January 2008

Evaluating the Effectiveness of Wildlife Crossing Structures in Southern Vermont

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Bellis, Mark, "Evaluating the Effectiveness of Wildlife Crossing Structures in Southern Vermont" (2008). *Masters Theses 1896 - February 2014*. Paper 202.
http://scholarworks.umass.edu/theses/202

EVALUATING THE EFFECTIVENESS OF WILDLIFE CROSSING STRUCTURES IN SOUTHERN VERMONT

A Thesis Presented

by

MARK A. BELLIS

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

September 2008

Wildlife and Fisheries Conservation

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DEDICATION

This work is dedicated to the memory of my loving stepfather, Bobby Peddie,

who provided me unconditional support throughout my pursuit of this dream

ACKNOWLEDGEMENTS

The success of this project was made possible through the encouragement, assistance and supports of many individuals, first and foremost my committee. I am especially grateful to my co-chairs Dr. Curtice Griffin and Dr. Paige Warren who accepted me into UMass, providing me the opportunity to pursue my dream of wildlife conservation. Many thanks to Scott Jackson, who provided continued guidance and support throughout my three years here at UMass and to Dr. Craig Wells for his availability and ability to elucidate statistical concepts.

This project would not have been possible without the assistance of my hard working field technicians, especially my friend and fellow biologist Alan Thompson, who was given the task of initiating my project while I was a continent away. Lauren Gilpatrick and Nadine Bader, also provided impeccable work during my remaining two field seasons. My winter field seasons were made possible with the dedication of snow tracker extraordinaire, Noah Charney.

I would like to thank the Vermont Agency of Transportation (VTrans) and Vermont Fish & Wildlife, who provided funding and the impetus for this project. VTrans personnel Jennifer Fitch, Chris Slesar and Rob Faley and VT Fish & Wildlife personnel John Austin, Forrest Hammond and Doug Blodgett provided enthusiasm and support for our project since its inception. Locally, thanks go out to game warden Travis Buttle and all the landowners who let me trample around their property.

Most importantly, thanks go out to my sister Robyn, mother and late stepfather Bobby. They maintained enthusiasm and generosity throughout these three sentinel years of my life.

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CHAPTER 1

INTRODUCTION

Roads are prominent, contiguous features covering approximately 1% of the United States land mass (Forman and Deblinger 2000) and have been built for decades with little consideration for ecological effects. Increasingly, the impacts of roads are being recognized and the science of road ecology is emerging as an important area of study for conservation biologists. For wildlife, the impacts of roads are disproportionate to the area of land they occupy (Reed et al. 1996, Forman and Alexander 1998, Jackson and Griffin 2000).

Direct impacts on wildlife include mortality via vehicle collision and restriction or alteration of movement (Forman et al. 2003). Road kill exceeds hunting as the leading direct human cause of vertebrate mortality, with approximately one million vertebrates a day killed on roads in the United States (Putman 1997). Roadways also affect wildlife through habitat loss and fragmentation, isolation of wildlife populations, disruption of gene flow and metapopulation dynamics (Andrews 1990, Bennett 1991, De Santo and Smith 1993, Trombulak and Frissell 2000).

A variety of strategies have been used with mixed success to mitigate the impacts of roads on wildlife (Jackson and Griffin 1998). Commonly, underpasses are used to facilitate movement of wildlife across roadways in Europe, Australia, Canada and the U.S. (Cramer and Bissonette 2006). However, the effectiveness of these underpasses to facilitate wildlife movement depends on a number of variables, including: size, proximity to natural wildlife corridors, noise levels, substrate, vegetative cover, moisture, temperature, light, and human disturbance (Jackson and Griffin 2000). For example, cover can play a key role in passageway effectiveness for small mammals. The installation of gutters in culverts significantly increased small mammal movement (Foresman 2004). Numerous studies reported the importance of vegetation at crossing structure entrances to enhance use by wildlife (Hunt et al. 1987, Clevenger and Waltho 2000, Cain et al. 2003). Further, different species typically have different requirements. Thus if crossing structures are designed for use by a singles species, they may constitute an absolute barrier for other species that have different requirements (Barnum 2004).

Most attempts to evaluate wildlife crossing structures focus exclusively on documenting wildlife use of structures (Forman et al. 2003). While tracking beds, cameras, and counters document the species using structures, they provide little information on those species or individuals that fail to use a structure. In contrast, telemetry, trapping and tracking studies are more useful for determining the extent to which roadways inhibit wildlife movements and the degree to which crossing structures mitigate these effects (Cain et al. 2003, McCoy 2005). Thus, to fully assess the effectiveness of wildlife passageways, a combination of monitoring techniques across a variety of taxa is needed to evaluate structure use impacts of transportation systems on animal movements (Jackson 1999, Hardy et al. 2004).

The goal of this study was to assess the effectiveness of wildlife crossing structures constructed as part of the Bennington Bypass (Highway 279) in southern Vermont. The bypass was completed in October 2004 and includes three wildlife crossing structures, including two extended bridges and a large culvert. This study monitored the effectiveness of these crossing structures and compared rates of wildlife movement across the highway in mitigated and unmitigated sections.

In Chapter 2, I present the results of research using track beds and remote cameras to determine what species use the crossing structures. I also compared the two techniques in their ability to detect species use of the structures. In Chapter 3, I present the results of research conducted using snow-tracking as a method to determine the permeability of the road landscape to wildlife in the study area, and also to compare relative use of the crossing structures to road crossings. In Chapter 4, I present results of road kill surveys which were used to determine if the number of road kills decreased as a function of proximity to the crossing structures and the relationship between traffic volume and numbers of road kills. In Chapter 5, I present the results of a mark-recapture study used to determine if the roadway serves as a barrier to movement for small mammals and in addition to an evaluation of use of the structures by small mammals.

The importance of incorporating mitigation for wildlife into highway construction projects is gaining acceptance by many state transportation and natural resource agencies but unfortunately monitoring is currently not a major component of wildlife crossing design. Consequently, more rigorous studies and evaluations of crossing structures are needed to optimize design of these structures. This work is an effort to provide a broader approach to evaluating effectiveness, potentially serving as a template for monitoring techniques and assessment of future wildlife crossing structures, both in Vermont and nationwide.

Literature cited

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

Barnum S. 2004. Identifying the best locations to provide safe highway crossing opportunities for wildlife. Pages 246-252 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-29 August, Lake Placid, NY, USA.

Bennett, A. F.. 1991. Roads, roadsides, and wildlife conservation: a review. Pp. 99-118 *In* D.A. Saunders and R.J. Hobbs, editors. Nature Conservation 2: The Role of Corridors. Surrey Beatty & Sons, London.

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

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.

Cramer, P. C. and J. A. Bissonette. 2006. Wildlife crossings in North America: The state of the science and practice. Pages 442-447 *in* Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 29 August – 2 September 2005, San Diego, CA, USA.

De Santo, R.S. and D.G. Smith. 1993. Environmental auditing: an introduction to issues of habitat fragmentation relative to transportation corridors with special reference to high-speed rail (HSR). Environmental Management 17:111-114.

Foresman, K. R., 2004. Small mammal use of modified culverts on the Lolo south project of western Montana – an update. Pages 342-343 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-29 August 2003, Lake Placid, NY, USA.

Forman, T. T. and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecological Systems 29:207-231.

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

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.

Hardy, A., A. P. Clevenger, and M. Huijser. 2004. An overview of methods and approaches for evaluating the effectiveness of wildlife crossing structures: Emphasizing the science in applied sciences. Pages 319-330 *in* Proceedings of the

2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-29 August, Lake Placid, NY, USA.

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

Jackson, S.D. and C.R. Griffin. 1998. Toward a practical strategy for mitigating highway impacts on wildlife. Pages 17-22 *in* Proceedings of the International Conference on Wildlife Ecology and Transportation. Center for Transportation and the Environment. 9–12 February 1998, Fort Myers, FL, USA.

Jackson, S.D. 1999. Overview of transportation related wildlife problems. Pages 1-4 *in* Proceedings of the Third International Conference on Wildlife Ecology and Transportation. Center for Transportation and the Environment. 13-16 September 1999, Missoula, MT, USA.

Jackson, S. D., and C. R. Griffin. 2000. A strategy for mitigating highway impacts on wildlife. Wildlife and Highways: Seeking solutions to an ecological and socio-economic dilemma. The Wildlife Society Bethesda, MD.

McCoy, K.. 2005. Effects of transportation and development on black bear movement, mortality, and use of the Highway 93 corridor in NW Montana. Masters Thesis. University of Montana, Missoula. 142 pp.

Putman, R. J.. 1997. Deer and road traffic accidents: Options for management. Journal of Environmental Management 51:43-57.

Reed, R. A., J. Johnson-Barnard and W. L. Baker. 1996. Contribution of roads to forest fragmentation in the Rocky Mountains. Conservation Biology 10:1098-1106.

Trombulak S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

CHAPTER 2

USING TRACK BEDS AND REMOTE CAMERAS FOR MONITORING WILDLIFE CROSSING STRUCTURES

Abstract

Increasingly, crossing structures are used to mitigate impacts of roads on wildlife; yet, few structures are monitored for their effectiveness. We used track beds and remote cameras to determine the use of two large extended bridge crossing structures and track plates to determine use of a long, narrow culvert on the Bennington Bypass in southern Vermont. We recorded 786 sets of animal tracks ($\geq$26 taxa) on track beds over 349 track nights during three field seasons for the two large crossing structures. The numbers of crossings differed between the two crossing structures for several species, especially white-tailed deer and woodchuck. Using indices, we detected significant differences ($P = 0.020$) in monthly track bed crossings with the highest crossing index in May and the lowest in July. Digital cameras at track beds during two field seasons recorded 65 observations of animals, behaviors which were critical in our analysis of two species, white-tailed deer and woodchuck. Cameras mounted along streams recorded 90 animal crossings of six species. The additional crossing data recorded by the cameras increased the overall numbers of structure crossings for six species by 38% in 2006 and 41% in 2007, with bobcat, raccoon, deer, and turkey accounting for the majority of these increases. Using track plates, we recorded relatively few mammals using the narrow culvert, with the exception of ermine. Although track beds were effective for recording a wide variety of vertebrate taxa moving within a crossing structure, we were not always

able to identify tracks to the species level. Cameras were critical for recording behaviors at track beds and evaluating the effectiveness of track beds for recording crossings. Track beds and remote cameras only provide an index to crossing structure use because individuals typically cannot be identified. In lieu of population studies, the combination of track beds and cameras provided the most accurate assessment of crossing structure use in our study area.

Introduction

A wide variety of ecological impacts on wildlife are caused by vehicles and the roadways that carry them. There are both direct and indirect effects, including mortality from vehicles, habitat loss and degradation, habitat and population fragmentation and modification of animal behaviors (Jackson 1999, Trombulak and Frissell 2000). Considerable efforts are being made to mitigate these road impacts, especially the construction of wildlife crossing structures. As of 2005, Cramer and Bissonette (2005) reported there were 460 terrestrial crossing structures in the United States. Yet, relatively few of these structures were monitored for effectiveness (Romin and Bissonette 1996, Clevenger and Waltho 2005, Cramer and Bissonette 2005). In a sample of 21 studies that monitored crossing structure use by wildlife, typically larger carnivores and ungulates were the taxa groups most frequently monitored. Many studies monitored only a single species (Gordon and Anderson 2004, Kaye et al. 2006).

Several monitoring techniques are used for evaluating crossing structure effectiveness, including road kill and vehicle collision data, snow-tracking, track beds and plates, camera and video monitoring, anecdotal information, observational data, radio monitoring, DNA assignment testing and fecal stress measures (Hardy et al. 2004). The most prevalent methods used are track beds and camera monitoring. A summary of 17 studies reviewed by Forman et al. (2003) showed that 71% of the studies utilized track beds (n = 12) and 29% (n = 5) used remote camera sensing. In only two studies were the two techniques used concurrently.

Use of tracks provides a non-invasive means to document species presence, and potentially population trends and relative population densities (Beier and Cunningham 1996, Huijser and Bergers 2000); however, track bed data cannot distinguish between individual animals. Thus, it is difficult to determine if an individual animal is repeatedly using a crossing structure or whether multiple animals are using the structure. Consequently, absolute numbers of animals using a structure cannot be determined. Additionally, effective track beds are typically difficult to construct and monitor.

Remote sensing cameras can overcome some of the limitations of track beds (Kucera and Barrett 1993). We used track beds/plates and remote cameras at three wildlife crossing structures in southern Vermont to 1) determine what species used the crossing structures, and 2) evaluate the effectiveness of track beds/plates and cameras for monitoring crossing structures.

Study Area

The Bennington Bypass (Hwy. 279) is a 7-km long highway connecting NY Rte. 7 in Hoosick Falls, NY to VT Rte. 7 in Bennington, VT. It is a 2-lane highway with several 3-lane zone passing areas. The bypass was the first part of a 3-phase highway project designed to move traffic around downtown Bennington. This segment of the highway opened in October 2004 and included three wildlife crossing structures; two extended bridges and a long culvert.

The bridges were constructed as overpasses over two streams, East Airport Brook and West Airport Brook. The two streams are separated by 0.9km, both occur in the eastern half of the 7km-long bypass and flow north into the Walloomsac River (Fig. 2.1). Both streams are about 2m-wide with East Airport Brook intermittent and West Airport Brook perennial. Both streams are off-center of the crossing structures, closer to the western end of each overpass opening. The West Airport Brook crossing structure (WAB) is 55m long, 14m wide with a rise varying from 3m at the east abutment to 13m at the stream. A 16m high, 45° stone embankment was constructed at the east abutment of the WAB structure. The side slope of the eastern side of West Airport Brook is moderately vegetated (herbaceous, shrub and sapling vegetation) with a gradual (14°), 2.2m-high slope. In contrast, there is no vegetation on the western slope of the stream which is covered by rip rap and has a steeper (34°), 7.9m-high slope. The East Airport Brook crossing structure (EAB) is 47m long, 14m wide with a rise varying from 12m at the abutments to 18m at the stream. No embankments were constructed at either abutment. The side slopes of East Airport Brook are heavily vegetated and steep on both the east (39°, 11.2m high) and west sides (47°, 9.1m high) of the stream. There is a 0.6 - 2m-wide game trail under the East Airport Brook structure where the slope (27°) is lower. Both overpasses create relatively large crossing structures underneath the highway, with openness ratios (x-section/length in meters, Reed and Ward 1985) for WAB 48.5m and EAB 43m. The long culvert (crossing structure) is located approximately 200m west of WAB. This 1.65m-diameter, 124m-long culvert connects two retention ponds located on either side of the highway. The openness ratio of the culvert is 0.02.

Fencing occurs along the entire length of the Bennington Bypass. Most of this consists of 1.2m right of way fencing providing a 50m buffer of open land adjacent to the roadway, covered in the spring and summer with grasses and wildflowers. The right-of-way fencing transitions to 2.4m lead fencing near each crossing structure entrance, designed to funnel wildlife through the structures. The lead fencing extends approximately 61m from each corner of the crossing structures (4 lead fences per structure). The length and configuration of the fencing differs slightly for each entrance due to topography, variation in vegetation, and the presence of two retention ponds.

The majority of property in our study area is private land, consisting of 4-48ha parcels. Sparsely-spaced houses occur on either side of the roadway with most located approximately 300m away from the roadway. The only public land adjacent to the roadway is a 176ha parcel about 1km southwest of WAB owned by the State of Vermont (Vermont Fish and Wildlife) that provides wintering habitat for deer. The vegetation community adjacent to the roadway is a Northern hardwoods broadleaf complex dominated by American Beech (*Fagus grandfolia*), Maple (*Acer spp.*) and Eastern hemlock (*Tsuga canadensis*). Much of the understory is dominated by Canada honeysuckle (*Lonicera Canadensis*).

Methods

Track beds

We constructed track beds along the midline of each crossing structure (Fig. 2.2) by placing 1.2m x 1.2m sheets of 1.2cm-thick Oriented Strand Board (OSB) end to end along the entire width of each crossing structure, except in streams and areas where the vegetation was too dense or slope too steep. The two track bed segments (one on each side of the stream) in WAB were 25.2m and 6m in length, and the two within EAB were 9.6m and 4.8m in length. Next, we placed a fine layer (~2 mm thick) of marble dust on top of the OSB sheets as described by Yanes et al. 1995.

We inspected and reconditioned track beds one to three times/week following nights without rainfall. We were unable to collect data during periods of disturbance. For each track set we recorded species (or at a minimum, family) and direction of travel. For difficult to identify tracks, we photographed and measured foot width and length, stride and straddle for subsequent identification. If a mammalian family or species could not be determined, we classified tracks as small- (chipmunk or smaller) and medium-sized (larger than a chipmunk) mammals. Track beds were monitored during three field seasons: 28 Apr to 26 Aug 2005 (120 days), 24 Apr to 13 Oct 2006 (173 days), 30 Apr to 8 Oct 2007 (162 days). Each track set was recorded as a track bed crossing. However, we were not able to confirm that track bed crossings represented structure crossings.

We analyzed our data to determine, 1) differences in numbers of crossings per species by structure between years, and 2) monthly differences in numbers of crossings for all species adjusted by number of track nights (Index of Crossing (IOC)). We used the Chi-square test to compare the numbers of species-specific crossings (only for species with $\geq$ 10 crossings excluding *Peromyscus* spp.) between structures by year and all years combined. We used a one-way ANOVA to test for monthly and annual differences in IOC between years by structure, and the overall average (2005-07) IOC between structures.

Track plates

We used two sooted track plates as described by Foresman and Pearson (1998) to monitor wildlife using the culvert crossing structure. Track plates were 1m x 1m aluminum sheets of metal (8 gauge), sooted with an acetylene torch with a 1m x 30cm strip of contact paper placed in the middle of the sheets to record the soot laden footprints of animals. A track plate was placed at each end of the culvert within 5m of the opening. Plates were checked two to three times/week, recording species, date and direction of travel. Only animals with tracks recorded on both track plates were considered to have crossed through the structure.

