Click on the paper title below to link directly to it.

Habitat Connectivity: Monitoring of Crossing Structures

Chapter 8
....Habitat Connectivity
Monitoring of Crossing Structures

EFFECTIVENESS OF WILDLIFE CROSSING STRUCTURES AND ADAPTED CULVERTS IN A HIGHWAY IN NORTHWEST SPAIN

C. Mata (Phone: 91-397-80-11, Email: cristina.mata@uam.es), I. Hervàs, J. Herranz, F. Suàrez, and J.E. Malo, Dpto. Interuniversitario de Ecología, Facultad de Ciencias, Universidad Autónoma de Madrid, E-28049 Madrid, Spain

J. Cachón, CETA, CEDEX, C/ Alfonso XII, 3. E-28014 Madrid, Spain

Abstract: An intensive monitoring was carried out between June and September 2002 in different passage types across a highway in NW Spain in order to determine their use by terrestrial vertebrates. We used marble dust-beds to get footprints and a complementary photographic system to identify species which cannot be distinguished by tracks. Footprint data (820 passage-days) were collected from 82 passage structures (33 circular culverts, 10 adapted culverts, 14 wide underpasses, 7 wildlife underpasses, 16 overpasses and 2 ecoducts). The number of recorded vertebrates was high (1,424 tracks, 78.8% wildlife, and 21.2% related to human activity; and 490 photographic contacts, 54.3% and 45.7% respectively). Small mammals (mice, voles and shrews) used the passageways most frequently (414 tracks), followed by lagomorphs (Iberian hare, *Lepus granatensis,* and rabbit, *Oryctolagus cuniculus,* N= 158), canids (*Canis familiaris* and *C. lupus*, N = 142), fox (*Vulpes vulpes*, N= 137) and lacertids (*Lacerta* spp. and *Podarcis* spp., N= 73). Underpasses and non-wildlife-engineered overpasses were the most used structures. Differences were found in the selection of crossing structures by the two lagomorphs, hares selecting wildlife underpasses while rabbits did not show a significative preference. Anurans and ophidians (Fam. *Colubridae* and *Viperidae*) showed a clear preference for adapted culverts, avoiding overpasses. Lacertids and small mammals crossed most frequently through circular culverts, but generally used all passage types. Hedgehog (*Erinaceus europaeus*) and Badger (*Meles meles*) always selected highway underpasses while small mustelids (*Mustela nivalis* plus *M. erminea*) used culverts exclusively. Finally, foxes used all types of crossing structures, showing a preference for wide underpasses. Red deer (*Cervus elaphus*) were found to use wide passages under or above the road, and more frequently ecoducts, but roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa)* were never detected in crossing structures though very abundant in the area.

Four recommendations arise from the study: (1) as a differential use among animal species has been found, it is necessary to keep several crossing structure types; (2) functional structures of the motorway (non-wildlife-engineered) play an important role in the permeability of the road, and their adaptation for wildlife enhances their use by some taxa. Thus, the adaptation of structures related to human activity plays a key role in the achievement of the best solution from a benefit-to-cost point of view. (3) The set of passageways necessary to mitigate the barrier effect suffered by a known mammal community can be established taking into account the animal sizes and the wideness and relative position of crossing structures to the road (over *vs.* under); however ,(4) it seems that some species may not cross through structures up to 20m wide, and thus some of the passageways should be wider (in the form of tunnels and/or viaducts).

Introduction

Most European countries have extensive transportation networks. However, in comparison with countries in Central Europe, the road and railway networks are poorly developed in Spain, though they are expanding quickly (i.e., 1,300km/year in 1987-2002), and they comprised 177,000km by the year 2000 (0.35km by km^2, Mº Fomento 2000). Since the European Environmental Impact Assessment Directive (85/337/EEC) was passed, the Spanish administration has increasingly forced the establishment of mitigation measures for the barrier effect to the road and railway projects to be approved. However, because of the high costs imposed on such projects by fauna passes, little effort has been devoted to assess of their effectivity. Thus, the improvement of their design and even the justification of their need are restricted by the lack of information on effectiveness.

Wildlife passes should help the preservation of local animal populations thanks to their capacity to connect habitats, a function that contributes to the restoration of home ranges and migratory routes as well as to the diminution of road kills (Keller and Pfister 1997). Therefore, the correct functionality of fauna passes should be assessed in terms of their effectiveness in the re-establishment of vertebrate movements with a special focus on the species that are to be promoted (Saunders *et al.* 1991, Beier and Loe 1992, Clergeau 1993, De Santo and Smith 1993, Velasco *et al*. 1995, Rodrígez *et al*. 1996). Though the number of studies and recommendations on the subject is high (see the review by Forman *et al.* 2002), we are still far from having a definitive design to alleviate the barrier effect suffered by a vertebrate community. In this respect, it is important to stress the relevance of two facts: the potential complementarity among passageway types and the final cost of the whole permeability system.

Given the necessity of the transportation infrastructure, several trades-offs arise regarding how to best mitigate the negative effect of the road or railway on animal populations. The first one is its cost in relation to effectiveness. The relevance of pass wideness as a recognized as determinant for the use by big as well as small vertebrates and the construction of wide crossing structures, therefore, are recommended (Reed *et al*. 1975; Reed 1981; Veenbass and Brandjes 1999). However, the cost of fauna passes increases as its size does, and the number of feasible wide crossing structures will be always restricted. Assuming the normal situation of a limited budget and a reasonable knowledge of the vertebrate community in one area, technicians face the question of what is the best solution from a vertebrate community connectivity point of view to maximize the size of fauna passes or to maximize their number?

The second trade-off is related to the potential selective nature of different passageway types. A differential use of crossing structures has been found in several studies (Reed 1981; Singer & Doherty 1985; Vassant *et al.* 1993a,b; Foster and Humphrey 1995; Rosell and Velasco 1999), and it potentially has community-scale effects. Thus, the investment on any type of crossing structure improves the connectivity for a species, but what will be the effect on other species? Is it best to reach a suboptimal solution for the majority of the species even though it may play against some of them? Other trade-offs in the detailed design of fauna passes exist and have potential implications for their effectiveness (Oxley *et al.* 1974; Madder 1984; Camby and Maizeret, 1987), though they are linked to those already mentioned and/or have a secondary relevance.

Within such a framework, our study focuses on a modest but interesting point: the evaluation of the use by fauna of crossing structures in a motorway of Northwest Spain. We compare the use by vertebrates of crossing structures specifically designed for them as well as "functional" (non-wildlife-engineered) structures of the motorway and some modifications of the latter to enhance their use by animals. The results should be applicable not only for Spain but for vast regions of Europe, as most vertebrates in the area have large, geographic distributions (Bang and Dahlström 1995; Blanco 1998).

Methods

Study Area

The study has been conducted along 71.5km of the Rías Baixas motorway (A-52), between the kilometric posts 2,75 and 74,25. The motorway runs across NW Spain, and it was built in 1993-2000. Climate is mild mediterranean with an average temperature of 11ºC and ca. 700mm precipitation (Castillo and Ruiz Beltrán 1977). Cereal dry-crops dominate the first 20km of the study area and are substituted by suboceanic holm oak (*Quercus rotundifolia*) woods and scrubs in the following 30km. The rest of the road runs across *Quercus pyrenaica* forests, tall scrubs dominated by species of *Cytisus* and *Erica*, low scrubs (*Genista tridentata, Halimium ocymoides, and H. lasianthum*) and wet meadows.

Types of Crossing Structures

The six types of crossing structures monitored in the motorway (N=82) and their main characteristics are presented in table 1.

Table 1
Main characteristics of the crossing structures analyzed in the study.

Structure type	Section	Size	Openness index	Specificity	N
Circular culverts	Circular	D: 1.80	0.04-0.09	F	33 (16)
Adapted culvert	Rectangular	W: 2- 3; H: 2	0.05-0.19	M	10 (5)
Wide underpasses	Rectangular	W: 4-9; H: 4-6	0.37-3.31	M	14 (9)
Wildlife underpasses	Rectangular	W: 20; H: 5-7	1.17-4.04	S	7 (6)
Overpasses	-	W: 7- 8	-	F	16 (9)
Wildlife overpasses	-	W: 16 (center) 20 (ends)	-	S	2 (2)

The structures are grouped in the types used along the paper and the total number of them monitored for footprints presented together with that of those provided with the photographic system (in brackets). Sizes are presented in meters for diameter (D), width (W) and/or height (H) and openness as the section to length ratio. The three specificity levels differentiated are functional or non-wildlife engineered (F), modified (M) and specifically designed for fauna (S).

Culverts are concrete pipes that collect running water from the roadsides as well as from creeks. We distinguish between the traditional circular culverts and adapted culverts (rectangular), as these represent the vertebrate-adapted sort of structures thanks to their flat-enlarged base. Underpasses also have rectangular sections and they are built to restore the connection of rural tracks and small roads. Wide underpasses are non-wildlife-engineered passages with square or rectangular sections designed for vehicle traffic. Wildlife underpasses are not crossed by tracks and have a gap in the ceiling between lanes that allows some natural illumination to reach the ground to promote plant growth. Overpasses are bridges that restore road or track connections over the motorway. They are designed for traffic, but they can be used by animals as well. Wildlife overpasses (hourglass-shape overpasses in our case) are exclusive for fauna, and they have been planted with grass and low stature scrubs (*Spartium junceum*). Though none of the wildlife overpasses connected tracks, they were used by vehicles in some occasions.

Five sections of the motorway (ca. 7km each) were selected to conduct the monitoring. The selection was aimed at having a representation of the three traversed landscapes with an over-representation of the two forest-dominated habitats due to their higher abundance and diversity of vertebrates. Thus, one study section was located within the crop-dominated area and two in each of the more forested landscapes. The selection of structures to monitor within each section was carried out with two premises: (1) the inclusion of all specific designs in the section, and (2) the inclusion of representatives from all crossing structure types.

Passageway Monitoring
Monitoring was carried out between the last week of June and the first of September 2002. Detection of crossing structure use by animals was based on track analysis and supplemented by the use of a photographic system specifically designed for the occasion. Marble dust was selected as an experimental tracking ground due to its odorless nature and the high quality of footprints it renders due to its density (Yanes *et al*. 1995). Control marble dust beds 1m wide and 3-10mm depth were laid down covering the whole passageway width near its mid-point (fig. 1). Footprint monitoring lasted in each crossing structure until 10 valid control-days were obtained, as those days in which weather conditions did not allow correct footprinting were not taken into account. Daily monitoring consisted of the identification of the number of tracks, species and crossing direction, following Bang and Dahlström (1995), Strachan (1995), Sanz (1996) and Blanco (1998) for track identification.

Fig. 1. Marble dust beds used for footprint monitoring in a wildlife underpass and a circular culvert. In both cases dust beds are 1m wide.

Some tracks could not be identified at the species level, and identification had to be carried out for species groups in the following taxa:

- Anurans: includes all frog and toad species
- Small mustelids: may include tracks from weasel (*Mustela nivalis*) and stoat (*Mustela erminea*)
- Cats: encompasses domestic cat (*Felis catus*) and european wildcat (*Felis silvestris*)
- Lacertids: several species of lizards and small lizards (*Lacerta* spp. and *Podarcis* spp.)
- Lagomorphs: combines the tracks of rabbit (*Oryctolagus cuniculus*) and Iberian hare (*Lepus granatensis*)
- Ophidians: several species belonging to the Fam. *Colubridae* and *Viperidae*
- Canids: include dog (*Canis familiaris*) as well as wolf (*Canis lupus*) tracks
- Rats: include *Rattus* spp
- Water vole: include a *Arvicola sapidus* and maybe *A. terrestris*
- Small mammals: mice, shrew and vole species

In 47 crossing structures (57% of total, see their distribution among types in table 1) a photographic system was used simultaneously. The photographic system resembles those evaluated by Hernández et al. (1997) and is composed of three elements: an infra-red barrier with active sensors at ground level, a digital camera (Sanyo VPC R1) and an electronic control connecting both. The photographic system allowed the distinction between rabbits and hares, domestic and wild cats, dogs and wolves, and weasels from stoats.

Data Analysis
The basic data handled to analyze the use of crossing structures by different animal species have been the frequency obtained from the 10-day track monitoring (defined as the number of days the species was detected in each passageway). Only data from wild and potentially feral animals (dogs and cats) were taken into account. Data from photomonitoring are used only as complementary information for the species that could not be distinguished by tracks.

The differential use of structure types has been analyzed with a Kruskal-Wallis test due to the lack of normality in datasets. Infrequent species (in less than 10% of passageways) and the two wildlife overpasses have not been introduced in these analyses as the low sample size preclude the unravelling of significant differences. The results of tests are presented with the chi-squared value due to the large sample size.

A use index (UI) has been computed to facilitate the comparison of relative use without bias linked to sample size. The use index has been defined as:

eqn.1 $$UI = (n_{ij}/N_j)/(n_{Ti}/N_T)$$

in which n_{ij} is the number of day-detections of the i-species at structures of j-type, N_j is the number of j-type structures monitored, n_{Ti} is the number of day-detections of the i-species in all structures, and N_T is the total number of monitored structures.
This index compares the number of records in any structure type with the expected one based in the whole dataset, one being the reference value. This index has been applied to structure types independently as well as for the comparison of overpasses vs. underpasses, fauna-specific vs. mixed use, and narrow (<2m) vs. wide (>2m) as these are comparisons frequently found in literature (Foster and Humphrey 1995, Yanes et al. 1995, Rodríguez et al. 1997, Veenbaas and Brandjes 1999).

Results

Species Using Passageways
The total number of tracks recorded was 1,424 and 78.8 percent of them (1,122) belonged to wild and feral animals. Evidences of human use were found in all structure types, with non-wildlife-engineered over- and underpasses totaling 92 percent of their tracks. The photographic system detected 490 crossings, 54.3 percent of which corresponded to wild animals.

The 82 monitored passageways (820 control-days) thus registered an average daily use of 1.37 tracks/structure-day. Small mammals (mice, voles and shrews) are the animals most frequently found using the crossing structures with a total of 414 records (36.9%). Lagomorphs were the second most frequent group, with 158 records (14.1%), followed by canids and red fox with 142 (12.7%) and 137 records (12.2%), respectively. Lacertids were detected in 73 occasions (6.5%), and the rest of the species did not reach 5 percent of records.

Crossing Structure Selection
Underpasses were the most frequently used crossing structure type (UI=1.10), followed by culverts and overpasses. Figure 2 also shows a more intensive use of non-wildlife engineered over and under passes. However, the use of all structure types but ecoducts (wildlife-engineered overpasses, with a UI=0.62) is close to expectation.

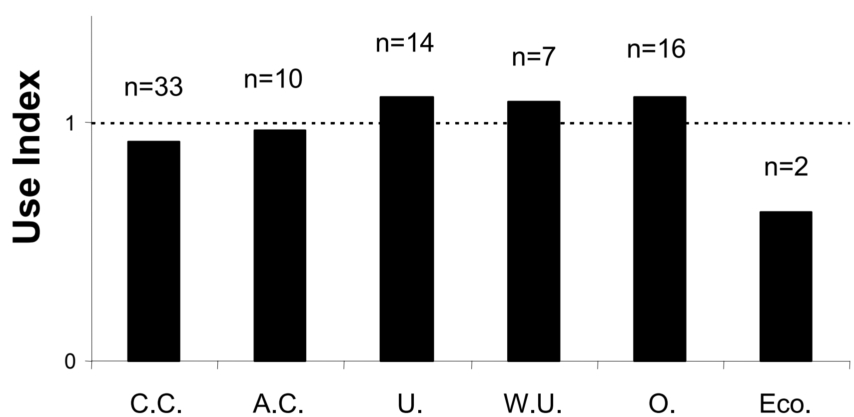


Fig. 2. Use index recorded in the five types of crossing structures differentiated in the study. CC: circular culverts, AC: adapted culverts, U: wide underpasses; WU, wildlife underpasses, O: overpasses and Eco: ecoducts. n: number of monitored structures.

Structure Type Selection by Species

Lagomorphs

Lagomorphs showed a differential use of crossing structure types (Fig. 2, Chi=31.61; 4 d.f.; P<0.001). The pass width seems to be the determinant factor for rabbits and hares, as the use index in wide structures (UI=1.89) is ten times bigger than in narrow structures. Open span and wildlife underpasses rank highest in use, though overpasses are also used.

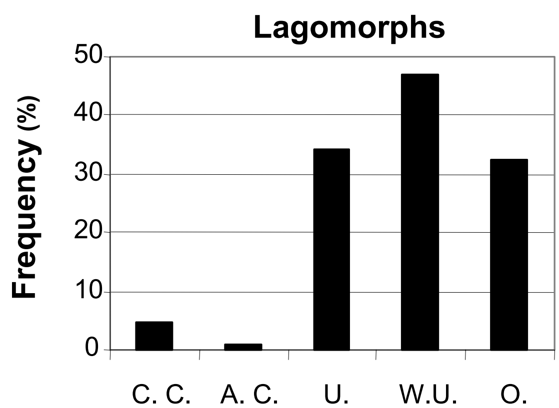


Fig. 3. Use frequency of different structure types by lagomorphs. CC: circular culverts, AC: adapted culverts, U: wide underpasses, WU: wildlife underpasses, O: overpasses.

The photographic system allowed the recognition of hares and rabbits (fig. 4). Thus, 60% percent of pictures (N=50) were from Iberian hares that showed a differential use among structure types (Chi=9.97; 4 d.f.; P=0.041). Hares use overpasses (UI=1.18) more frequently than underpasses (UI=0.87) and non-wildlife-engineered (UI=1.11) more than wildlife-specific structures (UI=0.76). Rabbits did not show significantly different use of structure types (chi = 7.852, 1 d.f., P = 0.097), but data suggest a slight selection of underpasses (UI= 1.47) faced to overpasses (UI= 0.35), and wildlife-engineered structures in general (UI= 2.28).

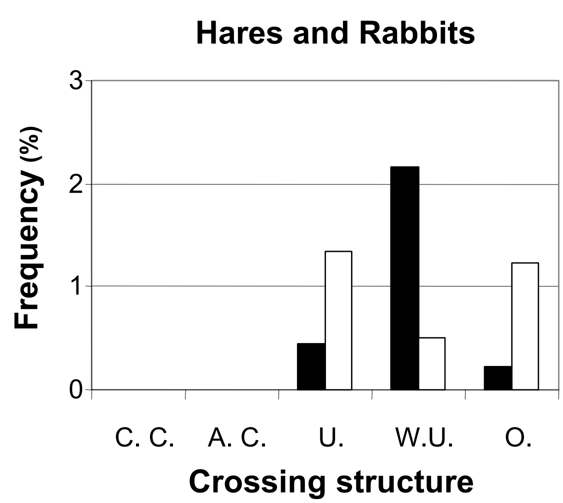


Fig. 4. Use frequency of different structure types by rabbits (empty bars) and hares (solid). CC: circular culverts, AC: adapted culverts, U: wide underpasses, WU: wildlife underpasses, O: overpasses.

Anurans, lacertids and Ophidians

Amphibians used all types of crossing structures, and no significant differences were found in their use (fig. 5.; Chi= 4.48; 4 d.f.; P = 0.344). Adapted culverts were slightly more used (UI=3.51) followed by wide underpasses (UI= 1.05) and circular culverts (UI= 0.71). Therefore, there is also a tendency for amphibians to use underpasses (UI=1.39) more than structures over the motorway (UI=0.54).

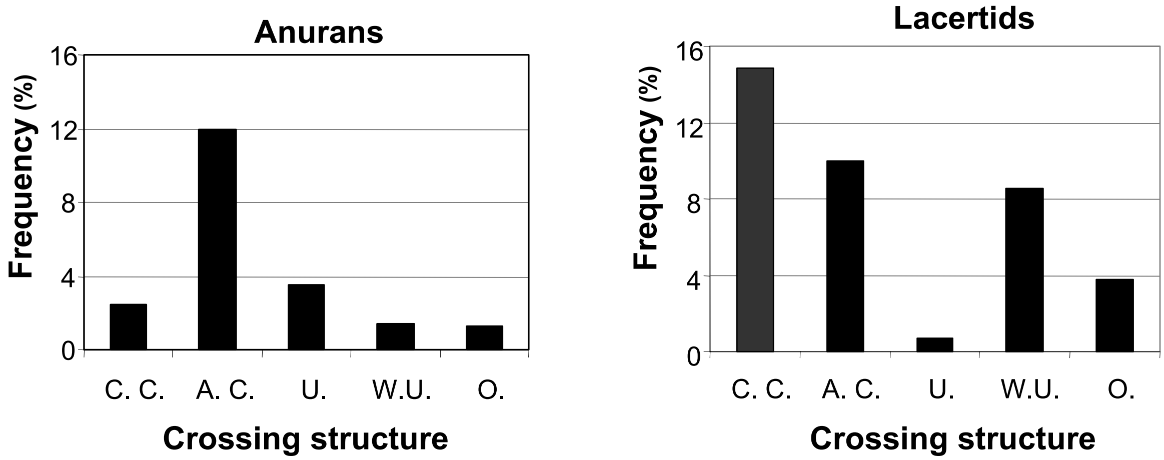


Fig. 5. Use frequency of different structure types by anurans and lacertids. CC: circular culverts, AC: adapted culverts, U: wide underpasses, WU: wildlife underpasses, O: overpasses.

Lacertids (73 records) also used all structure types with significant differences among them (Chi=13.15; 4 d.f.; P = 0.011). The highest crossing frequency was found in circular culverts (UI= 1.67) and a preference for narrow structures (UI=1.54) over wider ones (UI= 0.40) is noticeable. Similarily, lacertids were found to cross more frequently through wildlife engineered structures (UI= 2.17) than through the multi-purpose ones (UI= 0.65). No selection seem to occur between over and underpasses.

Ophidians were detected in only nine cases, precluding the formal test for preferences. Their tracks were found in all but wildlife-engineered passes, and adapted culverts had the highest use index (UI= 4.56).

Small Mammals and Rats

Small mammals (mice, voles and shrews) were found in all structure types but show relevant differences among them (fig.6.;Chi=30.94; 4 d.f.; P<0.001). Thus circular culverts (UI=1.34) and non-wildlife engineered overpasses (UI=1.28) rank highest, and wide passageways are selected over narrower ones (UI=1.24 and 0.74 respectively). The low use of wildlife engineered structures (UI<0.20) is noteworthy.

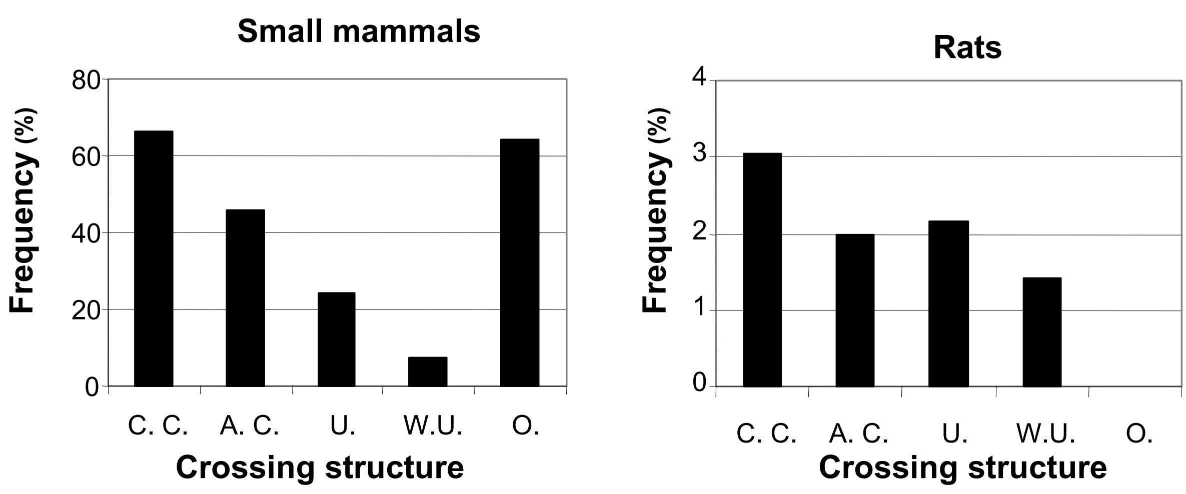


Fig. 6. Use frequency of different structure types by small mammals and rats. CC: circular culverts, AC: adapted culverts, U: wide underpasses, WU: wildlife underpasses, O: overpasses.

Rats showed a preferential use of circular culverts (UI=1.55) and narrow passageways, but differences among all types were not significant (Chi=4.25; 4 d.f.; P=0.373). They were never detected in overpasses nor in ecoducts.

Western Hedgehog *(Erinaceus europaeus)* and Eurasian Badger *(Meles meles)*

All hedgehog records were found in structures under the motorway, mainly in wildlife-engineered underpasses (UI= 5.86, fig. 7.). The use differed significantly among structure types (Chi=9.74; 4 d.f.; P=0.045) with a tendency to select wide passes (UI= 1.75), though circular culverts were also used (UI= 0.41).

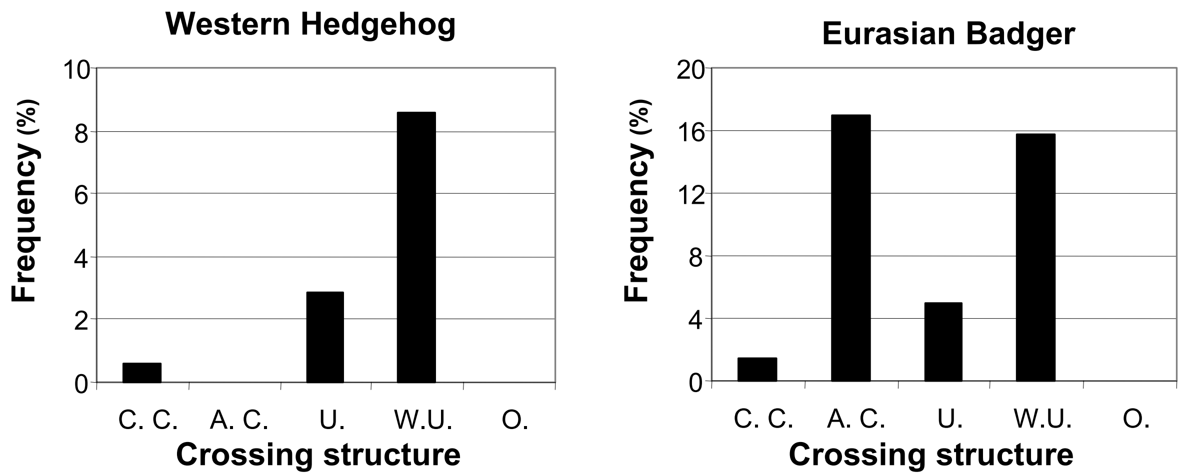


Fig. 7. Use frequency of different structure types by Western hedgehog and Eurasian badger. CC: circular culverts, AC: adapted culverts, U: wide underpasses, WU: wildlife underpasses, O: overpasses.

Eurasian badger used exclusively passageways under the motorway, thus showing a significant selection (Chi=12.79; 4 d.f.; P=0.012). Adapted culverts ranked highest in selection (UI=3.49) followed by wildlife-engineered underpasses (UI=3.22). Circular culverts were occasionally used (UI= 0.31).

Small Mustelids and Cats

Small mustelids show clear preferences among structure types (fig. 8.; Chi=11.23; 4 df; P=0.024) selecting in all cases culverts, both circular (UI= 2.19) and adapted (UI=0.98). All pictures from small mustelids (N=12) corresponded to weasel (*Mustela nivalis*).

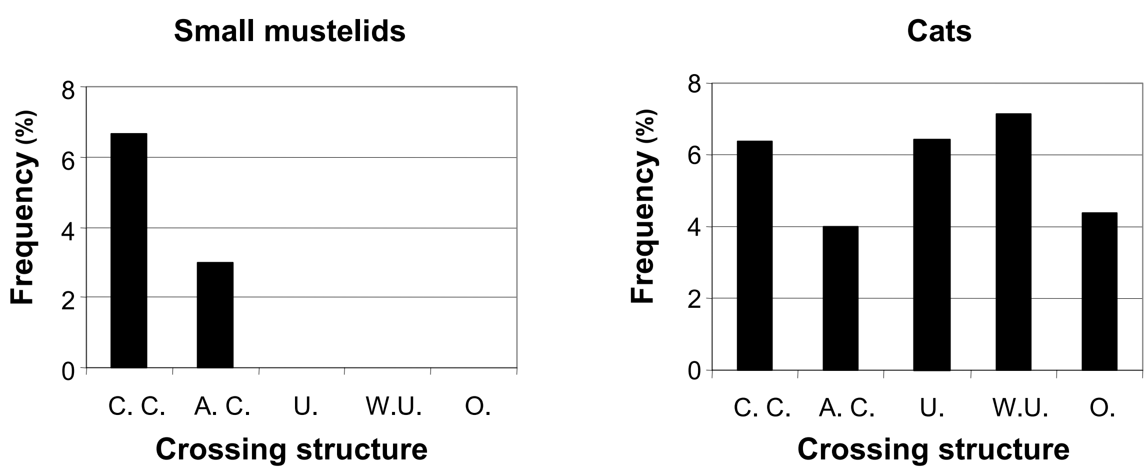


Fig. 8. Use frequency of different structure types by small mustelids and cats. CC: circular culverts, AC: adapted culverts, U: wide underpasses, WU: wildlife underpasses, O: overpasses.

Cats used all structure types but wildlife engineered overpasses (fig. 8.), and did not show preferences among them (Chi=2.57; 4 d.f.; P=0.632). Both types of underpasses and circular culverts ranked over the average (UI in the 1.13-1.27 range) and the rest wwas less used than expected. Twenty-six out of 27 photographic contacts corresponded to feral cats, and only one showed a wildcat using a wildlife-engineered underpass.

Red Fox (*Vulpes vulpes*) and Canids
Foxes used all types of crossing structures except wildlife-engineered overpasses, and they showed a significant selection among types (fig. 9.; Chi=18.58; 4 d.f.; P=0.001). Non-wildlife-engineered underpasses ranked the highest in preference (UI=2.05) followed by wildlife-engineered passageways (UI=1.88). Thus, foxes preferred wide passes (UI= 1.43), and used more frequently underpasses (UI=1.40) than structures over the motorway (UI= 0.54).

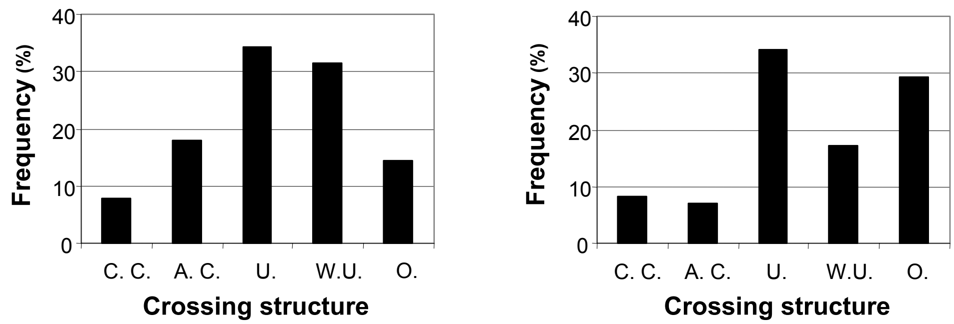


Fig. 9. Use frequency of different structure types by foxes and canids. CC: circular culverts, AC: adapted culverts, U: wide underpasses, WU: wildlife underpasses, O: overpasses.

Canid crossing was detected in all structure types, but a significant selection among them is found (fig. 9.; Chi=18.55; 4 d.f.; P=0.001). The highest use indexes were found for non-wildlife-engineered structures, both underpasses (UI=1.70) and overpasses (UI = 1.98). Wide passes are most frequently selected, but culverts are sometimes used by canids to cross the motorway (UI=0.47 and 0.40 for circular and adapted culverts respectively). Most records correspond to dogs as shown by the photographic system: only one in 33 snaps from canids was from a wolf. This picture was taken in a non-wildlife-engineered overpass.

Other Species
Finally, other species were detected on only a few occasions. Thus, a picture showed a garden dormouse (*Elyomis quercinus*) crossing through a circular culvert, and the only record of Red squirrel (*Sciurus vulgaris*) was taken in an adapted culvert. All records of water vole (*Arvicola* sp.) coincided in culverts, mainly in adapted ones (UI=4.92) and secondarily in circular (UI = 0.99). Photographic records (N=9) also point to a more intense use of adapted culverts (6 pictures) than circular ones (3), but species identification was not possible. Small-spotted genet (*Genetta genetta*) was found to use circular culverts (1 occasion) and wildlife-engineered underpasses (2 cases).

Red deer (*Cervus elaphus*) were detected in seven instances: four records were taken in wildlife-engineered overpasses and the rest in non-wildlife-engineered underpasses. On the contrary, roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*) were never detected in crossing structures, even though both species are rather abundant in the area.

Discussion
Our results show two interesting points: (1) all structure types, be they specifically designed for wildlife or not, are used by vertebrates, and (2) most species show some selectivity among passageway types, thus opening the possibility for various structures to play complementary roles in the connectivity of vertebrate communities.

The passageway width seems to be the structural characteristic that most determines the species that use it. This fact had been detected before for some taxa, as shown by the positive relation between ungulate and other mammal use of crossing structures and their width (Reed *et al*. 1975, Reed 1981, Veenbass and Brandjes 1999).

