Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies

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Abstract

Maintaining landscape connectivity where habitat linkages or animal migrations intersect roads requires some form of mitigation to increase permeability. Wildlife crossing structures are now being designed and incorporated into numerous road construction projects to mitigate the effects of habitat fragmentation. For them to be functional they must promote immigration and population viability. There has been a limited amount of research and information on what constitutes effective structural designs. One reason for the lack of information is because few mitigation programs implemented monitoring programs with sufficient experimental design into pre- and post-construction. Thus, results obtained from most studies remain observational at best. Furthermore, studies that did collect data in more robust manners generally failed to address the need for wildlife habituation to such large-scale landscape change. Such habituation periods can take several years depending on the species as they experience, learn and adjust their own behaviours to the wildlife structures. Also, the brief monitoring periods frequently incorporated are simply insufficient to draw on reliable conclusions. Earlier studies focused primarily on single-species crossing structure relationships, paying limited attention to ecosystem-level phenomena. The results of single species monitoring programs may fail to recognize the barrier effects imposed on other non-target species. Thus, systems can be severely compromised if land managers and transportation planners rely on simple extrapolation species. In a previous analysis of wildlife underpasses in Banff National Park (BNP), Canada, we found human influence consistently ranked high as a significant factor affecting species passage. Our results suggest that the physical dimensions of the underpasses had little effect on passage because animals may have adapted to the 12-year old underpasses. As a sequel to the above study, we examined a completely new set of recently constructed underpasses and overpasses which animals had little time to become familiar with. We investigated the importance of temporal and spatial variability using data obtained from systematic, year-round monitoring of 13 newly-constructed wildlife crossing structures 34 months post-construction. Our results suggest that structural attributes best correlated to performance indices for both large predator and prey species, while landscape and human-related factors were of secondary importance. These findings underscore the importance of integrating temporal and spatial variability as a priori when addressing wildlife crossing

structure efficacy, and the fact that species respond differently to crossing structure features. Thus mitigation planning in a multiple-species ecosystem is likely to be a challenging process. The results from this work suggest that mitigation strategies need to be proactive at the site and landscape level to ensure that crossing structures remain functional over time, including human use management. Continuous long-term monitoring of crossing structures will be key to ascertaining the strengths and weaknesses of design characteristics for a multi-species assemblage

LONG-TERM, YEAR-ROUND MONITORING OF WILDLIFE CROSSING STRUCTURES AND THE IMPORTANCE OF TEMPORAL AND SPATIAL VARIABILITY IN PERFORMANCE STUDIES

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Abstract: Maintaining landscape connectivity where habitat linkages or animal migrations intersect roads requires some form of mitigation to increase permeability. Wildlife crossing structures are now being designed and incorporated into numerous road construction projects to mitigate the effects of habitat fragmentation. For them to be functional they must promote immigration and population viability. There has been a limited amount of research and information on what constitutes effective structural designs.

One reason for the lack of information is because few mitigation programs implemented monitoring programs with sufficient experimental design into pre- and post-construction. Thus, results obtained from most studies remain observational at best. Furthermore, studies that did collect data in more robust manners generally failed to address the need for wildlife habituation to such large-scale landscape change. Such habituation periods can take several years depending on the species as they experience, learn and adjust their own behaviours to the wildlife structures. Also, the brief monitoring periods frequently incorporated are simply insufficient to draw on reliable conclusions.

Earlier studies focused primarily on single-species crossing structure relationships, paying limited attention to ecosystem-level phenomena. The results of single species monitoring programs may fail to recognize the barrier effects imposed on other non-target species. Thus, systems can be severely compromised if land managers and transportation planners rely on simple extrapolation species.

In a previous analysis of wildlife underpasses in Banff National Park (BNP), Canada, we found human influence consistently ranked high as a significant factor affecting species passage. Our results suggest that the physical dimensions of the underpasses had little effect on passage because animals may have adapted to the 12-year old underpasses. As a sequel to the above study, we examined a completely new set of recently constructed underpasses and overpasses which animals had little time to become familiar with.