Remote cameras

Track bed cameras. We used two types of cameras at track beds to record species occurrence and behavior within the crossing structures. A single 35mm camera (TrailMaster TM1050 Active Infrared Trail Monitor, Goodson and Associates, Inc., Lenexa, KS) was used to confirm what species occurred at the track beds. This single camera was rotated between the two crossing structures every month for two (2006 and 2007) field seasons with each segment of the track bed (two per crossing structure) monitored for two weeks before switching to the other side of the stream, except during the first month of both field seasons when two additional digital cameras were used to monitor track beds. The camera was checked weekly and pictures cataloged by date. Although this camera was in place continuously at track beds from 24 May - 13 Oct 2006 (143 days) and 29 May - 8 Oct 8 2007 (133 days), the camera sporadically ran out of film and at other times the triggering mechanism seemed unresponsive.

The second type of camera used at the track beds was a motion-sensing, infrared digital camera (Silent Image Professional Model PM35M13, Reconyx, LLP, Holmen, WI). Two of these cameras, one at each crossing structure, were used during the first month of two field seasons (24 April - 24 May 2006 (30 days) and 30 April - 25 May 2007 (26 days)) to record species occurrence and behavior at track beds. These digital cameras were equipped with SanDisk 512MB compact flash memory cartridges, and set to record 10 images/trigger at two frames/sec, date and time. We checked/downloaded images from the cameras weekly using MapView Image Management^{TM} (Reconyx, LLP, Holmen, WI).

Stream cameras. After the initial month of monitoring at track beds, the infrared digital cameras were moved to focus on wildlife movements in and adjacent to the stream where it was not possible to install track beds. These cameras were used to record what species were moving through the structures in areas not covered by track beds. These cameras were in place continuously from 24 May - 13 Oct 2006 (143 days) and 29 May - 8 Oct 8 2007 (133 days), and battery failure occurred only rarely. We compared numbers of crossings recorded by these cameras to track bed crossings only for the above dates when both cameras and track beds were operational.

Results

Track beds and plates

We recorded 786 sets of animal tracks on track beds over 349 track nights for the three field seasons, representing at least 26 taxa (Table 2.1). One hundred-ten of the 786 sets of tracks were unidentifiable and recorded as small- (n = 59) and medium-sized (n =

51) mammals. Sixty-two of the 786 tracks were only identifiable to family or genus level including *Ranidae* (n = 2), C*anidae* (n = 3), *Felidae* (n = 4), *Zapodidae* (n = 12) and *Peromyscus* (n = 41).

Eight species had $\geq$ 10 track bed crossings in one or more years (Table 2.1). For these eight species, there were more crossings in WAB than EAB for white-tailed deer (2005, 2006, 2007), Virginia opossums (2006), and woodchuck (2006, 2007), while there were more crossings in EAB than WAB for domestic cats (2006) and wild turkeys (2006, 2007). For all years combined, there were 434 crossings in WAB and 352 crossings in EAB, with most of the difference due to the differential use by white-tailed deer (WAB – 89 vs. EAB – 12) and woodchuck (WAB – 126 vs. EAB - 87).

Although there was much variation between months in the Index of Use (IOC) (Table 2.2), there were no differences between EAB and WAB for any of the seven monthly comparisons ($P \geq 0.340$). Similarly, the average IOC for all months combined did not differ between years for either EAB (F = 1.445, df = 18, P = 0.276) or WAB (F = 1.073, df = 18, P = 0.430). With all months combined, the average annual IOC was lower for EAB than WAB only in 2005 (F = 6.402, df = 9, P = 0.035), but not in 2006 (P = 0.714) or 2007 (P = 0.781). When both structures were combined, the average annual IOC differed between months (F = 2.985, df = 37, P = 0.020) with the highest crossing index in May and the lowest in July.

For the culvert, there were 43 crossings during 92 track nights between 23 July 2005 and 19 October 2007, representing five species: ermine (n =25), raccoon (n = 10), mink (n = 6), woodchuck (n =1) and long-tailed weasel (n = 1).

Remote cameras

Track bed cameras. The 35mm camera rotated between the two crossing structures recorded 41 observations of animals between 24 April - 13 Oct 2006 (172 days) and 30 April - 8 Oct 2007 (161 days), representing nine species, including: woodchuck (n =14), white-tailed deer (n = 7), wild turkey (n = 5), eastern cottontail (n = 5), American crow (n = 5), raccoon (n = 2), domestic cat (n =1), opossum (n = 1), and striped skunk (n = 1).

The digital cameras at track beds during the initial month of the 2006 and 2007 field seasons recorded 65 observations of animals, between 24 April - 24 May, 2006 (30 days) and 30 April - 25 May 2007(26 days), representing six species: white-tailed deer (n = 18), woodchuck (n =13), wild turkey (n = 20), domestic cat (n =1), eastern cottontail (n =10), and opossum (n = 3). Of the 18 white-tailed deer recorded approaching the track beds (17 at WAB and 1 at EAB), 13 jumped entirely over the track beds seven of which paused at the track bed before jumping over. Only three of the 18 deer walked over track beds and none of these deer paused at the beds. One deer walked around the track bed (over two and half minute duration) and another deer stopped abruptly at the track bed and reversed direction. These digital cameras also showed that many of the woodchuck tracks detected along the length of the track beds may be attributed to individuals moving back and forth multiple times, rather than numerous animals.

Stream cameras. Stream cameras recorded 90 animal crossings of six species for both structures combined between 24 May 2006 and 8 October 2007, including: white-tailed deer (n = 53), wild turkey (n = 12), bobcat (n = 9), raccoon (n = 9), woodchuck (n = 6) and domestic cat (n = 1)(Table 2.3). Fifty-seven crossings were recorded along streams at EAB and 33 at WAB with deer representing the majority of these differences (n = 36 at EAB, n = 17 at WAB). When these camera observations are added to the track bed observations, the overall numbers of structure crossings detected for six species increased by 38% in 2006 and 41% in 2007 with bobcat, raccoon, deer, and turkey accounting for the majority of these increases. The stream camera also recorded behavioral images of woodchucks on the west stream side of WAB. Thirteen images of woodchucks entering and exiting two burrows were recorded during the period the stream cameras were in place.

Calibrated white-tailed deer crossing data

Data collected from the track bed and stream cameras enabled us to recalculate the number of white-tailed deer crossings recorded on the track beds and overall crossings through the structures. For a 56-day monitoring period during the 2006 and 2007 field seasons, track bed cameras recorded 14 deer jumping over the track beds, representing 0.25 crossings/day. Similarly, we recorded an additional 53 deer crossings with the stream cameras during 276 days of monitoring during the 2006 and 2007 field seasons, representing 0.19 crossings/day along the streams where track beds were not constructed. If these crossing rates remained constant for the 455 days that track beds were in place over the three field seasons, the cameras would have detected an additional 200 deer crossings during our study, substantially greater than the 101 deer crossings detected by the track beds for the same monitoring period.

Discussion

Track beds and plates as indicators of use

A wide variety of species used (n ≥ 23) the two crossing structures, reflecting the diverse wildlife community in the area. The mixed hardwood forests adjacent to the roadway and mixed shrub and grass communities and streams within the crossing structures provide a variety of habitats for these wildlife species. Further, the track beds themselves provided nesting habitat for *Peromyscus* and jumping mice.

The large difference in white-tailed deer use between the two crossing structures for all three years (WAB (n = 89) and EAB (n = 12)) was unexpected considering the juxtaposition of the two structures in relation to the adjacent forest. Although the side slopes of East Airport Brook are steeper and more densely vegetated than along West Airport Brook, relatively flat, grassy areas (10 – 20m wide) occur on the eastern streamsides under each structure, providing relatively unobstructed passageways for deer. Despite the higher number of track bed crossings for WAB, the side slope camera in EAB indicated that deer frequently moved along the stream and game trail rather than across areas with steep vegetated slopes or where track beds occurred. Further, the digital cameras at track beds indicated that deer appeared hesitate to walk across track beds, frequently jumping entirely over them. The strong contrast of the white marble dust with the surrounding grass and the unnatural surface created by the wood sheets probably contributed to avoidance of track beds by these deer, but may not prevent them from moving through the crossing structures. However, the substantial numbers of deer using stream areas where track beds were absent and jumping over beds suggested that our track beds did not provide accurate counts of deer using the crossing structures.

We did not expect the high number of woodchuck crossings (n = 213) given the ecology of this species. Woodchucks are a semi-fossorial species with generally small home ranges (4.12ha) that are sometimes defended (Merriam 1966, Swihart 1992). Track bed cameras and tracks on the beds indicated that woodchucks using the crossing structures typically moved along the length of track beds rather than across them. We believe that the high number of woodchuck tracks on track beds may be attributed to only a few individuals who regularly moved to and from den sites we found within each structure. This behavior combined with our inability to identify individual animals with cameras or track beds provided inaccurate numbers of woodchucks using the structures.

We suspect that the differences in use between crossing structures for Virginia opossums and domestic cats in 2006 (Table 2.1) are most likely due to single individuals using a particular structure. The disproportionate high use of WAB in 2006 in comparison to similar numbers of opossum crossings for the two structures in 2007 suggest that individual opossums may have used the structures differently during these years. Further, opossum densities are typically low (1 opossum/4ha, McManus 1974) and densities are very likely even lower in southern Vermont where winters are harsh. Similarly, our snow-tracking observations during the 2005/06 and 2006/07 winters (Chapter 3) suggested that a single feral cat used EAB extensively.

Numbers of wild turkey crossings were much higher for EAB in 2006 and 2007. The occurrence of an abandoned agricultural field < 1km northeast of EAB where we frequently observed turkeys feeding probably explain the extensive use of EAB in these two years.

Although there were few crossing observations for river otter and mink, these two species used WAB more frequently than EAB. The perennial stream in WAB provides more suitable habitat for these two semi-aquatic species and the fish prey on which they depend, especially otter (Erlinge 1969, Burgess and Bider 1980). In addition, during our 2005/06 snow-tracking field season, two otter dens were discovered at the pond that serves as the headwaters for the West Airport Brook.

Seasonal behavioral differences may explain the overall IOC differences between months. When comparing the highest (May) and lowest (July) monthly indices, three species make up most of the differences in crossings: woodchuck [May (n = 79), July (n = 20)], wild turkey [May (n = 25), July (n = 5)], and striped skunk [May (n = 9), July (n = 0)]. The high activity of woodchuck in May can possibly be explained by their annual cycle. Woodchucks emerge from hibernation in February and March, when they use their fat stores for nourishment. Fat stores generally become depleted by May, leading to a peak period of foraging during this month (Fall 1971). Woodchucks also display more sociability during spring as well as peak metabolic activity in May (Bailey 1965*a*, Bailey 1965*b*). Increased wild turkey movement during May can possibly be explained by spring flock dispersal and increase in home ranges for adult and yearling females during spring (Ellis and Lewis 1967, Badyaev et al. 1996). High amounts of striped skunk movements in May can possibly be explained by increases of home ranges for males searching for mates and both sexes increased foraging in spring (Lariviere and Messier 1997, Bixler and Gittleman 2000). After May, average IOC values continued to decline through July after which IOC values began to increase again, presumably with increased foraging activity in late summer and fall.

The high use of the culvert by ermine relative to the crossing structures in our study was probably the result of the culvert's small, confining space (openness ratio = 0.02m). Clevenger et al. (2001) reported that ermine prefer culverts with low openness ratios and low through-culvert visibility. This low openness ratio for ermine contrasts greatly with the larger openness ratios recommended for mule deer (> 0.6) and Florida panther (*Felis concolor coryi*) (0.92) (Reed et al. 1982, Reed et al. 1975, Foster and Humphrey 1995). Further, the limited need by ermine for through visibility in a culvert may stem from their hunting strategy that requires travel through burrows and runway systems of rodents (King 1989).

Cameras as indicators of use

Although the 35mm camera used to monitor track beds recorded only one species (American crow) not detected by the track beds, this camera provided us few useful data on numbers of crossings through the structures. This camera was frequently inoperable, thereby missing many of the taxa that moved through the structures, and also failing to record any species smaller than domestic cats. In contrast to the limited data provided by the 35mm cameras, the digital cameras used at track beds provided us the ability to more accurately assess the frequency of structure use by deer and woodchucks. The ability of these digital cameras to record multiple frames over a short time period provided important information on deer and woodchuck behavior at track beds.

Although stream cameras recorded the occurrence of much fewer taxa (n = 6) than track beds (n = 26) for the monitoring periods that both were operational, these cameras provided important information on animal crossings through the structures in areas not monitored by track beds (Table 2.3). These camera observations were critical for recording the use of structures by bobcats and several other species, especially through EAB. These camera data also underscored the importance of using cameras in areas within structures that cannot be monitored by track beds.

We believe the higher numbers of crossings detected by stream cameras in EAB (n = 67) compared to WAB (n = 33) is related to several factors. Areas monitored by our camera in EAB included a distinct game trail that was frequently used for crossings. There was no obvious game trail within WAB. The occurrence of this game trail in EAB may have reduced the effects of the relatively steep, densely vegetated slopes on animal movements within this structure. Further, the camera within EAB frequently recorded animals using the intermittent stream channel to move through the structure. In contrast, we never recorded any animals moving through the perennial stream channel in WAB. The extensive riprap areas in WAB where track beds could not be constructed may have also discouraged animals moving through these sections of this structure. There was no riprap within EAB.

Effectiveness of track beds and remote cameras

Track beds are often difficult to construct and maintain. Using marble dust for the track bed substrate requires relatively flat areas free of woody vegetation and minimal exposure to disturbances. We first used sand for our tracking substrate. However, it was too coarse and lacked resolution for identifying tracks. Next, we used marble dust as recommended by Yanes et al. (1995). Although the marble dust provided excellent track resolution, the unevenness of the ground combined with vegetation growing through the dust rendered sections of the track bed inoperable and required extensive maintenance. Incorporating the OSB plywood as a foundation for the marble dust provided us a stable substrate for the track beds and eliminated vegetation growth in the beds.

Disturbance by weather, livestock or human activity is a limiting factor for track beds, frequently making track beds inoperable and requiring frequent maintenance (Rodriguez et al. 1996, Rodriguez et al. 1997, Norman and Finegan 1998, Veenbaas and Brandjes 1999). In our study, track beds were disturbed (inoperable) by rain for 21 of the 130 days we checked them during three field seasons. Although placement of track beds within culverts (Hunt et al. 1987, Yanes et al. 1995, Rodriguez et al. 1996) helps to reduce disturbance by rainfall, stormwater flow through culverts typically requires that track beds be reconstructed. In our study, we frequently reconditioned the sooted track plates within the single culvert following rainfall events over three field seasons.

Similar to other studies (Yanes et al. 1995, Rodriquez et al. 1996, Mata et al. 2004), we found that track beds are effective for recording a wide variety of vertebrate taxa moving through a crossing structure. However, we were not always able to identify to the species level for both medium- and small-sized mammals. Similarly, Rodriguez et al. (1996) reported difficulty in reliably identifying small mammals to species using track beds at 17 non-wildlife passages which were primarily culverts. Mata et al. (2004) also reported difficulty in identifying species of hare and rabbit, small mustelids, felids and canids to species in their track bed study in Spain.

Although our track beds recorded large numbers of woodchuck tracks, track bed cameras indicated that woodchucks typically moved along the length of track beds rather than across them. Similarly, we recorded relatively few actual crossings through structures in our small mammal mark/recapture study (Chapter 4). Thus, the moderately high numbers of small mammal tracks we recorded on track beds were most likely due to daily home range movements within structures rather than crossings through them, as also reported by Mata et al. (2004). These types of behaviors within structures confound using presence/absence data from track beds as a measure of crossing rate as reported by Rodriguez et al. (1996, 1997). We overcame this limitation for the culvert we monitored with sooted track plates by placing a plate at both ends of the culvert. A crossing was only recorded if the tracks of a particular species were recorded on both plates and moving in the same direction. Ng et al. (2004) reported using three sets of track beds within single structures to confirm actual passage through structures. Cameras can also reduce this limitation of track beds for determining numbers of crossings by recording behaviors at track beds.

The cameras we used at track beds were critical for recording behaviors at track beds and evaluating the effectiveness of track beds for recording crossings through the structures. Without these camera observations, we would not have detected deer jumping over track beds, thereby under-reporting the numbers of deer crossings. Likewise, without cameras, we would not have identified that the frequent movements of woodchucks along the track beds rather than crossing through structures. The recording of behaviors at track beds required a camera with the capacity to record multiple images/trigger over a short time period (10 images/trigger at two frames/sec in our study).

Several studies reported advantages of using cameras for monitoring structures compared to track beds, including: ease of use, less prone to disturbance factors such as rain, flexibility of placement, low cost of maintenance, high equipment reliability, and increased accuracy of species identification (Norman and Finegan 1998, Mata et al. 2004, Ng et al. 2003, Silveira et al. 2003). However, cameras are most effective for recording medium- and large-sized vertebrates within structures and probably miss many small-sized animals. Similarly, Norman and Finegan (1998) reported that multiple cameras mounted within three highway underpasses were not able to detect small reptiles, amphibians and mammals. The initial costs for some cameras, especially programmable units like the Reconyx cameras we used, are relatively high; however, they can be used for multiple years. Several crossing structure studies reported problems with vandalism and theft of cameras (Norman and Finegan 1998, Austin and Garland 2001, Ng et al. 2003). Although cameras have the potential to recognize some individual animals (Silveira et al. 2003), it is typically difficult to determine numbers of individual animals moving through a crossing structure. Mark/recapture or telemetry studies are needed to determine actual numbers of animals using a crossing structure.

Management Implications

Increasingly, wildlife crossing structures are being used in an attempt to reduce the impacts of roads on wildlife and provide safer roads for the driving public (Hardy et al. 2004). A key component in developing optimal crossing structures is the ability to accurately monitor the effectiveness of the structures. However, only a limited number of projects have implemented monitoring programs into their design and results of monitoring frequently go unreported (Romin and Bissonette 1996, Clevenger and Waltho 2005, Cramer and Bissonette 2005,). Monitoring needs to become a required component of crossing structure design. Refining and sharing of useful techniques can assist engineers in developing more effective crossing structures and study designs for monitoring.