This relationship seems to be linked to animal size, as the narrowest structures were mainly selected by small vertebrates. Thus, circular culverts were selected by lacertids, small mammals, rats and small mustelids, though they were more or less frequently used by most other species except ungulates. Due to the frequency of culverts, it is noteworthy the role they may play in the restoration of connectivity for small- and mid-sized mammal populations dissected by roads (Huijser *et al.* 1999, Clevenger 2001). With respect to this, it is worth nothing the high number of records produced by small mammals and the number of tracks that can be found in any structure in just one day (even more than 10). Such an intense use of crossing structures may probably be more related to their inclusion as part of the daily home range of small mammals than to their use as specific crossing points for long-distance movements (Clark *et al.* 2001). Moreover, the high number of records within passageways may be associated with an increase in small-mammal populations in the surrounding roads (Adams and Geis 1983).

Adapted culverts have been extensively used by anurans, water voles and ophidians, probably as a result of their affinity for wet habitats, a typical location for most passage structures under roads. Apart from a tendency of the most frequent snakes in the area (*Natrix* spp.) to live close to water, this finding for ophidians may be also linked to poiquilothermy, as the same trend is common to lacertids. Thus, it is possible that the role of culverts for reptiles is not only to offer them an opportunity to safely cross the road, but to provide them with a microhabitat with more constant temperature (Rodríguez *et a*l. 1996). It is also worth noting the use of adapted culverts by badgers, a result coherent with the findings by Broekhuizen *et al.* (1986) of a preferential use of underpasses.

The four types of wide passageways, over and under the road, specific and non-wildlife-engineered ones, are selected by lagomorphs, canids and red fox. Among them, fox also showed a tendency to use underpasses, as stated before by several authors (Trewhella and Harris 1990, Rodríguez *et al.* 1997). Such a tendency is shared by hedgehogs and small-spotted genets, though the low number of records precludes generalizations to be made for these species.

Canids also used wide passes, and the fact that most of them were feral and semi-domestic dogs wandering near villages probably led to their preference for the non-wildlife-engineered ones. In the case of cat records, most of them being from the domestic species, there raises more doubts for the implementation of conservation measures. Cats did not show preferences among passage types, but the extrapolation of the results to wildcats is especially risky as the wildcat is classified as a vulnerable species under IUNC criteria in the Spanish Red Data Book (Palomo and Gisbert 2002). The fact that only one picture is of a wildcat in a specific underpass reinforces this claim to caution.

Unexpectedly, small mammals were frequently detected crossing over bare-ground, non-wildlife-engineered overpasses. This observation contradicts the results of previous studies pointing to very infrequent road crossing by small mammals due to their avoidance of low-cover habitats where they can be easily predated (Oxeley *et al.* 1974, Mader 1984, Swihart and Slade 1984). Thus, differences arising from landscape structure or differential behaviour among populations cannot be disregarded.

Wildlife engineering of structures is also relevant for connectivity at the vertebrate community level, though our results could look somewhat disappointing at first sight. On the one hand, our green bridges (wildlife-engineered overpasses) had low use indexes and were among the least selected structures for many species, though the fact that we could only work with two cases may underlie this result. However, red deer used them almost exclusively, a very noteworthy point, taking into account that it is one of the species most reluctant to cross through any passageway. Specific underpasses, on the other hand, were selected by lagomorphs, hedgehogs, badgers and probably small-spotted genets.

With these results in mind, what can we say about the permeability of the motorway? Along the study section (71.5km) there is one crossing structure every 0.47km, an average distance that should be enough to allow a good permeability of the road (Keller and Pfister 1997). However, this theoretical permeability would only be valid for species like small mammals, lacertids, cats, red fox and canids that use most structures indifferently. Considering only wide passes, a structure used by most species, the average distance rises to 0.85km, and for the case of specific designs distance goes up to 4.76km. Such distance is out of daily ranging areas for most species, thus stressing the relevance of non-wildlife-engineered structures to avoid the barrier effect (Camby & Maizeret 1987, Singleton and Lehmkuhl 1999). In our case, non-wildlife-engineered structures were used by most species.

Special attention should be given to ungulates, as this group was rather under-represented in our records. Our results point to a low effectivity of crossing structures for ungulates, a finding common in literature (Thirion and Mallet 1984, Vassant *et al*. 1993a,b). Roe deer and wild boar were not detected in any structure, a result that points to serious fragmentation effects to both species (Virgós 2002). The infrequent use of crossing structures by roe deer had been reported previously (Jacques and Garnier 1982), but other studies suggest that wild boar acclimate quickly to motorway passageways (Vassant *et al.* 1993a).

Back to questions introduced at the beginning of the paper, several applied recommendations arise from this study. Firstly, the all-large versus all-small trade-off for crossing structures appears senseless, as using several kinds of passageways seems to be the best option due to their complementarity. The fact that some animals like ungulates will only cross through very wide passes suggests the need for investment in such structures, but the preference of other species points to the need of smaller structures aa well. The extensive use of non-wildlife-engineered structures by many species suggests in many instances the best solution may be to adapt the functional structures of the motorway for wildlife, thus reducing the costs of implementing mainly wildlife-specific passes.

Second, as most wild species show some preferences among crossing structure types, it would be theoretically feasible to design permeable systems in linear infrastructures based on the knowledge about vertebrate communities. The relative size of vertebrate species and passes, and their location with respect to road lanes, are the best predictors of fauna crossings at present, but we are still far from having the whole picture of animals' reaction to the establishment of passageways. This is especially noteworthy for the case of endangered or special interest species that may show unpredictable behaviour.

Moreover, some species may be especially reluctant to use even the widest crossing structures (in our case at least roe deer and wild boar), and special attention should be given to the design of crossing areas for them. In our study, pass size seems to underlie the lack of use by roe deer and wild boar, as populations of both species are dense in the area, and deep tree cover is present even up to both ends of many over- and underpasses. Therefore, the disturbing effect of the motorway may be enough to impede the crossing of these animals even through 20-meter-wide passes, and the only solution for such shy species may be the presence of larger stretches of road running above or below the ground (in viaducts and/or tunnels).

Finally, it should be stressed that there is a strong need to carry out extensive studies such as the present one and to improve the systems used for passageway monitoring. Relevant data on fauna use of crossing structures are still scarce, and results are conditioned by the fact that present-day methods do not allow the precise identification of many species. Thus, some species included within track species-groups could be threatened by the barrier effect of roads, but this problem may remain undetected due to poor monitoring devices.

Acknowledgements: This study was carried out within a UAM-CEDEX research agreement with funds from the Spanish Ministry for the Environment. Cristina Mata has a pre-doctoral grant from the FPI Program of the Madrid Regional Government.

Biographical Sketch: Cristina Mata graduated in biology at the Universidad Autónoma de Madrid (Spain) in 2000 and obtained her master's degree in ecology by the same university in 2003. At present she works at the Terrestrial Ecology Group at the Ecology Department of UAM and is preparing her Ph.D. dissertation on the effectiveness of wildlife crossing structures in Spanish highways, the subject she has been working on for the last three years. Her research is carried out in cooperation with CEDEX, the research center of the Spanish ministery for public works. Terrestrial mammals and electronic methods applied to the monitoring of fauna are her main research interests.

References

Adams, L.W. and Geis, A.D. 1983. Effects of Roads in Small Mammals. *Journal of Applied Ecology* 20: 403-415.

Bang, P. and Dahlstrom, P. 1997. *Huellas y señales de los animales de Europa*. Ediciones Omega, S.A., Barcelona.

Beier, P. and Loe, S. 1992. A Checklist for Evaluating Impacts to Wildlife Movement Corridor. *Wildlife Society Bulletin* 20: 434-440.

Blanco, J.C. 1998. *Mamíferos de España I y II.* Editorial Planeta, S.A., Barcelona.

Broekhuizen, S.; van't Hoff, C.A.; Maaskamp, F. and Pauwels, T. 1986. The importance of hedgerows for leading migrating badgers *Meles meles* (L., 1758). *Lutra* 29: 54-65.

Camby, A. and Maizeret, C. 1987 . Perméabilité des routes et autoroutes vis-a-vis des mammiferes carnivores: exemple des études menées dans les landes de Gascogne. *Routes Et Faune Sauvage.* 5-7 junio, 1985. Strasbourg. pp.173-181 .

Castillo, F.E.; Ruiz Beltrán, L. 1977. *Agroclimatología de España.* Ministerio de Agricultura, Instituto Nacional de Investigaciones Agrarias, Madrid. Spain.

Clark, B.K.; Clark, B.S.; Johnson, L.A. and Haynie, M.T. 2001. Influence of Roads on Movements of Small Mammals. *Southwestern Naturalist* 46: 338-344.

Clergeau, Ph. 1993. Utilisation des conepts de l'ecologie du paysage por l'élaboration d'un nouveau type de passage a faune. *Gibier et Faune Sauvage* 10: 47-57.

Clevenger, A.P. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. *Journal of Applied Ecology* 38: 1340-1349.

De Santo, R.S. and Smith, D.G. 1993. Environmental Auditing: An Introduction to Issues of Habitat Fragmentation Relative to Transportation Corridors With Special Reference te High-speed Rail (HSR). *Environmental Management* 17: 111-114.

Forman, R.T.T. *et al.* 2002. *Road Ecology. Science and Solutions*. Island Press, Washington, DC. E.E.U.U.

Foster, M.L. & Humphrey, S.R. (1995). Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin*, 23: 95-100.

Haila, Y. (2002). A Conceptual Genealogy of Fragmentation Research: From Island biogeography to Landscape Ecology. *Ecological Applications*, 12: 321-334.

Hernández, F.; Rollins, D. and Cantu, R. 1997. An evaluation of Trailmaster camera systems for identifying ground-nest predators. *Wildlife Society Bulletin* 25: 848-853.

Huijser, M. P.; Van Der Grift, E. A., and Bekker, G. J. 1999. Habitat fragmentation and infrastructure: a review of the proceedings of an european and north american conference. *Lutra*. 41:43-54.

Jacques, J.C. and Garnier, G. 1982. Influences des autoroutes sur la faune terrestre et aérienne. *Reveu Géneral des routes et aérodromes*. 582: 39-45.

Keller, V. and Pfister, H.R. 1997. Wildlife Passages as a Means of Mitigating Effects of Habitat Fragmentation by Roads and Railway Lines. *Habitat Fragmentation and Infrastructure*. 17-21 Sept. 1995. Maastricht and The Hague, The Netherlands.

Mader, H.J. 1984. Animal habitat isolation by roads and agricultural fields. *Biological Conservation.* 29: 81-96.

Mº Fomento 2000. Carreteras y Ferrocarriles. *Anuario Estadístico 2000.*

Oxley D.J.; Fenton, M.B. and Carmody, G.R. 1974. The effects of roads on populations of small mammals. *Journal of Applied Ecology* 11: 51-59.

Palomo, L.J. and Gisbert, J. (eds.) 2002. Atlas de los mamñiferos terrestres de España. Dirección General de Conservación de la Naturaleza-SECEM-SECEMU. Madrid, Spain.

Reed, D.F. 1981. Mule deer behavior at a highway underpass exit. *Joumal of Wildlife Management* 45: 542-543.

Reed, D.F.; Woodward, T.N. and Pojar, T.M. 1975. Behavioral response of mule deer to a highway underpass. *Journal of Wildlife Management*, 39: 361-367.

Rodríguez, A.; Crema, G. and Delibes, M. 1996. Use of Non-wildlife Passages across a High Speed Railway by Terrestrial Vertebrates. *Journal of Applied Ecology* , 33: 1527-1540.

Rodríguez, A.; Crema, G. and Delibes, M. 1997. Factors affecting crossing of red foxes and wildcats through non-wildife passages across a high-speed railway. *Ecography,* 20: 287-294.

Rosell Pagés, C. and Velasco Rivas, J.M. 1999. *Manual de prevenció i correció dels impactes de les infraestructures viáries sobre la fauna*. Generalitat de Catalunya. Departamet de Medi Ambient, Catalunya.

Sanz, B. 1996. Estudio comparativo de las huellas de garduña, gineta y gato. *Quercus*, 130: 16-18.

Saunders, D.A.; Hobbs, R.J. and (editors). 1991. *Nature Conservation 2 : the Role of the Corridors.* Surrey, Beatty, Chipping Norton, New South Wales, Australia.

Singer, F.J. and Doherty, J.L. 1985. Managing mountain goats at a highway crossing. *Wildlife Society Bulletin,* 13: 469-477.

Singleton, P. H. and Lehmkuhl, J. F. 1999. Assessing Wildlife Habitat Connectivity in the Interstate 90 Snoqualmie Pass Corridor, Washington. Proceedings of the International Conference on Wildlife Ecology and Transportation: Florida Department of Transportation. p.9.

Strachan, R. 1995. *Mammal Detective*. Whittet Books Limited, London.

Swihart, R.K. and Slade, N.A. 1984. Road crossing in *Sigmodon hispidus* and *Microtus ochrogaster. Journal of Mammalogy*. 65: 357-360.

Thirion, J. and Mallet, C. 1984. Passages réservés aux grands animaux pour le franchissement des autoroutes françaises. *Bulletin Mensuel de l'Office National de la Chasse*. 76: 15-19.

Trewhella, W.J. and Harris, S. 1990. The effect of railway lines on urban fox (*Vulpes vulpes*) numbers and dispersal movements. *Journal of Zoology (London).* 221: 321-326.

Vassant, J.; Brandt, S. & Jullien, J.M. 1993a. Effects of the wildlife passage over motorway A5 on the populations of red deer and wild boar in the Massif d'Arc-en-Barrois. Part 2: case of the population of wild boar. *Bulletin Mensuel de l'Office National de la Chasse.* 184: 24-33.

Vassant, J.; Brandt, S. & Jullien, J.M. 1993b. Effects of wildlife passage over motorway A5 on the populations of red deer and wild boar. Part 1: case of the population of red deer. *Bulletin Mensuel de l'Office Nationale de la Chasse.* 183: 15-25.

Veenbaas, G. and Brandjes, G.J. 1999. The use of faunapassages along waterways under motorways. *Proceedings of the International Conference on Wildlife Ecology and Transportation.* Florida Department of Transportation. pp.7.

Velasco, J.M.; Yanes, M. and Suárez, F. 1995. *El Efecto Barrera En Vertebrados. Medidas Correctoras En Las Vías De Comunicación.* CEDEX, Madrid.

Virgós, E. 2002. Factors affecting wild boar (*Sus scrofa*) occurrence in highly fragmented Mediterranean landscapes. *Canadian Journal of Zoology* 80: 430-435.

Yanes, M.; Velasco, J.M. and Suárez, F. 1995. Permeability of roads and railways to vertebrate: the importance of culverts. *Biological Conservation*. 71: 217-222.

THE INFLUENCE OF PREDATOR-PREY RELATIONSHIPS ON WILDLIFE PASSAGE EVALUATION

Stuart J. Little (Phone: 61-2-9762-8183, Email: stuart.little@dipnr.nsw.gov.au), Senior Environmental Policy Officer, Department of Infrastructure, Planning and Natural Resources, G.P.O. Box 3927, Sydney, NSW 2001 (Australia)

Abstract: The influence of predator-prey systems and interactions on wildlife passage use by mammals has received little attention to date. Predator-prey systems vary throughout the world and across regions. Europe and North America are characterised largely by predator-prey systems in which predator and prey have co-evolved. However, large predators are absent from many areas, enabling prey species (e.g., ungulates) to range in predator-free environments. In mainland Australia, the main predator species are evolutionary novel and have not co-evolved with native prey. These fundamental differences in predator-prey systems potentially influence species' behavior and, it is argued, species' response to passage environments. Predator-prey systems also operate at different spatial scales. The spatial distribution of large mammals is influenced by regional scale predator-prey interactions that potentially influence the species encountering passages. Medium-sized and small mammals tend to operate at more refined geographical scales and passage avoidance or acceptance may be more influenced by localised predator-prey interactions and in response to the passage structure. Biotic interactions at passage approaches and within passage confines potentially influence the successful transit of the passage.

This paper examines the documented and potential influence of predator-prey interactions on wildlife passage use by mammals, and passage effects on predator and prey interactions. It considers predator-prey relationships relative to various spatial scales and takes into account biotic interactions that may occur at passage sites. The potential influences of relaxed selection and co-evolution of predator and prey on predator-prey systems and mammalian responses to passage environments are particularly addressed. It is concluded that extrapolation of management recommendations resulting from passage studies under different predator-prey systems need to be treated cautiously. The influence of predator-prey interactions on passage response by mammalian fauna appears to have been underestimated in passage studies to date and warrants further scientific investigation.

Introduction

The creation and operation of road and railway corridors are known to have adverse effects on wildlife populations through direct habitat loss, fragmentation and barrier effects, and through road and rail-kill (Andrews 1990; Bennett 1991, 1999; Forman et al. 2003). To address these impacts to wildlife, and to maintain connectivity across the landscape, wildlife passages (fauna tunnels, bridges, overpasses and modified culverts) are often proposed in association with new road or railway corridors (Ballon 1985; Gossem et al. 2001) or are retrofitted to ameliorate existing areas of high human safety risk or wildlife impact (Singer and Doherty 1985; Mansergh and Scotts 1989; Roof and Wooding 1996).

Many early wildlife passage studies focused on single-species evaluations (Reed et al. 1975; Reed 1981; Schaal et al. 1985; Singer and Doherty 1985; Mansergh and Scotts 1989). While several of these studies demonstrated improvement in road permeability and alleviation of population stresses for wildlife [e.g., mountain goats (*Oreamnus americanus*), Singer and Doherty 1985; mountain pygmy possum (*Burramys parvus*), Mansergh and Scotts 1989], single-species evaluations fail to consider the cascading effects (positive and negative) on non-target species (Clevenger and Waltho 2000). In contrast, many multi-species evaluations have tended to examine the variety of species using passages and their frequency of movement but often without testing hypotheses or without local abundance or density information (Camby and Maizeret 1985; Hunt et al. 1987; Fehlberg 1994; Foster and Humphrey 1995; Nieuwenhuizen and van Apeldoorn 1995; Norman et al. 1998; Veenbaas and Brandjes 1999). In the absence of this information, such examinations provide little or no ecological context for species' use or passage effectiveness.

More recently, emphasis has been placed on multi-species evaluations and testing the performance of various wildlife passage and habitat attributes in influencing passage use by particular species or taxonomic groups (Yanes et al. 1995; Rodríguez et al. 1996; Rosell et al. 1997; Clevenger 1998; Clevenger and Waltho 1999, 2000; Clevenger et al. 2001). These studies have begun to reveal differences in predator and prey species' responses to different passage structural and habitat variables. However, little attention has been afforded to how fauna use of wildlife passages influences, or is influenced by, other ecological processes, such as predator-prey relationships (Little et al. 2002).

The study of wildlife passages is shifting from the consideration of ameliorating site specific road and rail impacts to examining how wildlife passages function in terms of providing regional connectivity in the landscape and sustaining wildlife communities (Bennett 1999; Clevenger and Waltho 2000; Forman et al. 2003). Animal individuals do not operate in isolation but form part of a complex set of ecological interactions that operate at multiple scales (Lord and Norton 1990; Gehring and Swihart 2003). Predator-prey systems may become destabilised through fragmentation and habitat modification (Cole 1987; Karieva 1987; Donovan et al. 1997; Collinge 1998). For example, in the absence of predators, prey populations such as ungulates may be unable to sustain an equilibrium with their food resources (Sæther 1997; Ripple and Larson 2000; Ripple et al. 2001). The absence of large predators can also lead to mesopredator release and have adverse flow-on effects to smaller species of prey (Terborgh and Winter 1980; Soulé et al. 1988). Hence, in order to sustain ecological integrity and processes, it is necessary for wildlife passages to sustain predator-prey relationships in the landscape. However, predator-prey interactions may also influence passage acceptance or avoidance by mammals, which in turn can have flow-on effects (positive and negative) to metapopulations.

This paper provides a review of how passage use by mammals is influenced by predator-prey systems and relationships. It also considers how passage structures in turn may affect predator and prey interactions, and thus have flow-on effects back to the predator-prey systems operating in the landscape. Consideration is given to both regional and local effects. International differences in predator-prey systems and species' composition are considered with examples being drawn from Europe, North America and Australia. Areas for future research are identified and implications for wildlife passage evaluation and management provided.

Literature Review

I conducted a literature survey in April 2003 using BIOSIS (Biological Abstracts). A search was conducted for the following key words: *wildlife* with any of the following additional terms: *passage, tunnel, culvert, underpass, overpass*, and *ecoduct*. Additional papers were obtained by examining the literature cited in the references and from considering the proceedings of the first, second and third international conferences on wildlife ecology and transportation (Evink et al. 1996, 1998, 1999) and the *2001 Proceedings of the International Conference on Ecology and Transportation* (CTE 2002) (Papers printed solely as abstracts in CTE 2002 have not been considered due to limited information on methods and results.) The available literature was then examined for evidence of predator-prey influences on wildlife passage use by mammals and any information on the effect of passages on predator-prey interactions. As a number of wildlife passage evaluations are provided in internal departmental reports and post-graduate theses not readily available to the public, this paper largely considers the published material that is available. The focus of this paper is also limited to spatial influences of predator-prey relationships on wildlife passage evaluation.

International Differences in Predator-Prey Composition

To date, little attention has been afforded the international differences in predator-prey systems and wildlife community characteristics and, therefore, the different ecological role played by wildlife passages in different countries and continents. Europe, North America, and Australia have major differences in the composition and distribution of their largest predator and prey species, and this potentially influences their predator-prey systems and mammalian interactions.

In Europe, mammalian predator and prey species have generally co-evolved, although larger predators are rare or absent from many areas. The largest carnivores are gray wolves (*Canis lupus*) and brown bears (*Ursus arctos*). These species occur in discrete populations. The brown bear mainly occurs in Northern Scandinavia adjoining Russia, although remnant populations exist in the Iberian Peninsula, Central Italy, and South-Eastern Europe (Macdonald and Barrett 1993). Wolves occur in Eastern Europe but only have relict populations in Italy, France, Spain, Portugal and Sardinia (Macdonald and Barrett 1993). Lynx (*Lynx lynx*) are scattered throughout Scandinavia but occur only in isolated pockets in other parts of Europe, while Iberian lynx (*L. pardina*) only occurs in isolated pockets in the Iberian Penisula (Macdonald and Barrett 1993; Palomares et al. 2000). In contrast, ungulates such as wild boar (*Sus scrofa*), red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) are widespread throughout Europe (Macdonald and Barrett 1993). The absence of large predators from many areas has resulted in many ungulate populations existing in predator-free environments (Sæther 1997). Consequently, European passage studies sometimes record use by ungulates coinciding with use by medium and small predator species (Ballon 1985; Nieuwenhuizen and van Apeldoorn 1995; Rosell et al. 1997).

Like Europe, mammalian predator and prey species in continental North America have generally co-evolved, although larger predators are rare or absent from many areas. In the contiguous United States and Mexico, for example, grizzly bears (*Ursus arctos*) and wolves are currently absent from 99 percent of their original range and this has freed many large herbivores (e.g., ungulates) from natural predation (Berger 1998). Rare carnivores in North America for which conservation efforts are in place include grizzly bear, black bear (*U. americanus*), gray wolf, wolverine (*Gulo gulo*), Canadian lynx (*Lynx canadensis*), fisher (*Martes pennanti*) cougar (*Puma concolor*), Florida panther (*P. c. coryi*), and ocelot (*Leopardus pardalis*) (Beier 1995; Foster and Humphrey 1995; Ruediger 1998; Tewes and Hughes 2001).

In mainland Australia, the main predators are evolutionary novel and include the dingo (*Canis lupus dingo*), dog (*C. l. familiaris*), red fox (*Vulpes vulpes*) and cat (*Felis catus*). The dingo is believed introduced from Asia about 3,500 – 4,000 years ago, dogs and cats shortly after European settlement (about 210 years ago), while the red fox was introduced about 140 years ago (Short et al. 2002). Medium-sized and small native carnivores [Tasmanian devil (*Sarcophilus laniarius*), <8kg; tiger quoll (*Dasyurus maculata*), <7kg; eastern quoll (*D. viverrinus*), 1.3kg] exist in Tasmania; however, all but the tiger quoll are believed extinct on the mainland. Dingos, dogs, foxes and cats are known to predate native macropods, such as kangaroos and wallabies and small native mammals (Triggs et al. 1984; Banks 2001; Short et al. 2003). Both the fox and cat have been implicated in the extinction of many ground-dwelling native mammals over the past 130 years (Short et al. 2002).

The implications of the above differences in predator-prey systems and their potential implication for wildlife passage studies can be summarised as follows:

1. In North America and Europe, the use of passages by predators (particularly large carnivores) is seen as a positive environmental outcome; whereas, in Australia, passage effectiveness is potentially compromised by high levels of introduced predator use.
2. Many areas of Europe and North America, have free-ranging large herbivores (e.g. ungulates) occurring in the absence of large predators. Relaxation of anti-predatory behavior may influence prey response to roads and passages.
3. Europe and North America are characterised by prey which, for the most part, have co-evolved with their predators. In Australia, the main predator species (cat, dog, fox) have not co-evolved. The absence of co-evolution appears to influence prey perception of predation risk (Banks 1998; Short et al. 2002) and may influence prey response to passages (Little et al. 2002).

Predator-Prey Relationships and Passage Effects

Do Wildlife Passages Service Species Equally?

In order to examine whether wildlife passage use is influenced by predator-prey interactions, it is first necessary to examine those studies that have examined and tested the response of predator and prey species and taxonomic groups to passage structures. A number of recent multi-species evaluation studies have examined multiple structures and tested whether wildlife passages service species equally by examining the frequency of use by species and taxonomic groups taking into account local abundance information (Yanes et al. 1995; Rodríguez et al. 1996; Clevenger and Waltho 1999, 2000; Clevenger et al. 2001). Two studies (Rosell et al. 1997; Clevenger 1998) have also examined equal use based on presence/absence of taxonomic groups, thereby omitting any influence from population densities or seasonal changes in behavior. These studies have found that passages do not service all species equally and that different passage attributes affect different species' groups in different ways.

Regional Predator-Prey Interactions and Connectivity

The interaction between an animal and a passage will depend on the interaction between regional and local scale influences operating to bring the animal into contact with the road (Opdam 1997; Barnum 2001), the ecological effects of the road operating as a repellent (or in some cases as an attractant) (Getz et al. 1978; Adams and Geis 1983; Forman and Deblinger 2000), and the response of the animal to the passage structure (Clevenger and Waltho 2000; Barnum 2001; Forman et al. 2003).

Large predators are known to be particularly susceptible to road effects and have received particular attention in wildlife passage studies because of their dependence on regional landscapes (Land and Lotz 1996; Ruediger 1998; Clevenger and Waltho 2000; Gloyne and Clevenger 2001). In terms of predator-prey relationships at a regional level, predators may align their territories with prey availability (Forbes and Therberge 1995; Gloyne and Clevenger 2001), seek out new territories when dispersing (Beier 1995; Sweanor et al. 2000), or extend foraging beyond their territories for prey (Forbes and Theberge 1995; Kunkel et al. 1999). In response to predators, prey can adopt a range of anti-predatory behaviors to minimise predation risk. This includes predator avoidance strategies that spatially separate prey from their predators. For example, in England, hedgehogs (*Erinaceus europaeus*) are known to use residential and urban environments to avoid badgers (*Meles meles*) (Doncaster 1994) while in North America, white-tailed deer (*Odocoileus virginianus*) are known to survive population declines by keeping to the periphery of wolf territories (Hoskinson and Mech 1976; Mech 1977). Therefore, passage acceptance or avoidance by mammals may be influenced by regional predator-prey interactions, such as the spatial segregation of predator and prey as well as local interactions at passage approaches (figure 1).

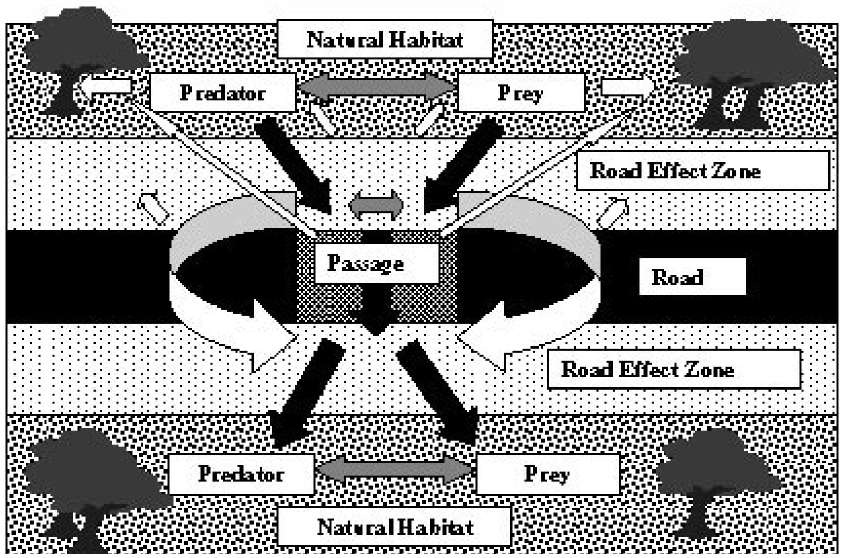


Fig. 1. Predator-prey interactions with respect to passages. Grey arrows indicate predator-prey interactions; white arrows indicate avoidance; black arrows indicate interactions bringing animals to passages and flow-on effects.

The potential influence of regional predator-prey interactions on predator and prey responses to wildlife passages has been considered in four passage studies (Foster and Humphrey 1995; Clevenger 1998; Clevenger and Waltho 2000; Gloyne and Clevenger 2001). The studies by Clevenger and others examined passages along the Trans-Canada Highway in Banff National Park, Alberta, Canada, while the study by Foster and Humphrey was conducted in Florida, U.S.A.

In his study of winter passage use by large mammals in 11 wildlife underpasses, Clevenger (1998) found that both large carnivores [wolves, coyotes (*Canis latrans*), cougars, black bears and grizzly bears] and ungulates [deer (*Odocoileus sp.*) and elk (*Cervus elaphus*)] were using underpass structures but showed different passage preferences. Ungulates used passages in areas of human activity whereas large carnivores were under-utilising or avoiding them. The difference in passage use was attributed to large predators avoiding areas of human occupation and the fact that elk (which accounted for 75% of the ungulate data) were seeking out wolf-free zones as refugia from predation. Clevenger and Waltho (2000) also found differences in predator-prey responses following 35 months of monitoring 11 underpasses. Carnivores had a tendency to use underpasses close to drainage systems whereas ungulates tended to avoid them. The authors argued that the inverse relationship between carnivores and ungulates with respect to drainage may have reflected predator-prey interactions rather than resulting from any direct effect of landscape attributes on underpass use. In their study of four underpasses in Florida, Foster and Humphrey (1995) observed the lowest recordings of deer in an underpass frequented by humans, bobcats and Florida panther, whereas panthers were lowest in the passage most used by deer. The authors commented that inter-specific interactions may have led to deer avoiding passages used by humans, bobcats and panthers.

In contrast, in their study of 22 wildlife crossing structures (open span bridge underpasses, culverts, and overpasses) by cougar and its prey species [mule deer (*Odocoileus hemionus*) and white-tailed deer)], Gloyne and Clevenger (2001) found a significant positive correlation between passages made by cougar through wildlife crossing structures and those made by the ungulates. This was attributed to cougar selecting home ranges based on deer presence, an important factor influencing cougar diet. Thus, the authors were able to demonstrate road permeability through the provision and acceptance of passages by cougar and deer, and connectivity in relation to cougar habitat based on continued access to prey. The study also found cougars preferring open-span bridge underpasses and cougar use being greatest in winter, reflecting seasonal variations in cougar and ungulate distribution.

The above studies demonstrate the need for regional connectivity between predator and prey species if predators are to have access to prey resources and if prey populations are to be able to sustain themselves through predator avoidance. However, regional connectivity for wildlife populations and predator-prey processes can also be influenced by localised predator and prey responses to passage structures. In Colorado, U.S.A., Barnum (2001) and Henke et al. (2001) examined passage use in comparison to road crossings at grade.

Both studies found passage use by predators (particularly felids and mustelids); whereas, ungulates avoided beneath-grade structures. However, large carnivore species have also been reported avoiding passage structures (e.g., wolves, Pacquet and Callaghan 1996, Kohn et al. 1999; coyote, Henke et al. 2001, Tigas et al. 2002; black bear, Roof and Wooding 1996; Singleton and Lehmkuhl 1999). Ungulates have also been reported acting hesitant towards, or avoiding, below-grade passage structures (Reed et al. 1975; Olbrich 1984; Schaal et al. 1985; Rodríguez et al. 1996; Rosell et al. 1997; Austin and Garland 2001; Henke et al. 2001; Barnum 2001) but appear to accept overpasses (Nieuwenhuizen and van Apeldoorn 1995; Berris 1997).

If a road acts as a barrier for movement of a species and that species also avoids passage environments, then this can lead to crowding effects, inter- and intra-specific competition for resources, genetic homogeneity, and greater susceptibility of populations to predation, stochastic processes and certain catastrophic events (Simberloff and Cox 1987; Collinge 1998; Lidicker 1999). Similarly, if passages provide connectivity for some species and not others, then this can disrupt predator-prey processes and have flow-on effects to predator and prey populations. Scientific testing of the reasons for avoidance and its ecological consequences has received little attention to date and requires further scientific investigation.

Local Predator-Prey Interactions and Connectivity

Different sized mammals perceive their environment at different spatial scales (Gehring and Swihart 2003). Species-specific responses to fragmentation are related to inter-specific differences in the perception of landscape structure and the degree of fragmentation (Lord and Norton 1990, Gehring and Swihart 2003). It stands to reason then that the perception of fragmentation and the opportunity it may provide for predator foraging, and its propensity to present a predation risk for a prey species, must therefore also be related to scale. Thus, different species are likely to respond differently to various habitat attributes due, at least in part, to their influence on predation risk and opportunity for foraging. The proximity and structure of habitat adjacent to passages may therefore influence predator or prey response at passage approaches.