We investigated the importance of temporal and spatial variability using data obtained from systematic, year-round monitoring of 13 newly-constructed wildlife crossing structures 34 months post-construction. Our results suggest that structural attributes best correlated to performance indices for both large predator and prey species, while landscape and human-related factors were of secondary importance. These findings underscore the importance of integrating temporal and spatial variability as a priori when addressing wildlife crossing structure efficacy, and the fact that species respond differently to crossing structure features. Thus mitigation planning in a multiple-species ecosystem is likely to be a challenging process.

The results from this work suggest that mitigation strategies need to be proactive at the site and landscape level to ensure that crossing structures remain functional over time, including human use management. Continuous long-term monitoring of crossing structures will be key to ascertaining the strengths and weaknesses of design characteristics for a multi-species assemblage.

Introduction

Major highways are superimposed on much of the North American landscape. Compared to other agents of fragmentation, roads are less conspicuous, but they cause changes to habitat that are more extreme and permanent. Many roads are barriers or filters to horizontal natural processes such as animal movement (Spellerberg 1998, Forman et al. 2003). Road systems also alter the patterns of wildlife and the general function of ecosystems within landscapes.

The Trans-Canada Highway (TCH) is a potential barrier for wildlife movement in the mountain parks and the significantly larger Central Rocky Mountain ecosystem. Given the national importance of the cross-country transportation corridor and popular attraction of Banff National Park, traffic volumes are increasing at 3 percent per year (McGuire and Morrall 2000). Reduced landscape connectivity and impeded movements due to roads may result in higher mortality, lower reproduction and ultimately smaller populations and lower population viability. These deleterious effects have underscored the need to maintain and restore essential movements of wildlife across the TCH and other roads in the Rocky Mountain region (Banff-Bow Valley Study 1996, Carroll et al. 2001).

To mitigate the effects of roads, passage structures for wildlife are now being designed and incorporated into some road construction projects (Foster and Humphrey 1995, Marshik et al. 2001). Wildlife passages are in essence site-specific movement corridors strategically placed over a deadly matrix habitat of pavement and high-speed vehicles. Yet the impact of transportation systems on wildlife ecology and remedial actions to counter these effects is an emerging science. Currently, there is limited knowledge of effective and affordable passage designs for most wildlife species (Transportation Research Board 2002).

One reason for the lack of information is because few mitigation programs implemented monitoring programs with sufficient experimental design into pre- and post-construction (Underwood 1997). Thus, results obtained from most studies remain observational at best. Furthermore, studies that did collect data in more robust manners generally failed to address the need for wildlife habituation to such large-scale landscape change. Such habituation periods can take several years depending on the species as they experience, learn and adjust their own behaviours to the wildlife structures. Also, the brief monitoring periods frequently incorporated are simply insufficient to draw on reliable conclusions.

Earlier studies focused primarily on single-species crossing structure relationships, paying limited attention to ecosystem-level phenomena (Reed et al. 1975, Singer and Doherty 1985, Rodriguez et al. 1997). The results of single species monitoring programs may fail to recognize the barrier effects imposed on other non-target species. Thus, systems can be severely compromised if land managers and transportation planners rely on simple extrapolation species. To date, we are unaware of any monitoring program that addresses this issue specifically.

In this paper we address some of these issues based on nearly seven years of continuous monitoring and analysis of wildlife use patterns at 24 crossing structures in the Banff-Bow Valley. We report on (1) what attributes of crossing structure design facilitates passage for large mammals, including fragmentation-sensitive species, (2) the importance of incorporating experimental design in crossing structure performance assessments, and (3) we make inferences regarding duration of monitoring schemes necessary to sample range of variability, based on animal behaviour and adaptation periods. These data are based on two performance analyses, similar in methodology, but carried out on two distinct sections of the TCH. We indicate in the methods how the two analyses differed in the methods section.