While both track beds and remote cameras are important tools for monitoring use of crossing structures by wildlife, they only provide an index to crossing structure use because individuals typically cannot be identified using these two monitoring techniques. If the objective of a study is to document frequency of structure use by individuals, mark/recapture and telemetry monitoring may be necessary. Further, measuring the effectiveness of a structure is limited by the difficulty of monitoring crossings or avoidance of the road by animals in areas away from crossing structures. However, winter snow-tracking provides a monitoring tool to overcome this limitation for some species during times of the year when suitable snow conditions occur (Chapter 3). Although not possible in our study, it is also critical to conduct pre-construction monitoring using telemetry and snow-tracking to better evaluate how construction of the roadway may have affected the behaviors of animals.

Results from this study indicated that rip rapped areas do not provide suitable habitat for a wide variety of wildlife moving through crossing structures and should be minimized as much as possible in crossing structure designs. Additionally, natural vegetation within structures should be maintained to the maximum extent possible during structure construction. Existing game trails need to be identified prior to roadway construction and incorporated in crossing structure placement whenever possible. Small diameter culverts with low openness ratios do not provide effective crossing structures for many mammal species in our study area, but were used preferentially by ermine.

Finally, effective fencing to funnel animals into the crossing structure would probably enhance crossing structure use for a wide variety of taxa.

Literature cited

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

Badyaev, A. V., W. J. Etges, and T. E. Martin. 1996. Ecological and behavioral correlates of variation in seasonal home ranges of wild turkeys. Journal of Wildlife Management 60:154-164.

Bailey, E. D.. 1965*a*. Seasonal changes in metabolic activity of non-hibernating woodchucks. Canadian Journal of Zoology 43:905-909.

Bailey, E. D.. 1965*b*. The influence of social interaction and season on weight changes in woodchucks. Journal of Mammalogy 46:438-445.

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

Bixler, A., and J. L. Gittleman. 2000. Variation in home range and use of habitat in the striped skunk (*Mephitis mephitis*). Journal of Zoology 251:525-533.

Burgess, S. A., and J. R. Bider. 1980. Effects of stream habitat improvements on invertebrates, trout populations, and mink activity. Journal of Wildlife Management 44:871-880.

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

Clevenger, A. P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation 121:453-464.

Cramer, P. C. and J. A. Bissonette. 2005. Wildlife crossings in North America: The state of the science and practice. Pages 442-447 *in* Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 29 August – 2 September 2005, San Diego, CA, USA.

Ellis, J. E., and J. B. Lewis.. 1967. Mobility and annual range of wild turkeys in Missouri. Journal of Wildlife Management 31:568-581.

Erlinge, S.. 1969. Food habits of the otter Lutra lutra L. and the mink Mustela vison Schreber in a trout water in southern Sweden. Oikos 20:1-7.

Fall, M. W.. 1971. Seasonal Variations in the Food Consumption of Woodchucks (*Marmota monax*). Journal of Mammalogy 52:370-375.

Foresman, K. R., and D. E. Pearson. 1998. Comparison of proposed survey procedures for detection of forest carnivores. Journal of Wildlife Management 62:1217-1226.

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

Foster, M. L., and S. R. Humphrey. 1995. Use of Highway Underpasses by Florida Panthers and Other Wildlife. Wildlife Society Bulletin 23:95-100.

Gordon, K. M. and S. H. Anderson. 2004. Mule deer use of underpasses in western and southeastern Wyoming. Pages 309-318 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-29 August 2003. Lake Placid, NY, USA.

Hardy, A., A. P. Clevenger, and M. Huijser. 2004. An overview of methods and approaches for evaluating the effectiveness of wildlife crossing structures: Emphasizing the science in applied sciences. Pages 319-330 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-29 August 2003, Lake Placid, NY, 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.

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

Jackson, S.D. 1999. Overview of transportation related wildlife problems. Pages 1-4 *in* Proceedings of the Third International Conference on Wildlife Ecology and Transportation. Center for Transportation and the Environment. 13-16 September 1999, Missoula, MT, USA.

Kaye, D. R. J., Walsh, K. M. and C. C. Ross. 2006. Spotted turtle use of a culvert under relocated Route 44 in Carver, Massachusetts. Pages 426-432 *in* Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 29 August – 2 September 2005, San Diego, CA, USA.

King, C.M. 1989. The advantages and disadvantages of small size to weasels, Mustela species. Pages 302-334 *in* J. L. Gittleman, editor. Carnivore behavior, ecology, and evolution. Comstock Publishing Associates. Ithaca, NY, USA.

Kucera, T. E., and R. H. Barrett. 1993. The Trailmaster® camera system for detecting wildlife. Wildlife Society Bulletin 21:505-508.

Lariviere, S., and F. Messier. 1997. Seasonal and daily activity patterns of striped skunks (*Mephitis mephitis*) in the Canadian prairies. Journal of Zoology 243:255-262.

McManus, J.J. 1974. "Didelphis virginiana." Mammalian Species. The American Society of Mammalogists. No. 40:1-6.

Mata, C., I. Hervas, J. Herranz, F. Suarez, and J. E. Malo. 2004. Effectiveness of wildlife crossing structures and adapted culverts in a highway in northwest Spain. Pages 265-276 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-29 August 2003, Lake Placid, NY, USA.

Merriam, H. G.. 1966. Temporal Distribution of Woodchuck Interburrow Movements. Journal of Mammalogy 47:103-110.

Ng, S. J., J. W. Dole, R. M. Sauvajot, S. P. D. Riley, and T. J. Valone. 2004. Use of highway undercrossings by wildlife in southern California. Biological Conservation 115:499-507.

Norman, T., and A. Finegan. 1998. The role of fauna underpasses in New South Wales. Pages 69-68 *in* Proceedings of the International Conference on Wildlife Ecology and Transportation. Center for Transportation and the Environment . 9-12 February 1998, Fort Myers, FL, USA.

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.

Reed, D. F., T. D. I. Beck, and T. N. Woodard. 1982. Methods of Reducing Deer-Vehicle Accidents: Benefit-Cost Analysis. Wildlife Society Bulletin10:349-354.

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

Rodriguez, 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.

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.

Silveira, L., A. T. A. Jacomo, A. Alexandre, and F. Diniz-Filho. 2003. Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation 114:351-355.

Swihart, R. K.. 1992. Home-Range Attributes and Spatial Structure of Woodchuck Populations. Journal of Mammalogy 73:604-618.

Trombulak S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

Veenbaas, G., and J. Brandjes. 1999. Use of fauna passages along waterways under highways. Pages 253-258 *in* Proceedings of the Third International Conference on Wildlife Ecology and Transportation. Center for Transportation and the Environment. 13-16 September 1999, Missoula, MT, USA.

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.

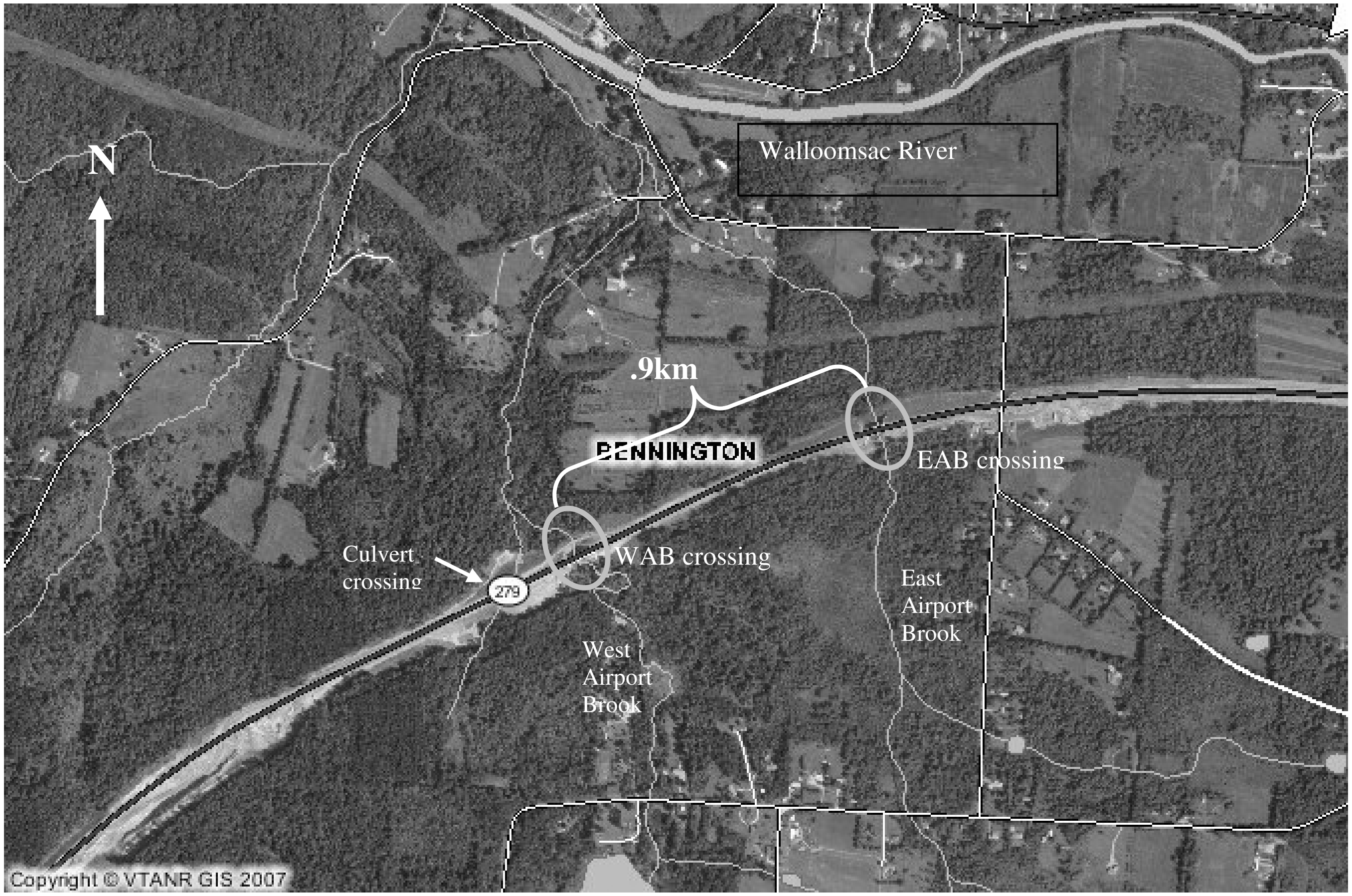

Figure 2.1. Location of three crossing structures along the 7km-long Highway 279 (Bennington Bypass) near Bennington, VT.

Figure 2.2. West Airport Brook (WAB) crossing structure showing rip rap slope, white track bed and perennial stream. Bennington, VT.

Table 2.1. Numbers of wildlife track bed crossings at East Airport Brook (EAB) and West Airport Brook (WAB) crossing structures, Bennington, VT. 2005 - 2007

	2005 (99)[a]			2006 (141)			2007 (109)			Totals (349)	
Species	EAB	WAB	*p* [b]	EAB	WAB	*p*	EAB	WAB	*p*	EAB	WAB
White-tailed deer (*Odeocoileus virginianus*)	4	27	< 0.000	0	35	< 0.000	8	27	< 0.000	12	89
Bobcat (*Lynx rufus*)	1			2	3			1		3	4
Felidae		4								0	4
Coyote (*Canis latrans*)	2	1		1	1			3		3	5
Canidae				1	1			1		1	2
Gray fox (*Urocyon cinereoargenteus*)	1	1								1	1
Fisher (*Martes pennanti*)		4								0	4
River otter (*Lontra canadensis*)		2								0	2
Mink (*Mustela vison*)		2		1	3		1			2	5
Long-tailed weasel (*Mustela frenata*)				3			1			4	0
Ermine (*Mustela erminae*)					1					0	1
Striped skunk (*Mephitis mephitis*)				1			8	1		9	1
Raccoon (*Procyon lotor*)	3	5		9	11	0.655	2	2		14	18
Porcupine (*Erithizon dorsatum*)		1								0	1
Virginia opossum (*Didelphis virginiana*)				1	12	0.002	6	8	0.593	7	20
Eastern cottontail (*Sylvilagus floridanus*)	1	2		8	3	0.132	3			12	5
Woodchuck (*Marmota monax*)	31	22	0.216	35	60	0.010	21	44	0.004	87	126
Gray squirrel (*Sciurus carolinensis*)		2		5	6	0.763	11	7	0.346	16	15
Red squirrel (*Tamiasciurus hudsonicus*)							1	2		1	2
Eastern chipmunk (*Tamias striatus*)				2	3		4	3		6	6
Muskrat (*Ondatra zibethicus*)	3	3			2					3	5

Continued Next Page

Jumping mouse (meadow or woodland)		9		2	1					2	10
Peromyscus (white footed or deer mouse)				8	19	0.034	3	11	0.033	11	30
Domestic cat (*Felis domesticus*)	12			36	3	< 0.000	3			51	3
Medium mammal		4		8	3	0.132	21	15	0.317	29	22
Small mammal	7	27	< 0.000	7	1		13	4	0.029	27	32
Wild turkey (*Meleagris gallopavo*)	10	10	1.000	19	1	< 0.000	22	6	0.003	51	17
Common garter snake (*Thamnophis sirtalis*)		1								0	1
Snapping turtle (*Chelydra s. serpentina*)		1								0	1
Ranidae (frog)		1			1					0	2
Totals	75	129	< 0.000	149	170	0.240	128	135	0.666	352	434

[a] = number track nights, [b] = p for chi-square goodness-of-fit test

Table 2.2. Index of use (# recorded crossings/# track nights) for wildlife track bed crossings at East Airport Brook (EAB) and West Airport Brook (WAB) crossing structures, Bennington, VT, 2005 – 2007.

		Month							
Structure		April (4,14,3)[a]	May (30,17,18)	June (31,15,18)	July (22,22,23)	August (12,28,20)	September (0,29,20)[b]	October (0,16,7)	Yearly average
East Airport Brook	2005	1.250	0.900	0.677	0.727	0.500	n/a	n/a	0.758
	2006	1.000	1.824	0.467	0.955	1.143	1.138	0.688	1.057
	2007	3.333	3.000	1.000	0.130	0.600	0.750	2.286	1.174
	Averages	1.861	1.908	0.715	0.604	0.748	0.944	1.487	0.996
West Airport Brook	2005	2.000	1.800	0.807	1.318	1.250	n/a	n/a	1.323
	2006	0.714	1.177	0.600	0.864	1.679	1.586	1.188	1.206
	2007	2.000	2.667	1.444	0.652	0.550	0.800	1.857	1.239
	Averages	1.571	1.881	0.950	0.945	1.160	1.193	1.523	1.256
Overall	2005	3.250	2.700	1.484	2.045	1.750	n/a	n/a	1.040
	2006	1.714	3.001	1.067	1.819	2.822	2.724	0.938	1.131
	2007	5.333	5.667	2.444	0.782	1.150	1.550	4.143	2.413
	Averages	3.432	3.789	1.665	1.549	1.907	2.137	2.541	1.528
ANOVA - *P*		0.752	0.973	0.473	0.340	0.345	0.627	0.971	0.114

. [a] = number track nights for (2005,2006,2007), [b] = no data collected September-October 2005

Table 2.3. Number of wildlife crossings by six species detected by track beds and cameras in two wildlife crossing structures, 24 May - 13 Oct 2006 and 29 May - 8 Oct 8 2007, Bennington, VT.

	2006 (128 track nights)						**2007** (84 track nights)					
	East Airport Brook			West Airport Brook			East Airport Brook			West Airport Brook		
Species	Track bed	Camera	Total	Track bed	Camera	Total	Track bed	Camera	Total	Track bed	Camera	Total
White-tailed deer	0	21	21	34	16	49	8	15	23	25	1	26
Woodchuck	10	1	11	48	4	49	8	1	9	22	0	22
Raccoon	5	2	7	4	2	7	1	3	4	0	2	2
Bobcat	0	0	0	0	1	1	0	6	6	0	2	2
Wild turkey	11	7	18	1	0	1	13	0	13	6	5	11
Domestic cat	34	1	35	3	0	3	3	0	3	0	0	0
Totals	60	32	92	90	23	113	33	25	58	53	10	63

CHAPTER 3

APPLYING A CONCEPTUAL MODEL OF MOVEMENT TO SNOW-TRACKING AS A MEANS TO EVALUATE EFFECTIVENESS OF WILDLIFE CROSSING STRUCTURES

Abstract

A variety of strategies, primarily in the form of underpasses and overpasses, have been used with mixed success to mitigate the impacts of transportation systems on wildlife. Although the construction of such structures is increasing, limited research has been conducted to assess their efficacy. Structures that were monitored for effectiveness focus primarily on passage use with less consideration given to animal movements in the surrounding landscape. We used snow-tracking as a means to determine permeability of the roadway and to evaluate differences in use of the road vs. the crossing structures for movement through the landscape of the eight species for which we recorded tracks. We analyzed our data using chi-square tests applied to a conceptual model of movement. Based on sets of tracks, our results indicate that the roadway appears to be permeable for most species in our study area and that use of the crossing structures relative to the road increased over the two years of our study, primarily due to increased used by white-tailed deer. Overall, the structures mitigate some of the barrier effect created by the road but many animals remain vulnerable to vehicle collision. Our study underscores the need for well defined pre-construction objectives and landscape scale monitoring of wildlife crossing structures.

Introduction

As long linear features on the landscape, roads and highways (roadways) impact wildlife and wildlife habitats disproportionately for the land area they occupy (Trombulak and Frissell 2000). Roadways affect wildlife through direct loss and fragmentation of habitats, as a source of additive mortality for wildlife and by disrupting animal movements (Jackson 1999, Forman et al. 2003). The barrier effect created by linear infrastructures such as roads can lead to isolation of wildlife populations and disruption of gene flow and metapopulation dynamics (Andrews 1990, Bennett 1991, De Santo and Smith 1993, Yanes et al. 1995).

Attempts have been made to increase permeability of roads to animals through use of crossing structures (Clevenger and Waltho 2000). Crossing structures generally come in the form of either underpasses or overpasses of a variety of types and sizes. Underpasses are the most commonly used form of crossing structure and can range in size from a small amphibian tunnel (<1m high and wide) (Jackson 1989) to large extended bridges (>10m high) such as the one in this study. Only a few studies have attempted to quantify the efficacy of these structures. A 2005 review found 460 terrestrial crossing structures in the United States but noted that few were being monitored for effectiveness (Cramer and Bissonette 2005). The scope of most monitoring studies is generally narrow, focusing primarily on larger carnivores and ungulates, focusing almost exclusively on use of the structures (Forman et al. 2003).