Passage design may also influence predation risk. Wide, open passages have the advantage of enabling large prey species to detect predators early (Little et al. 2002); however, open areas may present a predation risk to small mammals (Hunt et al. 1987; Rodríguez et al. 1996). Culverts and passages with smaller cross-sections have the advantage of providing protection from aerial predators (Rodríguez et al. 1996). However, long, narrow passages may present a higher predation risk from terrestrial predators due to limited escape opportunity should an encounter take place (Little et al. 2002).

Localised habitat, passage and road structural variables may be particularly important for small and medium-sized mammals with smaller territories (Yanes et al. 1995; Rodríguez et al. 1996; Clevenger and Waltho 1999; Clevenger et al. 2001; Cain et al. 2003). While small mammals have been reported using larger passage structures (e.g. Ballon, 1985; Nieuwenhuizen and van Apeldoorn 1995; Norman et al. 1998), the response of small and medium-sized mammals has largely been tested in studies of culverts (Yanes et al. 1995; Rodríguez et al. 1996; Clevenger and Waltho 1999; Clevenger et al. 2001).

In Spain, both Yanes et al. (1995) and Rodríguez et al. (1996) each examined 17 passages (mainly culverts) and found that small mammals constituted the majority of crossings (77% and 55.6%, respectively) whereas medium-sized wild carnivores showed relatively low rates of crossing (4% and 25.2%, respectively). Yanes et al. (1995) found that small mammals avoided long culverts and preferred culverts that had greater openness and surrounded by more complex vegetation structure. While carnivore use was low, the authors commented that one tunnel serviced all genet (*Genetta genetta*) and almost half the wildcat (*Felis sylvestris*) crossings. In contrast, Rodríguez et al. (1996) found that small mammals preferred border rather than scrubland and farmland habitat and showed significant preferences for culverts with small entrances (less than or equal to 2m width); whereas, carnivores preferred culvert structures and significantly preferred scrubland with crossing rates being six times higher than border habitat and 20 times higher than in farmland. Rosell et al. (1997) also found that carnivores selected structures within a short distance of forest or shrub vegetation although individual carnivore species tended to respond to different habitat and structural attributes. Small mammals favoured passages with a natural substratum and which had their entrance at the same level as surroundings. The studies by Yanes et al. (1995) and Rosell et al. (1997) made little comment regarding predator-prey interactions; however, Rodríguez et al. (1996) considered that small mammals may have preferred narrower passages due to predation risk.

Studies in Banff have also revealed differences in predator and prey use of culverts (Clevenger and Waltho 1999; Clevenger et al. 2001). In three months of winter monitoring of 24 culverts, Clevenger and Waltho (1999) found that carnivores [weasels (*Mustela sp.*) and American martens (*Martes americana*)] used more passages and used them more frequently than small mammals [snowshoe hares (*Lepus americanus*), red squirrels *(Tamiasciurus hudonicus*), deer mice (*Peromyscus maniculatus*), voles (Arvicolinae) and shrews (*Sorex sp.*)]. Weasels were present in 19 (79%) of the culverts while voles and red squirrels were only present in three and four of the culverts, respectively, although deer mice were recorded in 14 (58%) passages. Conversely, small mammals were more prevalent on transects outside the culverts (red squirrels and hares accounted for 50% of all species detections in adjacent transects while weasels and martens comprised 38%). The authors also observed that voles used the fewest number of culverts yet meadow voles (*Microtus pennsylvanicus*) and red-backed voles (*Clethrionomys gapperi*) were the dominant species in the road corridor. Clevenger et al. (2001) also found differences between predator and prey use of 36 culverts. The authors found that weasels (*Mustela erminea* and *M. frenata*) and deer mice used the culverts most frequently whereas red squirrels and snowshoe hares were the most common in adjacent habitats. In both studies, the authors commented that the inverse relationship between predator and prey was noteworthy.

While the influence of habitat and passage structural attributes on passage response by mammals has yet to tested in Australia, in their study of fauna tunnels and culverts in New South Wales, Hunt et al. (1987) observed that feral predators predominated at the recently-established tunnels which lacked vegetative cover; whereas, small mammals were absent from these structures. Conversely, small mammals predominated in established culverts which had cover near passage entrances and where predator use was much lower. However, more recent studies (Norman et al. 1998; Taylor and Goldingay *in press)* have found low levels of passage use by feral predators.

It has been suggested that small mammal preference to smaller passages with lower openness may be related to predation risk which may be potentially greater in larger passages than smaller ones (Hunt et al. 1987; Rodríguez et al. 1996; Clevenger and Waltho 1999; Clevenger et al. 2001). However, predominant use by predators may also lead to prey avoidance even of small passages (Clevenger and Waltho 1999; Clevenger et al. 2001). In terms of predator behavior, cover near passage entrances may favour use by native carnivore species (Rodríguez et al. 1996, 1997; Clevenger et al. 2001; Cain et al. 2003). However, in Australia, it has been suggested that feral predators may focus their activities on tunnels which lack vegetative cover (Hunt et al. 1987).

Importantly, the above studies have found that rather than providing regional connectivity, the main species using culverts tend to have small home ranges. Culverts, therefore, appear to service their own unique subpopulations (Yanes et al. 1995; Clevenger and Waltho 1999; Clevenger et al. 2001). For example, Clevenger and Waltho (1999) noted that individual ranges for red squirrel and deer mice were at least an order or two magnitude less than the spatial scale of the 24 culverts (range = 55km). Given the decreased territorial range of these animals, it is possible that these smaller passages may be more important as habitat and be used more regularly by individuals. It is possible then that smaller passages may be more potentially prone to biotic interactions at passage entrances and within passage sites than larger underpasses. Also, while several of the above studies made observations regarding predator and prey responses, none actually correlated predator and prey use to each other, nor tested the reasons for the avoidance or attraction responses encountered. Therefore, the degree to which predator and prey interactions may be influencing passage use can only be inferred and may be masked by responses to the road, passage and habitat attributes.

Scent-Marking

It has been proposed that predator scent may be the means through which prey can detect predators and avoid encounters at passage sites (Doncaster 1999; Clevenger and Waltho 1999; Clevenger et al. 2001; Little et al. 2002). Scent marking of passage entrances by predators has been reported in three recent studies (Clevenger and Waltho 1999; Mathiasen and Madsen 2000; Clevenger et al. 2001); however, only one study (Mathiasen and Madsen 2000) has quantified scent marking by predators. In their study of a single 155m-long fauna underpass in Denmark, Mathiasen and Madsen (2000) recorded frequent use by red foxes, badgers, stone martens (*Martes foina*) and roe deer. The authors recorded territorial marking at the passage entrance by fox (13 times of 122 passages), badgers (4 of 16 passages) and stone martens (6 of 18 passages). Interestingly, the passage marking coincided with observations of prey avoidance. The observations of roe deer were from a single male when eight other deer were observed in the area. Brown hares (*Lepus europaeus*) were observed entering the underpass twice, but on both occasions, they showed reluctant behavior, and exited rapidly (Mathiasen and Madsen 2000).

In their examination of culverts in Banff, Clevenger and Waltho (1999) and Clevenger et al. (2001) observed scent marking by American marten and weasels as a common occurrence (Clevenger and Waltho 1999; Clevenger et al. 2001). These studies also found small carnivores (weasels and martens) predominating within the culverts which coincided with prey (snowshoe hares, red squirrels, voles) avoidance of the passages. Both studies commented that the inverse relationship between predator and prey was noteworthy.

Within-Passage Effects

Passage Occupation

Little information exists regarding the use of passages by species' individuals for purposes other than transit and how this may inhibit movement by other animals. In Texas, USA, bobcats (*Lynx rufus*) have been observed using culverts as day-beds to rest during hot summer days (Hewitt et al. 1998; Tewes and Hughes 2001). Cain et al. (2003) comment that bobcats in Texas used culverts for purposes such as resting, hunting and thermoregulation. In the Netherlands, Douwel (1997) noted the use of purpose-built badger pipes by badgers as setts. Such resident occupation by predators may deter prey species from using the passages. However, such occupation may also deter other carnivores from using passages. For example, Tewes and Hughes (2001) suggested that culvert occupation by antagonists or competitors of ocelots [e.g., bobcats, coyotes, skunks (*Mephitis mephitis*) and rattlesnakes (*Crotalus atrox*)] could function as a barrier to ocelot passage and that scent marking by coyotes or bobcats could deter ocelot use of culverts. In their study of an underpass in Denmark, Mathiasen and Madsen (2000) attributed the presence of other mammals as a possible source of avoidance in the few instances that approaching carnivores (red foxes, badgers, stone martens) failed to enter the passage. The degree to which passage dominance by individuals or species inhibits movement by other animals has been little studied and warrants further investigation.

Wildlife Passages as Prey-Traps

Several papers have suggested the possibility of wildlife passages acting as 'prey-traps' with prey species being effectively funnelled into areas of high concentration (Hunt et al. 1987; Reading 1989; Norman et al. 1998). The issue of whether wildlife passages act as prey-traps was subject to a recent review (Little et al. 2002). The authors found only one confirmed report of passages increasing predation risk, an instance where a purpose-built tunnel, designed to facilitate the movement of the mountain pygmy-possum through road-fragmented habitat, was intruded by a red fox (Little et al. 2002 cit I. Mansergh, personal communication). The authors concluded that evidence of the existence of prey-traps was scant, largely anecdotal and tended to indicate infrequent opportunism rather than recurring patterns of predation. However, they also noted that the conclusions need to be treated cautiously due to the absence of scientific studies examining whether predator density and behavior are influenced by passage presence and whether passages act as prey-traps.

Prey Perception of Predators

The acceptance or avoidance of wildlife passages by prey species may be influenced by predation risk (Doncaster 1999; Clevenger and Waltho 1999; Little et al. 2002). Predation risk in turn is influenced by how a prey species perceives a predator. Prey perception of predators may be influenced by relaxed selection and whether the predator and prey species have co-evolved (Banks 1998; Berger 1998; Blumstein et al. 2000; Short et al. 2002). These influences have direct implications for predator-prey systems and may affect predator-prey interactions at all scales.

Relaxed Selection

Isolation of a prey species from its predator may occur naturally or result from human-induced effects, such as fragmentation (Berger 1998). When a prey species becomes isolated from its predator, it can exhibit a relaxation in its anti-predatory behavior (Berger 1998; Bøving and Post 1997; Blumstein et al. 2000). For example, wolves are known predators of caribou (*Rangifer tarandus*) (Seip 1991; Bøving and Post 1997). However, female caribou in predator-free Greenland display greater predation-vulnerable postures and behaviors (such as lying down flat, foraging in smaller groups and displaying less vigilance during feeding) than caribou in Alaska (Bøving and Post 1997). In Florida, where road mortality constitutes 75-80 percent of Key deer (*Odocoileus viginianus clavium*) deaths, Key deer neither migrate seasonally or form large groups and are more solitary than northern white-tailed deer (Hardin et al. 1976, Calvo and Silvy 1996). It has been suggested that the lack of predators and different competitive and selective pressures may have resulted in these behavioral differences (Calvo and Silvy 1996).

No study appears to have yet examined whether the effect of relaxed selection influences prey response to passage environments. If passages present a predation risk to prey, then it is possible that inhibition towards a passage structure may be reduced under relaxed selection or a prey species may be more willing to accept a passage with lower openness in predator-free environments than would otherwise occur. In this context, caution needs to be exercised if extrapolating passage structure recommendations for prey from studies undertaken under different predation pressures or risk, particularly if extrapolating passage structural designs for prey based on predator-free environments. In situations where predators exist and prey species are found to be avoiding wildlife passages, comparative studies with areas where relaxed selection has occurred may assist in determining whether, and the degree to which, prey avoidance of passages may be due to perceived predation risk or other factors (e.g., road or passage structural characteristics). Such studies may also assist in determining whether predation risk influences the length of time it takes for prey species to become accustomed to using a passage environment.

Co-Evolution of Predator and Prey

In situations where prey species are present with their predators, the influence of co-evolution between predator and prey may influence passage use by prey species (Little et al. 2002).

In Australia, introduced predators (cat, dog, fox) are known to utilise roads for foraging and movement (Bennett 1991; May and Norton 1996; Meek and Saunders 2000). For example, in their study of red foxes in coastal New South Wales, Meek and Saunders (2000) observed that foxes were recorded on or beside a road on 33 percent of sampling occasions. Foxes, dogs, and cats have also been recorded using wildlife tunnels and culverts for movement (Hunt et al. 1987; Norman et al. 1998; Taylor and Goldingay *in press*), although no data exists regarding their frequency of use relative to their local abundance.

While prey may exhibit antipredatory defences towards evolutionary novel predators (Banks 2001), a number of papers suggest the susceptibility of native prey due to the absence of co-evolution between predator and prey (Banks 1998; Little et al. 2002, Short et al. 2002). There is some evidence that prey may not be able to detect predators from olfactory cues if the predator and prey species have not co-evolved (Dickman 1992, 1993; Banks 1998). In Australia, for example, small mammals, such as native bush rats (*Rattus fuscipes*) and brown antechinus (*Antechinus stuartii*), show no response to fox odor despite these species co-existing with the fox for more than 140 years (Banks 1998). Surplus killing events in Australia by foxes has also been related to ineffective anti-predator defences by prey species when encountering a novel and highly effective predator to which they had no previous exposure (Short et al. 2002).

The absence of co-evolution between predators and prey has a number of potential consequences for prey in relation to wildlife passages, particularly in Australia where introduced predator predominate. At a wider regional scale, increased landscape connectivity through the use of passages may have the negative consequence of increasing connectivity for introduced predators (and increase survivorship by decreasing the opportunity for mortality from vehicular collisions), thereby increasing the exposure of native prey species to predation. At a more localised scale, the absence of co-evolution may result in prey species being less likely to avoid wildlife passages used by predators even if their entrances are scent marked. While this may have the unintended advantage of increasing the propensity of wildlife passages to connect native prey populations in spite of the potential presence and use by predators, it also has the disadvantage that wildlife passages may have a greater propensity to act as prey-traps if prey are unable to recognise predator scent (Little et al. 2002). If the aim is to sustain regional populations of native prey species, clearly the aim should be to reduce introduced predator use of passages as much as possible. Passage systems in Australia may therefore need to focus on strategically placing passages in habitats and areas where feral predators are absent or low in number, or consider supplementary predator control programs.

In the case of North America and Europe where the main predators and prey have co-evolved, prey may more readily exhibit predator avoidance behavior and be able to detect predator scent (Muller-Schwarze 1972; Gorman 1984; Jedrzejewski et al. 1993; Parsons and Bondrup-Nielsen 1996). At a regional scale, such avoidance strategies may be reflected in spatial segregation between predators and their prey (Hoskinson and Mech 1976; Mech 1977; Doncaster 1994; Clevenger 1998). At a local scale, in the vicinity of passages, prey may be more able to avoid passages scent marked by their predators (Clevenger and Waltho 1999, 2000; Doncaster 1999, Clevenger et al. 2001), and the prey-trap phenomenon may be less likely to occur. However, while predator avoidance may safeguard prey from predation, predator use of passages may create a biotic barrier inhibiting the movement of prey and potentially reducing connectivity, particularly if wildlife exclusion fencing is used to prevent crossing at grade (Bergers and Nieuwenhuizen 1999; Doncaster 1999). Further research is required to test whether use of passages and scent marking at passage entrances by predators influences prey avoidance and, if so, whether the duration of any repellence is short lived (Little et al. 2002; Parsons and Bondrup-Nielsen 1996).

Discussion

Fundamental differences exist in the predator-prey systems of Europe, North America and Australia. The potential of wildlife passages in influencing and eliciting predator-prey responses is therefore different between these continents. North America and Europe are characterised generally as co-evolved predator and prey species although large predators are absent from many areas enabling populations of large free-ranging herbivores (e.g., ungulates) to exist under relaxed selection. In contrast, Australia's largest and predominant predators are introduced species which are widespread. In light of these differences, the *context* for evaluating wildlife passage success differs between continents. For example, use of passages by large predators in North

America is seen a positive management outcome (Foster and Humphrey 1995; Reudiger 1998; Gloyne and Clevenger 2001); whereas, use by predators in Australia is viewed as an environmental problem (Hunt et al. 1987; Norman et al. 1998; Little et al. 2002). The response of prey to a passage structure under relaxed selection may also be different to that where predators are present. The differences in predator-prey systems and differing criteria for measuring success has important implications in determining conservation priorities, appropriate passage location and design, management, and evaluation. Therefore, caution needs to be exercised when extrapolating passage evaluations and management recommendations between countries and under different predator-prey systems.

The absence of predators and relaxation of anti-predatory behavior by prey, and the presence or absence of co-evolution between predator and prey, has the potential to influence predator and, more particularly, prey behavior at all scales. These influences therefore potentially affect predator-prey relationships at a landscape and regional level influencing the spatial distribution of predator and prey species, at a local level influencing mammalian response at passage approaches, and at the passage itself. They therefore have the propensity to affect the response of predator and prey to one another and influence mammalian interactions with passage environments.

Recent passage studies are revealing that predator and prey species are responding to different passage structural and habitat attributes (Rodríguez et al. 1996; Rosell et al. 1997; Clevenger 1998; Clevenger and Waltho 1999, 2000; Clevenger et al. 2001). However, despite the increasing recognition that predator and prey species and groups may respond differently to passage structures, passage evaluation studies examining multiple structures have been reluctant to consider whether differences are occurring because of predator-prey responses to one another. Future passage studies would benefit by correlating predator and prey use and testing whether predator-prey interactions are directly influencing predator and prey use of passages. Such correlation would help determine the degree to which predator and prey are using the same or different passages and the degree to which this may be a response to passage structure or habitat preferences, human influences, or directly as a result of predator-prey interactions. To date only one published passage study has directly correlated predator and prey use of passages (Gloyne and Clevenger 2001).

Wildlife passage studies to date have tended to give little appreciation to the different spatial scales of predator-prey interactions and how this may influence passage use. Increasingly, there is a need for passage systems to provide landscape connectivity if wildlife populations and ecological processes such as predator-prey interactions are to remain stable. Passage systems need to provide permeability for large, dispersing animals dependant on regional landscapes if metapopulations are to survive (Beier 1995; Opdam 1990, 1997). They also need to ensure that rare predators have access to their prey (Gloyne and Clevenger 2001). However, equally, they need to be sufficiently permeable to allow spatial separation of predator and prey in order for prey populations to be sustained. Spatial differences between large predator and prey species have been observed in a number of passage studies to date (Foster and Humphrey 1995; Clevenger 1998; Clevenger and Waltho 2000). Regional landscape connectivity has also been demonstrated by providing access for cougar to its prey (Gloyne and Clevenger 2001). However, the above trends indicate the need for passage systems to be positioned relative to both predator and prey species' ranges if regional predator-prey relationships and processes are to be sustained.

At smaller, more localised scales, there may be more complex interactions between predators, prey and passages. Large carnivores such as bears and cougars are known to avoid roads and areas of human activity (van Dyke et al. 1986; McLellan and Shackleton 1988; Sweanor et al. 2000). The loss or absence of predators from fragments can change the abundance and ecological impacts on prey species, which in turn can have major effects on the structure of animal and plant communities in isolates (Terborgh and Winter 1980; Soulé et al. 1988; Ripple and Larson 2000; Ripple et al. 2001). The loss or absence of predators may in turn result in an increased abundance of mesopredators which in turn may have negative consequences on small mammals and other species (Terborgh and Winter 1980, Soulé et al. 1988). Whether such changes in animal community structure may also influence, or be reflected in, predator and prey use of passages, has yet to be examined.

While smaller passages (e.g., culverts) may sometimes service wide-ranging animals, smaller passages are more likely to be used by smaller-ranging species and therefore service localised subpopulations on either side of a road (Yanes et al. 1995; Clevenger and Waltho 1999; Clevenger et al. 2001). It is possible, then, that smaller passages, such as culverts, may play a larger role in defining the territories of smaller species and be used more frequently than larger underpasses. If smaller ranging carnivorous species adopt passages as part of their territories (as may be evidenced by scent marking), then avoidance strategies by small mammals may render the passage ineffective for small mammal transit. As small mammals are particularly prone to road barrier effects (Oxley et al. 1974; Swihart and Slade 1984; Burnett 1992; Goosem 2001), this could potentially create crowding effects placing pressure on small mammal populations and making them more susceptible to predation, stochastic processes and certain catastrophic events (Simberloff and Cox 1987; Collinge 1998; Lidicker 1999; Short et al. 2002). This emphasises the need for multiple structures, possibly of varying size, in order to sustain connectivity for local subpopulations of prey species.

Biotic interactions within the passage environment itself (such as predation, territoriality, avoidance, and competition) may also influence use (Foster and Humphrey 1995; Tewes and Hughes 2001; Little et al. 2002). There is a need for passage studies to focus on the biotic interactions that occur at passage entrances and within passages to test whether this influences predator and prey acceptance or avoidance of wildlife passages. The employment of predator scent experiments at passage entrances to test the effect on prey (and predator) species would be particularly useful in this regard (Doncaster 1999; Little et al. 2002).
Future passage evaluations would benefit by identifying the predator-prey systems existing in the locality and considering the role of wildlife passages within this context. Evaluations would also benefit by examining the role and net effect of the wildlife passage system across the landscape. Is there a net benefit of the passage system to the ecology of the area? Does the passage system maintain regional connectivity for predator and prey species? Is the stability of predator-prey relationships maintained? In this regard, the net benefit of the passage system needs to be evaluated taking into account positive outcomes (e.g., reduced mortality from roadkill, facilitated movement, overcoming of barrier effects, genetic exchange, improved population viability, maintenance of native predator access to prey) and any negative effects (potential increased predation risk, prey avoidance, biotic barriers, flow-on effects to predator and prey species from increased connectivity).

The points canvassed in this paper need to be treated cautiously as there is currently very limited scientific testing of road and passage effects on predator-prey relationships and the influence of these relationships on wildlife passage use by mammals. The possibilities discussed here should be used to help guide future hypotheses for further testing.

Implications for Management

The following management and research recommendations are suggested:

1. Extrapolation of passage recommendations to mammals existing under different predator-prey systems needs to be treated cautiously.
2. To capture community-level movements and crossings, structures should be spatially extensive and frequent, and relevant to predator and prey habitat and territories. It is important to have at least one passage or culvert within an individual's home range (Gerlach and Musolf, 2000; Clevenger et al. 2001).
3. The possibility that biological barriers may inhibit movement supports the development of more than one passage at critical crossing points (Tewes and Hughes 2001). Ideally, there should be a mixed size class of passages provided to help ensure that use by predators does not preclude use by prey (Little et al. 2002).
4. Vegetative cover should be considered at passage entrances and interconnect with other adjacent habitat as this enhances passage use by native carnivores (Rodríguez et al. 1996, 1997) and prey species (Hunt et al. 1987; Clevenger and Waltho 1999; Clevenger et al. 2001; Goosem 2001) but tends to preclude use by feral predators (Hunt et al. 1987; Norman et al. 1998).
5. In Australia, wildlife passage strategies may need to focus on where and where not to place passages so that areas with high densities of feral predators can be avoided.
6. Monitoring through the use of video and trip cameras at passage entrances would assist in determining biotic interactions and predator and prey behavior at passage approaches (e.g., scent marking, predator or prey avoidance, potential use of entrances as prey-traps).
7. Use of wildlife exclusion fencing should be treated cautiously. Where predator and prey species have co-evolved, frequent use and scent marking by predators may preclude use by prey species. Fencing together with biotic interactions at passage sites may create barriers for prey movement (Bergers and Nieuwenhuizen 1999; Doncaster 1999).
8. Sampling a limited number of passages may indicate passage avoidance when, in fact, species may be utilising other passages due to predator-prey avoidance or in response to passage habitat or structural attributes. Researchers need to be cautious when basing conclusions on limited sampling.
9. Future research examining predator and prey responses to passages needs to correlate and examine possible predator-prey interaction effects.
10. Further research is required in order to examine whether predator scent influences prey (and predator) avoidance of passages, the duration of any effect, and whether co-evolution of predator and prey influences the perception of olfactory cues.

Acknowledgements: I gratefully thank the ICOET organising committee for assistance to partake in the conference. I am grateful to Tony Clevenger who provided comments and advice on an earlier draft of this manuscript. Rob Harcourt and Macquarie University Graduate School of the Environment assisted by providing access to BIOSIS. The Department of Infrastructure, Planning and Natural Resources provided use of supplementary resources and time. The assistance of Jenny Birrell with library searches and Birgit Flöhrmann with German translations is gratefully acknowledged.

Biographical Sketch: Stuart Little is a senior environmental policy officer with the New South Wales Department of Infrastructure, Planning and Natural Resources (previously NSW Department of Planning). He holds degrees in earth sciences and ecology. His current policy work includes threatened species, native vegetation conservation and wildfire protection in relation to urban development and planning. Stuart's involvement in road ecology stems from environmental impact assessment and policy development for highways proposed through coastal wetland and threatened species habitat. He is a member of the New South Wales Roadside Environment Committee, State Wetlands Advisory Committee, and NSW Biodiversity Strategy Implementation Group.

References

Adams, L.W., and A. D. Geis. 1983. Effects of roads on small mammals. *Journal of Applied Ecology* 20: 403-415.

Andrews, A. 1990. Fragmentation of habitat by roads and utility corridors: a review. *Australian Zoologist* 26: 130-141.

Austin, J.M., and L. Garland. 2001. Evaluation of a wildlife underpass on Vermont State Highway 289 in Essex, Vermont. Pages 616-624. *Proceedings of the International Conference on Ecology and Transportation*. Keystone, Colarado, September 24-28, 2001. Center for Transportation and the Environment, North Carolina State University, USA.

Ballon, P., 1985. Premierès observations sur l'efficacité des passages à gibier sur l'autoroute A36. Pages 311-316. Routes et Faune Sauvage. Actes du colloque. Ministere de l'Equipment, du Logement, du l'Aménagement du Teritore et des Transports, Bagneux-Cedex, France.

Banks, P.B. 1998. Responses of Australian bush rats, *Rattus fuscipes*, to the odor of introduced *Vulpes vulpes*. *Journal of Mammalogy* 79:1260-1264.

Banks, P.B. 2001. Predation-sensitive grouping and habitat use by eastern grey kangaroos: a field experiment. *Animal Behaviour* 61:1013-1021.

Barnum, S. 2001. Preliminary analysis of locations where wildlife crosses highways in the Southern Rocky Mountains. Pages 565-573. *Proceedings of the International Conference on Ecology and Transportation.* Keystone, Colorado, September 24-28, 2001. Center for Transportation and the Environment, North Carolina State University, USA.

Beier, P. 1995. Dispersal of juvenile cougars in fragmented habitat. *Journal of Wildlife Management* 59:228-237.

Bennett, A.F. 1991. Roads, roadsides, and wildlife conservation: a review. Pages 99-117 D.A. Saunders and R. J. Hobbs, editors. *Nature Conservation 2: The Role of Corridors*. Surrey Beatty & Sons, Chipping Norton, New South Wales, Australia.

Bennett, A.F. 1999. *Linkages in the Landscape: the Role of Corridors and Connectivity in Wildlife Conservation.* IUCN, Gland, Switzerland and Cambridge, U.K. 254 pp.

Berger, J. 1998. Future prey: some consequences of the loss and restoration of large carnivores. Pages 80-100 T. Caro, editor. Behavioural Ecology and Conservation Biology. Oxford University Press, Oxford, U.K.

Bergers, P.J.M, and W. Nieuwenhuizen. 1999. Viability of hedgehog populations in central Netherlands. *Lutra* 42:65-76.

Berris, L. 1997. The importance of the ecoduct at Terlet for migrating mammals. Pages 418-420 K. Canters, editor. *Proceedings of the International Conference on Habitat Fragmentation, Infrastructure and the Role of Ecological Engineering.* Maastricht and the Hague, the Netherlands 17-21 September 1995.

Blumstein, D.T., J.C. Daniel, A.S. Griffen, and C.S. Evans. 2000. Insular tammar wallabies (*Macropus eugenii*) respond to visual but not acoustic cues from predators. *Behavioural Ecology* 11:528-535.

Bøving, P.S., and E. Post. 1997. Vigilance and foraging behaviour of female caribou in relation to predation risk. *Rangifer* 17:55-63.

Burnett, S.E. 1992. Effects of a rainforest road on movements of small mammals: mechanisms and implications. *Wildlife Research* 19:95-104.

Calvo, R.N., and N.J. Silvy. 1996. Key deer mortality, U.S. 1 in the Florida Keys. G.L. Evink, P. Garrett, D. Zeigler, and J. Berry, editors. *Trends in Addressing Transportation Related Wildlife Mortality. Proceedings of the Transportation Related Wildlife Mortality Seminar.* FL-ER-58-96. Florida Department of Transportation, Tallahassee, Florida, U.S.A.

Cain, A.T., V.R. Tuovila, D.G. Hewitt, and M.E. Tewes. 2003. Effects of a highway and migration projects on bobcats in Southern Texas. *Biological Conservation* 114:189-197.

Camby, A., and C. Maizeret. 1985. Perméabilité des routes and autoroutes vis-à-vis des mammiféres carnivores: exemple des études menées dans les Landes de Gascogne. Pages 183-203. Routes et Faune Sauvage. Actes du colloque. Ministere de l'Equipment, du Logement, du l'Aménagement du Teritore et des Transports, Bagneux-Cedex, France.

Clevenger, A.P. 1998. Permeability of the Trans-Canada Highway to wildlife in Banff National Park: importance of crossing structures and factors influencing their effectiveness. Pages 109-119 G. L. Evink, P. Garrett, D. Zeigler, and J. Berry, editors. *Proceedings of the International Conference on Wildlife Ecology and Transportation.* FL-ER-69-98. Florida Department of Transportation, Tallahassee, Florida, U.S.A.

Clevenger, A.P., and N. Waltho. 1999. Dry drainage culvert use and design considerations for small- and medium-sized mammal movement across a major transportation corridor. Pages 263-278 G. L. Evink, P. Garrett, and D. Zeigler, editors. Proceedings of the Third International Conference on Wildlife Ecology and Transportation. FL-ER-73-99. Florida Department of Transportation, Florida, U.S.A.

Clevenger, A.P., and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology* 14:47-56.

Clevenger, A.P., B. Chruszcz, and K. Gunson. 2001. Drainage culverts as habitat linkages and factors affecting passage by mammals. *Journal of Applied Ecology* 38:1340-1349.

Cole, G.F. 1987. Changes in interacting species with disturbance. *Environmental Management* 11:257-264.

Collinge, S. 1998. Spatial arrangement or habitat patches and corridors: clues from ecological field experiments. *Landscape and Urban Planning* 42:157-168.

Center for Transportation and the Environment (CTE). 2001. *Proceedings of the International Conference on Ecology and Transportation.* Keystone, Colarado, September 24-28, 2001. North Carolina State University, U.S.A.

Dickman, C. R. 1992. Predation and habitat shift in the house mouse, *Mus domesticus*. *Ecology* 73: 313-322.

Dickman, C. R. 1993. Raiders of the last ark: cats in island Australia. *Australian Natural History* 24: 44-52.

Doncaster, C.P. 1994. Factors regulating local variations in abundance: field tests on hedgehogs, *Erinaceus europaeus*. *Oikos* 69:182-192.

Doncaster, C. P. 1999. Can badgers affect the use of tunnels by hedgehogs? A review of the literature. *Lutra* 42:59-64.

Donovan, T.M., P.W. Jones, E.M. Annand, and F.R. Thompson III. 1997. Variation in local-scale edge effects: mechanisms and landscape context. *Ecology* 78:2064-2075.

Douwel, C. K. 1997. Provisions for badgers realised in the Heumen/A73-area. Pages 404-408 K, Canters, editor. *Proceedings of the International Conference on Habitat Fragmentation, Infrastructure and the role of Ecological Engineering.* Maastricht and the Hague, the Netherlands 17-21 September 1995.

Evink, G., P. Garrett, D. Zeigler, and J. Berry. 1996. *Trends in Addressing Transportation Related Wildlife Mortality.* No. FL-ER-58-96. Florida Department of Transportation, Tallahassee, Florida.

Evink, G., P. Garrett, D. Zeigler and J. Berry. 1998. *Proceedings of the International Conference on Wildlife Ecology and Transportation.* FL-ER-69-98, Florida Department of Transportation, Tallahassee, Florida. 263pp.

Evink, G., P. Garrett, and D. Zeigler. 1999. *Proceedings of the Third International Conference on Wildlife Ecology and Transportation.* FL-ER-73-99. Florida Department of Transportation, Tallahassee, Florida. 330 pp.

Fehlberg, U., 1994. Ökologische barrierewirkung von straßen auf wildlebende säugetiere – ein tierschutzproblem. Dtsch. tierärztl. Wschr. 101, 125-129.

Forbes, G.J., and J.B. Theberge. 1995. Influences of a migratory deer herd on wolf movements and mortality in and near Algonquin Park, Ontario. In: Carbyn, L.N. (Ed.) *Wolves: Ecology and Conservation of Wolves in a Changing World.* Occasional Publication Canadian Circumpolar Institute. No. 35:303-313.

Forman, R.T.T., and R.D. Deblinger. 2000. The ecological road-effect zone of a Massachusetts (U.S.A.) suburban highway. *Conservation Biology* 14:36-46.

Forman, R.T.T., D. Sperling, J.A.Bissonette, A.P. Clevenger, C.D. Cutshall, V.H. Dale, L.Fahrig, R. France, C.R. Goldman, K. Heanue, J.A. Jones, F.J. Swanson, T. Turrentine, and T.C. Winter. 2003. *Road Ecology: Science and Solutions*. Island Press, Washington, U.S.A.

Foster, M.L., and S.R. Humphrey. 1995. Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin* 23:95-100.