Study Area

Our research was located in the Central Canadian Rocky Mountains, approximately 150km west of Calgary in southwestern Alberta (51°15'N, 115°30'W). The study area encompassed mountain landscapes in Banff National Park. We focused on the TCH transportation corridor and accompanying mitigation passages in the Bow River Valley. The highway is a major commercial motorway between Calgary and Vancouver. In 2001, annual average daily traffic volume at the park east entrance was 15,600 vehicles per day.

The first 45km of the TCH from the eastern park boundary is four lanes and bordered on both sides by a 2.4m high wildlife-exclusion fence (see Gloyne and Clevenger 2001). Twelve wildlife underpasses were built in the mid-1980s (phases 1 and 2; 27km), while recently 12 wildlife passages (including two overpasses) were constructed in 1997 (phase 3A; 18km) to permit wildlife movement across the four-lane section of TCH. Plans are to upgrade the two-lane phase 3B section (=25km) with fencing and passages within the next five years.

Methods and Study Design

Wildlife Crossing Structure Monitoring and Data Collection

Our wildlife crossing structure monitoring began in November 1996. Since this time we have consistently checked the crossing structures for wildlife use, on average every three days. We quantified wildlife visits and through passages at the crossing structures by identifying tracks at 2m-wide, raked track-sections. At the two wildlife overpasses, infra-red-operated TrailMaster™ 35mm camera systems were used in addition to the raked tracking sections to photo-document wildlife passage across the overpass. Wildlife was defined herein as wolves *Canis lupus*, coyotes *C. latrans*, cougars *Puma concolor*, lynx *Lynx canadensis*, black bears *Ursus americanus*, grizzly bears *U. arctos, deer Odocoileus* sp. (mule and white-tail), elk *Cervus elaphus*, Rocky Mountain bighorn sheep *Ovis canadensis* and moose *Alces alces*. In addition, the amount of human use (foot, bike, ski, horse) at the crossing structures was quantified.

Analysis of Attributes Facilitating Passage of Underpasses on Phase 1 and 2

To mitigate the barrier effect on Banff's TCH, highway engineers constructed 22 wildlife underpasses and two wildlife overpasses. The effectiveness of such structures to facilitate large mammal movements is, however, unknown. As no two underpasses are similar in all structural and ecological aspects, we propose that species (i.e., large mammals) select crossing structures that best correlate with their ecological needs and behaviour. Attributes that best characterize high-use structures can then be integrated into new designs for an eventual phase 3B twinning process.

In our first analysis of phase 1 and 2 underpasses, we tested this premise at three scales of taxonomic resolution (species, species groups, and large mammal community). These scales were used because: we anticipate the explanatory power of each attribute is dependent, at least in part, on the ecological resolution used (Rahel et al. 1984; Rahel 1990; Collins and Glenn 1991); and the information needs of land managers and transportation planners with respect to mitigation structures can best be met by a variable scale approach. We chose phase 1 and 2 underpasses for our first study only, as the recent completion of phase 3A mitigation structures did not permit sufficient time for wildlife habituation to occur at such landscape scales.

We monitored 11 wildlife underpasses on phases 1 and 2. We characterized each underpass with 14 variables encompassing structural, landscape, and human activity attributes. Structural variables included underpass width, height, length (including median), openness = width x height/length (Reed and Ward 1985) and noise level = mean of A-weighted decibel readings taken at the centre point within the underpass and 5m from each end.

Landscape variables included distances to the nearest forest cover, Canadian Pacific Railway, town site, closest major drainage, and eastern-most park entrance (hereafter referred to as East Gate). Human activity variables included types of human use in the underpasses characterized by counts of people on foot, bike, horseback and a human-use index calculated from the mean monthly counts of the three former variables combined.

Observed Crossing Frequencies
We measured wildlife use for the 11 underpasses on phases 1 and 2, of which 9 of the 11 underpasses were cement, open-span underpasses and 2 were metal culverts. We used the monitoring methods described above.