Even with a broad approach to monitoring, it is hard to define criteria for success for a crossing structure project without a clear set of mitigation objectives. Crossing structures are frequently installed with a broad or poorly defined set of objectives (Hardy et al. 2004). If the primary purpose is preventing animal-vehicle collisions (i.e. human safety), the most direct measure of success would be a reduction in the number of collisions or the risk of collisions. Where wildlife conservation is the primary objective of a project, long-term measures of population viability of target species are the only direct measures of success (Sanderson et al. 2002). Data on the movement of wildlife species through a crossing structure is, at best, only an indirect and partial measure of the success of a mitigation project. To interpret patterns of use of structures, a point of reference is needed (Forman et al. 2003). For example, differences in total crossing counts for a species between two structures might simply reflect differences in population densities of that species at the two locations (Forman et al. 2003). Ideally, comparisons should be drawn between pre- and post-construction movements of target species in the area and include an evaluation of the extent to which the roadway (including crossing structures) inhibits wildlife movement through the area. When pre-construction surveys are not available, the only available standard of comparison is *non-use* of structures.

Movements of animals in the vicinity of roads and crossing structures can range from movements parallel to the road to various kinds of crossings to complete avoidance of the road (Fig. 3.1). To create a framework for assessing both "use" and "non-use" movements, we developed a conceptual model (Fig. 3.1). Crossings through structures are the most commonly detected movements in conventional monitoring (Fig. 3.1*e,f*), but the same species using the structures might also cross via the road surface (Fig. 3.1*a,b*). In some cases, wildlife may use structures not specifically designed for wildlife passage such as drainage culverts (Fig. 3.1*j*; Ng et al. 2004, Brudin 2004, Clevenger at al. 2001*a*). Some animals actively avoid road corridors (Fig. 3.1*h*). Several studies found that bobcat and black bears cross roads less than expected relative to their movements in an unaltered landscape (Brody and Pelton 1989, Lovallo and Anderson 1996, Riley et al. 2006). Average Daily Traffic (ADT) and road width are commonly cited as the factors inhibiting road crossings (Brody and Pelton 1989, Lovallo and Anderson 1996, Rondinni and Doncaster 2002, Riley et al. 2006). The 12 movements illustrated in Fig. 3.1 define the scope of monitoring needed to assess relative use and non-use of crossing structures.

Few monitoring techniques have the ability to detect the full range of movement types shown in Fig. 3.1. Track beds and cameras are usually placed at or within the crossing structures, limiting their detections to use of the structures (Fig. 3.1 *e, f* and *m*). Radio telemetry can be used to detect broad scale animal movements across the landscape shown in Fig. 3.1 (Brody and Pelton 1989, Lovallo and Anderson 1996), and it can be used to assess demographic differences in crossing frequency, such as whether males or females are more likely to cross roads (McCoy 2005). Dodd and colleagues (2007) used GPS telemetry to examine Rocky Mountain Elk (*Cervus elaphus nelsoni*) permeability across a 30km stretch of road in Arizona. However, telemetry cannot be used to distinguish finer scaled movements, such as crossings via the structures vs. via the road. In addition, it can be invasive, time consuming, expensive and prone to location error (Weckerly and Ricca 2000, Fedak 2002). Less expensive, non-invasive monitoring methods such as snow-tracking are gaining popularity in wildlife research (Schauster et al. 2002).

Snow-tracking consists of recording sets of tracks encountered through systematic searching after recent snowfalls, usually along transects or trails (Beauvais and Buskirk 1999, Alexander et al. 2005*a*). For collecting information about dispersal, individual identity, or social affiliations snow-tracking cannot replace telemetry (Alexander et al. 2005*a*). However, snow-tracking can document presence and fine-scaled movements of species in relation to roads and mitigation structures (Clevenger et al. 2002). While snow-tracking cannot provide absolute numbers of individuals using crossing structures or roads, it can provide relative rates for different types of movement both near and far from roads (Huijser and Bergers 2000). Through systematic searching, trackers can detect the presence and movement trajectories for any species with identifiable tracks. Fore-tracking and back-tracking of trails encountered provides detailed descriptions of movements of animals within their home ranges. This is especially effective when monitoring effects of discrete landscape features, such as road corridors, fences, and crossing structures. Ideally, efficacy of structures should be assessed through a combination of methods, including telemetry, cameras, track beds and snow-tracking. When funding or personnel are limiting, snow-tracking is perhaps an ideal single-method monitoring approach.

Here, we demonstrate a snow-tracking based method of evaluating use and non-use of crossing structures along a highway in Bennington, VT. With the conceptual model of movement as our framework for analysis, the objectives of our study were to 1) assess the degree of permeability of the road including the crossing structures, and 2) determine relative use of the structures versus use of the road for crossing.

Study Area

We conducted our research during the winters of 2005-06 and 2006-07 in Bennington, Vermont along a 1.9km stretch of highway that encompassed three wildlife crossing structures, two extended bridges and one large culvert (Fig. 2). The Bennington Bypass (Hwy. 279) is a 7km long highway connecting NY Rte. 7 in Hoosick Falls, NY to VT Rte. 7 in Bennington, VT. It is a two lane highway with several three-lane passing zones. The Bypass opened in October 2004 and is part of a three phase highway project which will move traffic around downtown Bennington. The average daily traffic (ADT) for Highway 279 was 4,674 and 4,882 for the 2005-06 and 2006-07 winter field seasons respectively. The Bennington Bypass is a moderate to high volume road according to the classification of Alexander et al. (2005*b*).

The majority of property along the Bennington Bypass is private land consisting of plots ranging in size between 4 and 48 ha. The only public land adjacent to the Bypass is a 176 ha parcel located 250m southwest of the West Airport Brook crossing structure, which is owned by the State of Vermont (Vermont Fish and Wildlife) and serves as wintering grounds for deer. The vegetation community adjacent to the roadway is a Northern hardwoods broadleaf complex dominated by American Beech (*Fagus grandfolia*), Maple (*Acer spp.*) and Eastern hemlock (*Tsuga canadensis*). Much of the understory is dominated by Canada honeysuckle (*Lonicera canadensis*).

The Bypass' two extended bridges are constructed over two streams, East Airport Brook and West Airport Brook, which both flow south to north into the Walloomsac River. The two streams are separated by 0.9km and both occur in the eastern half of the 7km long bypass. East Airport Brook is a 2m-wide intermittent stream, whereas the similar-sized West Airport Brook is perennial. The streams within each crossing structure runs off center, closer to the western edges of the bridge openings. The West Airport Brook crossing structure (WAB) is 55m long, 14m wide with a rise varying from 3m at the east abutment to 13m at the stream. A 16m high, 45° stone embankment was constructed at the east abutment of the WAB structure. The side slope of the eastern side of West Airport Brook is moderately vegetated (herbaceous, shrub and sapling vegetation) with a gradual (14°), 2.2m-high slope. In contrast, there is no vegetation on the western slope of the stream which is covered by rip rap and has a steeper (34°), 7.9m-high slope. The East Airport Brook crossing structure (EAB) is 47m long, 14m wide with a rise varying from 12m at the abutments to 18m at the stream. No embankments were constructed at either abutment. The side slopes of East Airport Brook are heavily vegetated and steep on both the east (39°, 11.2m high) and west sides (47°, 9.1m high) of the stream. There is a 0.6 - 2m-wide game trail under the East Airport Brook structure where the slope (27°) is lower. Both overpasses create relatively large crossing structures underneath the highway, with openness ratios (x-section/length (meters), Reed and Ward 1985) for WAB 48.5m and EAB 43m. The long culvert (crossing structure) is located approximately 200m west of WAB. This 1.65m-diameter, 124m-long culvert connects two retention ponds located on either side of the highway. The openness ratio of the culvert is 0.02m.

Fencing occurs along the entire length of the Bennington Bypass. Most of this consists of 1.2m right of way fencing providing a 15.2m buffer of open land adjacent to the roadway, covered in the spring and summer with grasses and wildflowers. The right-of-way fencing transitions to 2.4m lead fencing near each crossing structure entrance, designed to funnel wildlife through the structures. The lead fencing extends approximately 61m from each corner of the crossing structures (4 lead fences per structure). The length and configuration of the fencing differs slightly for each entrance due to topography, variation in vegetation, and the presence of two retention ponds.

Methods

We laid out a 39.5ha grid for snow-tracking consisting of four transects parallel and twelve perpendicular to the highway (Fig. 3.3). The grid extends 500m to the east of EAB and 500m to the west of WAB. We placed two of the parallel transects on each side of the highway, one along each highway edge, and the other two 100m into the forest on either side of the road. The 12 perpendicular transects start at the road's edge and extend to the farther parallel transect, 100m into the forest. Taken together, the transects allow us to detect animal movements both near and far from the road as well as at key barriers such as fencing.

We conducted snow-tracking sessions between 24 and 72 hours after snowfalls of >1in (1.3cm) as reported by the National Weather Service station in Bennington. We used Palm Pilots with cybertracker software integrated with GPS to record: species, direction of movement, markings (e.g. – scat, scent marking), locations of highway crossings, weather, number of days since last snowfall, snow depth, date and time. In addition, we measured tracks, gaits and gait pattern to confirm uncertain species identifications. Due to its size, we were unable to walk the entire grid in a single day. To distribute our search effort amongst tracking sessions, we varied our search pattern through the grid.

When we encountered animal tracks along any of the transects, we backtracked and foretracked using GPS as long as they were discernible up to 200m from the roadway edge. Crossing points were recorded with the GPS units where the tracks crossed over the road or through a structure. We tracked all species weasel size or larger with the exception of white-tailed deer (*Odocoileus virginianus*) and domestic cat (*Felis domesticus*). For deer, we recorded only road and structure crossings, due to the volume of tracks and the difficulty in differentiating individual trails. We did not track domestic cat due to lack of conservation concern for the species.

Snow plowing typically disturbs the snow pack approximately 5m to either side of the highway. Thus, we checked the areas just beyond the "snowplow zone" carefully to capture tracks heading towards the highway, attempting to match tracks on either side of the roadway for potential road crossings. When matched tracks were not found, the tracks were marked and classified as a probable crossing but were not included in the analyses.

We imported all GPS points into ArcGIS 9.1 and overlaid the points onto orthophoto images of our study area downloaded from Vermont's GIS database, VCGI, Waterbury, VT (Fig. 3.2). We grouped all GPS points into sets of tracks. We defined a set of tracks as all of the GPS points collected for an animal trail from starting point to an end point. We used Hawth's Analysis Tool (Beyer 2004) to connect points and identify direction of movement of each set of tracks. Each set of tracks was examined and classified independently by 3 observers (M. Bellis, N. Charney and D. Paulson) by identifying the predominant pattern for each set. Final classifications into one of the 11 movement categories (Fig. 3.1) were determined by consensus among the observers. Any set of tracks that contained too few tracks or did not have a distinguishable pattern was classified as not identifiable (Table 1, NI). Most non-identifiable trails were too short to define a trajectory of movement, consisting of just 2-3 tracks.

We used the frequencies for each movement type to analyze: 1) permeability of the roadway, 2) relative use of the structures vs. the road for crossing and 3) effectiveness of lead fencing for funneling animals through crossing structures. Because we cannot distinguish individuals with this method, we focus on the relative frequencies of different movement types. Based on home range sizes and natural history of the species we detected (DeGraaf and Yamasaki 2001), we expect that the movement data represents activities of at least 2 individuals per species, and many more individuals for coyote (*Canis latrans*) and white-tailed deer.

Permeability of roadway

According to Cramer and Bisonette (2005) a permeable landscape feature is one that allows free daily movement of a species across its home range. The four species (coyote, bobcat (*Lynx rufus*), mink (*Mustela vison*) and fisher (*Martes pennanti*) which comprise 88% of our movement data, all have home ranges (from 3km^2 for mink to 52km^2 for coyote) that would require them to move across the roadway because core habitat on either side of the road is limited (DeGraaf and Yamasaki 2001). We evaluated permeability by using the conceptual model in Figure 3.1 to create a metric that provides a general determination of whether the roadway imposed a barrier to movements. Following Dodd et al. (2006), we considered any tracks detected in our grid as an approach to the roadway. When analyzing permeability, constrained movement or reduced permeability, should result in fewer crossings than non-crossing movements, i.e. movements along or away from the road. Crossings are movements *a, c, e, f, l* (Fig. 3.1) and non-crossing movements are *b, d, g, h, i, k* (Fig. 3.1). Our metric is simply the number of successful crossings divided by the number of non-crossing movements. Any value >1 suggests the roadway is a permeable landscape feature and a value <1 suggests the roadway is non-permeable feature. The greater the value above 1 suggests a higher degree of permeability and vice versa for values less than 1. In cases where the denominator is 0 (no movements along or away) we assigned a metric value equal to the numerator (across roadway). In cases where the numerator is 0 we assigned a metric value of 0. For this analysis we used combined data from both years since we lacked data for several species in one of the two field seasons. We evaluated the permeability of the roadway both at the species level and overall.

Relative use of crossing structures vs. road

Next, we analyzed whether crossings were more frequent through the structure than across the road surface. Each road crossing puts an animal at risk of mortality. Thus, a successful mitigation project should have more structure crossings (Fig. 3.1*e-f*) than road crossings (Fig. 3.1*a,c*). We conducted chi-square tests with adjusted expected probabilities based on the number of nights since snowfall (NSS) in order to account for differences in sampling effort along the road and structure transects. We used NSS since this incorporates both the number of tracking sessions and number of days over which tracks accumulate since a snowfall. We conducted separate analyses for the two tracking seasons, 2005/2006 and 2006/2007. We excluded gray fox from this analysis since no road or structure crossings were detected for this species. We also evaluated differences in structure use (WAB vs. EAB) using a chi-square test. We used $\alpha = 0.05$ and two-tailed tests for significance for all tests.

Effectiveness of lead fencing in funneling animals through crossing structures

We evaluated the effectiveness of the fencing by testing a null model that the animal response to the fencing is neutral, meaning that animals move in equal proportions away from and towards the crossing structures after encountering the lead fencing. We categorized movements *c* and *d* (Fig. 3.1) as movements away from the crossing structures and movement *e* as effectively funneling animal through the structures (Fig. 3.1). For the chi square test, our expected distribution of occurrences for movements away from the structures was 67% (2 out of 3 possible movement types) and 33% (1 out of 3) for movements through the structures. Expected probabilities are not adjusted by NSS since both directions of movement along fences were detected along the same transects.

Results

We recorded a total of 162 sets of animal tracks over 24 snow-tracking surveys representing a total of 47 track nights between 11 December 2005 and 25 February 2007. Fifteen surveys representing 30 track nights were conducted during the 2005-06 field season and nine surveys representing 17 track nights were conducted during the 2006-07 field season. We recorded sets of tracks for the following species: coyote, bobcat, mink, fisher, long-tailed weasel (*Mustela frenata*), river otter (*Lontra canadensis*), gray fox (*Urocyon cinereoargenteus*) and raccoon (*Procyon lotor*) (Table 3.1). For white-tailed deer and domestic cat, we only recorded road and passage crossings.

We were able to classify a total of 117 sets of tracks into movement categories (Table 3.1). Movement *a*, (successful movement across the roadway) (n = 39), was the most commonly recorded movement followed by *f* (direct movement through crossing structure) (n = 25) and *k* (movement parallel to roadway) (n = 17) (Table 3.1). No animals used the culvert for passage (Fig. 3.1, *l*) during our two winter field seasons, though we detected regular crossings through the culvert by five species during our summer field seasons. No animals we tracked were hit by vehicles (Fig. 3.1, *b*).

Permeability of the roadway

Using our permeability metric we derived an overall permeability value of 1.66 (73/44) (Table 3.2) for the two crossing structures across both years. We calculated value >1, denoting permeability, for six of the eight species we snow-tracked including; coyote (1.39), bobcat (1.83), mink (9), long-tailed weasel (4), river otter (3) and raccoon (3). Values <1, denoting limited permeability, were calculated for two species, including fisher (.57) and gray fox (0).

Relative use of crossing structures vs. road for movement

A further measure of the effectiveness of the crossing structures is a comparison of the frequency of crossings through structures versus over the road surface. We detected 30 structure and 42 road crossings during the 2005-06 field season and 38 structure and 17 road crossings during the 2006-07 field season (Table 3.3). All 9 of the species detected in this portion of the study used the structures, and 7 of the 9 species crossed via the road. The two species that only crossed using the structures were mink and otter, species that typically travel along streams like the ones in these structures. Four species used the crossing structures in 2006-07 that were not recorded in 2005-06:

bobcat, long-tailed weasel, domestic cat and raccoon. White-tailed deer had the most frequent number of structure crossings in both 2005-06 (n = 12) and 2006-07 (n = 21). Coyote had the most frequent number of road crossings in both 2005-06 (n = 23) and 2006-07 (n = 8).

Using chi square tests, we detected significant differences in road crossings vs. structure crossings for four species in 2005-06. Coyote ($x^2 = 4.51$, df = 1, p = 0.034) and bobcat ($x^2 = 4.00$, df = 1, p = 0.046) were detected using the road more frequently. By contrast, mink ($x^2 = 10.50$, df = 1, p = 0.001) and river otter ($x^2 = 4.50$, df = 1, p = 0.034) used the structures more frequently. In 2006-07, only two species, domestic cat ($x^2 = 4.65$, df = 1, p = 0.031) and white-tailed deer ($x^2 = 27.74$, df = 1, p = <0 .000), were detected using the structures more frequently. There appeared to be a shift in use by deer between the first and second field seasons. Fifty-seven percent of deer crossings (n = 12) were through the structures in 2005-06 but 91% (n = 21) were through the structures in 2006-07.

Effectiveness of lead fencing in funneling animals through crossing structures

We recorded a total of 11 sets of tracks from 4 species that encountered the 2.4m lead fencing with responses falling into three possible outcomes; 1) skirts around fencing and crosses roadway (n = 5), 2) approaches fencing then moves away from road and crossing structure into the forest (n = 2) and 3) approaches fencing then moves towards and through the crossing structure (n = 4) (Fig. 1, *c* - *e*). Using an expected distribution of 67% for movements away from the crossing structures (*c* and *d*) and 33% for successfully funneling animals through the structures (*e*), we detected no significance ($x^2 = 0.056$, df =

1, p = 0.813) in wildlife responses to the lead fencing, suggesting that the fencing appears not to funnel animals though the crossing structures.