Gehring, T.M., and R.K. Swihart, 2003. Body size, niche breadth, and ecologically scaled responses to habitat fragmentation: mammalian predators in an agricultural landscape. *Biological Conservation* 109:283-295.

Getz, L.L., F.R. Cole, and D.L. Gates. 1978. Interstate roadsides as dispersal routes for *Microtus pensylvannicus*. Journal of Mammalogy 59:208-213.

Gerlach, G., and K. Musolf. 2000. Fragmentation of landscape as a cause for genetic subdivision in bank voles. *Conservation Biology* 14:1066-1074.

Gloyne, C.G., and A.P. Clevenger. 2001. Cougar *Puma concolor* use of wildlife crossing structures on the Trans-Canada highway in Banff National Park, Alberta. *Wildlife Biology* 7:117-124.

Goosem, M. 2001. Effects of tropical rainforest roads on small mammals: inhibition of crossing movements. *Wildlife Research* 28:351-364.

Goosem, M., Y. Izumi, and S. Turton. 2001. Efforts to restore habitat connectivity for an upland tropical rainforest fauna: a trial of underpasses below roads. *Ecological Management and Restoration* 2:196-202.

Gorman, M.L. 1984. The response of prey to Stoat (*Mustela erminea*) scent. *Journal of Zoology* 202:419-423.

Hardin, J.W., N.J. Silvy, and W.D. Klimstra. 1976. Group size and composition of the Florida Key deer. *Journal of Wildlife Management* 40:454-463

Henke, R.J., P. Cawood-Hellmund, and T. Sprunk. 2001. Habitat connectivity study of the I-25 and US 85 corridors, Colorado. Pages 499-508. *Proceedings of the International Conference on Ecology and Transportation.* Keystone, Colorado, September 24-28, 2001. Center for Transportation and the Environment, North Carolina State University, USA.

Hewitt, D.G., A. Cain, V. Tuovila, D.B. Shindle, and M.E. Tewes. 1998. Impacts of an expanded highway on ocelots and bobcats in southern Texas and their preferences for highway crossings. Pages 126-134. G.L. Evink, P. Garrett, P., D. Zeigler, and J. Berry, editors. *Proceedings of the International Conference on Wildlife Ecology and Transportation.* FL-ER-69-98. Florida Department of Transportation, Tallahassee, Florida, U.S.A.

Hoskinson, R.I., and L.D. Mech. 1976. White tailed deer migration and its role in wolf predation. Journal of *Wildlife Management* 40: 429-441.

Hunt, A., H.J. Dickens, and R.J. Whelan. 1987. Movement of mammals through tunnels under railway lines. *Australian Zoologist* 24:89-93.

Jedrzejewski, W.I., I. Rychlik, I., and B. Jedrzejewska. 1993. Responses of bank voles to odors of seven species of predators: experimental data and their relevance to natural predator-vole relationships. *Oikos* 68: 251-257.

Kareiva, P. 1987. Habitat fragmentation and the stability of predator-prey interaction. *Nature* 326:388-390.

Kohn, B., J. Friar, D. Unger, T. Gehring, D. Shelley, E. Anderson, and P. Keenlance. 1999. Impacts of a highway expansion project on wolves in northwestern Wisconsin. Pages 53-65. G.L. Evink, P. Garrett, and D. Zeigler, editors. *Proceedings of the Third International Conference on Wildlife Ecology and Transportation*. FL-ER-73-99. Florida Department of Transportation, Florida, U.S.A.

Kunkel, K.E., T.K. Ruth, D.H. Pletscher, and M.G. Hornocker. 1999. Winter prey selection by wolves and cougars in and near Glacier National Park, Montana. *Journal of Wildlife Management* 63:901-910.

Land, D., and M. Lotz. 1996. Wildlife crossing designs and use by Florida panthers and other wildlife in southwest Florida. G.L. Evink, P. Garrett, D. Ziegler, and J. Berry, editors. *Trends in Addressing Transportation Related Wildlife Mortality. Proceedings of the Transportation Related Wildlife Mortality Seminar.* FL-ER-58-96. Florida Department of Transportation, Tallahassee, Florida, U.S.A..

Lidicker, W.Z. Jr. 1999. Responses of mammals to habitat edges: a review. *Landscape Ecology* 14:333-343.

Little, S.J., R.G. Harcourt, and A.P. Clevenger. 2002. Do wildlife passages act as prey-traps? *Biological Conservation* 107:135-145.

Lord, J.M., and D.A. Norton. 1990. Scale and the spatial concept of fragmentation. *Conservation Biology* 4:197-202.

MacDonald, D. and P. Barrett. 1993. *Collins Field Guide: Mammals of Britain and Europe*. HarperCollins Publishers, London.

Mansergh, I.M., and D.J. Scotts. 1989. Habitat continuity and social organization of the mountain pygmy-possum restored by tunnel. *Journal of Wildlife Management* 53:701-707.

Mathiasen, R., and A.B. Madsen. 2000. Infrared video-monitoring of mammals at a fauna underpass. Zeitschift für Saugetierkunde. *International Journal of Mammalian Biology* 65:59-61.

May, S.A., and T.W. Norton. 1996. Influence of fragmentation and disturbance on the potential impact of feral predators on native fauna in Australian forest ecosystems. *Wildlife Research* 23:387-400.

McLellan, B.N., and D.M. Shackleton. 1988. Grizzly bears and resource-extraction industries: effects of roads on behaviour, habitat use and demography. *Journal of Applied Ecology* 25:451-460.

Mech, L.D., 1977. Wolf-pack buffer zones as prey reservoirs. *Science* 198:320-321.

Meek, P.D., and G. Saunders. 2000. Home range and movement of foxes (*Vulpes vulpes*) in coastal New South Wales, Australia. *Wildlife Research* 27:663-668.

Muller-Schwarze, D., 1972. Responses of young black-tailed deer to predator odors. *Journal of Mammalogy* 53: 393-394.

Nieuwenhuizen, W., and R.C., van Apeldoorn, 1995. Mammal use of fauna passages on national road A1 at Oldenzaal. Road and Hydraulic Engineering Division, Ministry of Transport, Public Works and Management, The Netherlands. Report No. P-DWW-95.737.

Norman, T., A. Finegan, and B. Lean. 1998. The role of fauna underpasses in New South Wales. Pages 195-208. Evink, G.L., P. Garrett, D. Zeigler, and J. Berry, editors. *Proceedings of the International Conference on Wildlife Ecology and Transportation*. Fl-ER-69-98, Florida Department of Transportation, Tallahassee, Florida, U.S.A.

Olbrich, P. 1984. Untersuchung der wirksamkeit von wildwarnreflektoren und der eignung von wilddurchschlassen. Zeitschrift fur Jagdwissenschaft 30:101-116.

Opdam, P. 1990. Dispersal in fragmented populations: the key to survival. Pages 3-17. R.G. H. Bunce and D.C. Howard, editors. Species Dispersal in Agricultural Habitats. Belhaven Press, London.

Opdam, P. 1997. How to choose the right solution for the right fragmentation problem? Pages 55-60 Canters, K., editor. Proceedings of the International Conference on Habitat Fragmentation, Infrastructure and the role of Ecological Engineering. Maastricht and the Hague, the Netherlands 17-21 September 1995.

Oxley, D.J., Fenton, M.B., and Carmody, G.R. 1974. The effects of roads on populations of small mammals. Journal of Applied Ecology, 11:51-59.

Pacquet, P.C., and C. Callaghan. 1996. Effects of linear developments on winter movements of gray wolves in the Bow River Valley in Banff National Park, Alberta. G.L. Evink, P. Garrett, D. Ziegler, and J. Berry, editors. *Trends in Addressing Transportation Related Wildlife Mortality. Proceedings of the Transportation Related Wildlife Mortality Seminar.* FL-ER-58-96. Florida Department of Transportation, Tallahassee, Florida, U.S.A.

Palomares, F., M. Delibes, P. Ferreras, J.M. Fedriani, J. Calzada, and E. Revilla. 2000. Iberian Lynx in a fragmented landscape: predispersal, dispersal, and postdispersal habitats. *Conservation Biology* 14: 809-818.

Parsons, G.J., and S. Bondrup-Neilsen. 1996. Experimental analysis of behaviour of meadow voles (*Microtus pennsylvanicus*) to odors of the short-tailed weasel (*Mustela erminea*). *Ecoscience* 3:63-69.

Reading, C.J., 1989. Opportunistic predation of common toads *Bufo bufo* at a drift fence in southern England. Pages 105-112 T.E.S. Langton, editor. *Amphibians and Roads. Proceedings of the Toad Tunnel Conference.* Rendsburg, Federal Republic of Germany, 7-8 January, 1989. ACO Polymer Products, Bedfordshire, England.

Reed, D.F., T.N. Woodard, and T.M. Pojar. 1975. Behavioral responses of mule deer to a highway underpass. *Journal of Wildlife Management* 39:361-367.

Reed, D.F. 1981. Mule deer behavior at a highway underpass exit. *Journal of Wildlife Management* 45: 542-543.

Ripple, W.J., and E.J. Larsen. 2000. Historic aspen recruitment, elk, and wolves in northern Yellowstone National Park, USA. *Biological Conservation* 95:361-370.

Ripple, W.J., E.J. Larsen, R.A. Renkin, and D. W. Smith. 2001. Trophic cascades among wolves, elk and aspen on Yellowstone National Park's northern range. *Biological Conservation* 102:227-234.

Rodríguez, A., G. Crema, and M. Delibes. 1996. Use of non-wildlife passages across a high speed railway by terrestrial vertebrates. *Journal of Applied Ecology* 33:1527-1540.

Rodríguez, A., G. Crema, and M. Delibes. 1997. Factors affecting crossing of red foxes and wildcats through non-wildlife passages across a high-speed railway. *Ecography* 20:287-294.

Roof, J., Wooding, J., 1996. Evaluation of the S.R. 46 wildlife crossing in Lake County, Florida. G.L. Evink, P. Garrett, D. Ziegler, and J. Berry, editors. *Trends in Addressing Transportation Related Wildlife Mortality. Proceedings of the Transportation Related Wildlife Mortality Seminar.* FL-ER-58-96. Florida Department of Transportation, Tallahassee, Florida, U.S.A..

Rosell, C., J. Parpal, R. Campeny, S. Jové, A. Pasquina, and J.M. Velasco. 1997. Mitigation of barrier effect of linear infrastructure on wildlife. Pages 367-372 Canters, K., editor. *Proceedings of the International Conference on Habitat Fragmentation, Infrastructure and the role of Ecological Engineering.* Maastricht and the Hague, the Netherlands 17-21 September 1995.

Ruediger, B. 1998. Rare carnivores and highways - moving into the 21st century. Pages 10-16 Evink, G.L., P. Garrett, D. Zeigler, and J. Berry, editors. *Proceedings of the International Conference on Wildlife Ecology and Transportation. Fl-ER-69-98, Florida Department of Transportation.* Tallahassee, Florida, U.S.A.

Sæther, B-E. 1997. Environmental stochasticity and population dynamics of large herbivores: a search for mechanisms. *Trends In Ecology and Evolution* 12:143-149.

Schaal, A. L. Humblot, and D. Guilminot. 1985. Premières données sur la fréquentation de passages à faune par le cerf (*Cervus elaphus*), Autoroute A26, Haute-Marne, N.E. France. Pages 269-274. *Routes et Faune Sauvage.* Actes du colloque. Ministere de l'Equipment, du Logement, du l'Aménagement du Teritore et des Transports, Bagneux-Cedex, France.

Seip, D.R. 1991. Predation and caribou populations. *Rangifer*, Special Issue No. 7: 46-52.

Short, J., J.E. Kinnear, and A. Robley. 2002. Surplus killing by introduced predators in Australia - evidence for ineffective anti-predator adaptations in native prey species? *Biological Conservation* 103:283-301.

Simberloff, D., and J. Cox. 1987. Consequences and costs of conservation corridors. *Conservation Biology* 1: 67-71.

Singer, F.J., and J.L. Doherty. 1985. Managing mountain goats at a highway crossing. *Wildlife Society Bulletin* 13:469-477.

Singleton, P.H., and J.F. Lehmkuhl.1999. Assessing wildlife habitat connectivity in the Interstate 90 Snoqualmie Pass Corridor, Washington. Pages 75-83 G.L. Evink, P. Garrett, D. Zeigler, editors. *Proceedings of the Third International Conference on Wildlife Ecology and Transportation.* FL-ER-73-99. Florida Department of Transportation, Florida, U.S.A.

Soulé, M.E., D.T. Bolger, A.C. Alberts, J. Wright, M. Sorice, and S. Hill. 1988. Reconstructed dynamics of rapid extinctions of chapparal requiring birds in urban habitat islands. *Conservation Biology* 2:75-92.

Sweanor, L.L., K.A. Logan, and M.G. Hornocke. 2000. Cougar dispersal patterns, metapopulation dynamics, and conservation. *Conservation Biology* 14:798-808.

Swihart, R.K., and N.A. Slade. 1984. Road crossing in *Sigmodon hispidus* and *Microtus ochrogaster*. *Journal of Mammalogy* 65:357-360.

Taylor, B.D. and R. Goldingay. *In press*. Cutting the carnage: wildlife usage of road culverts in New South Wales. *Wildlife Research*.

Terborgh, J., and B. Winter. 1980. Some causes of extinction. Pages 119-133 M.E. Soulé and B.A. Wilcox, editors. *Conservation Biology: An Evolutionary-Ecological Perspective*. Sinauer Associates: Sunderland, Massachusetts.

Tewes, M.E., and R.W. Hughes. 2002. Ocelot management and conservation along transportation corridors in southern Texas. Pages 559-564. *Proceedings of the International Conference on Ecology and Transportation.* Keystone, Colarado, September 24-28, 2001. Carolina State University. U.S.A.

Tigas, L.A., D.H. Van Vuren, and R.M. Sauvajot. 2002. Behavioural responses of bobcats and coyotes to habitat fragmentation and corridors in an urban environment. *Biological Conservation* 108:299-306.

Triggs, B., H. Brunner, and J.M. Cullen. 1984. The food of the fox, dog, and cat in Croajingalong National Park, south-eastern Victoria. *Australian Wildlife Research* 11:491-519.

Veenbaas, G. and J. Bradjes. 1999. Use of fauna passages along waterways under highways. Pages 253-258 G. L. Evink, P. Garrett, and D. Zeigler, editors. *Proceedings of the Third International Conference on Wildlife Ecology and Transportation.* FL-ER-73-99. Florida Department of Transportation, Florida, U.S.A.

van Dyke, F.G., R.H. Brocke, H.G. Shaw, B.B. Ackerman, T.P. Hemker, F.G. Lindzey. 1986. Reactions of mountain lions to logging and human activity. *Journal of Wildlife Management* 50:95-102.

Yanes, M., J.M. Valesco, and F. Suarez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. *Biological Conservation* 71:217-222.

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

Anthony P. Clevenger (Phone: 403-760-1371, Email: tony.clevenger@pc.gc.ca), 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, Fax: 403-762-3240

Nigel Waltho, Faculty of Environmental Studies, York University, 4700 Keele Street, North York, Ontario M3J 1P3 Canada.

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.

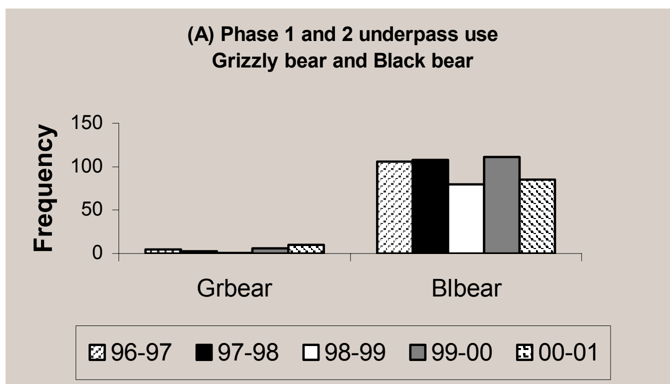
Annual trends not only reflect inherent effectiveness of the structures in facilitating animal passage across the TCH, but also adaptation of resident wildlife to the new structures. As on phases 1 and 2, use of underpasses by black bears and grizzly bears has remained consistent over the monitoring 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.



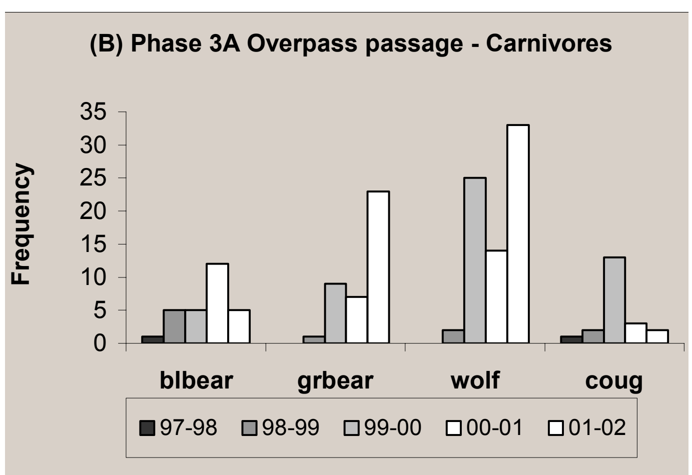


Fig. 1. Summary of large carnivore passage frequencies through (A) phase 1 and 2 underpasses and (B) phase 3A overpassees during a five-year period (November 1996 to October 2002).

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.

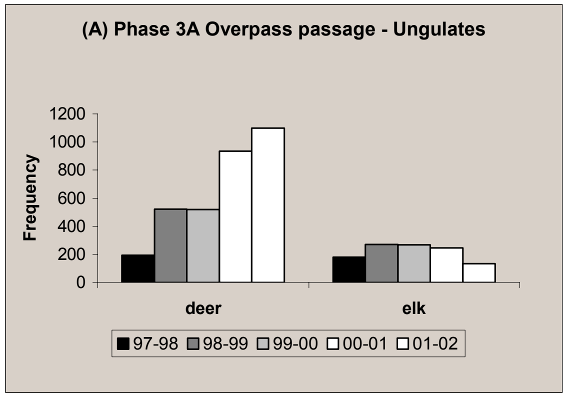
Discussion

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.



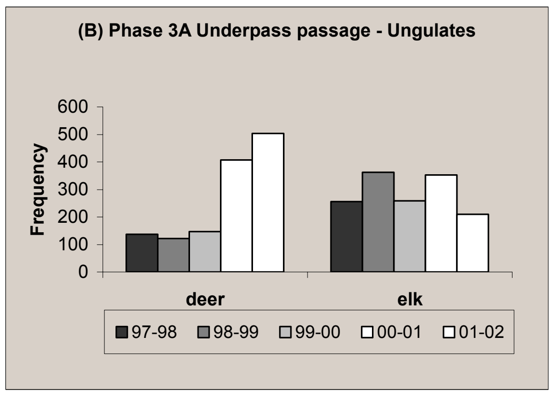


Fig. 2. Summary of ungulate passage frequencies through (A) phase 3A overpasses and (B) phase 3A underpassees during a five-year period (November 1996 to October 2002).

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.

Acknowledgements: This study was funded by Parks Canada and Public Works and Government Services Canada (contracts C8160-8-0010 and 5P421-010004/001). We are deeply appreciative of the following organizations and people for their generous support and recognition of the importance of long-term research for assessing the efficacy of highway mitigation measures: Steve Albert of the Western Transportation Institute, Gary Tabor of the Wilburforce Foundation, and Susan Hagood of the Humane Society of the United States.

Biographical Sketches: 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.

Nigel Waltho is an assistant professor in Environmental Studies at York University in Toronto, Ontario. He has a Ph.D. in quantitative ecology from McMaster University (Hamilton, Ontario). His areas of research include fish ecology within temperate fresh water (Sharbot Lake, Ontario), and tropical coral reef (Jamaica), and large mammal conservation biology in Banff National Park, Alberta.

References

Agriculture Canada. 1989. Ecosites of the Lower Bow Valley Banff National Park East Gate-Castle Junction. Map Reproduction Centre, Department of Energy, Mines and Resources, Ottawa, Ontario.

AMBS Consulting. 1997. Fauna usage of three underpasses beneath the F3 freeway between Sydney and Newcastle. Final report to New South Wales Roads and Traffic Authority, Sydney, Australia.

Ballon, P. 1985. Premières observations sur l'efficacité des passages à gibier sur l'autoroute A36. Routes et faune sauvage, pp. 311-316. Service d'Etudes Techniques de Routes et Autoroutes, Bagneaux, France.

Banff-Bow Valley Study. 1996. Banff-Bow Valley: at the crossroads. Summary report for the Banff-Bow Valley Task Force. Canadian Heritage, Ottawa, Ontario.

Carroll, C., Noss, R.F. and Paquet, P. 2001. Carnivores as focal species for conservation planning in the Rocky Mountain region. *Ecological Applications* 11:961-980.

Clevenger, A.P. and Waltho, N. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology* 14 :47-56.

Collins S.L. and S.M. Glenn. 1991. Importance of spatial and temporal dynamics in species regional abundance and distribution. *Ecology* 72:654-664.

Environmental Systems Research Institute. ESRI. 1998. ArcView GIS version 3.1. Redlands, California, USA.

Forman, R.T.T., Sperling, D., Bissonette, J., Clevenger, A., Cutshall, C., Dale, V., Fahrig, L., France, R., Goldman, C., Heanue, K., Jones, J., Swanson, F., Turrentine, T. and Winter, T. 2003. *Road ecology: Science and solutions*. Island Press, Washington, D.C.

Foster, M.L. and Humphrey, S.R. 1995. Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin* 23:95-100.

Gloyne, C.C. and Clevenger, A.P. 2001. Cougar use of wildlife crossing structures on the Trans-Canada highway in Banff National Park, Alberta. *Wildlife Biology* 7:117-124.

Holroyd, G.L. and Van Tighem, K.J. 1983. Ecological (biophysical) land classification of Banff and Jasper national parks. Volume 3. The wildlife inventory. Canadian Wildlife Service, Edmonton.

Hunt, A., H.J. Dickens, and R.J. Whelan. 1987. Movement of mammals through tunnels under railway lines. *Australian Zoologist* 24:89-93.

Jandel Scientific. 1994. Tablecurve 2D Version 3 for Win32. Jandel Scientific, San Rafael, CA.

Kansas, J.L. and Raines, R.M. 1990. Methodologies used to assess the relative importance of ecological land classification units to black bears in Banff National Park, Alberta. *International Conference on Bear Research and Management* 8:155-160.

Land, D. and Lotz, M. 1996. Wildlife crossing designs and use by Florida panthers and other wildlife. In Evink, G., Zeigler, D., Garrett, P., and Berry, J. (eds.): *Transportation and wildlife: reducing wildlife mortality and improving wildlife passageways across transportation corridors.* Florida Department of Transportation, Tallahassee, Florida, pp. 323-328.

LaPoint, S.D., Kays, R.W. and Ray, J.C. 2003. Animals crossing the Northway : are existing culverts useful? *Adirondack Journal of Environmental Studies*, Spring/Summer: 11-17.

Marshik, J et al. 2001. Preserving a spirit of place: US Highway 93 on the Flathead Indian Reservation, in *2001 ICOET proceedings*, pp. 244-56.

McGuire, T.M. and Morrall, J.F. 2000. Strategic highway improvements to minimize environmental impacts within the Canadian Rocky Mountain national parks. *Canadian Journal of Civil Engineering* 27 :523-32.

Ng, S.J., Dole, J.W., Sauvajot, R.M., Riley, S.P., Valone, T.J., In press. Use of highway undercrossings by wildlife in southern California. *Biological Conservation*.

Norman G.R. and Streiner, D.L. 1999. PDQ Statistics. B.C. Decker Inc., Hamilton, Ontario. Opdam, P.F.M. 1997. How to choose the right solution for the right fragmentation problem? Pages 55-60 in K. Canters, editor. *Habitat fragmentation and infrastructure*. Ministry of Transportation, Public Works & Water Management, Delft, The Netherlands.

Pfister, H.P., Keller, V., Reck, H. and Georgii, B. 1997. Bio-okologische Wirksamkeit von Grunbrucken uber Verkehrswege [Bio-ecological effectiveness of wildlife overpasses or “green bridges” over roads and railway lines]. Herausgegeben vom Bundesministerium fur Verkehr Abeteilung Straβenbau, Bonn-Bad Godesberg, Germany.

Rahel, F.J 1990. The hierarchical nature of community persistence: a problem of scale. *American Naturalist* 136:328-344

Rahel, F.J., Lyons, J.D. and Cochran, P.A. 1984. Stochastic or deterministic regulation of assemblage structure? It may depend on how the assemblage is defined. *American Naturalist* 124:583-589

Reed, D.F. and Ward, A.L. 1985. Efficacy of methods advocated to reduce deer-vehicle accidents: research and rationale in the USA. Pages 285-293 in *Routes et faune sauvage*. Service d’Etudes Techniques de Routes et Autoroutes. Bagneaux, France.

Reed, D.F., Woodard, T.N. and Pojar, T.M. 1975. Behavioral response of mule deer to a highway underpass. *Journal of Wildlife Management* 39:361-367.

Rodríguez, A., Crema, G. and Delibes, M. 1996. Use of non-wildlife passages across a high speed railway by terrestrial vertebrates. *Journal of Applied Ecology* 33:1527-1540.

Rodríguez, A., Crema, G. and Delibes, M. 1997. Factors affecting crossing of red foxes and wildcats through non-wildlife passages across a high-speed railway. *Ecography* 20:287-294.

Roof, J. and Wooding, J. 1996. Evaluation of the S.R. 46 wildlife crossing in Lake County, Florida. Pages 329-336 in G.L. Evink, D. Zeigler, P. Garrett, and J. Berry, editors. *Highways and movement of wildlife: improving habitat connections and wildlife passageways across highway corridors*. Florida Department of Transportation, Tallahassee, Florida, USA.

Rosell, C., Parpal, J. Campeny, R. Jove, S. Pasquina, A. and Velasco, J.M. 1997. Mitigation of barrier effect on linear infrastructures on wildlife: Pages 367-372, in K. Canters, editor. *Habitat fragmentation and infrastructure*. Ministry of Transportation, Public Works and Water Management, Delft, The Netherlands.

Sarakinos H.C. and Rasmussen, J.B., 1998. Use of bioassy-based whole effluent toxicity (WET) tests to predict benthic community response to a complex industrial effluent. *Journal of Aquatic Ecosystem Stress and Recovery* 6 :141-157.

Singer, F.J. and Doherty, J.L. 1985: Managing mountain goats at a highway crossing. *Wildlife Society Bulletin* 13:469-477.

Smith, D. 1999. Identification and prioritization of ecological interface zones on state highways in Florida. Pages 209-230 in G.L. Evink, P. Garrett, and D. Zeigler, editors. *Proceedings of the Third International Conference on Wildlife Ecology and Transportation.* FL-ER-73-99. Florida Department of Transportation, Tallahassee, Florida. 330 pp.

Spellerberg, I.F. 1998. Ecological effects of roads and traffic: a literature review. Global *Ecology and Biogeography* 7 :317-333.

Transportation Research Board. 2002. *Surface transportation environmental research: a long-term strategy*. Special report 268, National Academy Press, Washington, D.C.

Underwood, A.J. 1997. *Experiments in ecology: their logical design and interpretation using analysis of variance.* Cambridge University Press, Cambridge, U.K.

Veenbaas, G. and Brandjes, G. 1999. The use of fauna passages along waterways under motorways. Pp. 315-320. In *Key concepts in landscape ecology*. J.W. Dover and R.G.H. Bunce (eds.), IALE (UK), Preston, UK.

Waltho N.D. and Kolasa, J., 1996. Stochastic determinants of assemblages patterns in coral reef fishes: a quantification by means of two models. *Environmental Biology of Fishes* 47:255-267.

Woods, J.G. 1990. Effectiveness of fences and underpasses on the Trans-Canada highway and their impact on ungulate populations. Report to Banff National Park Warden Service, Banff, Alberta, Canada.

Yanes, M., J.M. Velasco, and F. Suárez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. *Biological Conservation* 71:217-222.

MONITORING THE USE OF THE SLATY CREEK WILDLIFE UNDERPASS, CALDER FREEWAY, BLACK FOREST, MACEDON, VICTORIA, AUSTRALIA

Rodney N. Abson (Phone: 03-5444-7869, E-mail: r.abson@bendigo.latrobe.edu.au),
Centre for Sustainable Regional Communities, La Trobe University, PO Box 199, Bendigo Australia 3550
Fax: (03) 5444 7848

Dr. Ruth E. Lawrence (Phone: 03-5444-7267, E-mail: r.lawrence@bendigo.latrobe.edu.au), Department of Outdoor Education and Nature Tourism, La Trobe University, PO Box 199, Bendigo Australia 3550
Fax:03 5444 7848

Abstract: The Slaty Creek Wildlife Underpass was built into the Calder Freeway, Macedon, Victoria, to facilitate safe passage for species between forest block, now affected by this new section of freeway through the Black Forest. A 12-month monitoring regime was established, consisting of 14 monitoring methods to detect a variety of animals. Intensive sampling was conducted for one week per month, within the underpass, and with two control sites on either side of the underpass, along the Slaty Creek. The monitoring sampled for mammals, reptiles, amphibians and birds, encountering a total of 116 species within the Black Forest region, with most of these also being detected within the underpass.

Introduction

The design of roads to mitigate potential negative effects on animals is a relatively new area of research in Australia. Compared to work done overseas, there are only a few articles published on mitigation structures such as underpasses in Australia (Mansergh and Scotts 1989; Hunt *et al.* 1987; Goosem *et al*. 2001). Given that there is over 800,000 kilometers of roads within Australia (Australian Bureau of Statistics, 2002), there is a great need to develop measures that minimize road impacts on the natural environment. Australia's unique animals and varied environmental conditions require road designs that are effective for both Australian conditions and wildlife.

The Slaty Creek wildlife underpass (figure 1) was built by VicRoads (Victorian Government Roads Corporation) in the Black Forest section of the Calder Freeway in 1997 to mitigate the impacts of a new freeway on wildlife passage. This structure was designed primarily to provide access for wildlife moving between the forest blocks that the freeway bisected, but also allowed for creek flows and access for firefighting crews, maintenance vehicles and pedestrians. The Black Forest section of the Calder Freeway cost approximately (AU) $46 million, with the Slaty Creek underpass cost approximately (AU) $3 million.

Fig. 1. The Slaty Creek Wildlife Underpass.

The Slaty Creek underpass is approximately 70 metres wide at the base and supports a split dual carriageway bridge on two 12-metre piers for each section of carriageway. The distance between the continuous forest patches on either side of the underpass is approximately 100 metres. An important design component of the underpass was the retention of remnant vegetation during the construction of the road and bridges. This enabled some mature Eucalypts and middle and understorey vegetation to be retained within the underpass. Further indigenous species were planted after the completion of construction with the intention of recreating a similar vegetation structure to the adjacent forest.

The Centre for Sustainable Regional Communities, La Trobe University, Bendigo, was contracted by VicRoads for approximately (AUD) $70,000 to:

- Determine what fauna species were using the Slaty Creek underpass (and adjacent culverts and roads).
- Determine whether the animals were using the underpass during day or night.
- Determine the use of the underpass by potential predators such as domestic and feral animals.
- Include an assessment of suitability of the proportions of the underpass for facilitating fauna movement and suggest possible improvements to the underpass which may optimise its use by native fauna and minimize risk of predation.
- Outline requirements for any future monitoring programs or further investigation if required.

This paper reports on only those species that used the Slaty Creek underpass.

Monitoring Sites and Methods

This study examined the presence or absence of mammals, reptiles, amphibians and birds within the underpass and adjacent forest over a 12-month period. The adjacent forest sites measured 50m x 50m in size and were located 320 metres to the west and 100 metres to the east of the underpass along Slaty Creek.

There were four issues that had to be addressed when designing the monitoring regime. Firstly, there was a great variety in the size of species anticipated to use the underpass: sizes varied from 1.5m-tall Eastern Grey Kangaroos (*Macropus giganteus)* to amphibians about 3cm long. Secondly, the animals to be monitored had varying movement techniques, ranging from jumping and running, to gliding and flying. Thirdly, there was variation in the time of day or night that the animals would be active. Fourthly, the underpass was located close to residential properties, which posed a considerable risk of vandalism if expensive monitoring equipment was left unattended on site. The latter factor, in combination with the substantial vegetation covering the underpass floor and the large dimensions of the underpass, effectively precluded the use of cameras. Consequently, the monitoring program was both varied and substantial. A total of 14 monitoring methods was chosen for this study, and a brief outline of the methods and frequency of monitoring is given in table 1. Between July 2002 and June 2003, Rod Abson spent one week each month camping in the Black Forest and collecting the data.