Expected Crossing Frequencies
If the 11 underpasses occur in an homogeneous habitat-landscape that includes random distribution of species abundances, then the following assumptions may apply: the 11 underpasses serve the same population of individuals and each individual, is aware of all 11 underpasses and can choose between underpasses based on underpass attributes alone. The Banff Bow Valley is a highly heterogeneous landscape, for example, lakes, mountain barriers and narrow corridors may restrict underpass accessibility on multiple spatio-temporal scales. If habitat fragmentation is perceived extreme then we may assume that each underpass serves its own unique subpopulation. If this were true, then differences in observed crossing frequencies between underpasses would reflect differences in subpopulation sizes alone and not attributes of the underpasses themselves. Although these two sets of assumptions represent endpoints along a continuum of possible interactions, the relative extent species interact with the habitat landscape and distribution of underpasses is unknown. It is therefore necessary to examine observed crossing frequencies in the context of expected crossing frequencies (i.e., performance indices).

Expected crossing frequencies were obtained from three independent data sets that included radio telemetry location data, relative abundance pellet transects and habitat suitability indices. As it remains unclear the proportion of individuals from these data sets that use the underpasses directly, we defined our expected crossing frequencies as equal to the abundance data found at radii 1, 2, and 3km from the centre of each underpass. Specifically, we used radio telemetry location data for black bears (*n* = 255 locations), grizzly bears (*n* = 221 locations), wolves (*n* = 2,314 locations) and elk (*n* = 1,434 locations; Parks Canada, unpublished data); and relative abundance pellet transects for deer (*n* = 1,579 pellet sites), elk (*n* = 26,614 pellet sites), moose (*n* = 43 pellet sites) and wolves (*n* = 30 sites containing scat: Parks Canada, unpublished data); and habitat suitability indices for black bears, cougars, wolves, deer, elk and moose (Holroyd and Van Tighem 1983; Agriculture Canada 1989; Kansas and Raines 1990).

Analysis
We derived species performance ratios for each of the three independent data sets by dividing observed crossing frequencies by expected crossing frequencies. Performance ratios were designed such that the higher the ratio, the more effective the underpass appears to facilitate species crossings.

We examined the premise that wildlife crossing structures serve species equally by testing the null hypothesis that performance ratios do not differ between species (paired t test with Bonferroni adjusted probability values). In the event that we rejected the null hypotheses, we proceeded with three steps to determine which of 14 underpass attributes species performance ratios were most closely associated with. First, all performance ratios were standardized to zero mean and standard deviation of one to remove absolute differences between the three models.

We used a family of simple curvilinear and polynomial regression curves to optimize the fit between species performance ratios and each underpass attribute (Tablecurve 2D; Jandel 1994). We used the following criteria to choose the most optimal equation for each regression analysis:

- The regression model must be statistically significant (at $p < 0.05$).
- The beta coefficient for the highest ordered term must be statistically significant.
- Once an equation meets the above criteria we compared its *F* statistic with the *F* statistic for the next equation that also meets these criteria but has one less ordered term. We chose the model with the higher *F* statistic.
- Iterate the above process for equations with consecutively fewer terms.
- If no curvilinear or polynomial equation was accepted, we chose the simple linear regression model (equation no. 41) to describe the relationship, assuming it has not already been chosen through the iterative process.
- If these criteria failed to produce a significant regression model for per se species and per se underpass attribute, we deleted the underpass attribute as being a significant factor influencing the species performance ratio.

Third, for each species we ranked the regression models thus obtained according to the absolute value of each model's coefficient of determination. This three-step process allowed for the identification and ordering of underpass attributes (in order of importance) associated with each species performance ratio. However, it failed to separate ecologically significant attributes from those that appeared significant but were statistical artifacts of the underpasses themselves.

The three-step process was repeated for each of the three scales of ecological resolution. For species groups, however, it was first necessary to identify group types according to similarities in species performance ratios as compared to some arbitrary definition. We used principal component analysis (PCA) to identify these species groups. Since none of the performance models contains a full species list it was necessary to include all species performance ratios from each of the models into the single PCA.