Discussion

Snow-tracking provided a useful approach to measuring the effectiveness of mitigation crossing structures along the Bennington Bypass by allowing us to compare use with non-use of the structures. Overall, we found that the Bypass is a relatively permeable landscape feature to most of the eight species detected. Once they were within our study area (100m from the road's edge), most species were at least as likely to cross the road (over the road surface or through a structure) as they were to move away from it or along it. The crossing structures are used frequently and by most species. However, this finding is tempered by continued crossings via the road, putting animals in danger of collision. Several species, including river otter, mink and white-tailed deer, are using the crossing structures more often than expected by chance. Deer, in particular, increased their use of the crossing structures over the course of the study. Bobcat and coyote, however, do not preferentially cross using the structures. Instead, they appear to be crossing at junctions between the road and pre-existing game trails at least as frequently as they use the crossing structures.

Permeability of the roadway

Several factors other than the presence of crossing structures may contribute to the degree of permeability we found along Bennington Bypass. Several species that we tracked adapt well to altered landscapes. Coyote and bobcat, for example, have been well documented as urban adaptive animals (Grinder and Krausman 2001, Tigas et al. 2002). Likewise, raccoon also readily use roadside areas (Prange et al. 2003).

Another factor may be the lack of barrier fencing bordering the roadway. The majority of the Bypass is lined with 1.2m right of way fencing, which is easily crossed by most species based on our findings here and in remote camera images taken in the summer season. Tall, lead fencing (2.4m) only extends approximately 65m on either side of the crossing structures. Mitigation fencing has been found to minimize vehicle-animals collisions by keeping wildlife off the road, but only if it is both high enough and extends along major portions of a highway's length (Clevenger et al. 2001*b*). Similar to findings by Cain et al. (2003), our snow-tracking data suggests that the lead fencing employed along the Bennington Bypass does not extend far enough to funnel animals through the structure or to pose a significant barrier to movement in general.

Traffic volume is another important contributing factor to loss of permeability along roadways. Alexander et al. (2005) found that traffic volumes had no significant impact on permeability for ungulates but led to significant decreases in permeability for carnivores at high (ADT = 5,000 – 10,000) and very high (ADT = >10,000) traffic volumes. The Bennington Bypass would be classified by Alexander and colleagues as a moderate to high volume road with an Average Daily Traffic count of 4,778 for our study period. With the construction of a second phase of the bypass underway, traffic levels are expected to increase and with it a potential for decreased permeability for carnivores in the area.

The Bennington Bypass crossing structures may be important in maintaining permeability for a few particular species. Semi-aquatic species such as mink and otter benefit from the placement of the structures along this riparian area (Melquist and Hornocker 1983). Mink and otter forage along streams and ponds for fish and invertebrates and can coexist within the same habitat (Erlinge 1969, Burgess and Bider 1980, Bonesi and Macdonald 2004). The stream may serve as an important movement corridor for otter in this area, given that two dens were found at a pond serving as headwaters for West Airport Brook. West Airport Brook flows into the Waloomsac River, a river abundant with fish. Places where streams cross roads are often handled with culverts and viaducts, which disrupt stream flow and do not protect streamside habitat important for wildlife crossings (Jackson 2004).Thus, the size and openness of the crossing structures along Bennington Bypass renders them of potential importance to semiaquatic species.

Relative use of crossing structures and roadway for movement

Direct comparisons of our findings are hampered by a paucity of studies addressing both use and non-use of structures. Using a combination of monitoring techniques, Singleton and colleagues (1999) detected only 2 structure crossings out of 37 roadway crossings along 30 miles of road in Snoqualmie Pass, WA. Their study monitored 13 species ranging in size from deer mice (*Peromyscus sp.*) to mule deer (*Odocoileus hemionus*). Our ratio of structure crossings to road crossings (nearly 2:1) far exceeds that found by Singleton and colleagues. None of their crossing structures were designed as wildlife crossings, and the highway they monitored is an interstate with more than 5 times the traffic volume (24,400 vehicles/day) at the Bennington Bypass. Using both telemetry and track bed data, Cain and colleagues (2003) found that bobcat frequently crossed a 32.3km section of highway in south Texas leading to 25 road killed bobcat over two years. They also found that bobcat used the 18 crossing structures located throughout the highway (five of which were modified for felid use) and exhibited a preference for structures with higher openness ratios. In both instances, the availability of preferred bobcat habitat adjacent to the structure entrances and road crossing area was the primary characteristic that influenced their crossings in these areas.

The large size of the Bennington Bypass crossing structures does not appear to inhibit movement of medium and large mammals. Only 7% of animals (n = 2) that encountered the crossing structures moved away from them. Instead, they appear to provide favorable habitat for many species due to the presence of streams within the two crossing structures. Species such as white-tailed deer, coyote, Virginia opossum (*Didelphis virginiana*) and raccoon use streams as movement corridors (Spackman and Hughes 1995, Allen et al. 1985). In addition, the Bennington Bypass passage structures are relatively large and far exceed the openness ratio (x-section/length in meters; Reed and Ward 1985) recommended for larger species (Foster and Humphrey 1995, Jackson and Griffin 2000, Gordon and Anderson 2004). By contrast, the large size of the structures may inhibit movement of smaller mammals (Rodriguez et al. 1996, Clevenger and Waltho 1999, Foresman 2004). Other experiments are addressing this issue through management of cover for small mammals in the openings. Snowtracking is not able to capture movements of these species.

Deer in our study showed an almost three fold increase in use of the crossing structures between the first and second years of our study (Table 3.3). There are several possible explanations for this increase: a) natural shifts in populations, b) shifts in geographical distribution, c) habituation by wildlife to the crossing structures, or d) improved vegetative cover over time. Our findings are consistent with several other studies that reported an increase in use of crossing structures over time, suggesting there is an initial acclimation period (Land and Lotz 1996, Clevenger and Waltho 2004, Baofa et al. 2006). Clevenger and Waltho (2004) found a more than five fold increase in use by ungulates, especially deer, over a 5-year period. Monitoring of the Bennington Bypass over a longer period is needed to determine whether the increase in deer use of the structures is due to habituation or to unrelated population shifts.

Two species, coyote and bobcat, are noteworthy for their low use of the crossing structures. Sixty nine percent of all road crossings were by coyote and bobcat. Detections of coyotes along the road remained constant between 2005-06 (79%) and 2006/07 (80%). While bobcat showed a decrease in use of the road from 2005-06 (100%) to 2006-07 (57%), the shift in use was almost certainly due to the presence of a road killed deer heavily fed on by bobcat in the WAB structure for all of the 2006-07 field season. We suggest that the primary reason these species used the road for crossings is their association with game trails that intersect the roadway away from the crossing structures. Thirteen coyote trails followed an unused logging road at the far southwest corner of our grid and was heavily scent marked throughout its length. Scent marking may indicate the presence of coyote packs in the area since lone coyotes do not scent mark (Barrette and Messier 1980).

Bobcat used two game trails, one trail used by the coyote (n = 4) and a second game trail approximately 250m to the east of the WAB crossing structure (n = 7). Bobcat use of the southwest game trail may be attributed to the limited open space that bobcat need to cross the road in this area. The distance from the forest edge on the south side to the north side of the roadway in this area (40m) is shorter than most areas along the Bypass. The location of this game trail is consistent with findings by Cain et al. (2003), who found that bobcat crossed roads most frequently in areas where distances between dense vegetation was shortest. The second game trail used by bobcat followed a footpath on the north side and along a stone wall on the south side of the roadway. Bobcat showed signs of foraging along the wall, a typical habitat for numerous small mammal species (Fahrig and Merriam 1985). After we identified these game trails in the 2005/2006 season, we confirmed the year-round use of these trails by both bobcat and coyote through motion-sensing cameras placed along both trails in the summer. If a goal of the crossing structures was to mitigate impacts of the road on these species, pre-construction surveys of their movements could have been used to identify these game trails as important sites for mitigation.

Another factor that likely influenced coyote road crossings here and elsewhere is the abundance of prey in the right-of-way. We also found numerous subnivean tunnels in the road right-of-way, a likely indication of meadow voles (Madison et al. 1984). While tracking in this area, we frequently noted signs of active coyote foraging, e.g. pouncing and digging. Thus, the right-of-way represents a typical foraging area for coyotes, increasing the probability that they would cross the road rather than use the structures.

Potential Avoider Species

Several species may be avoiding the road area altogether, or in the case of fisher, generally avoiding the road or structures. More fisher tracks were detected moving across and along or away from the roadway. Four of the 14 fisher tracks that we detected went across the road or through the structures, four sets were parallel to and three sets moved away from the roadway (an additional 3 were unidentifiable). The parallel tracks were detected in forested areas away from the road. This can possibly be explained by fisher preference for foraging in forested habitat and avoidance of open areas in winter (Powell 1994). The riparian areas within the structures would generally be favorable habitat for fisher but the lack of canopy cover in these areas may inhibit their movement (Witmer et al. 1998). The limited movement of fisher across the road or structures illustrates the importance of identifying target species and their required habitat when designing wildlife crossings.

It was unexpected that that few gray fox and no red fox were detected in the area since the habitat is suitable and they are both generally urban adaptive animals (Doncaster and Macdonald 1991, Harrison 1997). The habitat in the area adjacent to the Bypass is suitable for both species since a variety of habitats ranging from dense forests to pastures exist in the area. In addition, both species are known to coexist in areas with low densities of coyote but avoid areas with high coyote densities (Voigt and Earle 1983, Chamberlain and Leopold 2005, Farias et al. 2005). Coyote densities may be high in the area based on the high number of coyote tracks detected throughout the study area. In addition, anecdotal evidence in the form of coyote pack howling was detected on numerous occasions throughout the summer field seasons, possibly signaling high densities.

Two species that may have occupied this area prior to construction are black bear (*Ursus americanus*) and moose (*Alces alces*). The presence of a forest dominated landscape and wetlands in the area create favorable habitat for both species (DeVos 1958, Samson and Huot 1998). Anecdotal evidence of their presence was provided during discussions with local landowners and the area game warden. In addition, we identified several bear clawed beech trees in the area, a sign of black bear foraging (Faison and Houston 2004). These observations may support findings by Brody and Pelton (1989) who found that bear attraction or avoidance of roads depends on the amount of threat perceived by them. In public parks where vehicles drive slowly and humans are seen as a food source, bears are attracted to roads, while in areas with heavy traffic roads may be perceived as a threat. It is unknown whether black bear will repopulate the Bypass area. Clevenger and Waltho (2004) observed a slight increase of crossing structure use by black bears over a five-year period in Banff, Canada.

Conclusions

The overall barrier effect created by the road in our study area may be limited for those species we detected through snow-tracking. Conversely, the road may serve as an absolute barrier for several species that appear to avoiding the area altogether (e.g. – black bear, red fox). Although the Bennington Bypass has displaced habitat, altered the vegetative community and landscape processes in the immediate and surrounding areas it occupies, many species still persist and moves readily across the roadway. Many attributes of the structures facilitate movement of animals. The large size of the structures, hence openness ratios (x-section/length (meters), Reed and Ward 1985) for WAB $\geq$ 86.0 and EAB $\geq$ 97.4, far exceed those recommended for carnivores such as Florida panther (*Felis concolor coryi*) (> 0.92) and ungulates such as mule deer

(*Odocoileus hemionus*) (> 0.60) (Reed et al. 1982, Foster and Humphrey 1995). In addition to their large size, they span riparian areas, thereby encompassing the some of the most diverse, dynamic and complex biophysical habitats in terrestrial zones (Naiman et al. 1993). As with many other highway mitigation projects (Hardy et al. 2004), pre-construction surveys and specific conservation objectives were not incorporated into the planning process for Bennington Bypass. Yet, the size and location of these structures appear to be providing safe movement for a variety of wildlife species.

Management Implications

Our snow-tracking study provided a useful means for evaluating the overall effectiveness of the Bennington Bypass wildlife crossing structures and has applicability for transportation and wildlife professionals nationwide. A major benefit of snow-tracking is the ability to monitor a large number of continuous sets of animal tracks. Methods such as track beds and remote cameras are useful for determining species use of crossing structures, but provide limited data when evaluating behavioral responses to the structures and use of the surrounding landscape. Snow-tracking is a low cost alternative to telemetry, especially for the smaller study areas associated with crossing structure monitoring. The sample size collected for the effort is quite significant for snow-tracking, relative to the effort required for a similar sample size for a telemetry study.

Although an excellent monitoring technique, snow-tracking provides only winter movement of animals, which may differ from movements during other times of the year. For example, Tierson and colleagues (1985) found that female deer in New York expanded their home ranges in summer and that home range fidelity for both sexes was less pronounced in winter. Parker and Maxwell (1989) studied coyote in New Brunswick and found that their movement patterns changed seasonally from movement through open, mature deciduous-dominated forests in summer to a shift to moving through mature conifer stands in winter. The game trail used heavily in our study area by coyote is dominated by a large stand of eastern white pine (*Pinus strobus*) on the south side of the highway which may explain their heavy use of this area. Litvaitis and colleagues (1987) radio collared bobcat in Maine and found that their movement patterns varied seasonally and was primarily driven by prey availability, predominantly snowshoe hare (*Lepus americanus*).

During non-winter seasons and in warmer climates lacking snow, similar kinds of movement data can still be derived from combining track beds at crossing structures and along roadsides with other approaches like motion-sensing cameras and telemetry. Roadside track beds have great potential in areas where rain is limited. During our 2007 summer field season we experimented with use of roadside track beds constructed of pond-fill, an excellent tracking substrate. We placed pairs of track beds on opposite sides of the road at random areas in order to detect road crossings. The construction and maintenance of them required extensive labor. The maintenance labor may have been lessened if rain was not consistently washing out much of the substrate. Over time, the amount of data collected per man hour became uneconomical.

Our study underlines the importance of developing objectives and the incorporation of landscape scale monitoring when planning mitigation projects. If the goal is to prevent animals' exposure to vehicle collisions, our data suggest these crossing structures are not fully effective. If, alternatively, the primary goal is to enhance permeability of the roadway, allowing a portion of each species' population to cross, then these structures appear to be effective for the species we detected. Greater information on the demographics and population trends of particular species are needed, however, to identify the minimum numbers of crossings per species to maintain population viability and likely effects of road kill on population persistence. In addressing any of these conservation objectives, monitoring should be conducted at a landscape scale, assessing both use and non-use of structures.

Literature Cited

Allen, C.H., R.L. Marchinton, and W. M. Lentz. 1985. Movement, habitat use and denning of opossums in the Georgia piedmont. American Midland Naturalist 113:408-412.

Alexander, S. M., P. C. Pacquet, T. B. Logan, and D. J. Saher. 2005[a]. Snow-tracking versus radiotelemetry for predicting wolf-environment relationships in the Rocky Mountains of Canada. Wildlife Society Bulletin 33:1216-1224.

Alexander, S.M., N.M. Waters, and P.C. Paquet. 2005[b]. Traffic volume and highway permeability for a mammalian community in the Canadian Rocky Mountains. The Canadian Geographer 49:321-331.

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

Baofa, Y., H. Huyin, Z. Yili, Z. Le, and W. Wanhong. 2006. Influence of the Qinghai-Tibetan railway and highway activities of wild animals. Acta Ecologica Sinica 26:3917-3923.

Barrette, C., and F. Messier. 1980. Scent marking in free ranging coyotes, *Canis latrans*. Animal Behaviour 28:814-819.

Beauvais, G. P., and S. W. Buskirk. 1999. An Improved Estimate of Trail Detectability for Snow-Trail Surveys. Wildlife Society Bulletin 27:32-38.

Bennett, A.F. 1991. Roads, roadsides, and wildlife conservation: a review. Pages 99-118 *in* D.A. Saunders and R.J. Hobbs, editors. Nature Conservation 2: The Role of Corridors. Surrey Beatty & Sons, London. UK.

Beyer, H. L. 2004. Hawth's Analysis Tools for ArcGIS. Available at http://www.spatialecology.com/htools

Bonesi, L., and D. W. Macdonald. 2004. Differential habitat use promotes sustainable coexistence between the specialist otter and the generalist mink. Oikos 106:509-519.

Brody, A. J., and M. R. Pelton. 1989. Effects of roads on black bear movements in western North Carolina. Wildlife Society Bulletin 17:5-10.

Brudin, C. O.. 2004. Wildlife use of existing culverts and bridges in north central Pennsylvania. Pages 344-352 Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-29 August 2003, Lake Placid, NY, USA.

Burgess, S. A., and J. R. Bider. 1980. Effects of stream habitat improvements on invertebrates, trout populations, and mink activity. Journal of Wildlife Management 44:871-880.

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

Chamberlain, M. J., and B. D. Leopold. Overlap in space use among bobcats (Lynx rufus), coyotes (Canis latrans) and gray foxes (*Urocyon cinereoargenteus*). The American Midland Naturalist 153:171-179.

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 263-277 *in* Proceedings of the Third International Conference on Wildlife Ecology and Transportation. 13-16 September 1999, Missoula, MT, USA.

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.E. Gunson. 2001[a]. Drainage culverts as habitat linkages and factors affecting passage by mammals. Journal of Applied Ecology 38:1340-1349.

Clevenger, A.P., B. Chruszcz, and K.E. Gunson. 2001[b]. Highway mitigation fencing reduces wildlife-vehicle collisions. Wildlife Society Bulletin. 29:646-653.

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. 2004. Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies. Pages 293-302 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-29 August 2003, Lake Placid, NY, USA.

Cramer, P. C. and J. A. Bissonette. 2005. Wildlife crossings in North America: The state of the science and practice. Pages 442-447 *in* Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment. 29 August – 2 September 2003, Lake Placid, NY, USA.

DeGraaf, R. M., and M. Yamasaki. 2001. New England Wildlife: Habitat, Natural History and Distribution. University Press of New England, Lebanon, NH.

De Santo, R.S. and D.G. Smith. 1993. Environmental auditing: an introduction to issues of habitat fragmentation relative to transportation corridors with special reference to high-speed rail (HSR). Environmental Management 17:111-114.