Table 1
Summary of types and frequency of monitoring methods used in this study

Monitoring method	Description	Frequency
Active Searching	Lifting logs and rocks to find reptiles and amphibians at three sites and surrounding forest.	One day every three months
Anabat	An electronic device used to detect and record the echolocation frequencies of bat calls. Used only in the underpass.	Used shortly after dusk on three nights in three different months.
Audio Recordings	A small note taker and directional microphone used to record bird calls during bird surveys, incidental and night frog and bird calls during spotlighting.	Operated during bird surveys and spotlighting each month.
Bird Survey	A 20-minute bird survey conducted at each of the three sites at dusk.	Survey conducted at dusk for three successive days per month for 12 months
Elliott Trap	Seven of these small metal traps were placed on the ground at each of the three sites to catch small mammals.	Checked at dawn and dusk for three successive days each month for 12 months.
Hair Funnel	Tapered half funnels baited at the narrow end and containing a sticky wafer for removal of a small sample of mammal hair when the animal investigates the funnels; five funnels were placed at each of the three sites, two in trees and three on the ground.	Hair funnels were baited and left out for the entire year; the bait and wafer were changed once per month and hair samples were analysed each month for 12 months.
Harp Trap	Five harp traps used for catching bats were placed within the underpass and surrounds.	Used only on one night; not found to be successful and so not used again.
Incidental Observations	Recording of animals that were seen during the time spent in the forest and that did not come under one of the other monitoring methods.	Observations made for one week every month for 12 months.
Nest Boxes	Four nest boxes were placed at each of the three sites to monitor for arboreal mammals; the boxes were designed for Feathertail Glider (1 box per site), Leadbeaters Possum (1 box per site) and Sugar Glider (2 boxes per site).	Checked monthly for signs of use or habitation for 12 months.
Pitfall Trap	Eight pitfall traps of 15cm diameter, 30cm depth with a 4m fence were established at three sites to catch reptiles and amphibians.	Checked at dawn and dusk for three successive days each month for 12 months.
Road Walk	The freeway near the underpass was checked for evidence of animal road kill; both edges of the freeway and the median strip were checked: a length of 2.5 km	One day each month for 12 months.
Sand Tray	An 80m long by 2m wide sand tray was placed along the service road that runs adjacent to the freeway, which ground dwelling animals needed to cross to pass through the underpass.	Checked and raked smooth at dawn and dusk for three days per month for 12 months.
Scat Collection	At each of the three sites, five randomly placed 1 m^2 plots were checked for any signs of animal scats, bones or hair and collected for analysis.	Conducted once per month for 12 months.
Spotlighting	A high-powered red filter spotlight and nightscope were used at night to check for nocturnal animals; this was conducted at each of the three sites.	Approximately 1 hour per night for three nights per month for 12 months.

Results

There were 116 species of fauna detected within the Black Forest region throughout the duration of the study. Table 2 depicts the species groups of animals detected, along with comparisons between the total number of species detected and the number detected within the underpass compared to the surrounding forest or road. Figure 1 shows the number of species in each group detected at each location. The results suggest that the number of animals detected within the underpass is comparable to species found in the adjacent forest.

Table 2:
Species detected during the Slaty Creek underpass fauna survey

Species Group	Total Number of Species Detected	Species Detected in Forest or Road	Species Detected in the Underpass
Amphibians	7	6	6
Bats	12	Not monitored	12
Birds	63	59	37
Introduced medium to large mammals	8	6	6
Koala, Wombat, Echidna	3	3	3
Macropods	2	2	2
Possums & Gliders	7	7	4
Reptiles	8	5	5
Rodents & Dasyurids	5	5	4

Possums and Gliders
A close inspection of the study results has identified that some arboreal animals were detected within the surrounding forest, but not within the underpass (table 2). Based on other underpass studies (Queensland Department of Main Roads 2000), gliders and possums were not expected to move through underpass structures. Gliders and possums demonstrate a reluctance to come to ground, as their preferred movement is through tree canopies.

In this study, the possums and glider species detected within both the underpass and adjacent forest include:

- Sugar Glider (*Petaurus breviceps*)
- Ringtail Glider (*Pseudocheirus peregrinus*)
- Common Brushtail Possum (*Trichosurus vulpecula*)
- Squirrel Glider (*Petaurus norfolcensis*) (a possible recording)

The species that were detected in the forest but not within the underpass included:

- Feathertail Glider (*Acrobates pygmaeus*)
- Mountain Brushtail Possum (*Trichosurus caninus*)
- Greater Glider (*Petauroides volans*) (a possible recording)

These results suggest that the design of the underpass with its large dimensions and retained vegetation is suitable for most species to move through, but may require additional features to become attractive to other species such as possums and gliders.

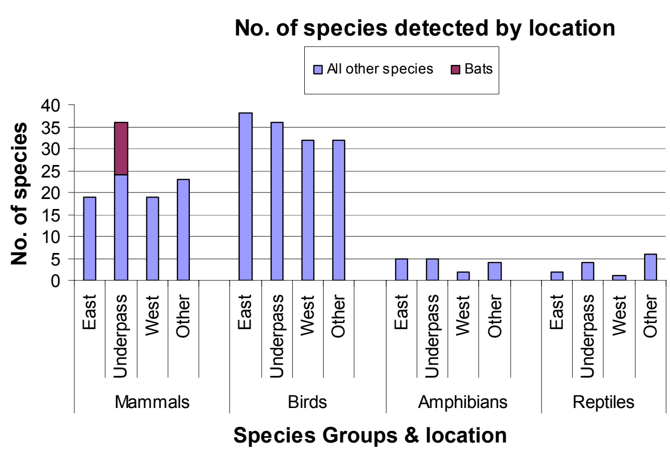


Fig. 1. Number of species detected at each location: 'East' = 50m x 50m quadrant 100 east of the underpass; 'Underpass' = within the Slaty Creek underpass; 'West' = 50m x 50m quadrant 320 west of the underpass; ' Other' = other location within a 1.2km radius of the underpass.

Introduced species
A variety of introduced animals were detected within the underpass and surrounding forest. Introduced animals were detected predominantly using the underpass at night. Although it has been suggested that predators use underpass structures as prey traps, no evidence was found to suggest that was happening at the Slaty Creek underpass. Small native and introduced animals, which would be suitable prey for predators such as foxes, cats and dogs, were regularly detected within the underpass. Table 3 presents data on predator scats collected from within the underpass and surrounding forest, and demonstrates that introduced mammals prey on both native and introduced species. However, it was not possible to determine the exact location of the predation event, as some prey species (cow and sheep) were never physically present in the underpass. This suggests that predators range quite widely for their prey and operate independently of underpass structures for their prey.

Table 3:
Predator and prey analysis based on scats collected within the underpass and surrounding Black Forest

Predator		**Prey**	
Common Name	**Scientific Name**	**Common Name**	**Scientific Name**
*Cat	*Felis catus*	Ringtail Possum	*Pseudocheirus peregrinus*
*Dog	*Canis lupus familiaris*	Ringtail Possum	*Pseudocheirus peregrinus*
		*Sheep	*Ovis aries*
*Fox	*Vulpes vulpes*	*Black Rat	*Rattus rattus*
		Bird sp.	
		*Cow	*Bos taurus*
		Mountain Brushtail Possum	*Trichosurus caninus*
		Ringtail Possum	*Pseudocheirus peregrinus*
		Swamp Wallaby	*Wallabia bicolor*

* Introduced species

Bats
Up to 12 species of bats were detected moving through the underpass. There is scope for bat roosts similar to those successfully installed in bridge structures in the United States (Keeley and Tuttle 1999) to be fitted to the bridges spanning Slaty Creek.

Vegetation
Vegetation monitoring within the Slaty Creek Underpass, and comparisons with the forest structure surrounds identified imbalances in the vegetation structure through the underpass, which could be a factor influencing animal choice to move through the underpass.

The forest surrounding the Slaty Creek Underpass is almost entirely privately owned. While it is currently provides some high quality habitat, the long-term effectiveness of the underpass will be relative to the surrounding environment.

Fencing
The entire Black Forest Section of the Calder Freeway is fenced with 2m-high chain wire fencing, with colorbond corrigated sheet metal on the forest side of the fence to prevent arboreal mammals from climbing the fence.

The base of the fence has a 30cm skirting of chain wire fencing pegged to the ground to prevent animals burrowing beneath the fence. Koala escape poles were placed on the inside of the fence, so that if a Koala were to access the roadway, there would be opportunity for them to scale the fence from the road side.

Recommendations
While the Slaty Creek Underpass has been found to be used by a large variety of fauna, there are still some works that could enhance its use, which include:

- The construction of rope canopy bridges and glider poles for arboreal animals
- Fitting bat roosts into the bridge structure
- Additional revegetation of indigenous species within the underpass, particularly middle storey species, to replicate the forest structure

- The design and maintenance of fencing that minimises road kill
- Involvement of community environmental groups in ongoing monitoring
- Ensuring the integrity of surrounding forest is maintained in perpetuity

Biographical Sketch: Rodney Abson has been employed as a research assistant with La Trobe University, Bendigo, to monitor the Slaty Creek Wildlife Underpass, in Macedon, Victoria. This has also contributed to his masters in environmental management, which he is currently completing. Rodney also has a bachelor of arts in nature tourism from La Trobe University.

References

Australian Bureau of Statistics. 2002. *Year Book Australia 2002. Transport Infrastructure* [online]. Australian Bureau of Statistics. Available from: http://www.abs.gov.au/ausstats/abs@.nsf/0/28e9843de0d1c7efca256b360006202d?OpenDocument [Accessed 14th July, 2003].

Goosem, M., Izumi, Y., Turton, S. (2001). Efforts to restore habitat connectivity for an upland tropical rainforest fauna: A trial of underpasses below roads. *Ecological Management & Restoration*, Vol. 2 (3) 196-202.

Hunt, A., Dickens, H., and Whelan, R. 1987. Movement of mammals through tunnels under railway lines. *Australian Zoologist*, Vol. 24 (2) 89-93.

Keeley, B., Tuttle, M. 1999. Bats in American Bridges. Bat Conservation International, Inc. Austin.

Mansergh, I., and Scotts, D. (1989). Habitat continuity and social organization of the Mountain Pygmy-Possum restored by tunnel. *Journal of Wildlife Management*, Vol. 53 (3) 701-7.

Queensland Department of Main Roads. 2000. *Fauna Sensitive Road Design. Volume 1 – Past and Existing Practices*. Queensland Department of Main Roads, Technology and Environment Division. Brisbane.

MULE DEER USE OF UNDERPASSES IN WESTERN AND SOUTHEASTERN WYOMING

Kelly M. Gordon (Phone: 307-766-5415, Email: kgordon@uwyo.edu), Research Scientist, and Stanley H. Anderson, Unit Leader, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, Box 3166, Laramie, WY 82071 USA, Fax: 307-766-5400

Abstract: Underpasses have been found to be a valuable mitigation tool in increasing permeability of roads to wildlife while preventing roadside mortality. Underpasses are currently used in Wyoming on Interstate 80 near Arlington and Walcott Junction in conjunction with 2.4meter-high fencing to allow mule deer to pass under two stretches of road that bisect migration routes of mule deer. One experimental underpass has been installed in Nugget Canyon on U.S. Highway 30 between Kemmerer and Cokeville in western Wyoming to assess the effectiveness of underpasses in mitigating deer-vehicle collisions along a 15-mile stretch of highway that bisects the migration route of a subunit of the Wyoming Range mule deer herd consisting of 14,000 animals. A monitoring study using 35mm cameras activated by Trailmaster TM1500 infrared sensors was initiated in fall of 2001 to assess mule deer use of six underpasses on Interstate 80. Results from this study were used to inform a project examining the response of mule deer to manipulations of the openness ratio of the Nugget Canyon underpass which entailed video monitoring of the underpass to gather data on deer behavior. We found that of the six underpasses we monitored along Interstate 80, only one was consistently used by mule deer. This underpass had a high openness ratio and was located near a historic mule deer migration route. At the Nugget Canyon underpass, we found that percentage of mule deer repelling from the underpass was significantly correlated with underpass openness. Mule deer responded more to alterations in underpass width than height. Based on our results, we recommend that future underpasses constructed in Nugget Canyon be at least 20 feet wide and 8 feet tall and have an openness ratio of at least 0.8.

Introduction

It is estimated that roads impact close to 20 percent of the land area of the United States (Forman and Alexander 1998, Forman 2000). Effects of roads include direct mortality from roadkills, road avoidance due to noise and traffic, and barriers to animal movement (Forman and Alexander 1998). Perforation of roads using underpasses or overpasses can partially mitigate the impacts of both direct mortality and barrier effects. Underpasses have been found to be effective tools in reducing highway mortality in a number of studies (Ward 1982, Ludwig and Bremicker 1983, Singer and Doherty 1985, Feldhamer et al. 1986, Hunt et al. 1989, Foster and Humphrey 1995, Yanes et al. 1995, Clevenger et al. 2001). However, the design of underpasses requires careful thought to ensure that they are suitable for use by wildlife. The openness of underpasses has been found to be important in determining whether wildlife, particularly deer, will be willing to use them (Clevenger and Waltho 2000, Reed 1981). Reed (1981) found that mule deer (*Odocoileus hemionus*) exhibited more behavioral indicators of hesitancy in response to smaller underpasses than larger, bridge type underpasses, and recommended that in planning the construction of underpasses for mule deer, openness ratios of at least 0.6be used (Reed 1975, Reed et al. 1979). Foster and Humphrey (1995) suggest that in considering underpass openness width may be more important than height, and recommend that underpasses be designed with a view of the habitat and horizon on the opposite side. Clevenger and Waltho (2000) likewise found that width and openness were correlated with deer underpass use and that height was not.

The State of Wyoming has been grappling with the problem of deer-vehicle collisions for over 30 years. In 1967 when Interstate 80 was constructed across the southern portion of Wyoming, it bisected the migration route of mule deer that move between their summer ranges in the Snowy Mountains onto their lower elevation winter ranges. Two areas of Interstate 80, near Arlington and Walcott Junction, experienced particularly high roadkills as a result of this movement. Between 1967 and 1975, 561 mule deer were killed in these areas (Ward 1982). In 1978, two stretches of 8-foot-high ungulate-proof fencing were constructed in these areas, one between mileposts 239 and 246 near Walcott Junction, and one between mileposts 279 and 286 near Arlington. Between 1973 and 1980, an initial monitoring study of underpasses associated with these fenced areas, conducted by Ward (1982), found that mule deer were using these underpasses to move across the highway. Underpasses in these areas were of varying construction, size and purpose, and received varying amounts of use depending on their structural attributes and ecological setting.

Mitigation measures for deer-vehicle collisions have been attempted elsewhere in the state as well. U.S. Highway 30 as it passes through Nugget Canyon between Kemmerer and Cokeville, Wyoming, bisects the migration route of mule deer of the Red Eye Basin subunit of the Wyoming Range mule deer herd, consisting of 14,000 animals. An average of 130 deer/vehicle collisions have occurred each year since 1990 as mule deer cross the highway between mileposts 27 and 42 while migrating between their winter and summer ranges. In 1986, the Wyoming state legislature passed the Nugget Canyon Wildlife Migration Project Act calling for state agencies to work together in attempting to mitigate the problem of deer/vehicle collisions in this area. Several mitigation measures have been attempted in Nugget Canyon. In 1989 a seven-mile-long, eight-foot high deer-proof fence was erected with a gap for mule deer crossings at milepost 30.5. Signs warning motorists of migratory deer crossings were installed in association with the fence, but deer mortality remained high. Swareflex reflectors were tested but were found to be ineffective in reducing deer/vehicle collisions (Reeve and Anderson 1993). A system which detected deer as they moved across the road and warned motorists when deer were present was also found to be largely ineffective in causing motorists to slow down (Gordon and Anderson 2001). Based on these experiences, the Wyoming Department of Transportation and Wyoming Game and Fish Department jointly decided that underpasses might be an effective mitigation technique in this area.

In order to guide decisions about the construction of a series of underpasses in Nugget Canyon, two studies of underpasses in Wyoming were initiated by the Federal Highway Administration and the Wyoming Department of Transportation and executed by the Wyoming Cooperative Fish and Wildlife Research Unit. The underpasses along Interstate 80 near the Medicine Bow Range in southern Wyoming were monitored to evaluate current use and to determine how structural and ecological attributes of these underpasses might influence use by mule deer. Additionally, during the summer of 2001, a preliminary underpass was constructed in Nugget Canyon to facilitate the movement of deer safely across the highway. A WYDOT-funded study evaluating this underpass was undertaken in the fall of 2001 that involved investigating patterns of deer movement through the underpass, deer response to size manipulations of the underpass, and potential future sites of underpasses in Nugget Canyon. This paper summarizes the results of both of these studies and draws conclusions and recommendations about underpass construction for mule deer in the state of Wyoming.

Methods

I-80 Underpasses

Twelve underpasses are located in the fenced stretches of Interstate 80 between mileposts 279 and 286 and between mileposts 239 and 246. Of these, we chose six for monitoring that represented a range of construction types and opennesses. We occasionally examined other underpasses for tracks and other signs of activity. Underpasses that we monitored were either box-type underpasses, with no open medians, designed for the passage of livestock under the highway, or machinery underpasses, with open medians, that have dirt or gravel roads for the passage of vehicles. We computed the openness of underpasses using the following equation:

$$\text{Openness} = (\text{width} * \text{height})/\text{length}$$

All measurements were in meters. Higher numbers indicate an underpass that appears more open. Table 1 lists the underpasses we monitored, their location, construction type and openness. During the migration seasons of 2001-2002 and 2002-2003, we used a still camera system to monitor the underpasses. This system consisted of 35mm Yashica AW-mini cameras activated by a Trailmaster TM1500 active infrared sensor. The systems were installed at both the north and south ends of each of the six underpasses listed in table 1, with the exception of underpass 1, which had no available mounting site at the north end of the underpass. We collected film and downloaded the times and dates of hits on the Trailmaster once every two weeks from November to May during 2001-2002 and October to May of 2002-2003.

Table 1.
Underpasses monitored near Arlington and Walcott Junction

UNDER-PASS #	MILE-POST	UNDERPASS TYPE	OPENNESS
1	286.4	Machinery	0.72
2	284	Livestock	0.20
3	244	Machinery	1.07
4	242.5	Livestock	0.20
5	241	Livestock	0.11
6	240.5	Livestock	0.08

We collected tracking data from the monitored underpasses by raking a section of the underpass floor on the north and south ends and counting the number of fresh track sets that appeared each time we visited the underpasses. In addition, we occasionally scanned for tracks at the unmonitored underpasses to determine if these underpasses were receiving ungulate usage.

Nugget Canyon Underpass

During the summer of 2001, an underpass was built under U.S. Hwy. 30 to facilitate the safe passage of mule deer across the road. The underpass is located at milepost 30.5 at the former location of the at-grade crossing. A deer-proof fence extends from milepost 28 to milepost 35 and funnels deer into the underpass to prevent access to the road. The underpass has solid concrete walls and ceiling and a dirt floor. It measures 20-feet wide x 60-feet long and, because of the dirt floor, varies in height between 10 feet and 11 feet.

We installed a videocamera system to monitor mule deer movement through the underpass. The system consisted of four infrared lenses that fed images of the underpass to a VHS videocassette recorder. We mounted lenses to monitor the entrance, exit, and approach areas of the underpass. The camera system was activated by four sets of infrared scopes, two each located on the north and south sides of the underpass. One of these was positioned at the outermost extremity of the wings of the deer-proof fencing, and the other was positioned approximately halfway along the wings of the deer-proof fencing. LED lights, visible to the infrared lenses but not to deer, were installed to improve the quality of nighttime images.

Beginning in late January 2002, we modified the height and width of the underpass using a series of plywood dividers according to the treatments described in table 2. Heights and widths were chosen to represent a range of openness ratios, computed as described above. Table 2 shows the underpass configurations used during the spring of 2002 and the openness ratio of each treatment. We extracted data from the video footage by recording the time each animal entered the view of the videotape, the time entering the area between the wings of the underpass (referred to as the staging area), the time entering the underpass itself, and the time the animal exited the underpass. Additionally, we recorded the gait of the animal at each of the stages described above, and tallied the number of head-up and nose-down responses in the staging area as behavioral indicators of hesitancy.

Table 2.
Treatments conducted during the spring of 2002.

Width	Height	Openness ratio
20 feet (unaltered)	10 feet (unaltered)	1.12
20 feet (dividers)	10 feet (unaltered)	1.12
20 feet	8 feet	.81
20 feet	6 feet	.61
15 feet	10 feet	.84
15 feet	6 feet	.46
11 feet	10 feet	.61
11 feet	8 feet	.45

During the fall 2002 and spring 2003 field seasons, we discarded the width alterations. We based this decision on the fact that data collected during the spring 2002 indicated that alterations in width to 15 or 11 feet resulted in a an extremely high percentage of animals refusing to use the underpass. We repeated the three different height treatments according to the schedule shown in table 3 in an attempt to capture possible seasonal variation in repel rates in response to each treatment. Gaps between treatments are due to lapses in videotape footage, periods during which there was no deer movement, or intervals during which the underpass was being altered. A significant gap between 3/13/03 and 4/16/03 was due to a malfunction in the VCR used to record the footage. The size treatment was altered approximately every two weeks during times when deer movement was minimal, and approximately once a week during the peak of migration.

Table 3.
Treatments conducted during the fall of 2002 and spring of 2003.

Treatment	Date
20 x 10	10/9/02 – 10/18/02
20 x 8	10/23/02 – 10/30/02
20 x 6	11/6/02 – 11/16/02
20 x 10	11/18/02 – 11/20/02
20 x 8	11/25/02 – 12/2/02
20 x 6	12/3/02 – 12/15/02
20 x 10	12/16/02 – 12/22/02
20 x 8	12/22/02 – 12/26/02
20 x 10	12/30/02 – 1/7/03
20 x 6	1/8/03 – 1/21/03
20 x 8	1/22/03 – 2/3/03
20 x 10	2/8/03 – 2/23/03
20 x 6	2/26/03 – 3/10/03
20 x 10	3/11/03 – 3/13/03
20 x 10	4/16/03 – 4/30/03
20 x 8	4/30/03 – 5/20/03

We analyzed the data gathered from the video footage by examining enter and repel data in response to varying size manipulations of the underpass. We performed a simple linear regression on the spring 2002, fall 2002, and spring 2003 data, looking at the effect of openness on percentage of repels for each treatment. We were also interested in whether changes in height or width had more impact on deer willingness to use the underpass, so we performed chi squared tests of independence on the distribution of enters and repels in response to three height manipulations and three width manipulations. Over the course of the study we realized that the proportion of repels to enters may be inflated by deer that approach the underpass several times before finally moving through the underpass. We were interested in the number of deer that eventually move through the underpass in response to a given size manipulation, as opposed to seeking an alternate route across the highway. In order to address this question, we stratified the fall 2002 and spring 2003 data for the three height manipulations into data collected during low activity times, medium activity times, and high activity times based on the total number of approaches to the underpass during two-week periods ranging from October 2002 to May 2003. For each of the height manipulations, we computed the average number of deer passing through the underpass per day during each of these activity periods. This enabled us to determine whether fewer deer are willing to pass through the smaller-sized underpass given a certain level of activity at the underpass.

We also examined the effect of underpass size on deer behavior. We recorded the number of head up behaviors, in which the deer looks up at the ceiling of the underpass, and nose down behaviors, in which the deer sniffs the ground, for each deer approaching the underpass. We computed average head up and nose down behaviors for each of the height and width manipulations and computed 95 percent confidence intervals in order to discern significant differences. We also examined the relationship between underpass size and the number of seconds before entering spent in the staging area.

Results

I-80 Underpasses

During the fall and spring migrations of 2001–2003 we monitored the underpasses using a still camera triggered by a Trailmaster 1500 active infrared sensor. Table 4 shows use of all underpasses for both field seasons according to data collected by the Trailmaster.

Table 4.
Total trailmaster hits at each underpass for two field seasons

Underpass	2001 - 2002	2002 - 2003
1	26	24
2	5	1
3	465	470
4	5	9
5	7	14
6	1	1

Underpass 3 received the heaviest use by far, with 91 percent of activity recorded by the trailmasters occuring at this underpass. Photographic and tracking data indicate that all of the activity recorded at this underpass was due to mule deer. Figures 1 and 2 show seasonal use by mule deer of underpass 3 for the 2001-2002 and 2002-2003 field seasons.

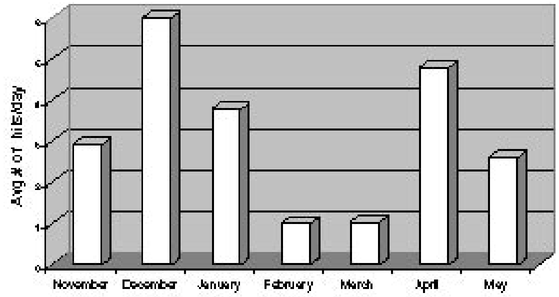


Fig. 1. Seasonal Deer Activity 2001-2002 (Underpass 3)

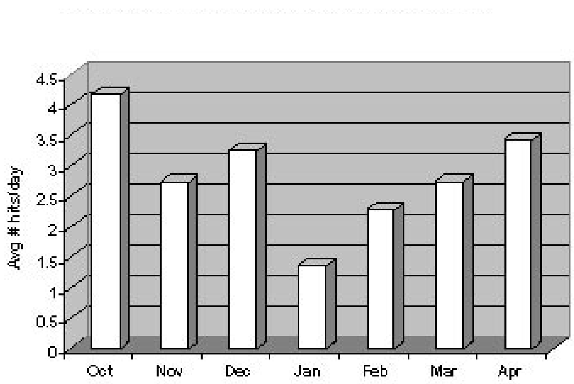


Fig. 2. Seasonal Deer Activity 2002-2003 (Underpass 3)

Peak activity occurred in December and April during the 2001-2002 field season and in October, December and April during the 2002-2003 field season. Deer movement during the fall seemed to be triggered by winter storm events.

Nugget Canyon Underpass

During the spring of 2002 we initiated manipulations of the width and height of the underpass at Nugget Canyon to simulate a range of different openness ratios (table 2). We performed a simple linear regression on openness ratio against percentage of repels and found a significant relationship between the two variables (Adj. R^2 =0.650, p = 0.0096). Figure 3 shows a scatterplot of the openness ratios and percentage of repels for eight different treatments performed during spring 2002.

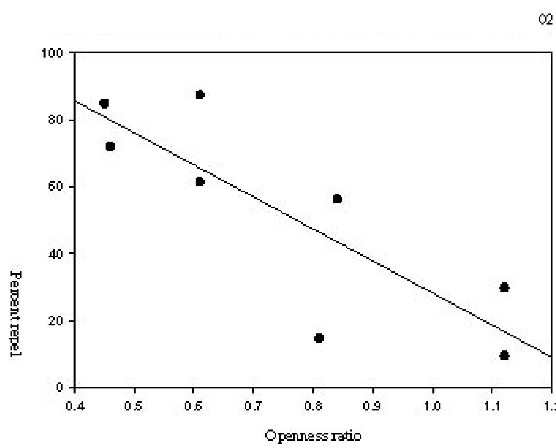


Fig. 3. Openness ratio and repel rates for
8 different treatments, Spring 2002.

We repeated this analysis on data collected during the fall of 2002 and the spring of 2003, during which time we conducted several trials of three different size manipulations, all of which involved altering the height of the underpass but not the width. We found no significant relationship between openness ratio and percentage of repels for these trials (Adj. R^2 = 0.117, p = 0.1059). All three trials had high repel percentages, although the 6' ceiling treatment was the highest. Figure 4 shows a scatterplot of the trials performed during fall 2002 and spring 2003.

During the spring of 2002, the 20ft x 10ft and 20ft x 8ft treatments (openness ratios 1.12 and 0.81 respectively) had extremely low percentages of repels, ranging from 10 percent to 30 percent. During the fall of 2002 and the spring of 2003 when these treatments were repeated, the percentages of repels ranged from 37 percent to 71 percent.

We were interested in determining whether the high percentages of repels we saw in response to many of our treatments were due to deer approaching the underpass several times before finally moving through, or whether deer were responding to the underpass by repelling and seeking an alternate route. Figure 5 shows the average number of deer passing through the underpass per day during low, medium, and high periods of deer activity for the three different height treatments during the spring of 2002, fall of 2002, and spring of 2003.

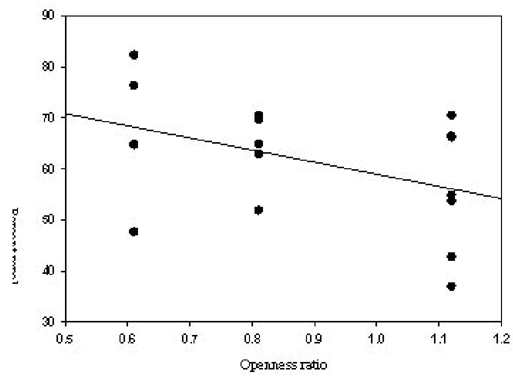


Fig. 4. Repel rates in response to three height treatments, 2002-2003.

During periods of low activity, there was little difference between the number of deer entering the underpass per day for each of the three treatments. However, during periods of medium and high activity, the number of deer entering the underpass per day decreased as the size of the underpass decreased. Some deer encountering the smaller underpass sizes during these times of higher activity may have been seeking alternate routes across the highway.

We also wished to determine whether deer were more sensitive to decreases in the width of the underpass or decreases in the height of the underpass. We used data gathered during the spring of 2002, since both height and width manipulations were conducted during this migration. We compared deer percentages of repels for the 20ft, 15ft, and 11ft widths at the full underpass height (10ft). The number of deer entering and repelling from the underpass as a function of the three different width treatments is shown in figure 6.

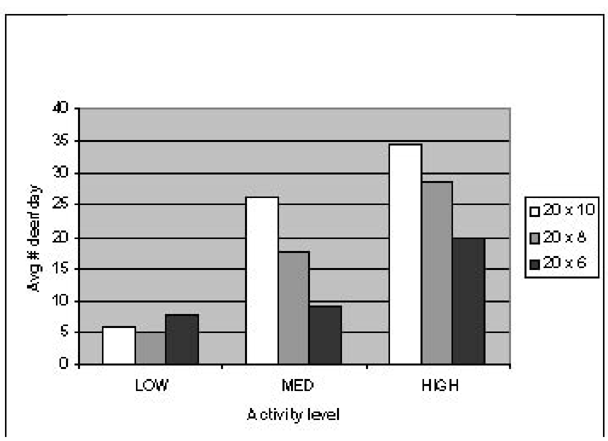


Fig. 5. Number of deer entering underpass per day for three different activity levels and treatments.

The percentage of repels increased dramatically as the width of the underpass decreased. We performed a chi-squared test of independence and found that deer response to the underpass was significantly different between the three treatments [X^2= 405.5 (df= 2; N= 2484); p< 0.0001]. Figure 7 shows deer response to the underpass at the full underpass width with three different height treatments.

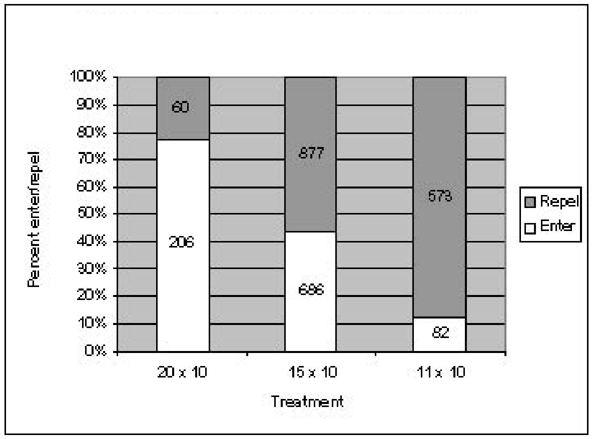


Fig. 6. Percent enter and repel for width treatments.

The percentage of repels is approximately the same for the 20ft x 10ft treatment and the 20ft x 8ft treatment, but increased drastically for the 20ft x 6ft treatment. A chi-squared test of independence revealed significant differences in deer response to the three treatments (X^2 = 43.02 (df = 2, n=507); p< 0.0001). Repels by deer increase in response to any of the reductions in width attempted in this study, but it would appear that a reduction in height from 10ft to 8ft does not result in any significant difference in percentage of repels.

We wished to determine whether behaviors associated with hesitancy varied in response to variation in underpass width and height. Using data collected during the spring of 2002, we computed the average number of head up and nose down responses per approach to the underpass for three width treatments (20ft x 10ft, 15ft x 10ft, and 11ft x 10ft) and three height treatments (20ft x 10ft, 20ft x 8ft, and 20ft x 6ft). Additionally, we computed 95 percent confidence intervals for each of these categories. Results of these analyses are shown in figures 8 and 9. Bars on the figures indicate 95 percent confidence intervals.

Head up and nose down behaviors increased as width of the underpass decreased, although differences between the 20ft and 15ft treatment were not significant. Head up and nose down responses showed no pattern in relation to height of the underpass. These results also indicate that mule deer appear to be more sensitive to smaller underpass widths than heights.

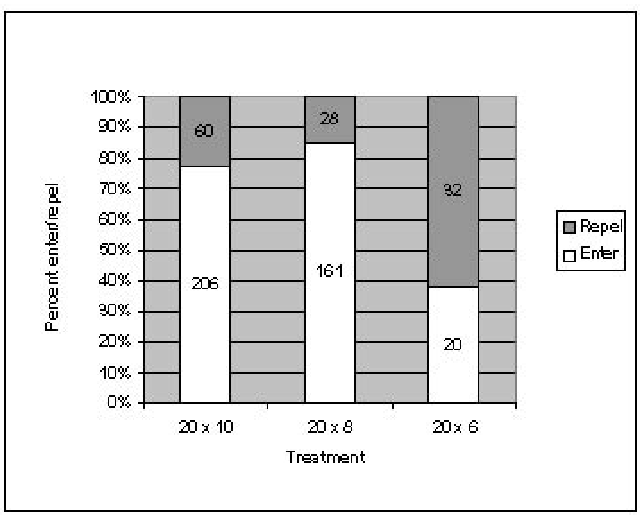


Fig. 7. Percent enter and repel for height treatments.

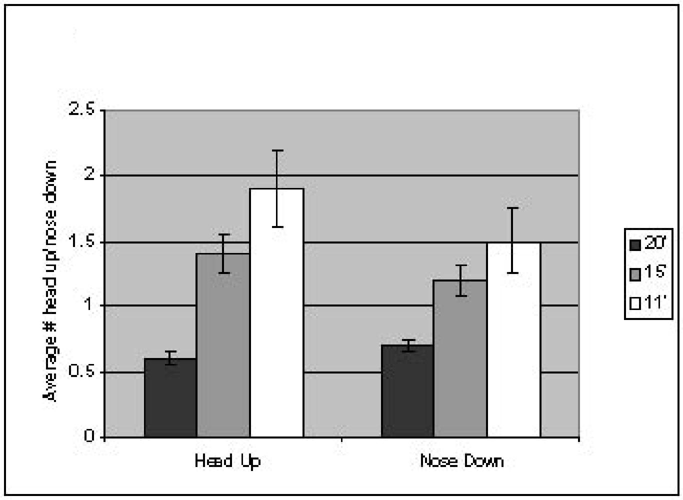


Fig. 8. Head up and nose down behaviors
in response to width modifications.