Analysis of Attributes Facilitating Passage of Crossing Structures on Phase 3A

Our second study involved 13 wildlife-crossing structures within phase 3A of the TCH. These crossing structures constituted four different structural designs: two creek bridge underpasses (3m-high and 11m-wide expanded bridges that span creeks and rivers), five elliptical, metal culvert underpasses (4m-high, 7m-wide), four prefabricated concrete box underpasses (2.5m x 3.0m) and two 50m-wide wildlife overpasses.

Observed Crossing Frequencies

Each crossing structure was characterized according to 13 independent variables encompassing structural, landscape and human activity attributes, as in our first analysis. With appropriate multivariate analyses (e.g., canonical and partial canonical correlation analysis), meaningful ecological relations may be teased out from the above data (Sarakinos and Rasmussen 1998). Such analyses require adequate null models to test the observed data against and sufficient sampling replicates to obtain statistically meaningful results – some argue 30 replicates per variable (Norman and Streiner 1999). In our study, both requirements were absent, i.e., manipulation or control of test variables in such a large-scale, ecosystem-level study was unfeasible, and there were only 13 statistical replicates (wildlife crossing structures). We addressed both issues by developing species-specific performance indices and regressing the indices against each of the crossing structure attributes.

Expected Crossing Frequencies

As in the first analysis, species performance indices we define as the ratio of observed through-passage use to expected through-passage use. Performance indices function in such a way that, the higher the index, the more effective the wildlife crossing structure appears to facilitate that species crossing. Our expected through-passage use was defined similarly as in our first analysis. However, we approached this issue of spatial and temporal habitat heterogeneity with the aid of a geographic information system (Environmental Systems Research Institute 1998). From the centre of each wildlife crossing structure we created buffers from 500-1,000m, 1,000-1,500m, 1,500-2,000m, 2,000-2,500m and 2,500-3,000m. For each buffer we overlaid an ecological land classification map with five possible habitat suitability ratings (0 = nil, 1 = low, 2 = moderate, 3 = high, 4 = very high) for each species per ecosite type (Holroyd and Van Tighem 1983; Kansas and Raines 1990). For a given buffer each habitat rating was multiplied by the absolute area it occupied to derive a "relative species occurrence" value. This was repeated for each buffer, at each crossing structure and for each of the six large mammal species in our study. We used seasonal habitat suitability data (winter and/or summer) to address temporal variation in the habitat template. Thus, for a given species, structures with a high proportion of high-quality habitat surrounding them generate greater relative species occurrences compared to crossing structures without (Clevenger and Waltho 2000).

Analyses

Using curvilinear regression analyses, we regressed species performance indices against each of the wildlife crossing structure attributes (Waltho and Kolasa 1996; Clevenger and Waltho 2000). This generated 13 coefficients of determinations for each species and for each season. We rank ordered the coefficient of determinations keeping only those that were statistically significant. We assumed that for each significant analysis ($P < 0.05$), the higher the coefficient of determination, the higher the rank importance that crossing structure attribute had in affecting species passage (positive influence or negative).

Attributes of Crossing Structures for Multiple Species

In our analysis of wildlife underpasses on phases 1 and 2, human influence consistently ranked high as a significant factor affecting species passage (Clevenger and Waltho 2000). Carnivores (black bears, grizzly bears, cougars, wolves) used underpasses close to drainages; whereas, ungulates avoided them. We believe underpass dimensions had little effect on passage because animals may have adapted to the 12-year old underpasses. Once adaptation had occurred, the dynamics of human activity and landscape heterogeneity might be more decisive in determining structure use than structure dimensions. Our results indicated that the best designed and landscaped underpasses might be ineffective if human activity is not controlled. Our findings suggest that in such a multi-species system, the most efficient and probably economic approach to retrofitting is to manage human activity near each underpass.

As a sequel to the above underpass study, we examined a completely new set of underpasses and overpasses (phase 3A) which animals had little time to become familiar with (Clevenger and Waltho, unpublished data). Contrary to earlier findings, our results suggest that structural attributes best correlated to passage for both large predator and prey species, while landscape and human-related factors were secondary. Passage by grizzly bears, wolves, elk and deer was strongly influenced by wildlife crossing structures that were high, wide and short in length. Black bears and cougars favoured more constricted crossing structures. The patterns we observed conform to the evolved species behaviours and life history traits, some species preferring open areas whereas others need cover.