DeVos, A. 1958. Summer observations on moose behavior in Ontario. Journal of Mammalogy 39:128-139.

Dodd, N. L., J. W. Gagnon, S. Boe, and R. E. Schweinsburg. 2007. Assessment of elk highway permeability by using global positioning system telemetry. Journal of Wildlife Management 71:1107-1117.

Doncaster, C. P., and D. W. Macdonald. 1991. Drifting territoriality in the red fox *Vulpes vulpes*. The Journal of Animal Ecology 60:423-439.

Erlinge, S.. 1969. Food habits of the otter Lutra lutra L. and the mink Mustela vison schreber in a trout water in southern Sweden. Oikos 20:1-7.

Fahrig, L., and G. Merriam. 1985. Habitat patch connectivity and population survival. Ecology 66:1762-1768.

Faison, E. K., and D. R. Houston. 2004. Black bear foraging in response to beech bark disease in northern Vermont. Northeastern Naturalist 11:387-394.

Farias, V., T. K. Fuller, R. K. Wayne, and R. M. Sauvajot. 2005. Survival and cause-specific mortality of gray foxes (*Urocyon cinereoargenteus*) in southern California. Journal of Zoology 266:249-354.

Fedak, M., P. Lovell, B. McConnell, and C. Hunter. 2002. Overcoming the constraints of long range radio telemetry from animals: Getting more useful data from smaller packages. Integrative and Comparative Biology 42:3-10.

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

Foresman, K. R.. 2004. The effects of highways fragmentation of small mammal populations and modifications of crossing structures to mitigate such impacts. Final report for Montana Department of Transportation. Helena, MT.

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

Gordon, K. M., and S. H. Anderson. 2004. Mule deer use of underpasses in western and southeastern Wyoming. Pages 309-318 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-29 August 2003, Lake Placid, NY, USA.

Grinder, M.I., and P.R. Krausman. 2001. Home range, habitat use, and nocturnal activity of coyotes in an urban environment. The Journal of Wildlife Management 65:887-898.

Hardy, A., A. P. Clevenger, and M. Huijser. 2004. An overview of methods and approaches for evaluating the effectiveness of wildlife crossing structures: Emphasizing the science in applied sciences. Pages 319-330. *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-29 August 2003, Lake Placid, NY, USA.

Harrison, R. L.. 1997. A comparison of gray fox ecology between residential and undeveloped rural landscapes. Journal of Wildlife Management 61:112-122.

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.

Jackson, S.D. and T.F. Tyning. 1989. Effectiveness of drift fences and tunnels for moving spotted salamanders Ambystoma maculatum under roads. pp. 93-99 *In* T.E.S. Langton (ed.) Amphibians and Roads, proceedings of the toad tunnel conference. ACO Polymer Products, Shefford, England.

Jackson, S.D. 1999. Overview of transportation related wildlife problems. Pages 1-4 *in* Proceedings of the Third International Conference on Ecology and Transportation. Center for Transportation and the Environment. 13-16 September 1999, Missoula, MY, USA.

Jackson, S. D., and C. R. Griffin. 2000. A strategy for mitigating highway impacts on wildlife. Wildlife and Highways: Seeking solutions to an ecological and socio-economic dilemma. The Wildlife Society. Bethesda, MD.

Jackson, S. D.. 2004. Ecological Considerations in the Design of River and Stream Crossings. Pages 20-29 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-29 August 2003, Lake Placid, NY, USA.

Land, D., and M. Lotz. 1996. Wildlife crossing designs and use by Florida panthers and other wildlife in southwest Florida. Pages 323-328 *in* Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment. June 1996, Tallahassee, FL, USA.

Litvaitis, J. A., J. T. Major, and J. A. Sherburne. 1987. Influence of season and human-induced mortality on spatial organization of bobcats (*Felis rufus*) in Maine. Journal of Mammalogy 68:100-106.

Lovallo, M. J., and E. M. Anderson. 1996. Bobcat movements and home ranges relative to roads in Wisconsin. Wildlife Society Bulletin 24:71-76.

Madison, D. M., R. W. Fitzgerald, and W. J. McShea. 1984. Dynamics of social nesting in overwintering meadow voles (*Microtus pennsylvanicus*): possible consequences for population cycling. Behavioral Ecology and Sociobiology 15:9-17.

Melquist, W. E., and M. G. Hornocker. 1983. Ecology of river otters in west central Idaho. Wildlife Monographs 60p.

McCoy, K.. 2005. Effects of transportation and development on black bear movement, mortality, and use of the Highway 93 corridor in NW Montana. Masters Thesis. University of Montana, Missoula. 142 pp.

Naiman, R. J., H. Decamps, and M. Pollock. 1993. The Role of Riparian Corridors in Maintaining Regional Biodiversity. Ecological Applications 3:209-212.

Ng, S. J., J. W. Dole, R. M. Sauvajot, S. P. D. Riley and T. Valone. 2004. Use of highway undercrossings by wildlife in southern California. Biological Conservation 115:499-507.

Parker, G. R., and J. W. Maxwell. 1989. Seasonal movements and winter ecology of the coyote, *Canis latrans*, in northern New Brunswick. Canadian Field-Naturalist 103:1-11.

Powell, R. A.. 1994. Effects of Scale on Habitat Selection and Foraging Behavior of Fishers in Winter. Journal of Mammalogy 75:349-356.

Prange, S., S. D. Gehrt, and E. P. Wiggers. Demographic Factors Contributing to High Raccoon Densities in Urban Landscapes. Journal of Wildlife Management 67:324-333.

Reed, D. F., T. D. I. Beck, and T. N. Woodard. 1982. Methods of Reducing Deer-Vehicle Accidents: Benefit-Cost Analysis. Wildlife Society Bulletin 10:349-354.

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

Riley, S. P. D., J. P. Pollinger, R. M. Sauvajot, E. C. York, C. Bromley, T. K. Fuller and R. K. Wayne.. 2006. A southern California freeway is a physical and social barrier to gene flow in carnivores. Molecular Ecology 15:1733-1741.

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

Rondinini, C., and C. P. Doncaster. 2002. Roads as barrier to movement for hedgehogs. Functional Ecology 16:504-509.

Samson, C., and J. Huot. 1998. Movements of female black bears in relation to landscape vegetation type in southern Quebec. Journal of Wildlife Management 62:718-727.

Sanderson, E. W., K. H. Redford, A. Vedder, P. B. Coppolillo, and S. E. Ward. 2002. A conceptual model for conservation planning based on landscape species requirements. Landscape and Urban Planning 58:41-56.

Singleton, P.H., and Lehmkuhl, J. F.. 1999. Assessing wildlife habitat connectivity in the Interstate 90 Snoqualmie Pass corridor, Washington. Pages 75-84 *in* Proceedings of the Third International Conference on Ecology and Transportation. Center for Transportation and the Environment. 13-16 September 1999, Missoula, MY, USA.

Schauster, E.R., E.M. Gese, and A.M. Kitchen. 2002. An evaluation of survey methods for monitoring swift fox abundance. Wildlife Society Bulletin 30:464-477.

Spackman, S. C., and J. W. Hughes. 1995. Assessment of minimum stream corridor width for biological conservation: Species richness and distribution along mid-order streams in Vermont, USA. Biological Conservation 71:325-332.

Tierson, W. C., G. F. Mattfield, R. W. Sage Jr., and D. F. Bahrend. Seasonal movements and home ranges of white-tailed deer in the Adirondacks. Journal of Wildlife Mangement 49:760-769.

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

Trombulak S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

Voight, D. R., and B. D. Earle. 1983. Avoidance of coyotes by red fox families. Journal of Wildlife Management 47:852-857.

Weckerly, F.W., and M.A., Ricca. 2000. Using presence of sign to measure habitats used by Roosevelt elk. Wildlife Society Bulletin 28:146-153.

Witmer, G. W., S. K. Martin, and R. D. Sayler. 1998. Forest carnivore conservation and management in the interior Columbia basin: issues and environmental correlates. Gen. Tech. Rep. PNW-GTR-420. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 51 p. (Quigley, Thomas M., ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

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.

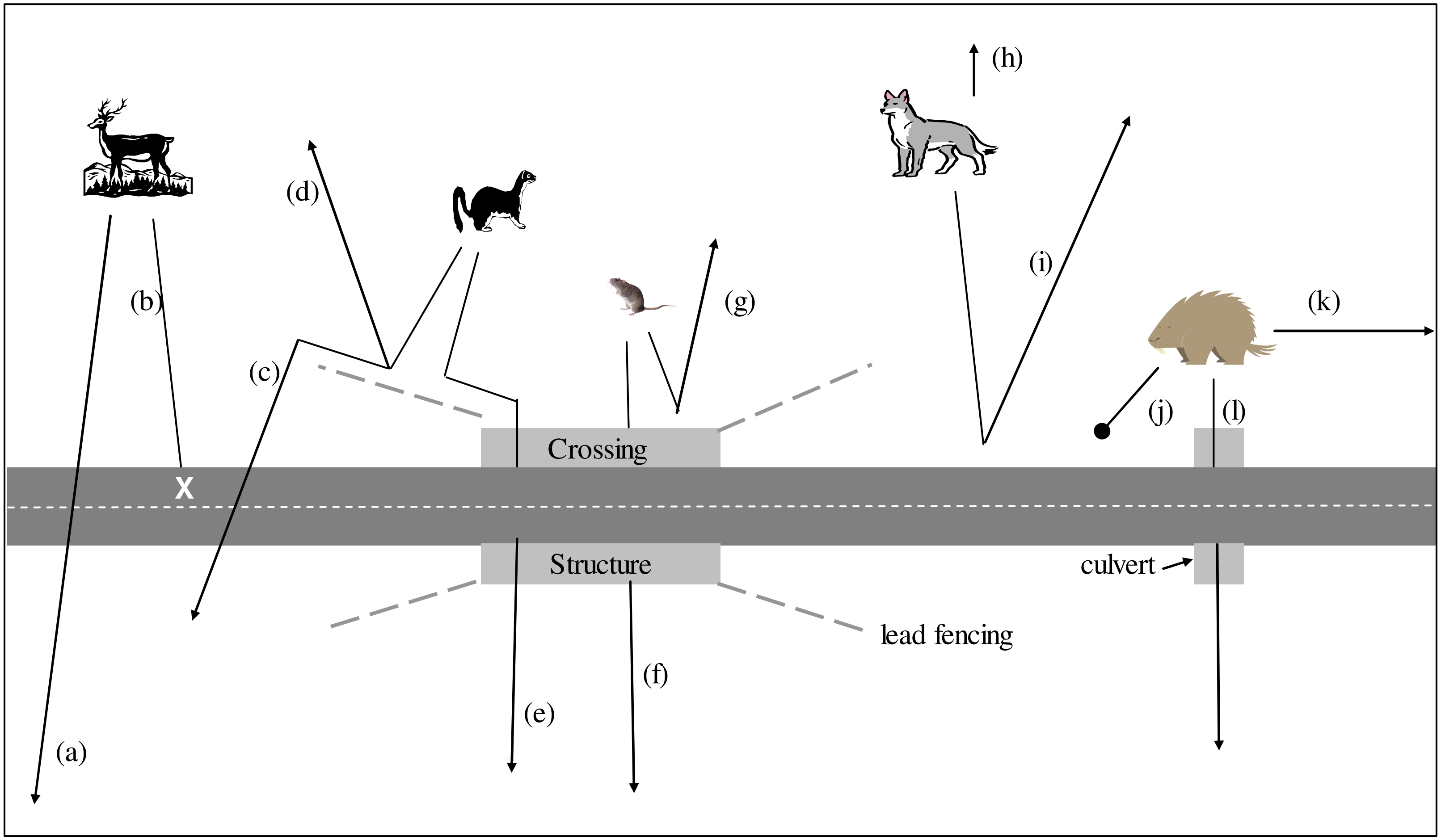

Figure 3.1. Potential wildlife movements relative to roadway and crossing structures (illustrations representative of ALL species) Key: **(a)** move successfully across the roadway, **(b)** vehicle collision, **(c)** approach lead fencing, moving away from crossing structure around lead fencing , **(d)** approach lead fencing and move away from roadway, **(e)** approach lead fencing and move successfully through crossing structure, **(f)** move through crossing structure directly, **(g)** approach and avoid crossing structure, **(h)** avoid roadway entirely, **(i)** approach and avoid roadway, **(j)** utilize right of way and **(k)** move parallel to roadway, **(l)** successful crossing through culvert

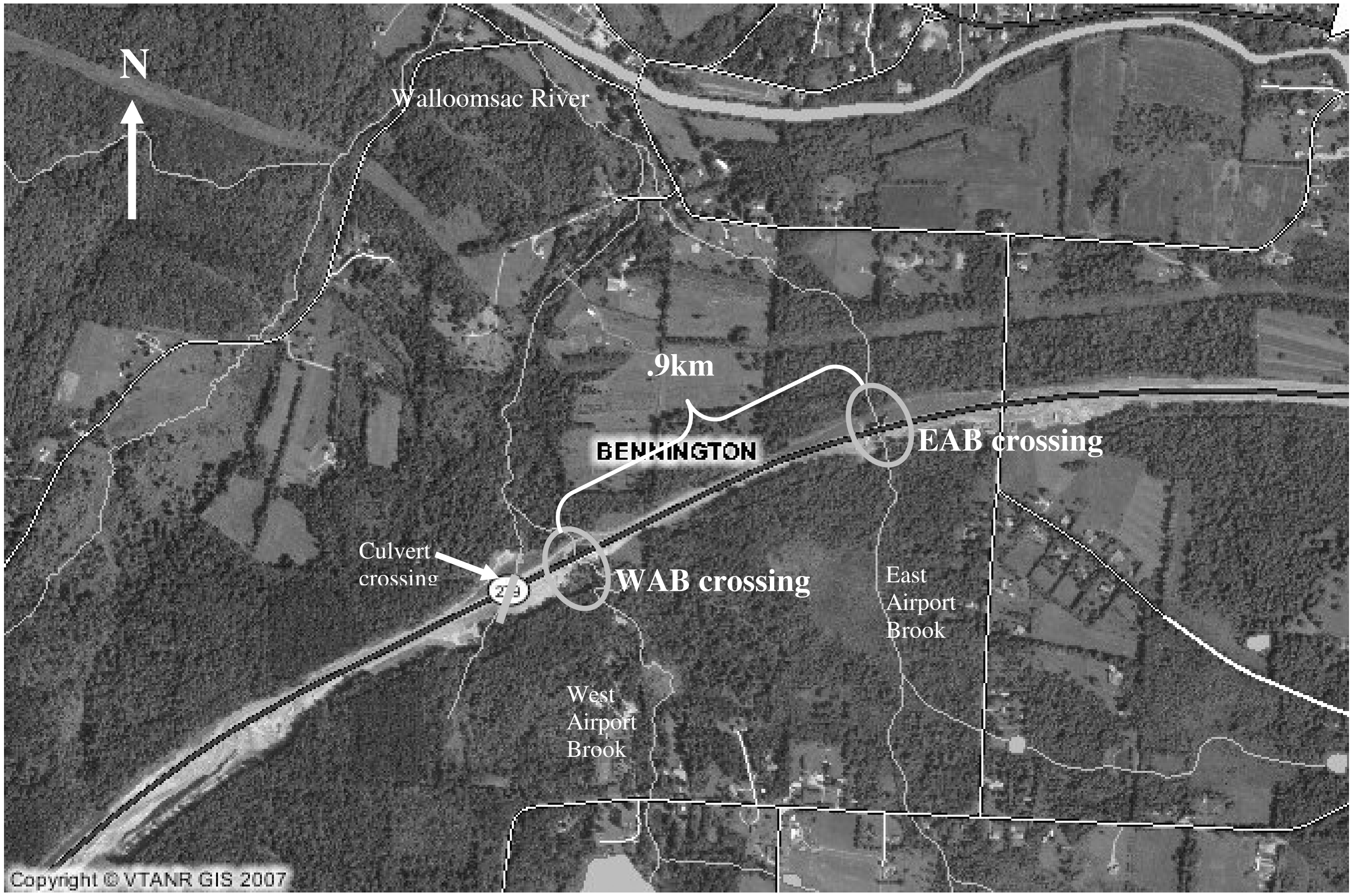

Figure 3.2. Location of three crossing structures along the 7 km long Highway 279 (Bennington Bypass). Bennington, VT.

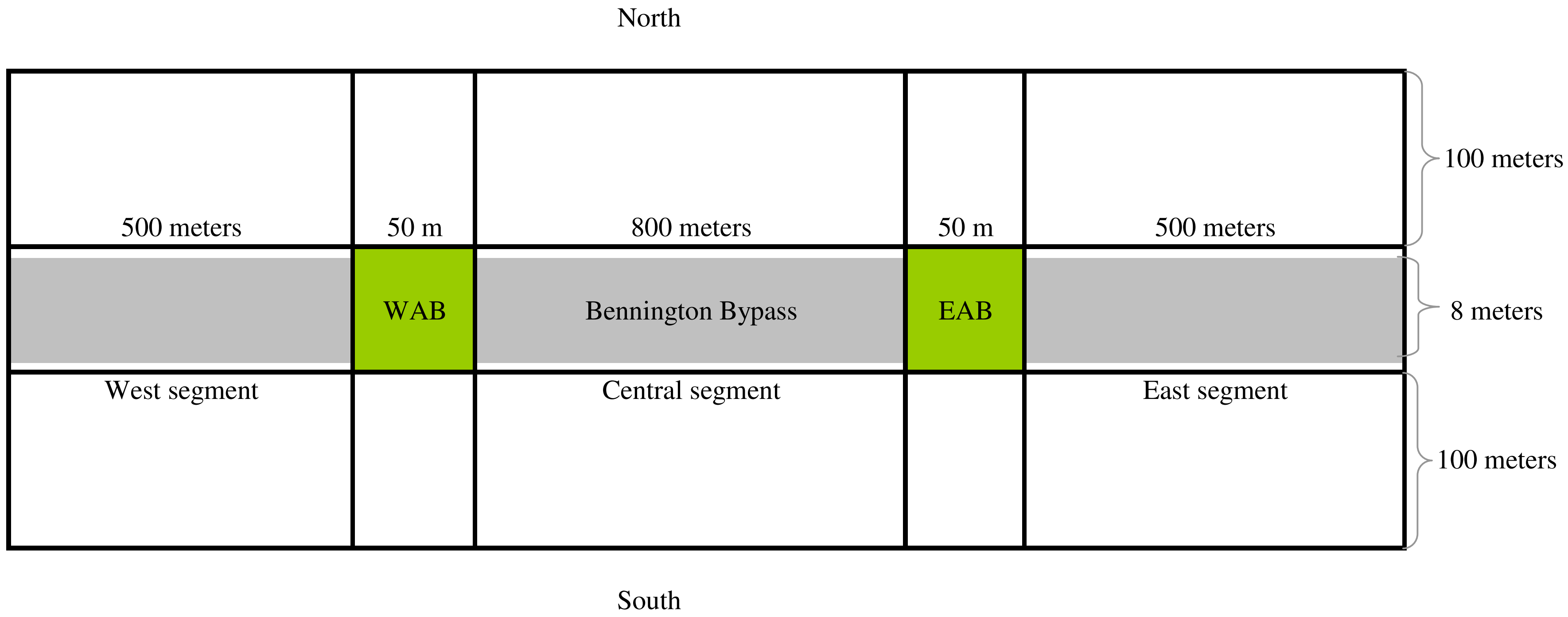

Figure 3.3. Snow-tracking grid at Highway 279, Bennington, VT

Table 3.1. Number of movements detected for each species. Tracking conducted January 2006 to February 2007 in Bennington, VT. See Fig. 1 for definitions of movement types. Deer and domestic cat are listed separately because only crossing data were collected for these species. NI = Pattern Not Identifiable.