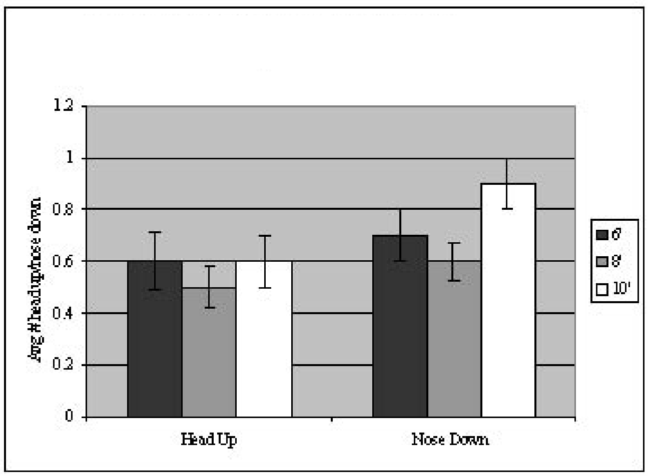


Fig. 9. Head up and nose down behaviors
in response to height modifications.

Time required to move out of the staging area and enter the underpass may also be an indicator of hesitancy. Using the data from spring 2002, we performed a simple linear regression of average number of seconds in the staging area against openness ratio of seven different size treatments. We found that average number of seconds in the staging area was not significantly correlated with openness ratio (R^2 = .051; p=.6269). There appears to be no relationship between openness ratio and amount of time required to enter the underpass. Furthermore, no pattern was discerned when treatments were broken down by height or width modifications.

Discussion

Data collected from underpasses on Interstate 80 in Wyoming seem to indicate that both structural and ecological attributes of underpasses influence mule deer use in this area. Underpass 3, an open construction machinery underpass with a high ceiling and a gap at the median, was the only underpass that received substantial use of those we monitored. Reed et al.'s (1979) work on underpasses suggests that a minimum openness ratio of 0.6 be employed when constructing underpasses for mule deer. Livestock underpasses that we monitored had extremely small openness ratios, ranging from 0.08 to 0.2. Additionally, underpasses 2, 5, and 6 were situated such that no view of the horizon was visible when looking down the length of the underpass. Foster and Humphrey (1995) suggest that this may be an important consideration when designing underpasses for wildlife. Underpass 3 has an openness ratio of 1.07, well in excess of the recommended 0.6. However, little activity was recorded at underpass 1, another machinery underpass with an open median which had an openness ratio of 0.72. Underpass 1 is located in relatively open, featureless terrain, whereas underpass 3 is located at the foot of a ridge that may guide mule deer movement. Ward (1982) notes that underpass 3 was located near a historic crossing site for mule deer before the construction of the game fence in 1978. During the migrations of 1978–1982, 90 percent of mule deer used underpass 3 during the spring migrations, and 60 percent during the fall migrations (Ward 1982). The location of a large, open machinery underpass near this historic crossing may explain its heavy use by mule deer during those migrations and presently.

At the Nugget Canyon underpass, openness impacted mule deer willingness to use the underpass during the spring of 2002. There was a strong relationship between openness of the underpass and percentage of repels at the underpass, with an increase in percentage of repels in response to treatments with opennesses of less than 0.8. The 20ft x 10ft and the 20ft x 8ft treatments exhibited repel percentages between 10 percent and 30 percent during the spring of 2002. It is not clear why the percentage of repels for these treatments increased to between 37 percent - 71 percent during the 2002-2003 field season. Increased human activity at the site during the 2002-2003 field season may have left increased odor and sign of disturbance, causing mule deer approaching the underpass to be more hesitant to use it. Clevenger and Waltho (2000) found that human activity was an important variable in determining deer use of underpasses in Banff National Park. Additionally, weather during the 2002-2003 field season was much milder than in past years. Although these data are not presented here, we did find that as snow depth increased at the underpass, the percentage of repels decreased (Gordon and Anderson 2003). Perhaps the reduced snowcover during the 2002-2003 field season resulted in mule deer being less motivated to pass through as they approached the underpass, and, consequently, spending more time in the vicinity of the underpass before moving through.

If a large number of deer approach the underpass several times before finally moving through the underpass, this could result in an inflated percentage of repels despite the fact that most deer are ultimately using the underpass. It is important to distinguish between a situation in which deer approach the underpass several times and then move through and a situation in which deer approach the underpass and then turn away, seeking an alternate route across the highway. We found that, after stratifying the data by seasonal activity level, number of deer passing through the underpass per day was related to the openness of the underpass at medium and high activity levels, indicating that at the larger size treatments, many deer that initially repel from the underpass multiple times eventually move through after a few attempts. Reed (1981) reports that a single collared deer approached an underpass 15 times over the course of three days before eventually passing through. Comparatively low numbers of deer moving through the underpass at the 20ft x 6ft treatment may indicate that deer are responding to the smaller sized treatments by seeking alternate routes across the highway. In addition to the smaller openness ratio of the 20ft x 6ft treatment, mule deer may also have increased hesitancy in response to this treatment as a result of the obscured view of the habitat and horizon beyond. The Nugget Canyon underpass is constructed such that the ground slopes up in either direction from the underpass, obscuring the view through the underpass when the height is reduced. Foster and Humphrey (1995) suggest that a view of the horizon through the underpass may be important in determining wildlife willingness to use underpasses.

Our data indicate that reductions in width may impact mule deer hesitancy to use the underpass more than reductions in height. Reduction in width of the underpass from 20ft to 15ft resulted in a significantly higher percentage of repels, whereas a reduction in the height of the underpass from 10ft to 8ft did not result in an increased repel percentage, although a reduction to 6ft did. Mule deer exhibited significant increases in number of head-up or nose-down behaviors in response to narrowing the underpass, but not in response to a reduction in underpass height. Clevenger and Waltho (2000) found that width significantly impacted deer use of underpasses in Banff, but that height did not. Foster and Humphrey (1995) suggest that in computing openness ratios it may be appropriate to weight width more heavily than height, as wildlife seem to respond more to variation in underpass width.

Based on these data, we recommended to WYDOT that future underpasses built in Nugget Canyon be at least 8ft tall and 20ft wide, with an openness ratio of 0.8 or greater, and situated near areas that currently are active migration paths for mule deer. Factors such as human activity, topography, noise, and view of the habitat and horizon beyond the underpass may also come into play in the success of underpasses built at Nugget Canyon.

Acknowledgements: The Wyoming Department of Transportation (WYDOT) and the Federal Highway Administration (FHWA) provided funding for these projects. John Eddins, District Engineer for WYDOT, sponsored the Nugget Canyon project and provided important input and support over the course of the study. William Gribble, Matt Johnson, and Kevin McCoy of the WYDOT counter shop were invaluable in developing and installing infrared detection systems and video cameras. William Rudd of the Wyoming Game and Fish Department (WGFD) provided important input into study design as well as deer mortality data for Nugget Canyon. Thanks are due to Paul Garrett of FHWA for support and assistance in the dissemination of the information contained in this paper. John Miller of the Research Support Shop at University of Wyoming assisted in the design of the underpass dividers. Tim McGary of WYDOT provided assistance in locating and initial assessment of the Interstate 80 underpasses. Regan Plumb, Jon Haschke, Scott Schaefer, Paul Sutherland, and Ken Keffer of the Wyoming Cooperative Fish and Wildlife Research Unit (WCFWRU) provided valuable assistance with data collection. Mark McKinstry provided important input in the initial stages of this project.

Biographical Sketch: Kelly Gordon completed her B.S. in biology at Cornell University in 1992 and her M.S. in biology at the University of New Mexico in 1996. She has worked as a research scientist for the Wyoming Cooperative Fish and Wildlife Research Unit since 1999 on a variety of different projects involving deer-vehicle collision mitigation as well as prairie dog research.

References

Clevenger, A. P., B. Chruszcz, and K.E. Gunson. 2001. Highway mitigation fencing reduces wildlife-vehicle collisions. *Wildlife Society Bulletin* 29(2):646-653.

Clevenger, A. P. and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology* 14: 47–55.

Feldhamer, G.A., J.E. Gates, D.M. Harman, A.J. Loranger, and K.R. Dixon. 1986. Effects of interstate highway fencing on white-tailed deer activity. *Journal of Wildlife Management* 50(3):497-503.

Forman, R.T.T. 2000. Estimate of the area affected ecologically by the road system in the United States. *Conservation Biology* 14: 31–35.

Forman, R.T.T. and L.E. Alexander. 1998. Roads and Their Major Ecological Effects. *Annual Review of Ecology and Systematics* 29:207-231.

Foster, M. L. and S.R. Humphrey. 1995. Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin* 23(1):95-100.

Gordon, K. and S. Anderson. 2001. Motorist response to a deer-sensing warning system in Western Wyoming. *Proceedings of the International Conference on Ecology and Transportation*, September 25, Keystone, Colorado. Center for Transportation and Environment, North Carolina State University.

Gordon, K. and S. Anderson. 2003. Mule deer response to an underpass in Nugget Canyon, Wyoming. Final report. Wyoming Department of Transportation, Cheyenne, Wyoming.

Hunt, A., H.J. Dickens, and R.J. Whelan. 1987. Movement of Mammals through Tunnels under Railway Lines. *Australian Zoologist* 24(2):89-93.

Ludwig, J. and T. Bremicker. 1983. Evaluation of 2.4m Fences and One-Way Gates for Reducing Deer-Vehicle Collisions in Minnesota. *Transportation Research Record* 913:19-22.

Reed, D. F., T. N. Woodard, and T. M. Pojar. 1975. Behavioral Response of Mule Deer to a Highway Underpass. *Journal of Wildlife Management* 39(2):361-367.

Reed, D.F., T.N. Woodward and T.D.I. Beck. 1979. Regional Deer-Vehicle Accident Research. Federal Highway Administration Report No. FHWA-CO-RD-79-11. 59 pp.

Reed, D. F. 1981. Mule deer behavior at a highway underpass exit. *Journal of Wildlife Management* 45(2): 542-543.

Reeve, A. F. and Anderson, S.H. 1993. Ineffectiveness of Swareflex Reflectors at Reducing Deer-Vehicle Collisions. *Wildlife Society Bulletin* 21: 127-132.

Singer, F. J. and J.L. Doherty. 1985. Managing Mountain Goats at a Highway Crossing. *Wildlife Society Bulletin* 13:469-477.

Ward, A. L. 1982. Mule Deer Behavior in Relation to Fencing and Underpasses on Interstate 80 in Wyoming. *Transportation Research Record* 859:8-13.

Yanes, M., J.M. Velasco, and F. Suarez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. *Biological Conservation* 71:217-222.

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 ($\geq$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.

References

Barnum, S. Preliminary analysis of locations where wildlife crosses highways in the southern Rocky Mountains. 2001. In: *Proceedings of the International Conference on Ecology and Transportation*. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina.

Bart, J. and W. Notz. Analysis of data. Pages 24-74 T.A. Bookhout, ed. *Research and management techniques for wildlife and habitats*. Fifth ed., rev. The Wildlife Society, Bethesda, Maryland.

Beier, P. and S.C. Cunningham. 1996. Power of track surveys to detect changes in cougar populations. *Wildlife Society Bulletin* 24:434-440.

Beier, P and R. Noss. 1998. Do habitat corridors provide connectivity? *Conservation Biology* 12:1241-1252.

Boyce, M. 1996. RAMAS/GIS: Linking landscape data with population viability analysis. *Quarterly Review of Biology* 71:167-170.

Boyce, M.S., Kirsch, E.M., and Servheen, C. 2002. Bet-hedging applications in conservation. *Journal of Biosciences 27:385-392.*

Chruszcz, B., Clevenger, A.P., Gunson, K., and Gibeau, M. 2003. Relationships among grizzly bears, highways, and habitat in the Banff-Bow Valley, Alberta, Canada. *Canadian Journal of Zoology* 81: 1378-1391.

Clevenger, A.P. and Waltho, N. 2000. Factors influencing the effectiveness of wildlife crossing underpasses in Banff National Park, Alberta, Canada. *Conservation Biology* 14:47-56.

Clevenger, A.P., Chruszcz, B., Gunson, K., and Wierzchowski, J. 2002. Roads and wildlife in the Canadian Rocky Mountain Parks – Movements, mortality, and mitigation. Final report to Parks Canada. Banff, Alberta, Canada.

Clevenger, A.P. and N. Waltho. 2003. Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies. In *Proceedings of the 2003 International Conference on Ecology and Transportation*. C. Leroy Irwin, Paul Garrett, and K.P. McDermott, editors. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University.

Clevenger, A.P. and N. Waltho. In press. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation*.

Conrey, R.C.Y. and Mills, L.S. 2001. Do highways fragment small mammal population? Pp. 448-457. In *Proceedings of the International Conference on Ecology and Transportation.* G. Evink and K.P. McDermott, Editors. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University.

Creel, S., Fox, J.E., Hardy, A.H., Sands, J., Garrott, B., and R.O. Peterson. 2002. Snowmobile activity and glucocorticoid stress responses in wolves and elk. *Conservation Biology* 16:809-814.

Dodd, N., J. Gagnon and R. Schweinsburg. 2003.Quarterly progress report 6. Evaluation of measures to minimize wildlife-vehicle collisions and maintain wildlife permeability across highways. Arizona Game and Fish Department Research Branch, Phoenix, AZ, USA.

Dyer, S.J., O'Neill, J.P., Wasel, S.M., and Boutin, S. 2002. Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. *Canadian Journal of Zoology* 80:839-845.

Evink, G. 2002. *Interaction between roadways and wildlife ecology. National Cooperative Highway Research Program Synthesis 305*, Transportation Research Board. 77 pp.

Ferreras, P., Gaona, P., Palomares, and Delibes, M. 2001. Restore habitat or reduce mortality? Implications from a population viability analysis of the Iberian lynx. *Animal Conservation* 4:265-274.

Forman, R.T.T., Bissonette, J., Clevenger, A., Cutshall, C., Dale, V., Fahrig, L., Goldman, C., Heanue, K., Jones, J., Sperling, D., Swanson, F., Turrentine, T. and Winter, T. 2002. *Road Ecology: Science and Solutions*. Island Press, Washington DC.

Forrest, L.R. 1988. Field guide to tracking animals in snow. Stackpole Books, Mechanicsburg, PA, USA.

Gibeau, M., A.P. Clevenger, S. Herrero and J. Wierzchowski. Grizzly bear response to human development and activities in the Bow River watershed, Alberta. *Biological Conservation* 103:227-236.

Halfpenny, J.C. and E. A. Biesiot. 1986. A field guide to mammal tracking in North America. Johnson Books, Boulder, USA.

Huijser, M.P. and P.J.M. Bergers. 2000. The effect of roads and traffic on hedgehog (*Erinaceus europaeus*) populations. *Biological Conservation* 95: 111-116.

Kucera, T.E. and R.H. Barrett. 1993. The Trailmaster camera system for detecting wildlife. *Wildlife Society Bulletin* 23:110-113.

Lancia, R.A., J.D. Nichols and K.H. Pollock. 1996. Estimating the number of animals in wildlife populations. Pages 215-253. T.A. Bookhout, ed. *Research and management techniques for wildlife and habitats*. Fifth ed., rev. The Wildlife Society, Bethesda, Maryland.

Luikart, G., and England, P.R. 1999. Statistical analysis of microsatellite data. *Trends in Ecology and Evolution* 14:253-255.

Manel, S., Schwartz, MK, Luikart, G., and Taberlet, P. 2003. Landscape genetics: combining landscape ecology and population genetics. *Trends in Ecology and Evolution* 18:189-97.

McKelvey, K.S., Y.K. Ortega, G. Koehler, K. Aubry, and D. Brittell. 1999. Canada lynx habitat and topographic use patterns in north central Washington: a reanalysis. Pages 307-36 in: Ruggiero, L.F., Aubry, K.B., Buskirk, S.W., Koehler, G.M., Krebs, C.J., McKelvey, K.S., and Squires, J.R.. (eds.) *Ecology and conservation of lynx in the United States*. General Technical Report RMRS-GTR-30WWW. Fort Collins, Colorado, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Murie, O.J. 1974. *A field guide to animal tracks*. 2nd edition. The Peterson Field Guide series 9. Houghton Mifflin, Boston, USA.

National Climatic Data Center. 2003. http://www.ncdc.noaa.gov.oa/ncdc.html

Powell, R.A. 1994. Effects of scale on habitat selection and foraging behavior of fishers in winter. *Journal of Mammalogy* 75:349-356.

Proctor, M.F. 2003. Genetic analysis of movement, dispersal and population fragmentation of grizzly bears in southwestern Canada. Dissertation. The University of Calgary, Calgary, Canada.

Ratti, J.T. and E.O. Garton. 1996. Research and Experimental Design. Pages 1-23. T.A. Bookhout, ed. *Research and management techniques for wildlife and habitats*. Fifth ed., rev. The Wildlife Society, Bethesda, Maryland.

Rezendez, P. 1999. *Tracking and the art of seeing. How to read animal tracks and sign*. HarperCollins, NY, USA.

Rodríguez, A., G. Crema, and M. Delibes. 1996. Use of non-wildlife passages across a high speed railway by terrestrial vertebrates. *Journal of Applied Ecology* 33:1527-1540.

Rosell, C., J. Parpal, R. Campeny, S. Jove, A. Pasquina, and J.M. Velasco. 1997. Mitigation of barrier effect on linear infrastructures on wildlife: Pages 367-372, K. Canters editor. *Habitat fragmentation and infrastructure*. Ministry of Transportation, Public Works and Water Management, Delft, The Netherlands.

Samuel, M.D. and M.R. Fuller. 1996. Wildlife radiotelemetry. Pages 370-418. T.A. Bookhout, ed. *Research and management techniques for wildlife and habitats*. Fifth ed., rev. The Wildlife Society, Bethesda, Maryland.

Scheick, B.K. and M.D. Jones. 1999. Locating Wildlife Underpasses prior to expansion of Highway 64 in North Carolina. G.L. Evink, P. Garrett and D. Zeigler eds. *Proceedings of the Third International Conference on Wildlife Ecology and Transportation*. FL-ER-73-99. Florida Department of Transportation, Tallahassee, Florida.

Serrouya, R. 1999. Permeability of the Trans-Canada highway to black bear movements in the Bow River Valley of Banff National Park. MSc thesis, University of British Columbia, Vancouver.

Singleton, P.H. and J.F. Lehmkuhl. 1999. Assessing wildlife habitat connectivity in the Interstate 90 Snoqualmie Pass corridor, Washington. G.L. Evink, P. Garrett and D. Zeigler eds. *Proceedings of the Third International Conference on Wildlife Ecology and Transportation*. FL-ER-73-99. Florida Department of Transportation, Tallahassee, Florida.

Smith, D. 1999. Identification and prioritization of ecological interface zones on state highways in Florida. Pages 209-230. G.L. Evink, P. Garrett and D. Zeigler eds. *Proceedings of the Third International Conference on Wildlife Ecology and Transportation*. FL-ER-73-99. Florida Department of Transportation, Tallahassee, Florida.

Sokal, R.R. and F.J. Rohlf. 1995. *Biometry. The principles and practice of statistics in biological research*. 3rd edition. W.H. Freeman and Company, New York, USA.

Stall, C. 1989. Animal tracks of the Rocky Mountains. The Mountaineers, Seattle, Washington.

Stephens, S.E., Koons, D.N., Rotella, J.J., and D. Willey. 2003. Effects of habitat fragmentation on avian nesting success: a review of the evidence at multiple spatial scales. *Biological Conservation* 115: 101-110.

Thompson, LM. 2003. Abundance and genetic structure of two black bear populations prior to highway construction in eastern North Carolina. MSc thesis, University of Tennessee, Knoxville.

Underwood, A.J. 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. *Ecological Applications* 4:3-15.

Van Manen, F.T., M.D. Jones, J.L. Kindal, L.M. Thompson, and B.K. Scheick. 2001. Determining the potential mitigation effects of wildlife passageways on black bears. In: *Proceedings of the International Conference on Ecology and Transportation*. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina.

Vucetich, J., and T. Waite. 2001. Is one migrant per generation sufficient for the genetic management of fluctuating populations? *Animal Conservation* 3:261-6.

Waser P.M. and C. Strobek. 1999. Genetic signatures of interpopulation dispersal. *Trends in Ecology and Evolution* 13:43-44.

Wasser, S.K., Bevins, K., King, G. and Hanson, E. 1997. Noninvaisive physiological measures of disturbance in the northern spotted owl. *Conservation Biology* 11:1019-1022.

Whitaker, Jr., J.O. 1997. National Audubon Society field guide to North American mammals. Knopf, New York, USA.

Whittington, J. 2002. Movement of wolves (*Canis lupus*) in response to human development in Jasper National Park, Alberta. MSc thesis, University of Alberta, Edmonton.

Wills, J. and M. Vaughan. 2001. Method to monitor travel corridor use by black bears along the earstern boundary of the Great Dismal Swamp National Wildlife Refuge. In: *Proceedings of the International Conference on Ecology and Transportation*. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina.

Yanes, M., J.M. Velasco, and F. Suárez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. *Biological Conservation* 71:217-222.

Zielinski, W.J. and T. E. Kucera. 1995. American marten, fisher, lynx, and wolverine: survey methods for their detection. Gen. Tech. Rep. PSW-GTR-157. Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Albany, CA, USA.

A SAMPLING OF WILDLIFE USE IN RELATION TO STRUCTURE VARIABLES FOR BRIDGES AND CULVERTS UNDER I-90 BETWEEN ALBERTON AND ST. REGIS, MONTANA

Christopher Servheen (Phone: 406-542-0637, Email grizz@selway.umt.edu), Rebecca Shoemaker (Phone: 406-542-0637, Email: okoshono@hotmail.com), and Lisa Lawrence (Phone: 406-542-0637, Email: l0lawrence@msn.com), School of Forestry and Conservation, University of Montana, Missoula, MT 59812

Fax: 406-329-3212

Abstract: Habitat fragmentation, habitat loss, and human caused mortality are the major factors contributing to wildlife decline throughout the world. High-speed, heavily-used highways can divide formerly contiguous blocks of habitat and isolate wildlife populations. Underpasses and culverts have the potential to mitigate the negative impacts of roads on wildlife populations by maintaining connectivity between wildlife populations and decreasing wildlife collisions with vehicles. Using heat and motion sensitive cameras, we monitored seven underpasses and three culverts for ten months along Interstate 90 in western Montana. We documented the type and frequency of wildlife use and compared the level of use to variables associated with the structures. Wildlife use was most frequent at underpasses and limited in culverts. Ungulates were the primary users of underpasses with limited use by medium and large carnivores. We found no significant relationships between wildlife use and structural variables. This is partly due to a small sample size but could be the result of animals using structures opportunistically.

Problem Statement

Highways have the potential to fragment wildlife populations and wildlife habitat. The extent of this fragmentation is likely a function of a combination of factors associated with roads, such as traffic volume, human development, and landscape variables. Given this, interstate highways may have the highest potential for fragmentation of any highway type. Knowledge about the extent of fragmentation for wildlife populations of concern, such as large carnivores, will aid in understanding the priority and importance of mitigation efforts by state agencies to minimize wildlife fragmentation.

Wildlife can get across highways either over the road surface at risk of mortality and human safety from collisions with vehicles, or under the highway using structures such as bridges or culverts. Knowledge of if and how much existing structures are used by wildlife for crossing and which structures are used most can aid in future structure design and rebuilding in order to maximize wildlife use.

Background

Habitat fragmentation occurs when contiguous blocks of habitat are broken into pieces, with the pieces being separated from one another by unsuitable habitats. Habitat fragmentation is accompanied by habitat loss as the area of the remaining parcels sum to less than the area of the original contiguous block. Recent advances in the science of island biogeography have led to the development of ecological principles that are relevant to our management of public lands (MacArthur and Wilson 1967). First, the number of species in an area of habitat is proportional to its size. As the area of a habitat is reduced, the number of constituent species is concurrently reduced. Populations that are dramatically reduced in size and isolated from one another on small habitat "islands" are at risk of extinction. Extinction risk is elevated because small populations are less able to absorb losses caused by random environmental, genetic, and demographic changes (Gilpin and Soule 1986).

The primary causes of grizzly bear habitat fragmentation are human activities, such as highway building, and residential, recreational, and commercial developments. The negative effects of human developments and the degree of habitat fragmentation are influenced by the spatial arrangement of the developments. In the Rocky Mountain west, human developments usually occur in a linear fashion along valley floors. When development reaches a certain concentration, grizzly bears can no longer cross the valley floor or use it as habitat. These areas have been termed "habitat fracture zones" (Servheen and Sandstrom 1993).

Human transportation corridors and their associated developments can cause fragmentation of the habitats of many different species (Garland and Bradley 1984). Highways are a major contributor to habitat fragmentation, and fracture zones occur in association with highways. The negative effects of transportation corridors, and high-speed highways in particular, have been documented for numerous wildlife species. Most of the literature concerns ungulate mortality (Bashore et al. 1985, Bruinderink and Hazebroek 1996, Gleason and Jenks 1993, Romin and Bissonette 1996). Florida panther mortality and habitat fragmentation has also been documented (Belden and Hagedorn 1993). However, the effects of highways on grizzly bears are largely unknown. Gibeau and Herrero (1998) found that the Trans Canada Highway in the Bow River Valley of Alberta is a barrier to female grizzly bear movement, and a significant filter for males, despite the installation of crossing structures.

Maintaining connectivity or “linkage” between small isolated populations could prevent many of the detrimental consequences of habitat fragmentation by preserving genetic diversity, reducing the chances of inbreeding, and dampening the effects of genetic drift. Effective linkage zones may combat the adverse effects of habitat fragmentation by allowing opportunity for movement between habitat patches. Linkage zones are defined as combinations of landscape structures that allow wildlife to move through and live within areas influenced by human actions, and their effectiveness relies largely on the level and types of human actions as well as the biology of the animal (Servheen et al. 2001a,b). Several linkage zones have been identified across Interstate 90 (I-90) in western Montana that could potentially link wildlife populations on both sides of the highway, including wolves, lynx, black bears, wolverines, and possibly grizzly bears (Servheen et al. 2001a,b).

Underpasses and culverts have the potential to mitigate the negative impacts of roads on wildlife populations by maintaining connectivity between wildlife populations and decreasing wildlife collisions with vehicles. Variables influencing wildlife use of culverts and underpasses must be identified and prioritized to maximize their effectiveness in the future. The degree and type of wildlife use of highway structures along I-90 in western Montana is unknown. This project was aimed at understanding the movements of medium to large wildlife species through the existing underpasses and culverts under a portion of I-90. Many ungulate species occur in the project area and the majority of crossing data were expected to be from ungulates. We documented the degree and frequency of wildlife using these structures and compared the level of use to structure variables.

Study Area

The study area is in the Clark Fork River Valley that is bisected by I-90, where an observable succession of human development is occurring (fig.1). The 50-mile section (between mileposts 33 and 82) of interstate being monitored is between Alberton and St. Regis and includes the Ninemile area west of Missoula, Montana. This is a four-lane highway, which has a high-posted speed limit (75 mph) and has an average traffic volume of 6,500 vehicles per day (MDOT 2003). The interstate follows the Clark Fork River drainage and the Montana Rail Link railroad.

Human settlement is primarily restricted to the valley, due to the fact that the majority of the rugged, mountainous terrain adjacent to the valley is public land. Human presence is increasing in the study area and forest and riparian habitats that were once converted into agricultural lands are now being developed as residential communities. Logging occurs throughout the surrounding mountains, and numerous localities in the area are becoming recreational attractions. Although the valley bottom is experiencing human population growth and development, the majority of the surrounding, mountainous land still possesses adequate habitat to support wildlife populations. These include threatened and sensitive carnivorous species, such as Canada Lynx (*Lynx canadensis*), wolves (*Canis lupus*), wolverines (*Gulo gulo*), and possibly grizzly bears (*Ursus arctos*). Four wildlife linkage zones to connect animals on both sides of the I-90 corridor have been identified, and three of the four linkage zones had suitable structures for monitoring (Servheen et al. 2001a, 2001b). Maintenance of linkage opportunities across I-90 is valuable to the long-term health of many wildlife species. This area offers potential for the existence of viable populations of large mammals, but the relationship of these animals to the highway and the numbers and locations of highway crossings, if any, are unknown.

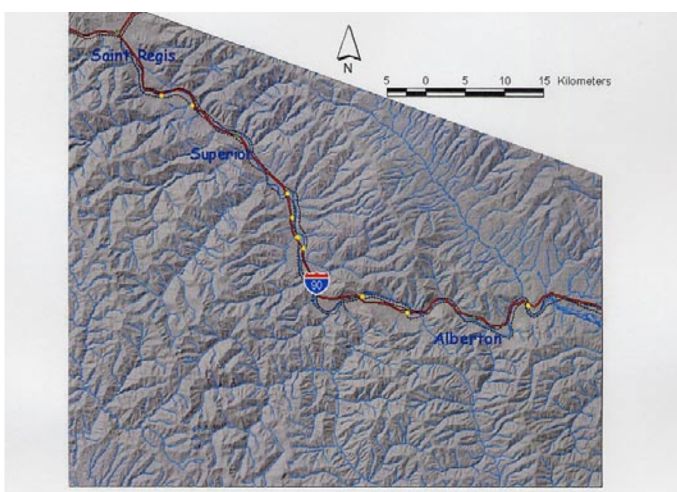


Fig. 1. The location of the study area in the Clark Fork River Valley between Alberton and St. Regis, Montana. Bridges monitored in yellow; culverts monitored in green.

Methods

The objectives of this study were to: (1) monitor and document selected underpasses and culverts on I-90 between the Ninemile area (west of Alberton) and St. Regis for wildlife activity using infrared, motion-sensitive 35mm cameras and snow tracking; (2) relate structure variables to the type and level of wildlife use; and (3) document levels and locations of wildlife mortality associated with the highway in the study area.

Infrared motion and heat sensor cameras were mounted at seven bridges and three culverts within the study area. We used TrailMaster TM550 and TM35-1 units in culverts and a combination of TrailMaster units and DeerCam Scouting Cameras at underpasses (Lenexa, KS & Park Falls, WI). We selected structures according to accessibility, established animal trails, human use, and equipment security. Each structure was given an ungulate use rating and a small, medium, and large carnivore use rating, and an omnivore/carnivore use rating according to the following formula so that they may be compared:

Use Rating = (∑#of photographs)/(∑#of functional camera days)

Snow tracking was opportunistically conducted at each structure we monitored whenever adequate conditions arose, and five track transects were established along the highway adjacent to structures we were monitoring to understand wildlife crossings close to bridges and culverts. We used published track measurements to identify wildlife species (Halfpenny and Biesiot 1986).

Past studies have examined a variety of factors affecting wildlife use of existing structures, including distance to hiding cover, surrounding terrain, degree of human development, traffic volume, time of day, and structural openness. Of these variables, landscape components, such as hiding cover and topography, as well as human influences are believed to play significant roles in the probability and frequency of underpass use (Bruinderink and Hazebroek 1996, Clevenger et al. 2002, Gleason and Jenks 1993, Haas 2001, Rodriguez et al. 1997).

We described each selected site in terms of location, structure, vegetation cover, and human activities (table 1). Landscape features documented for each structure include: distance to adequate hiding cover; surrounding topography; structural dimensions such as length, width, and height of each bridge or culvert; and human influence including type of human activity, and land ownership (table 2).

Table 1.
Crossing structure descriptions and general description of the surrounding area for each

Structure ID	Structure Type	Feature Spanned	LAND USE & GENERAL CHARACTERISTICS
81.5	Underpass	Clark Fork R.	Fishing access; light residential area w/ houses to the north & south, near wolf roadkill locations; deer trail parallel to I-90 on both sides & continues underneath bridge; high human activity directly underneath bridge on east side
69	Underpass	County road & railroad	Small housing development to the southwest; agriculture to the east; paved county road w/ low traffic; deer trail between pastures that parallels I-90 & leads underneath bridge
66.3	Underpass	Clark Fork R.	Steep terrain; canyons; kayaker launch on east side of bridge
58.5	Underpass	Clark Fork R.	Rest area to the west on both sides of I-90; USFS campground to the west; county road runs parallel to I-90 here
57.5	Underpass	Railroad	Low human activity; vegetative cover continuous below underpass; USFS campground to the east
53.7	Underpass	Clark Fork R.	Residential area to the west; vegetative cover continuous below road surface
39.8	Underpass	Clark Fork R. & county road	Agriculture; residences to the east; animal trails below underpass parallel to I-90; USFS campground to the southwest
57.5 C	Culvert	Intermittent stream	Low human activity; vegetative cover on both ends of culvert; USFS campground to the east
55.6 C	Culvert	Spring stream	Rapidly expanding residential development to the north; commercial activity to the north; landfill to the southeast; vegetative cover at both ends of culvert
42.4 C	Culvert	Intermittent stream	Light residential; residence directly north of culvert; railroad to the southwest

Distance to adequate hiding cover (>50%) from the entrance to each structure was determined in the field using a two-meter high vegetation cover pole (Bookhout 1996). ArcView GIS 3.3 was used to provide topographical information within 500m of each structure (ESRI Redlands, CA). The standard deviation of elevation and aspect were derived using a 500m buffer and DEM's for the area. Traffic volume data and structural dimensions were supplied by MDOT and analyzed (figure 3). Each culvert and underpass was given a Structural Openness (SO) rating (Foster and Humphrey 1995, Yanes et al. 1995; Henke et al. 2001) using the formula:

$$SO = \frac{(OW*OH)}{LOC}$$

OW = opening width
OH = opening height
LOC = length of crossing

We expected the structural openness rating to be a negligible factor in use differences between underpasses, but important among culverts when comparing the use ratings at each structure.