Our findings underscore the importance of integrating temporal and spatial variability as a priori when addressing wildlife crossing structure efficacy, and species respond differently to crossing structure features – thus mitigation planning in a multiple-species ecosystem is likely to be a challenging endeavour. Results from these two studies suggest that mitigation strategies need to be proactive at the site and landscape level, to ensure that crossing structures remain functional over time and to include human use management. Continuous long-term monitoring of crossing structures will be key to ascertaining the strengths and weaknesses of design characteristics for a multi-species assemblage.

In another analysis, we assessed wildlife crossing structure use by a single species using different measurements and analytical techniques (Gloyne and Clevenger 2001). Cougar passage was higher than expected during winter and less than expected during summer. Wildlife crossing structures that received the highest numbers of cougar passages were those situated close to high quality cougar habitat. We found the crossing structures were effective for cougars in the sense that they used them regularly, providing connectivity between habitats on both sides of the highway.

Adaptation Periods and Monitoring Schemes

At Banff we had a unique opportunity to monitor wildlife use of newly built wildlife crossing structures and observe trends and patterns of use over time. Unlike the crossing structures on the TCH's phases 1 and 2 that have been in place for nearly two decades, construction of phase 3A crossing structures was completed approximately five-and-a-half years ago. Today we have five complete years of continuous monitoring data from the recently constructed wildlife passages on phase 3A.

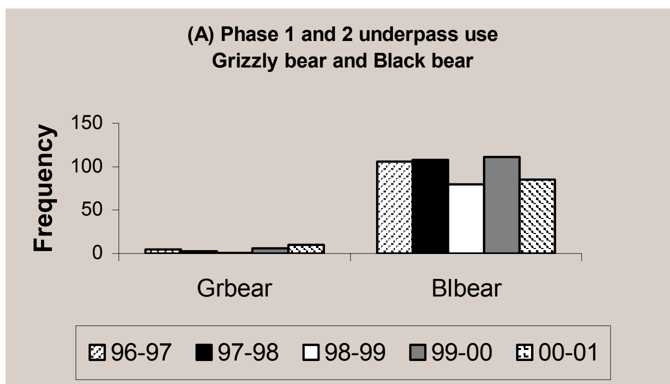
Annual trends not only reflect inherent effectiveness of the structures in facilitating animal passage across the TCH, but also adaptation of resident wildlife to the new structures. As on phases 1 and 2, use of underpasses by black bears and grizzly bears has remained consistent over the monitoring period (fig. 1A). There has been a general pattern of increased use at phase 3A overpasses for all carnivore species: grizzly bears, wolves, and black bears during the first five years of monitoring (fig. 1B). Increased annual passage frequencies were particularly remarkable for the four large carnivore species between years three and five of monitoring, i.e., 4 to 25 times greater than the average use during the first two years. Cougar use increased for the first three years and declined steeply in the fourth year of monitoring. This decline corresponds with a sharp decline in cougar numbers in the Bow Valley (Banff National Park Warden Service, unpublished data).

Consistent annual increases in use were also observed for deer and elk at the wildlife overpasses (fig. 2A). Deer use increased steeply and linearly from approximately 200 passes the first year after completion to roughly 1,100 passes during year five. Elk use did not increase as sharply, but did increase from year one and leveled out at year four and actually slightly decreased in year five. This may largely be due to population declines of elk in this part of the Bow Valley (Banff National Park Warden Service, unpubl. data).

We also observed consistent annual increases in ungulate use at the newly constructed wildlife underpasses on phase 3A (fig. 2B). Deer passage increased from year one to five without ever leveling out; whereas, a similar pattern to their use of the overpass was observed at the underpasses – a slight increase from year one to four and then a slight decline during year five.