	Movement											
Species	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**NI**	**Totals**
Coyote	29	0	2	2	2	6	1	8	4	2	11	18	85
Bobcat	6	0	2	0	0	3	0	4	1	0	1	9	28
Mink	0	0	0	0	1	8	0	0	0	0	1	6	16
Fisher	1	0	1	0	1	1	0	3	0	0	4	3	14
Long-tailed weasel	2	0	0	0	0	2	0	0	0	0	0	4	8
River otter	0	0	0	0	0	3	0	0	0	0	0	3	6
Gray fox	0	0	0	0	0	0	1	0	1	0	0	2	4
Raccoon	1	0	0	0	0	2	0	0	0	0	0	0	1
	39	0	5	2	4	25	2	15	6	2	17	45	162
WT deer	11	-	-	-	-	33	-	-	-	- -	-	-	
Domestic cat	2	-	-	-	-	6	-	-	-	- -	-	-	

[a] Movement not used in analysis.

Table 3.2. Permeability analysis. Values = movements across roadway/movements along or away from roadway. Higher values suggest higher degrees of permeability. Movements correspond to patterns defined in Figure 1. Bennington, VT, 2005/06 and 2006/07 winter field seasons.

	Movements														
	Across Roadway						Along or Away from Roadway								
Species	A	C	E	F	L	Totals	B	D	G	H	I	J	K	Totals	Value
Coyote	29	2	2	6	0	39	0	2	1	8	4	2	11	28	1.39
Bobcat	6	2	0	3	0	11	0	0	0	4	1	0	1	6	1.83
Mink	0	0	1	8	0	9	0	0	0	0	0	0	1	1	9
Fisher	1	1	1	1	0	4	0	0	0	3	0	0	4	7	0.57
Long-tailed weasel	2	0	0	2	0	4	0	0	0	0	0	0	0	0	4
River otter	0	0	0	3	0	3	0	0	0	0	0	0	0	0	3
Gray fox	0	0	0	0	0	0	0	0	1	0	1	0	0	2	0
Raccoon	1	0	0	2	0	3	0	0	0	0	0	0	0	0	3
	39	5	4	25	0	73	0	2	2	15	6	2	17	44	1.66

Table 3.3. Analysis of road vs. structure crossings for 2005/06 and 2006/07 field seasons using chi-square goodness of fit, with expected probabilities (EP) weighted by number of nights since snowfall (NSS). Highway 279, Bennington, VT, USA.

	2005/06			**2006/07**			**Totals**	
	NSS = 42 EP = .60	NSS = 28 EP = .40		NSS = 23 EP = .62	NSS = 14 EP = .38		NSS = 65 EP = .61	NSS = 42 EP = .39
	N road crossings	crossings crossings	*P*	N road crossings	crossings crossings	*P*	N road crossings	N structure crossings
Coyote	23	6	**0.034**	8	2	0.241	31	8
Bobcat	6	0	**0.046**	4	3	0.791	10	3
Mink	0	7	**0.001**	0	2	0.071	0	9
Fisher	1	2	0.346	1	0	0.434	2	2
Long-tailed weasel	2	0	0.248	0	2	0.071	2	2
River otter	0	3	**0.034**	0	0	n/a	0	3
Raccoon	1	0	0.414	0	2	0.071	1	2
Domestic cat	0	0	n/a	2	6	**0.031**	2	6
White-tailed deer	9	12	0.109	2	21	**< .000**	11	33
Overall	42	30	0.773	17	38	**< .000**	59	68

CHAPTER 4

USE OF ROAD KILL SURVEYS TO DETERMINE EFFICACY OF WILDLIFE CROSSING STRUCTURES AND IMPACTS OF TRAFFIC VOLUME ON WILDLIFE MORTALITY

Abstract

Wildlife/vehicle collisions (WVC) represent one of the most direct impacts that road systems have on both wildlife and people. These collisions yield human costs in property damage and bodily injury or even death, and a cost to wildlife through elevated mortality rates. Wildlife crossing structures are being constructed as a means to mitigate WVCs and other road impacts. We used road kill surveys to determine the efficacy of two wildlife crossing structures at the Bennington Bypass in southern Vermont in addition to determining correlations between traffic volume and road kill numbers. We tested the hypothesis that road kill numbers would be positively correlated with increasing distances from the structures and with increasing traffic volumes. We found that road kill numbers do not vary with distance from the crossing structures. There was also only a slight positive correlation between average daily traffic (ADT) and number of road kill. We discuss several possible causes for the apparent lack of road kill reduction associated with the crossing structures.

Introduction

Roadways represent one of the most widespread forms of landscape modification that have persisted over the past century (Noss and Cooperider 1994). Although roads only cover about 1% of the U. S. landmass, they impact up to twenty times that area (Forman 2000). Roads impose ecological effects on both vegetative and wildlife communities (Forman et al. 2003). Impacts on wildlife include direct loss and fragmentation of habitat, modification of behaviors and road mortality (Andrews 1990, Trombulak and Frisselll 2000). A variety of strategies have been used with mixed success to mitigate the impacts of highway systems on wildlife.

The most direct impact of highways is vehicle collisions with wildlife, which can lead to death of animals and safety issues for people. Wildlife/vehicle collisions (WVCs) can result in extensive vehicular damage, often leading to serious injury or fatalities for people. Most WVC data available addresses deer-vehicle collisions (DVC), estimated at between 720,000 and 1.5 million annually (Conover 1997, Forman et al. 2003). Approximately 29,000 injuries and 211 human fatalities occur annually in the United States (Conover et al. 1995).

Road kill is the leading direct human cause of vertebrate mortality. Approximately one million vertebrates are killed daily on roads in the United States (Forman and Alexander 1998). Few, if any terrestrial species are immune to roadkill (Trombulak and Frissell 2000). Due to the higher potential for vehicular damage and human injury/fatalities, the focus of most studies of road kill has been on larger ungulates (Bellis and Graves 1971, Lavsund and Sandegren 1991, Romin and Bissonette 1996).

Recent road kill studies cover a wide variety of species ranging from raccoon (*Procyon lotor*; Rolley and Lehman 1992) to green iguanas (*Iguana iguana*; Rodda 1990) to yellow baboons (*Papio cynocephalus linnaeus*; Drews 1995). Because of their need for seasonal movements between different habitats, amphibians may be especially vulnerable to roadkill. Traffic mortality has a significant negative effect on local densities of anurans (Fahrig et al. 1995). The majority of studies on amphibians are conducted in North America and Europe, but more work on this taxa is critical due to the rapid declines of amphibians worldwide (Puky 2006). As research on road kill expands beyond ungulates, so does the variety of approaches taken to mitigate road impacts.

Cramer and Bissonette (2005) reported 460 terrestrial crossing structures in the United States at the time of their review. Wildlife crossing structures have the potential to mitigate the impacts of roads by minimizing road crossings leading to fewer WVCs and reducing animal mortality. The construction of wildlife crossing structures has become more specialized, many now targeting particular species such as: Florida panthers (*Puma concolor coryi*) (Foster and Humphrey 1995), mountain pygmy possum (*Buramys parvus*) (Mansergh and Scotts 1989), and spotted salamanders (*Ambystoma maculatum*) (Jackson and Tyning 1989). Even if the primary goal of species specific crossings is not human safety, it is often considered a valuable byproduct. Conservation goals and safety goals do not have to be mutually exclusive. There is opportunity for collaboration in designing structures that accomplish both safety and conservation goals set forth by transportation and natural resource agencies.

In Vermont, the Agency of Transportation (VTrans) and the Fish & Wildlife Department have been collaborating on wildlife conservation and transportation since 1998 (Austin et al. 2006). As of 2005, Vermont has constructed 9 wildlife crossing structures, two of which are located along the Bennington Bypass (Highway 279) in southern Vermont (Cramer and Bissonette 2006). We evaluated the effectiveness of these structures in reducing mortality of wildlife by using road kill data. We tested whether there is a negative correlation between road kill and proximity to the structures. In addition. we tested whether there is a relationship between traffic volume and road kill.

Study Area

The Bennington Bypass (Hwy. 279) is a 7-km long highway connecting NY Rte. 7 in Hoosick Falls, NY to VT Rte. 7 in Bennington, VT. It is a 2-lane highway with several 3-lane zone passing areas. The Bypass was the first part of a 3-phase highway project designed to move traffic around downtown Bennington. This segment of the highway opened in October 2004 and included two extended bridge wildlife crossing structures.

The Bypass' two extended bridges are constructed over two streams, East Airport Brook and West Airport Brook, which both flow south to north into the Walloomsac River. The two streams are separated by 0.9km and both occur in the eastern half of the 7km long bypass. East Airport Brook is a 2m-wide intermittent stream, whereas the similar-sized West Airport Brook is perennial. The streams within each crossing structure runs off center, closer to the western edges of the bridge openings. The West Airport Brook crossing structure (WAB) is 55m long, 14m wide with a rise varying from 3m at the east abutment to 13m at the stream. A 16m high, 45° stone embankment was constructed at the east abutment of the WAB structure. The side slope of the eastern side of West Airport Brook is moderately vegetated (herbaceous, shrub and sapling vegetation) with a gradual (14°), 2.2m-high slope. In contrast, there is no vegetation on the western slope of the stream which is covered by rip rap and has a steeper (34°), 7.9m-high slope. The East Airport Brook crossing structure (EAB) is 47m long, 14m wide with a rise varying from 12m at the abutments to 18m at the stream. No embankments were constructed at either abutment. The side slopes of East Airport Brook are heavily vegetated and steep on both the east (39°, 11.2m high) and west sides (47°, 9.1m high) of the stream. There is a 0.6 - 2m-wide game trail under the East Airport Brook structure where the slope (27°) is lower. Both overpasses create relatively large crossing structures underneath the highway, with openness ratios (x-section/length (meters), Reed and Ward 1985) for WAB 48.5m and EAB 43m. The long culvert (crossing structure) is located approximately 200m west of WAB. This 1.65m-diameter, 124m-long culvert connects two retention ponds located on either side of the highway. The openness ratio of the culvert is 0.02m.

Fencing occurs along the entire length of the Bennington Bypass. Most of this consists of 1.2m right of way fencing providing a 15.2m buffer of open land adjacent to the roadway, covered in the spring and summer with grasses and wildflowers. The right-of-way fencing transitions to 2.4m lead fencing near each crossing structure entrance, designed to funnel wildlife through the structures. The lead fencing extends approximately 61m from each corner of the crossing structures (4 lead fences per structure). The length and configuration of the fencing differs slightly for each entrance due to topography, variation in vegetation, and the presence of two retention ponds.

Beyond this 15m right-of-way, the majority of property is private land consisting of plots ranging in size between 4 and 48 ha. Houses are sparsely spaced with most located at least 300m from the roadway. The only public land in the vicinity is a 176ha parcel about 1km west of the WAB owned by the State of Vermont (Vermont Fish and Wildlife) that provides wintering habitat for deer. The vegetation community adjacent to the roadway is a Northern hardwoods broad leaf complex dominated by American Beech (*Fagus grandfolia*), Maple (*Acer spp.*) and Eastern hemlock (*Tsuga canadensis*). Much of the understory is dominated by Canada honeysuckle (*Lonicera Canadensis*).

Methods

We conducted road kill surveys along the entire 7km of the bypass three times a week (Mondays, Wednesdays, and Fridays), weather permitting. In 2005 we conducted surveys between 21 June and 26 August, in 2006 between 14 April and 16 October and between 24 April and 15 October in 2007. Driving at 15 mph, each side of the road was scanned continuously, noting all animal carcasses. For each road kill we found, we recorded the species, direction traveling, and location to the tenth of a mile (using odometer readings). We classified road kill into size groupings of small, medium or large animals. We considered small animals to be anything that appeared smaller than a rabbit, medium animals to be anything from rabbit size to coyote (*Canis latrans*) size, and large animals to be white-tailed deer (*Odocoileus virginianus*) size or larger. We classified most snakes as medium and turtles as small animals. We did not incorporate birds into our analysis, since the crossing structures were chiefly designed for terrestrial species.

We used a monthly, road kill per survey (RPS) index (number of road kills/number of surveys) as the smallest sampling unit for our analyses (Table 4.1). We conducted our analyses using groupings of species due to the difficulty in differentiating species when animals are dead and flattened by traffic and to account for variation among observers in species identifications.

We evaluated two hypotheses using Pearson Correlations: 1) that road kill decreases with greater proximity to the crossing structures (i.e. increases with distance away from the structures), and 2) that road kill increases with Average Daily Traffic (ADT) levels. We obtained ADT volumes from the VTrans website (Vermont Agency of Transportation 2004) (Table 4.2). For the distance analysis, we analyzed within year correlations using the raw data and across year correlations using indices, since effort (surveys) differed between years. For the traffic volume analysis we used indices for all calculations since number of surveys varied monthly across all years.

Results

We recorded a total of 1,289 road killed animals during 148 surveys, conducted over three field seasons (2005-07). A total of 128 road killed animals were counted over 18 surveys in 2005, 451 over 68 surveys in 2006, and 710 over 62 surveys in 2007. The majority of the road kill we examined was not identifiable to the level of species. Seventy five percent of the road kill was categorized as small animal.

We found no significant within year correlations between distance from structures and number of road kill for any of the size groups (Table 4.1). For large animals (deer) there was a shift in correlation over time between 2005 ($r = 0.000$, $p = 1.000$) and 2007 ($r = -0.746$, $p = .089$) as well as a trend towards correlation overall ($r = .391$, $p = 0.108$). Results for large animals should be kept in context since sample sizes were small for this group with only six total deer recorded as being killed in our sampling area over 3 years.

We found few significant correlations between road kills and Average Daily Traffic (ADT). We found no correlations in 2005 or 2007 but found positive correlations between medium (r = -0.919, p = 0.003) and large (r = -0.848, p = 0.016) animal road kills and ADT in 2006 (Table 4.2). When correlating data across years we found no correlations for any grouping although there was a trend towards a positive correlation for small animals across years (r = .421, p = 0.092).

Extrapolating from our surveys, we estimate that an average of over 3.9 million animals may be killed daily on US roads. This assumes that each of our exhaustive surveys conducted every 2 days along the 7km stretch of Bypass represents 2 days worth of road kill (mean daily road kill=0.62 animals/km). There are approximately 6.3 million kilometers of public roads in the US, with 80% in rural areas like the area around the Bypass. This yields a total estimate of over 3.1 million animals killed per day on rural highways, with an estimate of 2,325,000 (75%) of these being small animals, 744,000 (24%) medium sized animals, and 31,000 (1%) large animals.

Discussion

We examined road kill as a potential indicator of the effectiveness of wildlife crossing structures. We hypothesized that road kill numbers would decrease with proximity to the structures along a stretch of highway. Although we found no correlation between distance and road kill, this does not mean that the structures are ineffective. Two factors, relatively independent of the presence of the crossing structures, are the most likely contributors to the lack of distance correlation: 1) slope of embankment, and 2) placement of retention ponds.

One of the embankments closest to the structures has only a slight gradient (17°) as compared with much steeper steep slopes (38°) in most areas located farther (>0.5km) from the crossing structures. Steep embankments are found to discourage movements of wildlife towards road surfaces (Goosem et al. 2001). These variations in gradient are probably more influential in determining location of road kill than the presence of the structures.

Construction of retention ponds along the road may also be serving as sources of animals crossing the road, with the proximity of road and pond functioning as an ecological trap for pond-breeding amphibians (Pulliam 1988, Battin 2004). The majority of road kill detected in the study consisted of small animals (75%). Thirty-one percent of these were identified as anurans, the largest identifiable group in our survey. It is likely that a large portion of the unidentified small animals were also anurans. There are three retention ponds adjacent to the roadway, two of which we found heavily populated by eastern American toad (*Bufo a. americanus*), northern spring peeper (*Pseudacris c. crucifer*), gray treefrog (*Hyla versicolor*), bullfrog (*Rana catesbeiana*), green frog (*Rana clamitans melanota*), and wood frog (*Rana sylvatica*). The ponds appeared to provide viable breeding habitat for all of these species. However, the proximity of the ponds to the Bypass (15m) also put many of the animals at risk. Adult frogs and toads may be less susceptible to road kill since they typically migrate away from breeding ponds along similar routes from those which they entered, but juvenile dispersal is much less directed, making them more likely to enter the roadway (Semlitsch 2007). This source-trap dynamic likely accounts for the few trends we found toward a relationship between road kill and proximity to crossing structures.