Additionally, each structure was given a Land Ownership (LO) rating (% private, % Plum Creek Timber Company, % state, % USFS). This was calculated, using a USFS map, within a two-mile-squared block of land surrounding each structure. The resulting percentages were transformed into proportions using the formula: [(% Private*4)+(% Pl.Cr.*3)+(% State*2)+(% USFS*1)]/100, with the assumption that a higher value (Private=4, Pl.Cr.=3, State=2, USFS=1) corresponds to lower wildlife value.

Table 2.
Variables and crossing rates associated with each structure

STUCTURE ID Underpass	Ungulate Use Rating	Sm. Carn. Use Rating	Med. Carn. Use Rating	Lge. Carn. Use Rating	Total Wildlife Use	Human Associated Use Rating	Structural Openness Rating	In Linkage Zone?	Avg. LZP Score (500m)	Std.Dev. of Elev. (500m)	Distance to Cover (m)
81.5	0.4729	0.003	0.0025	0	0.48306	0.020232676	811.6308	NO	4.4667	21.16	8.15
69	0.2003	0.011	0	0	0.21088	0.003514691	27.7500	NO	3.8053	10.21	22.65
66.3	0.1118	0.012	0.0029	0.0029	0.13535	0.294230147	1058.77	NO	3.6644	28.77	13.25
58.5	0.8934	0	0	0	0.89344	0.004702342	659.4167	YES	4.5236	57.88	19.35
57.5	0.4574	0.01	0	0	0.48013	0.00648824	169.5417	YES	3.1310	15.6	6.00
53.7	0.431	0.017	0	0	0.45758	0.020885547	642.6615	YES	3.4740	15.04	3.00
39.8	0.6136	0.004	0.0143	0	0.61932	0.020885547	457.2733	NO	3.8262	33.89	18.10
Culvert											
57.5 C	0	0	0	0	0.0872	0.0116	0.2638	YES	3.2943	20.07	9.50
55.6 C	0	0.041	0	0	0.0407	0	0.1255	NO	4.3954	21.55	0.25
42.4 C	0	0.226	0.0982	0	0.2259	0.0393	0.7576	NO	4.3714	41.55	7.40

U=Underpass
C= Culvert
Ungulates = White-tailed deer, mule deer, and elk
Sm. Carn. = small carnivores (skunks, raccoons, house cats)
Med. Carn. = medium carnivores (coyotes and foxes)
Lge. Carn. = large carnivores (black bear)
Total Wildlife includes birds, squirrels, rabbits, etc.
Human associated = humans and domestic dogs
Use Rating determined with the formula: Use Rating = (∑#of photographs)/(∑#of functional camera days)
Structural Openness (SO) rating determined with the formula: SO = (OW*OH)/LOC, where OW = opening width, OH = opening height, LOC = length of crossing
LZP Score 1=most suitable for wildlife; 5=less suitable for wildlife
Std. Dev. Of Elev. = standard deviation of elevation within a 500 meter radius of structure
Cover = Adequate Hiding Cover (50% at a height of 1 meter)

The four potential linkage zones within the study area were identified using the Linkage Zone Prediction (LZP) model (Servheen et al. 2001a,b). The LZP model incorporates road density, human-developed sites, and the corresponding influence zone, riparian areas, and vegetative hiding cover to create a weighted score between 1 and 5 that predicts the ease with which wildlife may move through and live within an area. GIS layers from the LZP model were used to calculate an average score within 500 meters of each structure. We expected structures with a lower LZP score, corresponding to minimal impacts by humans, would have higher use, and structures with a higher LZP score would have less use by wildlife.

Wildlife mortality due to I-90 was also opportunistically documented during our 10-month study period and combined with data provided by the Montana Department of Transportation (MDOT) maintenance crews from 1998 to 2002. We collected additional information on road kills during the study period regarding milepost, species, sex, and the traffic direction (relative to I-90) where the animal was killed.

Results

We monitored seven underpasses and three culverts for ten months, from October 2002 through July 2003. Each structure was monitored with infrared cameras and snow tracking through March 31, 2003. We collected a total of 1493 photographs during our study period of 3,213 functional camera days (tables 3 and 4). Wildlife species observed were placed into faunal groups. White-tailed deer, mule deer and elk were placed into the ungulate group; skunks, raccoons, and house cats were considered small carnivores; foxes and coyotes comprised the medium carnivores; and large carnivores consisted of black bears. Human-associated species included humans and domestic dogs (table 3). The number of photos for each species was as follows: white-tailed deer (791), mule deer (379), elk (100); skunks (9), raccoons (3), house cats (41); foxes (1), coyotes (3); black bear (1); humans (113) and domestic dogs (7) (table 4; figure 2). Twenty-eight photographs of other species of small mammals and birds were collected during the course of our study. We used SPSS (SPSS Chicago, IL) 11.5 to explore correlations between our variables and use ratings, but found no significant relationships.

Table 3.
Total number of days that each location was monitored and photos recorded.

Structure ID	# of Cams[a]	# of Rolls[b]	Fxn'al Days[c]	# Ung's[d]	# Sm. Carn.'s	# Med. Carn.'s	# Lge. Carn.'s	# Other[g]	Total # Wildlife[h]	# Human Associated[i]
81.5	2	15	395.40	187	1	1	0	2	191	8
69	1	6	284.52	57	3	0	0	0	60	1
66.3	2	14	339.87	38	4	1	1	2	46	100
58.5	2	10	212.66	190	0	0	0	0	190	1
57.5	2	9	308.25	141	3	0	0	4	148	2
53.7	2	15	526.68	227	9	0	0	5	241	11
39.8	4	34	700.77	430	3	1	0	0	434	9
57.5 C	1	4	172.00	0	0	0	0	15	15	2
55.6 C	1	2	171.87	0	7	0	0	0	7	0
42.4 C	1	3	101.81	0	23	1	0	0	24	3

[a] total number of cameras used at this structure
[b] total number of rolls of film taken at this structure
[c] sum of functional days of all cameras at the structure
[d] number of photos of ungulates
[e] number of photos of mesopredators
[f] number of photos of carnivores or omnivores
[g] number of photos of other wildlife
[h] number of photos of ALL wildlife (ungulates + mesopredators + other wildlife)
[i] number of photos of humans and/or domestic dogs

Table 4.
Number of photos taken at each location by species.

					SMALL		MEDIUM		LARGE				
Structure	UNGULATES			CARNIVORES			CARNIVORES		CARNIVORES	Other	Human Associated		
ID	WD	EK	MD	HC	SK	RC	FOX	CO	BB	Wildlife	HU	DD	TOTALS
81.5	181	0	6	0	0	1	0	1	0	2[a]	8	0	199
69	57	0	0	3	0	0	0	0	0	0	0	1	61
66.3	24	0	14	4	0	0	0	1	1	2[a,b]	98	2	146
58.5	67	0	123	0	0	0	0	0	0	0	1	0	191
57.5	121	0	20	2	0	1	0	0	0	4[a,c,d]	2	0	150
53.7	143	0	84	6	3	0	0	0	0	5[a,d]	11	0	252
39.8	198	100	132	3	0	0	0	1	0	0	9	0	443
57.5 C	0	0	0	0	0	0	0	0	0	15[e]	2	0	17
55.6 C	0	0	0	6	1	0	0	0	0	0	0	0	7
42.4 C	0	0	0	17	5	1	1	0	0	0	0	3	27
TOTALS	791	100	379	41	9	3	1	3	1	28	131	6	1493

WD = white tailed deer (*Odocoileus virginianus*)
EK = elk (*Cervus elaphus*)
MD = mule deer (*Odocoileus hemionus*)
HC = housecat (*Felis domesticus*)
SK = striped skunk (*Mephitis mephitis*)
RC = raccoon (*Procyon lotor*)
FOX = red fox (*Vulpes vulpes*)
HU = human (*Homosapien*)
DD = domestic dog (*Canis familiaris*)
CO = coyote (*Canis latrans*)
BB = black bear (*Ursus americanus*)

[a] bird
[b] squirrel
[c] turkey
[d] rabbit
[e] packrat

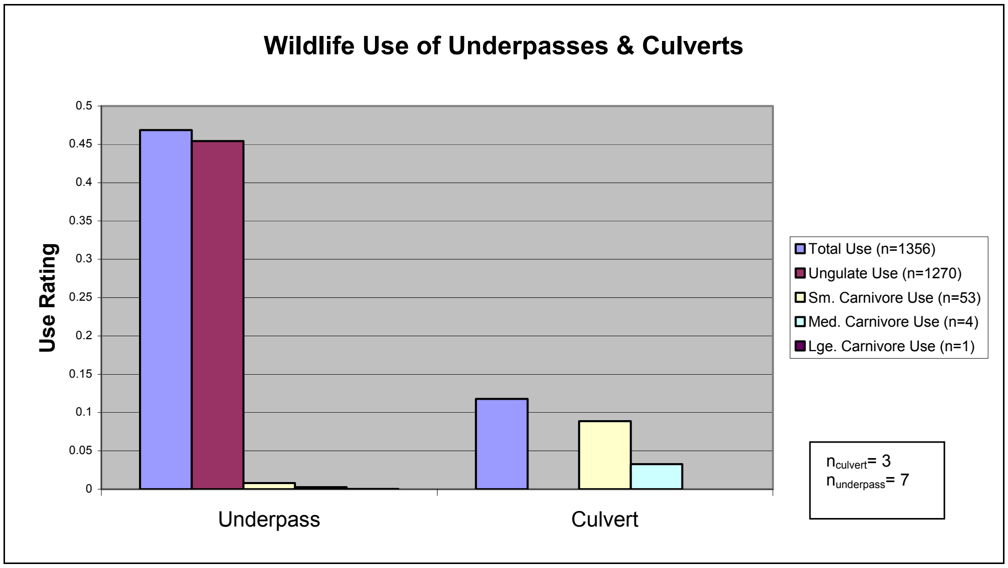


Fig. 2. The type and frequency of wildlife use compared between culverts and underpasses (Use Rating = (∑#of photographs)/(∑#of functional camera days)). Ungulates used underpasses exclusively while small carnivores were more frequent users of culverts. Medium carnivores were found at both underpasses and culverts and one black bear was recorded using an underpass.Total use ratings included other wildlife and humans.

Tracking was limited due to lack of precipitation. Some use of structures not captured by camera data were indicated by tracks. One bobcat was identified by tracks near a two-meter culvert, but did not use the culvert. Ungulate tracks comprised the majority of tracks recorded with a few other small predators, but no medium or large carnivore tracks were encountered. Additionally, no tracks were found in the track transects that were perpendicular to the road. Black bear hair and scat were found at an underpass (81.5), but not deposited during our study period.

We documented various road-kill including white-tailed deer, housecats, a coyote, and a black bear. Two wolves were killed in our study area prior to our study period (M. Jimenez. USFWS, pers. commun. 2003). Wildlife mortality distribution was independent of the crossing structures we monitored (figure 3).

Discussion

We monitored seven underpasses spanning the Clark Fork River, county roads, or railroads and three large culverts running underneath I-90 from October 2002 through July 2003. A total of 1,356 photos of animals were taken, with ungulates comprising the vast majority of these pictures (table 4). There were 1,270 photos of ungulates, 53 photos of small carnivores (with domestic and feral housecats being the most frequent users) 4 pictures of medium carnivores, and 28 photos of other wildlife, such as packrats and birds (tables 3 and 4). We recorded use by one black bear at an underpass, but no other larger omnivores and carnivores, such as wolves, lynx, or mountain lions, all of which are known to exist within our study area. We began monitoring in October assuming that animals would be more likely to move into valleys during winter. The winter of 2002-2003 was mild with average temperatures above normal and snowpack in our study area “below average” to “extremely below average” (USDA & NRCS MT 2003). Elk and mule deer did not make their normal fall migrations into the valley until late December and our first photos of these animals were on December 21, 2002.

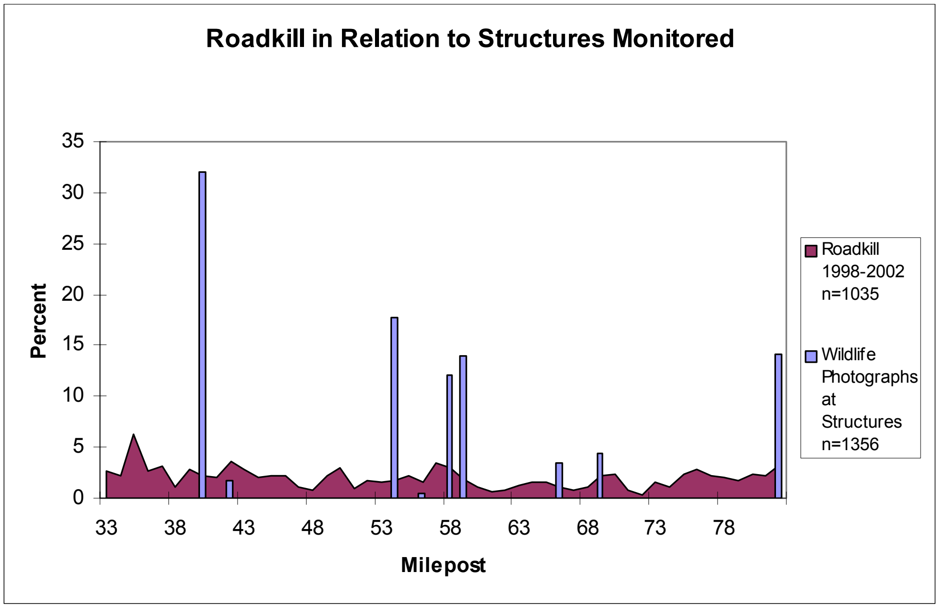


Fig. 3. Percentage of wildlife mortality along I-90 between mileposts 33 and 82, 1998-2002, combined with mortality recorded during this study from October 2002-March 2003 compared to percentage of wildlife photos at structures.

Crossing rates could have been affected by multiple factors that were uncontrolled for in our observational study. For instance, rates recorded by photos of unmarked animals could be high due to some individuals using the same structure repeatedly. We know this happened with housecats at several sites because we were able to identify individuals by their coloration patterns. Also, crossing rates at individual structures are at least somewhat reflective of densities of animals in the area and not necessarily related to the characteristics of the structure (Foster and Humphrey 1995, Rodriguez et al 1997). We suspect high population densities of ungulates due to abundant, available habitat to be at least partially responsible for the high numbers of photos at structure 39.8.

Wildlife use of structures was most frequent at underpasses and limited in culverts. Relative deer use was highest at underpasses; whereas, small carnivores were the most frequent users of culverts. We observed varying trends in the type and frequency of use between culverts and underpasses (fig. 2). Most culvert use consisted of skunks, raccoons, and house cats with a small portion of use attributed to rodents and humans. Although culverts were physically large enough to accommodate large mammal use, ranging in diameter from 2-4.6m, there were no ungulates or large carnivores recorded. We believe this is primarily a function of a lack of suitable substrate in the culverts and low structural openness ratios. This is partially in accordance with past studies which found that ungulates and most large mammals favor large, open structures with high structural openness ratings (Bruinderink and Hazebroek 1996, Foster and Humphrey 1995, Land and Lotz 1996, Reed et al. 1975, Ruediger 2001). Underpasses generally offer more natural lighting, vegetation, substrate, and moisture conditions; whereas, the cool, wet conditions found in culverts seems to favor use by small and medium carnivores, such as red foxes (*Vulpes vulpes*), wildcats (*Felis silvestris*), striped skunks (*Mephitis mephitis*), and raccoons (*Procyon lotor*) (Foster and Humphrey 1995, Land and Lotz 1996, Rodriguez et al. 1997). Mammal use of underpasses has consisted of ungulates, small, medium, and large carnivores, domestic animals, and humans.

Although we only recorded use by one black bear and three coyotes at our underpasses, we also encountered a coyote and black bear roadkill. The occurrence of these species in our opportunistic and limited collection of roadkills could suggest these animals cross the highway directly over the road surface often and show no preference for using crossing structures. Henke showed that deer, elk, coyotes, and foxes all demonstrated preference for crossing across the road surface (at grade) rather than using a crossing structure (below grade) but, when traffic volumes are extremely high, 24,000-37,000 vehicles per day (CDOT 2002), these animals used structures below grade more often than expected, as did a mountain lion and bobcats (2001). This could be a response to severe selection pressure against those animals that did not use crossing structures. The average traffic volume for our study area was comparatively low, 6480 vehicles/day, and may not be intense enough to disrupt carnivore and omnivore tendencies to cross at grade.

Furthermore, large, scavenging and predatory mammals could be displaying active avoidance of structures due to higher road densities and human presence associated with structures (tables 1 and 2) (Haas 2001, Rodriguez et al. 1997, Ruediger 2001). All underpasses that we monitored had either a railroad or county road running underneath the interstate were within 200m of the entrance to the structure. In addition to the road or railroad use, structures also usually possessed increased human activities, such as permanent residences associated with roads and exit ramps.

Most human-associated photographs were recreationists (hunters, fisherman, and kayakers). Seventy-five percent of all human associated photographs occurred at one location and were kayakers. Wildlife use was low at this structure, but included a black bear and coyote. Rugged topography may have limited the movement of ungulates while also limiting the degree of human development possible near the structure. It is interesting to note however, the deer and black bear that used this structure did so during the day, and the kayakers used the structure during dusk and at night.

One underpass is being monitored in the Ninemile area where a pack of wolves reside. One of the two wolf mortalities occurred at this location, and black bear hair and scat were also collected at this structure, but the use at this structure consisted almost entirely of ungulates, with one coyote recorded. High human activity underneath the bridge consisting of heavy equipment including chainsaws may account for this low use by medium and large carnivores.

The majority of crossing structures in our study area coincide with riparian areas. At three locations, we have located wildlife trails parallel to I-90, which then continue underneath the highway structures. These trails seem to indicate active avoidance of crossing I-90 at these sites and preference for crossing the interstate via the underpasses. The absence of tracks in transects that were located perpendicular to the highway between I-90 and standard MDOT right-of-way fencing suggests that wildlife may be using underpasses exclusively if within 50m of a structure. This is important and needs further monitoring to determine if this is true.

Underpasses were constructed in the mid-1960's, and most were upgraded in the 1980's; therefore, the surrounding wildlife knows of the existence of crossing structures. Some tree harvesting occurred below the underpasses during our study period. Few trees were cleared, but some that were blocked existing wildlife trails, thus disrupting animal movement. The culverts were originally installed below I-90 to facilitate movement of intermittent streams.

Wildlife that uses these structures may possibly be habituated to the associated surrounding interferences (noise, average traffic volume, seasonal and daily human activity, etc.) and make behavioral adaptations to minimize chances of mortality. For example, ungulate use of underpasses peaked around dawn and dusk as expected, but there was consistently high use throughout the night, corresponding to low traffic volumes (figure 4). The ability of grizzly bears to predict human activities has also been proposed as a possible explanatory variable in understanding grizzly bear movements (Chruszcz et al. 2003). Various seasonably predictable recreational activities occur within 500 meters of I-90 including USFS roadside campgrounds, kayaking and rafting, fishing, hunting, and rest areas. Timber harvests by Plum Creek Timber Company and the State of Montana are spread out on a larger temporal scale and may impact wildlife movement due to this unpredictability. A significant portion of the surrounding landscape was being logged during the latter part of our study period.

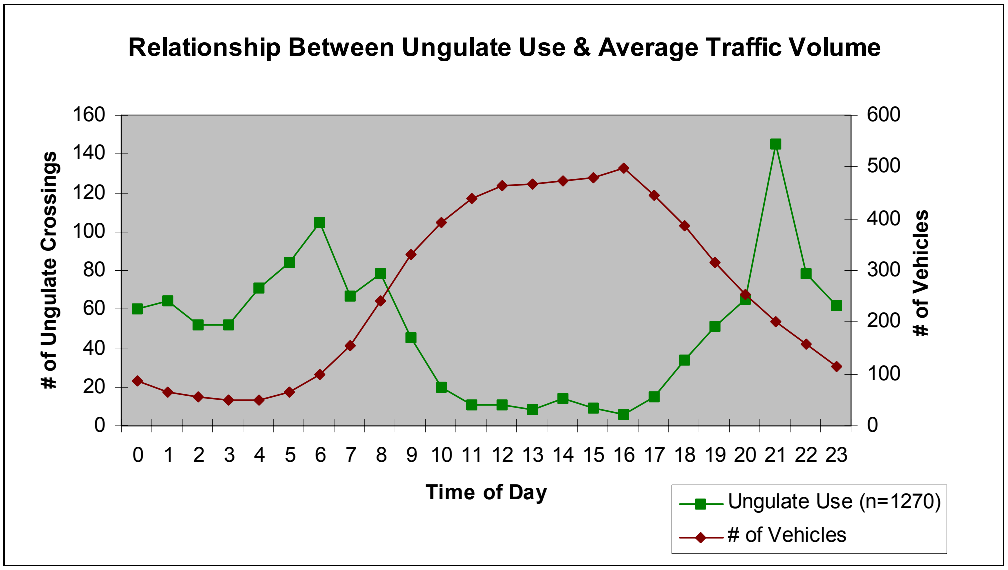


Fig. 4. Ungulate use of underpasses related to time of day and hourly traffic volume. The increased ungulate use throughout the night corresponds to low traffic volumes and could represent animals that are particularly sensitive to traffic and have made corresponding behavioral adaptations. N = 1270 ungulate crossing photos.

Future Studies and Management Implications

More rigorous studies and repeatable methods must be used to gain a better understanding of wildlife movements under differing conditions. Sample sizes must be adequately large enough to draw conclusions and significant relationships. Our failure to find any significant relationships was due in part to these discrepancies but also could be a result of animals using structures opportunistically. For example, many studies have found that crossing structures are more likely to be used when placed in areas already known as travel routes by wildlife (Bruinderink and Hazebroek 1996, Foster and Humphrey 1995, Land and Lotz 1996, Ruediger 2001).

Right-of-way fencing exists along both sides of the entire length of I-90, but was put in place to prevent cattle from wandering into the road, not to encourage wildlife use of crossing structures. As such, it is poorly maintained, if at all, and is not high enough to keep deer and elk from jumping over it and onto the road surface. It was interesting to find that ungulates did follow the fencing for at least 50m on either side of an underpass even though they were fully capable of jumping it. This suggests that properly maintained highway fencing that is of adequate height (>1.5m) could be an effective tool for funneling animals into underpasses. Care must be taken though to ensure that crossing structures are placed closely enough to each other so that the fencing does not simply make the highway a more effective barrier to movement between wildlife populations on both sides of the valley.

Key Conclusions

Our findings indicate that even large culverts may not be effective structures for movement of large- and medium-size mammals, probably due to a combination of unnatural surface substrate and the small openness ratios of these culverts. Continuity of the natural habitat on either side of the structure, and under bridges, when possible, is important and increases the probability of wildlife use of underpasses. The highest use occurred at sites that we subjectively judged to be the most remote from human use and where less disturbed habitat occurred right up to the structure. Structural openness was high at underpasses we monitored and may be the contributing factor to wildlife use. Levels of deer use may be a function of seasonal movements (fall migration, hunting pressures, and breeding), which may inflate assumed yearly use. Highway mortality of wolves, coyotes, and black bears was documented in our study area.

Acknowledgements: We gratefully acknowledge the support and assistance of the Wilburforce Foundation, American Wildlands, Deb Kmon, Pat Basting, USFWS, Turner Endangered Species Fund, and numerous individuals at MDOT offices in our study area, and in Helena, Wayne Kasworm, Tabitha Graves, John Waller, Ty Smucker, and Rick Yates.

Biographical Sketch: Christopher Servheen received his B.A./B.S. in zoology/wildlife biology and his Ph.D. in forestry at the University of Montana, and an M.S. in wildlife biology from the University of Washington. He is the grizzly bear recovery coordinator for the U.S. Fish and Wildlife Service and has been in this position for 23 years. As such, he is responsible for coordinating all the research and management on grizzly bears in the lower 48 states and working with biologists in Alberta and British Columbia. Much of his current work and that of his graduate students involve the impacts of highways and human developments on habitat fragmentation for bears and other large carnivores in the Rocky Mountains. He leads projects involving the application of Global Positioning System (GPS) collars on grizzly bears and black bears to learn more about their detailed movements in relationship to highways, and works with state and federal highway departments in developing ways to get animals across highways. He is also interested in international conservation issues and teaches a course each year at the University of Montana on international wildlife conservation. He has worked in many countries in Asia and in Europe on bears and bear conservation, and was a Fulbright Scholar in Greece in 1994. Rebecca Shoemaker and Lisa Lawrence are honors undergraduate students at the University of Montana and are working on aspects of this work as part of their senior honors theses.

References

Bashore, T. L., W. M. Tzilkowski, and E. D. Bellis. 1985. Analysis of deer-vehicle collision sites in Pennsylvania (USA). *Journal of Wildlife Management* 49:770-428.

Belden, R. and B. Hagedorn. 1993. Feasibility of translocating panthers into northern Florida. *J. Wildl. Manage*. 59:388-397.

Bookhout, T. A. (ed.) 1996. *Research and management techniques for wildlife and habitats*. The Wildlife Society, Bethesda, Maryland.

Bruinderink, G. and E. Hazebroek. 1996. Ungulate traffic collisions in Europe. *Conservation Biology* 10: 1059 - 1067.

Chruszcz, B., T. Clevenger, K. Gunson, and M. Gibeau. 2003. Relationships among grizzly bears, highways and habitat in the Banff-Bow Valley, Alberta, Canada. Can. J/. Zool. In press.

Clevenger, A.P., J. Wierzchowski, B. Chruszcz, and K. Gunson. 2002. GIS-Generated, expert-based models for identifying wildlife habitat linkages and planning mitigation passages. Conservation Biology 16: 503-514.

Colorado Department of Transportation (CDOT). Annual average daily traffic counts for US 85 and I-25. Website: http://www.dot.state.co.us. Accessed November 25, 2002.

Foster, M.L. and S.R. Humphrey. 1995. Use of highway underpasses by Florida panthers and other wildlife. Wildlife Society Bulletin 23: 95-100.

Garland, T., and V. G. Bradley. 1984. Effects of a highway on Mojave desert rodent populations. American Midland Naturalist 111(1):47-56.

Gibeau, M. and S. Herrero. 1998. Roads, rails, and grizzly bears in the Bow River Valley, Alberta. G. Evink et al., eds. *Proceedings International Conference on Ecology and Transportation.* FL-ER-69098, Florida Dept. of Transportation, Tallahassee, 263 pp.

Gilpin M. and M. E. Soule. 1986. Minimum viable populations: the processes of species extinctions. Pp13-34. M.E. Soule (ed.) *Conservation Biology: the Science of Scarcity and Diversity*. Sinauer associates, Sunderland, Mass.

Gleason, J. and J. Jenks. 1993. Factors influencing deer/vehicle mortality in east-central South Dakota. *Prairie Naturalist* 25: 281-287.

Haas, C.D. 2001. Responses of mammals to roadway underpasses across an urban wildlife corridor, the Puente-Chino Hills, California. *Proceedings of the international conference on wildlife ecology and transportation*. G. Evink and K.P. McDermott, Eds. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University.

Halfpenny, J. and E. Biesiot. 1986. *A field guide to mammal tracking in North America*. Johnson Books, Boulder.

Henke, R.J., P. Cawood-Hellmund, and T. Sprunk. 2001. Habitat connectivity study of the I-25 and US 85 corridors, Colorado. *ICOET 2001 Proceedings: A Time for Action*. 499-508.G. Evink and K.P. McDermott, Eds. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University.

Jimenez, M. 2003. Letter to the authors. 24 Apr. 2003.

Land, D. and M. Lotz. 1996. Wildlife crossings design and use by Florida panthers and other wildlife in southwest Florida. *Proceedings of the international conference on wildlife ecology and transportation*. Florida Department of Transportation, Tallahassee.

MacArthur, R.W. and E.O. Wilson. 1967. *The theory of island biogeography*. Princeton University Press. Princeton, NJ. 203 pp.

Montana Department of Transportation (MDOT). 2003. Average daily traffic volumes for 2002-2003.

Reed, D.F., T.N. Woodard, and T.M. Pojar. 1975. Behavioral response of mule deer to a highway underpass. *Journal of Wildlife Management* 39: 361-367.

Rodriguez, A., G. Crema, and M. Delibes. 1997. Factors affecting crossing of red foxes and wildcats through non-wildlife passages across a high-speed railway. *Ecography* 20: 287-294.

Romin L.A. and J.A. Bissonette. 1996. Deer-vehicle collisions: Status of state monitoring activities and mitigation efforts. *Wildlife Society Bulletin* 24: 276-283.

Ruediger, B. 2001. High, wide, and handsome: Designing more effective wildlife and fish crossings for roads and highways. *Proceedings of the international conference on wildlife ecology and transportation*. G. Evink and K.P. McDermott, Eds. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University.

Servheen, C. and P. Sandstrom. 1993. Ecosystem management and linkage zones for grizzly bear s and other large carnivores in the Northern Rocky Mountains in Montana and Idaho. *Endangered Species Technical Bulletin*. 18:10-13.

Servheen, C., J. Waller, and P. Sandstrom. 2001a. Identification and management of linkage zones for grizzly bears between the large blocks of public land in the northern Rocky Mountains. U.S. Fish and Wildlife Service, Missoula, Montana. 87 pp.

Servheen, C., J.S. Waller, and P. Sandstrom. 2001b. Identification and management of linkage zones for grizzly bears between the large blocks of public land in the Northern Rocky Mountains. *ICOET 2001 Proceedings: A Time for Action*. Pages 161-198. G. Evink and K.P. McDermott, Eds. Raleigh, NC: Center for Transportation and the Environment, North Carolina State University.

United States Dept. of Agriculture (USDA) and Natural Resources Conservation Service Montana (NRCS). 2003. Montana snow and water information. http://nris.state.mt.us/Nrcs/Snowater.html. Accessed 4/28/2003.

Yanes, M., J.M. Velasco, and F. Suarez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. *Biological Conservation* 71: 217-222.

SMALL MAMMAL USE OF MODIFIED CULVERTS ON THE LOLO SOUTH PROJECT OF WESTERN MONTANA - AN UPDATE

Kerry R. Foresman (Phone: 406-243-4492, Email: foresman@mso.umt.edu), Professor of Biology and Wildlife Biology, Division of Biological Sciences, University of Montana, Missoula, MT 59812, Fax: 406-243-4184

Abstract

A highway reconstruction project, termed the Lolo South Project, is currently underway in west-central Montana to expand Highway 93 from two lanes to four over a distance of approximately 45 miles from the town of Lolo to that of Hamilton. Portions of this highway bisect a series of wetlands which currently support a variety and abundance of wildlife. As one wildlife mitigation approach, several three- and four-foot-diameter culverts have been placed at these sites to encourage animal movement between the fragmented wetlands. Metal shelves serviced by ramps were installed in three of the culverts to allow animal movement during periods of high water. The current research project continued and expanded upon the initial pilot study which was begun in January 2001 (and reported at the ICOET 2001 meetings). In particular, additional culverts were added to the original study to increase the sample size, and modifications of the shelf design were made based upon early results, and these refinements were rigorously tested.

A total of 10 culverts spaced over a distance of approximately six miles along a series of wetlands along Highway 93 are now being studied, five with 25inch-wide shelves (experimentals) and five without (controls). Besides the 3 to 4-foot-diameter culverts originally employed, larger culverts have been added (ranging up to 10-foot-wide squash culverts). An additional four culverts along Interstate 90 through Missoula (ranging from 3- to 10-foot widths) are also being studied. This phase of the study was initiated in October 2001 and will continue through December 2003. Remote sensing TrailMaster® cameras, which are triggered by a combination of heat and motion, were mounted on the roof of each culvert, approximately 15 meters from one entrance. These cameras were positioned so that any mammals traversing the culvert either on the floor of experimental or control culverts or on the ramps in the experimental culverts would be photographed. Cameras are being checked once each week, and film is replaced as needed. Once each month (March - October) the small mammal populations which exist along the wetlands adjacent to the original six culverts are being censussed. For this purpose, 25 Sherman® live traps baited with rolled oats are placed in single transect lines approximately 10 meters from each entrance, with a trap spacing of five meters. Traps are checked twice per day at 6:00 am and 6:00 pm for a total of three days. All animals captured are identified to species, sexed, weighed, their reproductive status noted, aged (immature/juvenile/mature), and marked before being released at the point of capture. Environmental data loggers, which record temperature, light, and humidity levels at 30-second intervals 24 hours/day, were placed at three sites; information from each data logger is downloaded each week. Finally, habitat characteristics adjacent to each culvert entrance are being described. Given this experimental design we are able to determine which small mammal species are present adjacent to the culverts and which of these are actually using the culverts to move between wetland sites on each side of the highway. Seasonal use of the culverts and use of the shelves during periods of high water are being assessed. Activity patterns of those animals traversing the culverts is determined from date and time information imprinted on each photograph. Activity patterns are also being correlated with prevailing environmental conditions.

Trapping data to date have identified seven small mammal species living adjacent to the culverts: meadow voles (*Microtus pennsylvanicus*), deer mice (*Peromyscus maniculatus*), vagrant shrews (*Sorex vagrans*) short-tailed weasels (*Mustela erminea*), House mice (*Mus musculus*), Columbian ground squirrels (*Spermophilus columbianus*), and striped skunks (*Mephitis mephitis*). Other species surely reside here as well, though they are too large for the traps employed.

