transportation.

Graham Neale is a wildlife biologist with Garcia and Associates in Bozeman, Montana. Graham has worked with WTI on the US 93 wildlife crossing structure evaluation. Graham obtained his M.Sc. in wildlife biology from the University of Montana in 1998.

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