Our five-year study spanned a time when wolves in the Bow Valley ranged from nearly locally extinct, to 17 individuals divided between two year-round resident packs. Wolf behaviour towards the wildlife crossing structures also varied from nearly complete avoidance by the Cascade pack, to multiple passages per day at any given underpass by the Fairholme pack. The wildlife underpasses adjacent to and east of Banff obviously were not functional for this particular species, at least in winter for the six years the Cascade pack visited the Bow Valley.

The appearance of a group of resident wolves that adapted quickly to the same wildlife underpasses the Cascade pack shunned in winter, further underscores the need for long-term monitoring, in conjunction with co-lateral wildlife studies to properly assess the conservation value of wildlife crossing structures. Our data showing the annual patterns and trends of wildlife use of the overpasses and underpasses post-construction provide strong evidence that there is a learning curve or adaptation period for all wildlife regardless of structure type (overpass or underpass). Small sampling windows, typical of one- or two-year monitoring programs are too brief, can provide spurious results and do not adequately sample the range of variability in species wildlife crossing structure use patterns, in landscapes with complex wildlife-human-land use interactions.



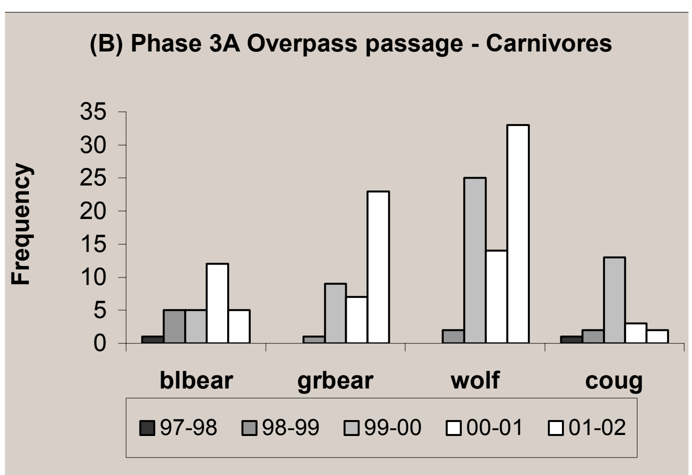


Fig. 1. Summary of large carnivore passage frequencies through (A) phase 1 and 2 underpasses and (B) phase 3A overpassees during a five-year period (November 1996 to October 2002).

We examined the duration of wildlife crossing structure monitoring periods from a sample of widely published mammal studies (table 1). Of 18 studies conducted since 1975, the average monitoring period was 17.3 months (SD = 13.2), or slightly less than 1.5 years (18 months), and ranged from 1.5 months to 48 months. With respect to findings from our research, monitoring periods for most studies have been short in duration. The studies most likely did not sample for sufficient duration to adequately assess how wildlife utilize crossing structures or give them enough time to adapt to the structures and the changes made to the surrounding habitat where they reside.

Table 1.
Duration of monitoring of wildlife crossing structures from a sample of mammal studies published in journals and conference proceedings.

Source [a]	**Location**	**Duration (months)**
Reed et al. 1975	Wyoming, USA	48
Ballon 1985	Upper Rhine, FRANCE	9
Hunt et al. 1987	NSW, AUSTRALIA	2
Woods 1990	Banff, Alberta, CANADA	36
Foster and Humphrey 1995	Florida, USA	2-16[b]
Yanes et al. 1995	Central SPAIN	12
Land and Lotz 1996	Florida, USA	24
Rodriguez et al. 1996	South-central SPAIN	11
Roof and Wooding 1996	Florida, USA	12
AMBS Consulting 1997	NSW, AUSTRALIA	9
Pfister et al. 1997	EUROPE	24
Rodriguez et al. 1997	South-central SPAIN	10
Rosell et al. 1997	Catalonia, SPAIN	11
Veenbaas and Brandjes 1999	NETHERLANDS	5
Clevenger and Waltho 2000	Banff, Alberta, CANADA	35
Clevenger and Waltho unpubl.	Banff, Alberta, CANADA	34
LaPoint et al. 2003	Adirondacks, USA	1.5
Ng et al. In press	Southern California, USA	12
Mean = 17.3 months (SD = 13.2)	**Range = 1.5 to 48 months**	

[a] See references.