Since the original pilot study the floor of the original shelves has been modified to provide a better surface for small mammals and a "vole tube" has been incorporated to address apparent shyness to enter culverts by meadow voles. Photographic evidence has so far demonstrated culvert use by a total of 23 species including the species listed above (with the exception of the house mouse), and muskrats (*Ondatra zibethicus*), raccoons (*Procyon lotor*), coyotes (*Canis latrans*), red foxes (*Vulpes vulpes*), and white-tailed deer (*Odocoileus virginianus*) among others.

During periods in which water has covered the floor of the culverts, deer mice, short-tailed weasels, striped skunks, raccoons, and domestic cats have used the shelves in the experimental culverts. Meadow voles, the most abundant small mammal species adjacent to the culverts, have now been observed freely moving through the culverts equipped with tubes. These tubes are also heavily used by weasels.

From these data several conclusions can be drawn. Most importantly, several species of small mammals appear to readily use the shelves when water in the culvert would otherwise prevent movement; thus, these devices seem to be very effective. Behavioral differences in some species, notably the meadow vole which will not expose itself to an open environment, have been overcome with the development of a protective tube. Further refinements are continuing to be made. The application of these devices for retrofitting small culverts, as well as their utility in large culverts with permanent water flow were examined.

Biographical Sketch: Kerry Foresman received his B.A. degree in zoology from the University of Montana in 1971. He then went on to receive an M.S. degree in zoology from the University of Idaho in 1973. In 1977 he earned his Ph.D in physiology from the University of Idaho. Kerry is currently a professor of biology and wildlife biology in the Division of Biological Sciences at the University of Montana. He is a Mammalian ecologist primarily working on sensitive and threatened species. Much of his research focuses on reintroduction of threatened species. He is also studying the effects of habitat fragmentation on wildlife populations and ways to mitigate such effects.

WILDLIFE USE OF EXISTING CULVERTS AND BRIDGES IN NORTH CENTRAL PENNSYLVANIA

Carl O. Brudin III (Phone: 717-731-9588, E-mail: cbrudin@admarble.com), A.D. Marble & Company, 3913 Hartzdale Drive, Suite 1302 Camp Hill, PA USA, 17011, Fax: 717-731-1170

Abstract: The Pennsylvania Department of Transportation (PENNDOT) District 3-0 initiated a study in North Central Pennsylvania evaluating existing bridges and culverts for use as underpasses by wildlife. This project was a two-phase study to investigate animal passage through existing drainage box culverts, arch culverts and bridges on existing highway systems. The objective of this study was to (1) determine whether wildlife are using existing structures as passageways based on wildlife sign and remote camera monitoring and (2) determine underpass dimensions, interior characteristics, location, topography, and adjacent habitat features that contribute to and enhance usage of underpass corridors by wildlife. These data will contribute to future highway design and mitigation measures in addressing wildlife corridors.

Introduction

Pennsylvania contains the nation's fifth largest state highway system. With increasing volumes of vehicular traffic and new highway development to meet these demands, there are growing concerns among wildlife authorities and transportation specialists about the effect of highways on wildlife populations and wildlife-vehicle interactions. The growing number of transportation corridors can fragment wildlife habitat and wildlife populations, impede wildlife movements and at the same time cause safety hazards for motorists when wildlife attempt to cross roadways. Providing safe passageway for wildlife across transportation corridors will (1) provide habitat connectivity (2) reduce animal road-kill and (3) improve motorist safety. Agency reviews of transportation projects are more frequently requiring wildlife corridor considerations during the environmental review process. PENNDOT is interested in opportunities to provide safe passageway for wildlife across transportation corridors, provide habitat linkages, and reduce wildlife/vehicle collisions.

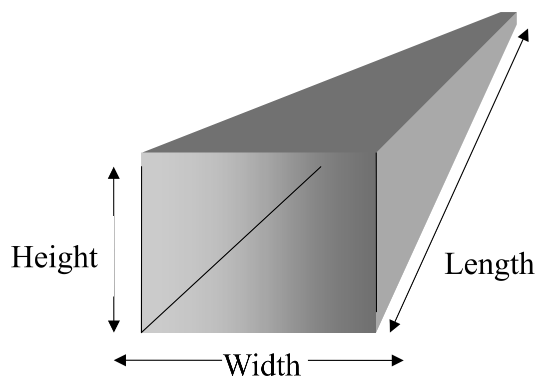
Purpose of Study

Many species of wildlife use riparian valleys as travel corridors and may encounter bridges and culverts along intersecting highway routes. Limited research has been published regarding wildlife movements across highway corridors and the use of underpasses in Pennsylvania.

A.D. Marble & Company (ADM) in conjunction with PENNDOT District 3-0 conducted this research to investigate animal passage through existing drainage box culverts, arch culverts and bridges on existing highway systems. The objectives of this study are to determine whether wildlife are using existing structures as passageways based from field screening surveys and remote camera monitoring, and determine underpass dimensions, interior characteristics, location, topography, and adjacent habitat features that contribute to and enhance usage of underpass corridors for wildlife in North Central Pennsylvania (see fig. 1). ADM evaluated existing structures being used and/or their potential use by wildlife based on field evaluation of structures, adjacent habitat cover, nearby land uses, identification of wildlife sign, and an infrared remote camera monitoring study.

Fig.1. Study Area of the Wildlife Underpass Evaluation.

Underpass Dimensions Characteristics
The width and height of the underpass opening, as well as the underpass length, are important factors in determining the type and size of animals that can use the underpass. These measurements are used to calculate an openness index (OI) (width x height/length) (see figure 2). The openness of an underpass influences the amount of light that penetrates the interior and the view of the other side. For example, an 80-foot long, 10-foot wide and 8-foot high box culvert has an OI = 1.0. Doubling the width or height to 20 feet, increases the OI to 2.0. Length, width and height of underpasses, and other factors including its "openness," can greatly influence animal use. The Openness Index number, however, does not differentiate between height and width, and special attention should be made to species' tolerance for recommended heights and widths.



(Height x Width) Divided by Length = OI (Openness Index)
Example (6ft. x 8ft.) / 150ft. = 0.32 OI

Fig. 2. R/C Box Culvert Dimensions.

Phase I Wildlife Underpass Study
The Phase I Study consisted of: (1) summarizing previous research regarding wildlife use of underpasses across highway corridors; (2) reviewing the District files to identify pertinent information on structures to be evaluated; (3) field screening study to evaluate existing bridges and culverts in North Central Pennsylvania for potential use by wildlife through the evaluation of site conditions and the observation of wildlife sign (tracks, trails, scat,); (4) camera monitoring study to monitor actual use by wildlife of selected culverts using infrared motion sensors and cameras and; (5) survey of other the PENNDOT Engineering Districts, the Pennsylvania Turnpike Commission and 12 other state DOT's in the northeast and mid-Atlantic region to determine how they addressed wildlife movements across transportation corridors.

In the Phase 1 Study, 46 existing road underpasses (18 bridges and 28 culverts) were studied to determine wildlife use. Dual structures that were separated by a median over 100 feet and twin cells culverts were evaluated as separate underpasses. The field screening study revealed that many of the larger bridges, i.e., multiple spans and viaducts that span the entire length of the floodplain, were used by a variety of wildlife from rodents to large mammals; however, it appeared most of the culverts were generally used by smaller mammals (e.g., raccoons, opossums, skunks). Wildlife signs were documented within 9 of 18 bridges; however, because of nearby animal signs and generally large travel spaces under bridges, we expect others may be used. No further study was conducted on wildlife movements under bridges.

Of the 28 culverts evaluated, all contained concrete bottoms, although approximately 50 percent had sediment and stream-bottom material deposited over the concrete. The average openness index for all culverts field evaluated was 0.5. Nine culverts were selected for infrared camera monitoring study. The majority of these culverts contained poor interior tracking conditions (i.e., concrete substrate and/or fast moving water) and could be better evaluated for wildlife use with a motion-sensor device and camera system.

Monitoring Device
Wildlife movements through culverts were recorded by the use of infrared sensor monitors. Three TM550 Passive Infrared Trail Master® Monitors ™ were selected (Goodson and Associates, Inc., 10614 Widmer, Lenex, KS 66215, 800-544-5415). Each monitor consists of a one-piece unit, which is designed to detect the presence of body heat and motion. Both body heat (temperature differentials) and motion must be present at the same time for an event to be recorded. Any animal activity in the area will cause the monitor to register

these movements and take a picture called an "event." A Trail Master TM35-1 camera kit was purchased separately, which consists of a Yashica T4 Super D camera, 25-foot camera cable, camera shield, and a tree pod for mounting. This camera requires 35mm film and has been specifically adapted for use with TrailMaster systems. The camera is triggered from the monitor to take a photograph when the infrared transmitter beam is broken. The monitor picks up any warm-blooded mammal movement through the area of sensitivity. This transmitter sends out an infrared beam which is 65 feet long and spreads an elliptical cone of 150° wide and 4° high. The 4°-vertical-beam height spreads one foot for every ten feet away from the monitor. Thus, at 40 feet, there is a four-foot-high beam. This monitor has a sensitivity setting, which allows the user to select the size and movement of the animals to be monitored. This sensitivity setting works by registering the amount of interrupted pulses within a selected time period. A larger animal (bear or deer) will interrupt more pulses in a given time frame than a smaller animal, such as a raccoon. There is also a camera delay setting allowing a delay between photographs from 0.1 to 98 minutes, so that a single event will not be counted multiple times.

Fig. 3. TM550 Trail Master Infrared monitor bolted to the culvert wall.

For this study, the level of sensitivity was set at high/medium. This setting is optimal for capturing animals ranging from small mammals (e.g., weasel) to large mammals (e.g., deer or bear). The camera delay was set to take a photograph every six seconds when an animal was within the zone of sensitivity. The Trail Master infrared monitor was housed in a metal container and the camera was mounted on top (figure 3.). The whole unit was then bolted to the inside of the culvert wall with lead anchors and 0.5in x 2in lag bolts for safety and security. The unit was always mounted at a height of 30 inches, a height recommended by Trail Master for best registering deer. We used Fuji Super HG, 1600-ASA speed film with 36 exposures for color prints. The film speed allowed for high quality photographs at night. During an initial test, we discovered that light illumination from the flash was bouncing off the bright sides of the concrete culverts causing the flash to prematurely shut down and blurring some photographs. To alleviate this problem, a 2ft x 3ft area adjacent to the camera flash was painted with a no-gloss flat black spray paint. In addition, black electrical tape was placed over a quarter of the infrared beam window to match the area with the camera view finder. Each camera unit remained in a culvert from Monday though Friday because of concern of vandalism, and each one was monitored for a total of a two-week time span separated by at least a month. Raccoons were the most abundant species using the drainage culverts in this study.

Fig. 4. Two examples of culverts monitored during the Phase I study with wildlife traveling through them.

Results of the Camera Monitoring Phase I

From September 18 to November 24, 2000, ADM monitored nine culverts to determine wildlife use. A variety of species were detected by the monitoring units, including white-tailed deer, black bear, raccoons, opossums (*Didelphis marsupialis*), long-tailed weasel (*Mustela frenata*), feral cat (*Felis domestica*), great blue heron (*Ardea herodias*), red fox (*Vulpes fulva*), striped skunk (*Mephitis mephitis*) and humans (see table 1). Only one culvert (structure #31) was confirmed through infrared monitoring to be used by white-tailed deer. This was the largest culvert monitored with an arch shape that was 19 feet high by 19 feet wide and 250 feet long. Bucks and does were observed heading in both directions on several nights during the monitoring session. All but one culvert, structure #34, had wildlife use.

The culverts evaluated in the Wildlife Underpass Study, "Phase I" of April 2001, varied considerably in size, interior substrate conditions, water depth, adjacent habitat, and presence of right-of-way (ROW) fencing. The average openness index (OI) of the culverts was 0.50. Because of a small sample size of culverts, statistical comparisons of structure characteristics between used and non-used culverts could not be made. A Phase II Study was initiated to further address the protection of wildlife travel corridors and roadway safety issues by gathering more data on wildlife underpass usage.

Phase II Mythology

An expanded study of culverts throughout PENNDOT District 3-0 was initiated to better determine what size drainage culverts would most likely be used by white-tail deer as underpasses. In this "Phase II" Study, ADM identified and studied culverts with larger openness indices (0.5 and above). ADM followed a methodology similar to the Phase I Study including (1) updated literature search, (2) structure identification, (3) field screening study, and (4) remote infrared camera monitoring survey. Each culvert was documented with regard to dimensions, interior characteristics, location, topography, and adjacent habitat features that contribute to and potentially enhance the usage of culverts by white-tailed deer. White-tailed deer were the target species as deer-vehicle accidents have dominated the yearly totals of incidents with alarming numbers of human fatalities, deer killed, vehicles damaged as well as increased personal liabilities in insurance costs (Romin 1994, Cook and Daggett 1995, Bruinderink and Hazebroek 1996, Danielson and Hubbard 1998, Jackson 1999).

A search of the Districts' database files was conducted for all the culverts within District 3-0. It was determined by PENNDOT to focus the study on reinforced concrete (R/C) box culverts which are commonly incorporated in their highway development plans for drainage. The search identified a listing of 70 potential box culverts that would be field screened to determine white-tailed deer use. A data form was filled out on-site for each of the culverts and photographs taken. From the final field screening efforts, 20 box culverts were considered to be the best potential underpasses for deer. Information for each of the selected culverts was collected from April 4 to April 19, 2002. Consistent with the Phase I Study, the evaluation information recorded included: length (opening to opening), width, height, openness index, interior substrate, percent visibility through the culvert, present/absent of right-of-way (ROW) fencing, nearby land use, habitat cover, roadway average daily traffic (ADT), and tracking conditions in and around culverts. The Phase II camera monitoring study was separated into two seasons: 10 culverts were monitored in the fall (September–November) of 2002, and 10 culverts in the spring (May-July) of 2003.

Results of the Phase II

A variety of species was detected in the culverts, including black bears, white-tailed deer, raccoons, ducks, muskrats, opossums, dogs and humans. The target species of the Phase II study, white-tailed deer, were photographed in nine culverts. Black bears were photographed in two culverts, and people were photographed in three culverts. Again, as in the Phase I study, raccoons were the most common species photographed in the culverts. However, white-tailed deer were the second most abundant species photographed in the culverts.

Fig 5. Four examples of culverts with white-tailed deer traveling through them.

Discussion

The Phase II study evaluated the use of box culverts by white-tailed deer as travel routes to access either side of the highway. A range of sizes of box culverts were included in the evaluation to determine the size most likely to be used by deer. Nine box culverts out of the twenty (9/20 = 45%) monitored were found to have deer movement. The average Openness Index of these nine culverts was 0.92. The average width was 15.3ft, the average height was 8.2ft and the average length was 164ft (table 2). The Openness Index of the culverts used by white-tailed deer ranged from 0.46 to 1.52. In the Phase II Underpass Study the longest culvert used by white-tailed deer was 286 feet long. Two culverts monitored with longer lengths of 356ft and 370ft had no white-tailed deer use. By comparison, the average dimensions of box culverts not having deer movements in this study was 212ft long, 7.5ft high and 14.8ft wide. The average Openness Index for those culverts that did not have deer movement was 0.68 and ranged from 0.19 to 1.62.

A culvert's suitability for wildlife should not be evaluated based solely on its Openness Index, but for new construction it should be a major consideration. Other criteria, such as surrounding habitat, fencing, noise levels, and approaches, also need special consideration in the design of successful underpasses.
Based on the field screening studies from the Phase II study, a majority of the culverts (50/70 = 71%) evaluated appeared not to have sufficient structural and surrounding characteristics to facilitate deer movements and were not monitored. Many culverts had longer lengths (300ft +) with small widths and heights which led to a tunnel effect. A number of culverts had irregular entrances, such as large plunge pools, blockages from woody debris, or overgrown vegetation concealing the culvert openings. Other culverts did not contain natural topographic features or right-of-way fencing to aid in directing the animals to the underpass.

Water Within the Culverts

All nine culverts with deer usage contained some level of water. Several culverts containing deeper water (0.5ft to 2ft) were found to be used by white-tailed deer. However, some culverts that were permanently inundated with several feet of water (3ft-5ft) were assumed not to facilitate deer and other mammal movements because of the submerged conditions. A field tracking and screening study of culverts in the winter of 2002-2003 revealed potential problems for deer movements through drainage culverts. The culverts that contained deer movements during the fall of 2002 monitoring were visited again during the winter screening study. In colder winter months with temperatures below freezing for extended periods of time, water inside of the structures froze. These conditions essentially turned the culverts into impassable barriers. No sign of deer was found within or around the culverts.

Substrate Within Culverts

Substrate surfaces within underpasses have been found to play an important role for certain species of wildlife using these structures (Jackson and Griffen 1998). Natural substrate compared to the concrete bottoms in the culverts did not appear to influence white-tailed deer movements in this study. No correlation between bare concrete bottoms and bottoms which contained a natural material were evident in influencing deer usage. Approximately two-thirds of the culverts (6/9 = 66%) which contained deer movements had bare concrete bottoms. The culverts, in which deer movements were photographed, contained a combination of substrates, including bare concrete, water up to 3ft deep, and natural sediment. Wildlife tracks in culverts with natural sediment are more apparent, which could cause the appearance of higher wildlife usage. One comparison was made between two culverts which were similar in size but containing different substrate in the highway median between the east and westbound lanes. Structure #105 contained a 310ft concrete chute between the east and westbound I-80 structures. This concrete surface did not allow any vegetation to grow within the stream corridor. Structures #103 also contained a 310ft open median between I-80 but did not contain the concrete chute which allowed vegetation to grow and provided a natural landscape between the culverts. Both culverts had deer use; however, structure #103 had a greater diversity of species use.

Other small mammal evidence (beaver and raccoon) were found in the median. Natural pool and riffle complexes containing small fish and macroinvertebrates were also noted in this median stream bed corridor of #103. Maintaining the natural stream bed and riparian corridor within a wide highway median can create some refuge for wildlife species when in the process of traveling through directed underpasses.

Approaches to Culverts

Approaches to the culverts (i.e., entrance and exit areas, land surfaces and surrounding vegetation) have been found to be an important factor in deer usage (Jackson and Griffen 1998). Eight of the nine culverts (8/9 = 88%) that had white-tail deer usage had a level approach, no vegetation obstacles, and no plunge pools. Numerous culverts during the field screening study were found to have steep drops resulting in large plunge pools (5ft-7ft wide with 3ft-5ft deep) on the downstream side of the culverts. This could affect deer and other wildlife's ability to reach the culverts' entrances. In several cases, trees and logs had fallen over or near the entrance, creating a barrier for large mammals such as deer to enter or exit the culvert freely. In the two most frequently culverts used by deer (structures #16A and #47B) entrances were open, and had level approaches.

Right-Of-Way Fencing

Of the 20 culverts selected for camera monitoring, 13 included right–of–way fencing that was tied into the culvert's wing walls (13/20 = 65%). The camera monitoring revealed that of the nine culverts that had white-tailed deer usage, six included R-O-W fencing (6/9 = 66%). In many underpass research studies, some type of fencing appeared to help guide wildlife species into underpasses and culverts (Jackson and Griffen 1998). In Europe, fences have been used extensively to keep wildlife off major highways. In past studies, research that endorses using fencing stresses the need for regular maintenance of the fencing, as deer will regularly test and look for holes or breaches to cross the fencing. In this study, white-tailed deer were crossing into the right-of-way at breaches in the fence near three sites (structures #16A, #12, and #105). PENNDOT has used taller fencing in the areas of known high wildlife/vehicle collisions in the past with moderate success. Surrounding topography can also play a part in naturally directing deer into culverts.

Conclusions

Based on the results of the Phase I "Wildlife Underpass Study" and the Phase II "White-Tailed Deer Use of Existing Culverts," it is evident that white-tailed deer and other wildlife species do use culvert structures. Whether they are being used specifically as underpasses or by accident, culverts can provide a safe conduit under highways. Some animals were only photographed using the structures in one direction, perhaps indicating that they were traveling for dispersal reasons or returned by crossing the road. Other wildlife were observed nightly, presumably as part of their routine search for food or travel patterns. Overall, the majority of culverts field screened and surveyed for the Phase II Underpass Study appeared not to facilitate deer usage. Seventy culverts were field evaluated for the Phase II Study, but only 20 culverts showed potential for deer usage (20/70 = 28%). Of these 20 culverts, nine contained deer movements. Consideration must be made that these culverts were placed specifically for the conveyance of waterways underneath highway corridors and not for animal corridors. Focusing on the features associated with culverts which had deer use will offer the best insight into designing successful underpasses. Culverts that did not have deer movements through them contained too many variables to conclude the reason for their non-usage. The average dimensions in this study of the culverts with white-tailed deer movement was 8.2ft (ht.) x 15.3ft (width) / 164 (length), suggesting these may be minimum ranges for underpass sizes. Ranges and averages of culverts that white-tailed deer traversed are available from this study (see table 2). The length of the culvert is often fixed based on the width of the roadway. Based on our data of no white-tailed deer usage in culverts over 286ft in length, we recommend when the length of the culvert is increased, the height and width should also be increased to help offset a narrow Openness Index for white-tailed deer.

Many states are using culverts of varying size in upland areas for a wide variety of wildlife species from small mammals to ungulates, as reported by Evink (2002), but he asserts there is a lack of formal research as the states experiment with different designs. Providing dry areas and/or upland culverts for wildlife could help to alleviate such problems and allow the structures to operate as underpasses throughout the year. Modifying existing drainage culverts to accommodate wildlife by constructing shelves, elevated concrete walkways, and docks have been successful for small mammal use, amphibians and reptiles in Texas, Montana and The Netherlands (Evink, 2002). There are many variables for different species and site conditions. In this study, features surrounding the culverts appeared to play an important role in increasing deer usage of culverts. A combination of right-of-way fencing, topography, land approaches, habitat cover, visibility and deer densities contributed highly to white-tailed deer movements through culverts. Post-construction monitoring of modified and constructed wildlife structures provides vital data in building successful wildlife underpasses.

Features such as eight-foot or higher fencing tied into the structures may funnel movement toward the underpass and encourage their use, but the fences need to be maintained. Maintenance for wildlife features can be easily overlooked in the planning, documentation, design and construction of wildlife structures; however, it can be critically important to the long-term success of such features (Evink, 2002). Jackson and Griffin (1998) recommend a height of at least 8 feet and the fencing should be tied into the opening of the underpass for a directional effect. This practice should also be incorporated to existing culverts and bridges as they have been documented as wildlife underpasses.

Culverts and bridges are inspected routinely for safety and maintenance measures. By expanding criteria over standard inspected items with wildlife use in mind, e.g., vegetation control, woody debris blockages in and around culvert entrances, condition of fencing around the structure and along the R-0-W, you could increase the usage of culverts by deer and other wildlife. Maintenance of fencing can be one of the most expensive activities for wildlife mitigation techniques. Run-off-the-road vehicles and falling trees often damage fencing and, unless quickly repaired, animals will find their way through these breaches and on to the right-of way (Evink 2002).

The size and openness of the culvert are important considerations; however, many other factors contribute to their use. Indigenous plantings adjacent to underpass openings may promote use. Avoiding the use of palatable plant species in roadside and median plantings may keep animals from entering the roadway, thus decreasing the chances of a wildlife-vehicle collision. To increase the chances of underpass use, they may be constructed in areas of known animal movements (e.g., valleys or riparian corridors). Wildlife movement corridors may be evaluated in the planning/environmental phases of a project to help identify potential areas where underpasses may be considered. Post-construction monitoring of modified and/or constructed wildlife structures is vital for refining information necessary to design and build successful wildlife underpasses. In defining species needs and requirements during early phases of the highway planning process, mitigation procedures in the form of underpasses can often offset potential fragmentation, wildlife mortality and wildlife-vehicle collisions. Of various mitigation measures, we feel box culverts can be used as successful white-tailed deer underpasses if constructed with the appropriate surrounding features, suitable size and proper placement.

Table 1.
Results of the Culverts Monitored During the Phase 1 Underpass Study.

Structure #	4A - eastbound	7	7A	8	10	11	31	34	52
BMS	59 0080 2000 1250	49 0180 0514 0644	Not available	41 0180 0484 0864	41 0180 0430 0105	41 0180 0420 1542	41 0015 0620 2614	41 0015 0701 0648	58 0015 0710 0000
Structure Type	RC Box Culvert	RC Box Culvert	Arch Culvert	Twin Cell RC Box Culvert	RC Box Culvert	RC Box Culvert	RC Tied Arch Culvert	RC Box Culvert	RC Box Culvert
Length (feet)[1]	105	360	184	356.75	450.75	406.25	250	378	315.5
Width (feet)	12	10	16	2@15	8	8	19.1	12	8
Height (feet)	9	6.5	10	7	4.5	8	19	9.5	5
Openness Index[2]	1.03	0.18	0.87	0.29	0.08	0.16	1.45	0.30	0.13
Stream/Road Crossing	Lick Run	B. Warrior Run	B. Warrior Run	Glade Run	Turkey Run	Twin Run	Trout Run	Steam Valley Creek	Bentley Creek
Visibility (%)	80	10	80	15	5	25	75	25	10
Land Use - N/E Approach[3]	forest / rangeland	forest / rangeland	forest / rangeland	forest / rangeland	agriculture	forest / rangeland	forest / rangeland	forest / rangeland	forest / rangeland
Land Use - S/W Approach	forest / rangeland	forest / rangeland	forest / rangeland	forest / rangeland	agriculture	forest / rangeland	forest / rangeland	forest / rangeland	forest / rangeland
1st Monitoring Session	Oct. 9-13, 2001	Oct 16-20, 2001	Oct 16-20, 2001	Oct. 2-6, 2001	Sep. 25-29, 2001	Sep. 25-29, 2001	Sep. 18-22, 2001	Sep. 18-22, 2001	Oct. 23-27, 2001
Wildlife Use	Raccoons	Raccoons	Great Blue Heron, Raccoons, Opossum, Long tailed Weasel, Feral Cat	2 sets of People, Raccoons, Skunk	Raccoons	2 Black Bears	White-tailed Deer- Several bucks, doe w/ fawn, Great Blue Heron, Raccoon	None	Red Fox
2nd Monitoring Session	Nov 13-17, 2001	Nov. 18-24, 2001	Nov. 18-24, 2001	Nov. 6-10, 2001	Oct. 30 - Nov. 3, 2001	Oct. 23-27, 2001	Not monitored [4]	Oct. 9-13, 2001	Nov. 13-17, 2001
Wildlife Use	Opossum, Person	Raccoons	Feral Cat, Opossum, Raccoons	Raccoons	Raccoons	None	NA	Person	Raccoons

[1] Length, width and height are of the underpass. Height represents clearance within the center of the underpass.
[2] Openness Index (OI) = (Height * Width) / Length
[3] Predominant land use within 1/4 mile of approach based on aerial photos, USGS topographic maps and field observations.
[4] Structure #31 was not monitored a second time due to confirmed use and time constraints.
[5] Structure #34 was monitored a third time (Oct. 30 - Nov. 3) to determine the effects of culvert modifications on wildlife use. No wildlife use was recorded during this third monitoring session.

Table 2.
Results of the culverts utilized by white-tailed deer during the Phase II Wildlife Underpass Study.

Structure #	#99	#105 West	#132	#46 A-East	#47 B-West	#103-West	#37	#16 A	#16B
BMS #	59-0015-0270-0000	59-0080-1965-1903	59-0015-0300-0044	47-0080-2180-0299	47-0080-2181-0354	59-0080-1951-2134	41-0973-0570-0000	41-6015-0380-0693	41-6015-0380-0693
County	Union	Union	Union	Montour	Montour	Union	Lycoming	Lycoming	Lycoming
Structure Type	R/C Box Culvert	R/C Box Culvert	R/C Box Culvert	R/C Box Culvert	R/C Box Culvert	R/C Box Culvert	R/C Box Culvert	Twin Cell Box Culvert	Twin Cell Box Culvert
Length (ft) [1]	129	142	235	112	116	89	81	286	286
Width (ft)[1]	18	13	12	19	19	13	12	16	16
Height (ft)[1]	10	7	9	8.5	8	6.5	7	9	9
Openness Index [2]	1.4	0.64	0.46	1.52	1.31	0.95	1.04	0.5	0.5
Median Width (ft)	N/A	310	N/A	330	330	300	N/A	N/A	N/A
Stream Corridor	T. Susq. River	Kurtz Gap Run	T. Susq River	T. Beaver Run	T. Beaver Run	SandSpring Run	T. LoyalSock	Beautys Run	Beautys Run
Substrate[3]	concrete/silt	concrete	concrete	concrete/silt/ 6-12" water	silt/sand/ 6-12" water	concrete	concrete/silt	silt/1' water	silt/water
Visibility %	80%	85%	75%	80%	80%	80%	90%	75%	75%
R-O-W Fencing	no	yes	no	yes	yes	yes	no	yes	yes
Land Use-N/E Approach[4]	Susq.River	forest	deciduous forest	agriculture	agriculture	mixed forest	deciduous forest	wetland/ag	wetland/ag
Land Use - S/W Approach[4]	agriculture	forest	agricul/forest	mixed forest (median)	mixed forest (median)	shrub/scrub (median)	mixed forest	wetland/shrub	wetland/shrub
Attractors[5]	corn field	none apparent	corn field	corn field	agriculture	thermal cover	PGC game farm	agriculture	agriculture
ADT[6]	20,000	20,000	23,000	13,738	14,345	20,000*	1165	16,000*	16,000
1st Monitoring Session	June 2 - 6, 2003	June 23 - 30, 2003	June 2 - 9, 2003	Oct. 21-28, 2002	Oct. 21-28, 2002	Oct. 7-14, 2002	Sept. 30-Oct. 7, 2002	Sept. 30-Oct. 7, 2002	Sept. 30- Oct 7, 2002
Wildlife Use	Raccoons	**White-tailed deer**	Person (fisherman)	No	**White-tailed deer**	Raccoons / Beaver	**White-tailed deer,** Bear	**White-tailed deer**	**White-tailed deer**
2nd Monitoring Session	June 30- July 7	June 23 - 30, 2003	June 23 - 30	Nov. 11-18	Nov. 11-18	Nov. 4-11	Oct. 28 -Nov. 4	Oct. 28-Nov. 4	Oct. 28- Nov.4
Wildlife Use	**White-tailed deer,** raccoons	No	**White-tailed deer**	**White-tailed deer**	**White-tailed deer**	**White-tailed deer,** Raccoons	**White-tailed deer,** Raccoons	**White-tailed deer**	**White-tailed deer**
Average Dimensions	**8.2 (Height)**	**15.3 (Width)**	**164 (Length)**						

[1]Length, width and height are of the underpass. Height represents clearance within the center of the underpass
[2]Openness Index (OI)=(Height*Width)/Length
[3]Material within culvert (e.g. concrete/natural bottom/water/sediment/silt)
[4]Predominant land use within 1/4 mile of approach based on USGS topographic maps and field observations
[5]Habitat features that may attract wildlife to the area
[6]ADT-Average Daily Traffic-based on file review and * asterisks are from Type 4 maps

Acknowledgements: This study was funded through Pennsylvania Department of Transportation (PENNDOT) by a Transportation Equity Act (TEA-21) grant. A. D. Marble & Company Project Managers: Peter Dodds and Andrew Parker. Field assistance and report production from Jessica Morrow Klinefelter, Amanda Krugh and Andy DeGregorio. PENNDOT liaison was Ray Kennedy. Pennsylvania Game Commission contact was Kevin Mixon. Engineering support was provided by Dewberry Company, Inc.

Biographical Sketches: A. D. Marble & Company is an environmental planning and design firm specializing in natural and cultural resource services to help our clients through the environmental process. Carl Brudin III has been an environmental scientist for A. D. Marble & Company for the past three years working on environmental planning and studies, threatened and endangered species and terrestrial ecosystems in the highway development process. He holds a B.S. degree from Ferrum College, Ferrum, Virginia, and a Certificate in Environmental Studies from Johns Hopkins University, Baltimore MD. He has worked in many parts of the United States, including Oregon, Maryland, North Carolina and South Dakota, for the U.S. Forest Service, U.S. Fish and Wildlife Service, and the National Park Service.

References

Bruinderink, G.W., and E. Hazebroek. 1996. Ungulate traffic collisions in Europe. *Conservation Biology* 10: 1059-1067.

Cook, K.E. and P. Daggett. 1995. Highway road kill. Associated issues of safety and impacts on highway ecotones. The Task Force on Natural Resources (A1F52) Transportation Research Board and National Research Council.

Danielson, B.J. and M. Hubbard. 1998. A literature review for assessing the status of current methods of reducing deer-vehicle collisions. The Task Force on Animal Vehicle Collisions. The Iowa Department of Transportation and Iowa Department of Natural Resources.

Evink, G. L., 2002. *Interaction Between Roadways and Wildlife Ecology: A Synthesis of Highway Practice. NCHRP Synthesis 305*, Washington, D.C. pp 29-38.

Jackson, S. D. and C. R. Griffin, 1998. "Towards a Practical Strategy for Mitigating Highway Impacts on Wildlife," *International Conference on Wildlife Ecology and Transportation*, FL-ER-69-98, Florida Department of Transportation, Tallahassee, pp. 17-22.

Jackson, S. 1999. Overview of transportation related wildlife problems. Pages 1-4. *Proceedings of the Third International Conference on Wildlife Ecology and Transportation*. G. Evink, P. Garrett and D. Zeigler (eds). Florida Dept. of Transportation, Tallahassee, Florida. FL-ER-73-99.

Romin, L.A. 1994. Factors associated with the highway mortality of mule deer at Jordanelle Reservoir, Utah. M.S. Thesis. Utah State University, Utah.