[b] Calculated as 16 months.

Discussion

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. No individual crossing structure design fits all. Moreover, the crossing structures will only be as effective as the land and resource management strategies around them.

Crossing structures are in essence small and narrow, site-specific habitat linkages or corridors. Consequently, for these measures to fulfill their function as habitat connectors, mitigation strategies must be contemplated at two scales. Site-level impacts from development and high levels of human activity near crossing structures will decrease habitat quality and likely disrupt animal movements, particularly of large predators (Smith 1999; Clevenger and Waltho 2000).

Similarly, alteration of landscape elements at a broader regional-scale could impede or obstruct movements towards the structures, preventing animals from using them entirely, thus rendering them ineffective.

We believe that mitigating highways for wildlife is a long-term process that will last for many decades and affect individuals and populations alike (Opdam 1997). Thus, highway 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 crossing structures remain functional over time. This requires continuous long-term monitoring, as exemplified in this study. We recommend that monitoring schemes designed to evaluate crossing structure efficacy cover a period of at least four years and longer if possible. The adaptation period in a protected area, Banff National Park, was approximately four to six years; whereas, in an unprotected area or areas with human disturbance (e.g., hunting), adaptation periods would likely be even longer in duration.

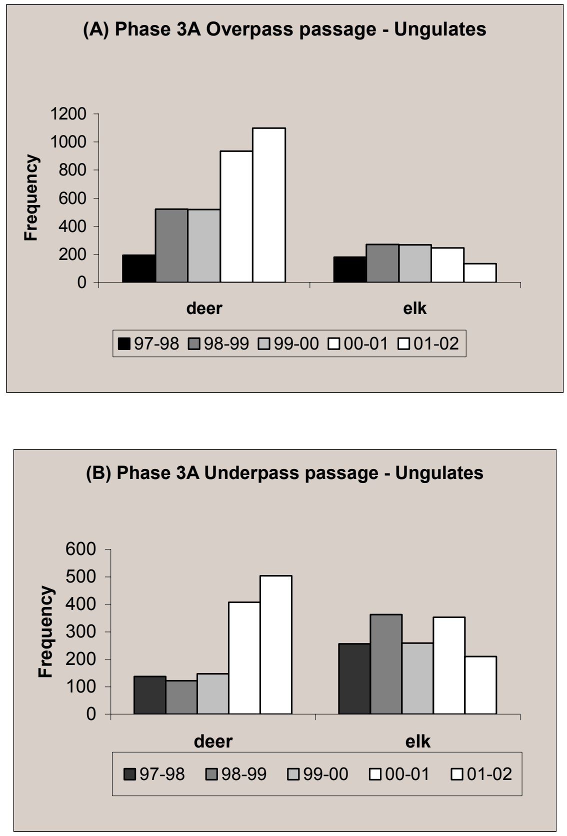


Fig. 2. Summary of ungulate passage frequencies through (A) phase 3A overpasses and (B) phase 3A underpassees during a five-year period (November 1996 to October 2002).

We underscore the need to remember in the planning process that crossing structure systems are permanently embedded in the landscape, but the ecological processes going on around them are dynamic. The physical structure of an underpass will remain in place for the next 50+ years. However, wildlife populations will undoubtedly vary geographically and fluctuate in number during this time. What looks like a crisis situation today for one wildlife species in terms of its response to crossing structures, may have an entirely different outlook and future in years to come. What would a biologist conclude in 2025 after a five-year study of the same wildlife crossing structures we monitored in Banff? Or in the year 2050?

For crossing structures to be effective over the long term, they will have to be able to accommodate the fluctuations in species, their demographics, and variances in animal behaviour, while maintaining viable populations around them. Continuous long-term monitoring of wildlife crossing structures, landscape changes around them, and the resident wildlife populations the structures are intended to sustain are key research components needed to assess the true conservation value of mitigation passages for wildlife.

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