For larger species such as deer, the number of animals hit by vehicles was relatively low (n = 6) over the three years of surveys, especially when considering the high numbers of deer observed in the area during other portions of our study. Larger animals, and deer in particular, receive a great deal of attention in studies of animal-vehicle collisions, due primarily to their large numbers, high visibility and high potential for causing vehicle damage and personal injury. Based on number of deer observed throughout the area and recorded on cameras during other portions of our study, we believe that many are successfully crossing the road, even with the medium to high traffic volumes along the Bypass. Our findings are consistent with Alexander et al. (2005) who found that permeability for larger fauna, measured by successful road crossings, did not vary significantly with traffic volume. Similarly, Case (1978) found no monthly or annual correlation between ADT and medium and large road killed animals.

One set of data that we excluded from our analyses was information on road killed birds. We found a surprising number of birds (n = 38) during our three years of road kill surveys. Large stretches of the Bennington Bypass are above grade, which puts most of the road surface at tree top level. Thus, the elevated roadway appears to make birds flying from tree to tree across the roadway vulnerable to vehicle collisions, findings supported by Clevenger et al. (2003).

Extrapolating from the surveys we reported here, we estimated 3.1 million road killed animals per day on rural US highways, a much larger estimate than is currently given by other studies. Other current estimates range from 725,000 annually to 1 million daily (White 2007). The majority of studies that have analyzed road kill across taxa group are relatively outdated and based on single-trip road counts (Forman et al. 2003). A multi-taxa study by Stoner (1936) calculated a mean daily road kill rate of 0.09 animals/km across six studies (ranging geographically from Iowa to Massachusetts), significantly lower than the 0.62 animals/km found in our study. A more recent study by Caro and colleagues (2000) found a mean daily road kill rate of 0.005 animals/km for a variety of species, ranging in size from gray squirrel (*Sciurus carolinensis*) to mule deer (*Odocoileus hemionus*), along a rural highway in California. Smaller animals such as amphibians did not appear in the Caro study, while the Stoner study recorded only 1% of the road kills as amphibians, compared to $\geq$31% amphibian road kills in our study. The high number of amphibian road kills in our surveys supports findings by Fahrig et al. (1995) and Carr and Fahrig (2001), whose studies reveal that the high rate of anuran road kills are probably contributing to declines in amphibian populations worldwide, particularly in populated areas. Although the results of these studies vary, the findings emphasize the significant impact of our country's highways on wildlife populations, especially smaller taxa such as amphibians.

Management Implications

Without pre-determined objectives, it is difficult to assess the effectiveness of the crossing structures in reducing road kill. The crossing structures at the Bennington Bypass were not designed to support smaller animals or amphibians, which generally require barrier wall and culvert systems for passage across roads (Dodd et al. 2004). However, the high numbers of road killed animals in this category, 75% of all road kill detected in the study, underlines the importance of considering smaller taxa when mitigating for road impacts.

Many larger animals are also clearly being killed on the Bypass, despite the presence of structures designed mainly with these species in mind. However, results of additional monitoring we conducted (Chapters 2 & 3) suggests that most of the larger species detected in the study area may be using the crossing structures and that the road poses little or no barrier to their movement across the study area. The regular use of the crossing structures likely reduces the number of damaging vehicle collisions, a desirable outcome. Clearly, the structures are mitigating some but not all of the impacts of the Bypass on wildlife and people.

Literature Cited

Alexander, S. M., N. M. Waters, and P. C. Paquet. 2005. Traffic volume and highway permeability for a mammalian community in the Canadian Rocky Mountains. The Canadian Geographer 49:321-331.

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

Austin J.M., K. Viani, F. Hammond, and C. Slesar. 2006. A GIS-based identification of potentially significant wildlife habitats associated with roads in Vermont . Pages 185-196 *in* Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 29 August 2 September 2005, San Diego, CA, USA.

Battin, J.. 2004. When good animals love bad habitats: Ecological traps and the conservation of animal populations. Conservation Biology 18:1482-1491.

Bellis, E. D., and H. B. Graves. 1971. Deer mortality on a Pennsylvania interstate highway. The Journal of Wildlife Management 35:232-237.

Caro, T. M., J. A. Shargel and C. J. Stoner. 2000. Frequency of medium-sized mammal road kills in an agricultural landscape in California. American Midland Naturalist 144:362-369.

Carr, L. W., and L. Fahrig. 2001. Effect of road traffic on two amphibian species of differing vagility. Conservation Biology 15:1071-1078.

Case, R. M.. 1978. Interstate highway road-killed animals: a data source for biologists. Wildlife Society Bulletin 6:8-13.

Clevenger, A. P., B. Chruszcz, and K. E. Gunson. 2003. Spatial patterns and factors influencing small mammal vertebrate fauna road-kill aggregations. Biological Conservation 109:15-26.

Conover, M. R., W. C. Pitt, K. K. Kessler, T. J. DuBow,, and W. A. Sanborn. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. Wildlife Society Bulletin 23:407-414.

Conover, M. R. 1997. Monetary and intangible valuation of deer in the United States. Wildlife Society Bulletin 25:298-305.

Cramer, P.C., and J. A. Bissonette. 2006. Wildlife crossings in North America: the state of the science and practice. IN: Proceedings of the 2005 International Conference on Ecology and Transportation, Eds. Irwin CL, Garrett P, McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 442-447.

Dodd, Jr., C. K., W. J. Barichivich., and L. L. Smith. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation. 118:619-631.

Drews, C.. 1995. Road kills of animals by public traffic in Mikumi National Park, Tanzania, with notes on baboon mortality. African Journal of Ecology. 33:89-100.

Fahrig, L., J. H. Pedlar, S. E. Pope, P. D. Taylor, and J. F. Wagner. 1995. Effect of road traffic on amphibian density. Biological Conservation. 73:177-182.

Forman, T. T. and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecological Systems. 29:207-231.

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

Foster, M. L., and S. R. Humphrey. 1995. Use of Highway Underpasses by Florida Panthers and Other Wildlife. Wildlife Society Bulletin. 23:95-100.

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.

Jackson, S.D. and T.F. Tyning. 1989. Effectiveness of drift fences and tunnels for moving spotted salamanders Ambystoma maculatum under roads. pp. 93-99 *In* T.E.S. Langton (ed.) Amphibians and Roads, proceedings of the toad tunnel conference. ACO Polymer Products, Shefford, England.

Lavsund, S., F. Sandegren. 1991. Moose-vehicle relations in Sweden: a review. Alces. 27:118-126.

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.

Noss, R. F., and A. Y. Cooperider. 1994. *Saving Nature's Legacy*. Island Press, Washington, D. C..

Puky, M.. 2006. Amphibian road kills: a global perspective. IN: Proceedings of the 2005 International Conference on Ecology and Transportation, Eds. Irwin CL, Garrett P, McDermott KP. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 325-338.

Pulliam, H. R.. 1988. Sources, sinks, and population regulation. The American Naturalist. 132:652-661.

Rodda, G. H.. 1990. Highway madness revisited: Roadkilled *Iguana iguana* in the Llanos of Venezuela. Journal of Herpetology. 24:209-211.

Rolley, R. E., and L. E. Lehman. 1992. Relationships among raccoon road-kill surveys, harvests, and traffic. Wildlife Society Bulletin. 20:313-318.

Romin, L. A., and J. A. Bissonette. 1996. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle reservoir, Utah. Great Basin Naturalist. 56:1-11.

Semlitsch, R. D.. 2007. Differentiating migration and dispersal processes for pond-breeding amphibians. Journal of Wildlife Management. 72:260-267.

Stoner, D. 1936. Wildlife casualties on the highways. Wilson Bulletin. 48:276-283.

Trombulak S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Cons. Biol. 14(1):18-30.

Vermont Agency of Transportation (VTrans). 2004. Traffic Data Electronic Publications. <http://www.aot.state.vt.us/Planning/Documents/TrafResearch/Publications/pub.htm>. Accessed 29 March 2008.

White, P. A.. 2007. *Getting up to Speed*: A conservationist's guide to wildlife and highways. Defenders of Wildlife, Washington, D. C..

Table 4.1. Number of road kills and indices for each species group at varying distances for 2005/06/07 field seasons. Index = number road kills/number surveys. P values calculated using Pearson's correlation. Within year comparisons calculated on raw data (same # surveys), across years on normalized data (indices) to account for between year differences in # surveys. Bennington, VT

		Distance from crossing structures (miles)												
		0 - .2		.3 - .4		.5 - .6		.7 - .8		.9 - 1.0		1.1 -1.2		
Size	Year	Index	#	Index	#	Index	#	Index	#	Index	#	Index	#	*P*
	2005	0.50	9	1.17	21	0.94	17	1.28	23	0.56	10	0.28	5	0.733
Small animal[a]	2006	0.41	28	0.40	27	0.49	33	0.47	32	0.37	25	0.47	32	0.861
	2007	1.31	81	0.74	46	0.61	38	0.89	55	0.87	54	0.60	37	0.506
	Average	0.74	39.3	0.77	31.3	0.68	29.3	0.88	36.7	0.60	29.7	0.45	24.7	0.267
	2005	0.00	0	0.06	1	0.00	0	0.06	1	0.00	0	0.06	1	0.503
Medium animal[b]	2006	0.25	17	0.21	14	0.29	20	0.25	17	0.18	12	0.13	9	0.688
	2007	0.26	16	0.26	16	0.34	21	0.24	15	0.18	11	0.10	6	0.221
	Average	0.17	11	0.18	10.3	0.21	13.7	0.18	11	0.12	7.7	0.10	5.3	0.304
	2005	0.00	0	0.00	0	0.00	0	0.06	1	0.00	0	0.06	1	1.000
Large animal[c]	2006	0.01	1	0.00	0	0.00	0	0.01	1	0.01	1	0.00	0	0.138
	2007	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.02	1	0.089
	Average	0.00	0.3	0.00	0	0.00	0	0.02	0.7	0.00	0.3	0.03	0.7	0.108

[a] = smaller than a rabbit, [b] = rabbit to coyote size, [c] = white-tailed deer

Table 4.2. Number of monthly road kills and indices for species groups during 2005/06/07 field seasons. Index = number road kills/number surveys. P values calculated using Pearson's correlation on normalized data (indices). ADT = Average Daily Traffic. Monthly Average Daily Traffic (ADT) for Highway 279, Bennington, VT.

		Month														
		April		May		June		July		August		September		October		
Year	Grouping	#	Index	#	Index	#	Index	#	Index	#	Index	#	Index	#	Index	*P*
	Small					2	0.67	59	5.90	60	12.00					0.152
2005	Medium					0	0.00	1	0.10	5	1.00					0.400
	Large					1	0.33	0	0.00	0	0.00					0.209
	Totals					3	1.00	60	6.00	65	13.00					0.280
	ADT					4,290		4437		4509						
	Small	81	11.57	17	1.89	9	1.13	61	5.08	74	6.17	33	3.00	24	3.43	0.392
2006	Medium	53	7.57	37	4.11	20	2.50	21	1.75	8	0.67	3	0.27	5	0.71	**0.003**
	Large	1	0.14	2	0.22	1	0.13	0	0.00	0	0.00	1	0.09	0	0.00	**0.016**
	Totals	135	19.28	56	6.22	30	3.76	82	6.83	82	6.83	37	3.36	29	4.14	0.085
	ADT	4,426		4,691		4,939		5,245		5,319		5,045		5,259		
	Small	19	6.33	74	6.73	85	8.50	140	12.73	190	21.10	33	4.13	10	2.00	0.282
2007	Medium	11	3.67	37	3.36	57	5.70	17	1.55	22	2.44	9	1.13	2	0.40	0.369
	Large	1	0.33	0	0.00	1	0.10	0	0.00	0	0.00	1	0.13	1	0.20	0.458
	Totals	31	10.33	111	10.09	143	14.30	157	14.28	212	23.54	43	5.38	13	2.60	0.469
	ADT	4,747		4,968		5,198		5,385		7,578		7,170		5,516		

CHAPTER 5

EVALUATING THE EFFECTIVENESS OF WILDLIFE CROSSING STRUCTURES IN MITIGATING ROAD IMPACTS ON SMALL MAMMAL MOVEMENTS

Abstract

Roadways impose a variety of impacts on wildlife, especially small mammals that have limited dispersal capabilities and low probability of surviving highway-crossing attempts. Crossing structures are used to mitigate impacts of roads on wildlife, but these structures are typically intended for large mammals. We assessed whether small mammals are using two extended bridge crossing structures in Bennington, VT. We used mark-recapture monitoring to determine the extent that small mammals moved across the roadway and through the crossing structures. Of 684 small mammals captured and tagged, 378 were recaptured at least once and 138 moved $\geq$65m. We detected only 13 individual small mammals that moved through the two crossing structures and one individual that crossed the roadway away from the structures. The roadway poses a barrier to movements by small mammals and only a few small mammals used the crossing structures to move across the roadway. The steep roadway embankments, large openness ration of structures, and limited natural vegetation at structure openings may reduce the numbers of small mammals moving through the crossing structures.

Introduction

Roadways affect wildlife through direct mortality from vehicles, habitat loss and fragmentation and modification of animal movements. These effects can isolate wildlife populations, thereby disrupting gene flow and metapopulation dynamics (Andrews 1990; Bennett 1991; De Santo and Smith 1993; Jackson 1999; Trombulak and Frissell 2000). Small mammals are particularly affected by these isolating mechanisms due to their low dispersal capabilities and low probability of surviving highway-crossing attempts (Conrey and Mills 2001), and roads may serve as a biological sink where low-quality habitat and greater predator access leads to depleting populations (Forman et al. 2003).

Small mammals play pivotal roles in ecosystem processes as prey for reptilian, avian and mammalian predators, consumers of invertebrates and plants, and dispersers of many plant species (Carey and Johnson 1995). Roads inhibit the movement of small mammals (Oxley et al. 1974), which may lead to local extinctions, social disturbance and morphological divergence (Dickman and Doncaster 1987). Several studies document the effects of roads on small mammals (Adams and Geis 1983, Clark et al. 2001, Kozel and Flaherty 1979, Oxley et al. 1974, McDonald and St. Clair 2004*a*, Forman et al. 2003, Conrey and Mills 2001, Garland and Bradley 1984), but few studies report on the effectiveness of crossing structures to mitigate these impacts. McDonald and St. Clair (2004*a,b*) tested the efficacy of crossing structures for murid rodents in Banff National Park. In Montana, installation of protective tubes increased meadow vole (*Microtus pennsylvanicus*) movements under a highway through a culvert (Foresman 2004). Similarly, Linden (1987) reported that the construction of stump rows facilitated small mammal movements through a viaduct under a highway in Zandheuvel, Netherlands.

We used a mark/recapture study at two wildlife-crossing structures in southern Vermont to determine 1) the extent of small mammal movements across the roadway, and 2) whether small mammals used the crossing structures to move across the roadway.

Study Area

The Bennington Bypass (Hwy. 279) is a 7-km long highway connecting NY Rte. 7 in Hoosick Falls, NY to VT Rte. 7 in Bennington, VT. It is a 2-lane highway with several 3-lane zone-passing areas. The bypass was the first part of a 3-phase highway project designed to move traffic around downtown Bennington. This segment of the highway opened in October 2004 and included three wildlife-crossing structures; two extended bridges and a long culvert.

The Bypass' two extended bridges are constructed over two streams, East Airport Brook and West Airport Brook, which both flow south to north into the Walloomsac River. The two streams are separated by 0.9km and both occur in the eastern half of the 7km long bypass. East Airport Brook is a 2m-wide intermittent stream, whereas the similar-sized West Airport Brook is perennial. The streams within each crossing structure runs off center, closer to the western edges of the bridge openings. The West Airport Brook crossing structure (WAB) is 55m long, 14m wide with a rise varying from 3m at the east abutment to 13m at the stream. A 16m high, 45° stone embankment was constructed at the east abutment of the WAB structure. The side slope of the eastern side of West Airport Brook is moderately vegetated (herbaceous, shrub and sapling vegetation) with a gradual (14°), 2.2m-high slope. In contrast, there is no vegetation on the western slope of the stream which is covered by rip rap and has a steeper (34°), 7.9m-high slope. The East Airport Brook crossing structure (EAB) is 47m long, 14m wide with a rise varying from 12m at the abutments to 18m at the stream. No embankments were constructed at either abutment. The side slopes of East Airport Brook are heavily vegetated and steep on both the east (39°, 11.2m high) and west sides (47°, 9.1m high) of the stream. There is a 0.6 - 2m-wide game trail under the East Airport Brook structure where the slope (27°) is lower. Both overpasses create relatively large crossing structures underneath the highway, with openness ratios (x-section/length (meters), Reed and Ward 1985) for WAB 48.5m and EAB 43m. The long culvert (crossing structure) is located approximately 200m west of WAB. This 1.65m-diameter, 124m-long culvert connects two retention ponds located on either side of the highway. The openness ratio of the culvert is 0.02m.

Fencing occurs along the entire length of the Bennington Bypass. Most of this consists of 1.2m right of way fencing providing a 15.2m buffer of open land adjacent to the roadway, covered in the spring and summer with grasses and wildflowers. The right-of-way fencing transitions to 2.4m lead fencing near each crossing structure entrance, designed to funnel wildlife through the structures. The lead fencing extends approximately 61m from each corner of the crossing structures (4 lead fences per structure). The length and configuration of the fencing differs slightly for each entrance due to topography, variation in vegetation, and the presence of two retention ponds.

Beyond this 15m right-of-way, the majority of property is private land consisting of plots ranging in size between 4 and 48 ha. Houses are sparsely spaced with most located at least 300m from the roadway. The only public land in the vicinity is a 176ha parcel about 1km west of the WAB owned by the State of Vermont (Vermont Fish and Wildlife) that provides wintering habitat for deer. The vegetation community adjacent to the roadway is a Northern hardwoods broad leaf complex dominated by American Beech (*Fagus grandfolia*), Maple (*Acer spp.*) and Eastern hemlock (*Tsuga canadensis*). Much of the understory is dominated by Canada honeysuckle (*Lonicera Canadensis*).

Methods

We used Sherman live traps (n = 226) to capture small mammals adjacent to the two crossing structures. Fourteen 500m-long transects were established parallel to the roadway with four transects on each side of the West Airport Brook (WAB) crossing structure and three transects on each side of the East Airport Brook (EAB) structure (Fig. 5.1). A wetland and limited access to private property reduced the number of transects used at EAB. Transects were spaced 50m apart into the adjacent forest. During part of the first field season in 2006 (31 May – 14 Aug), the first transect was placed in the adjacent forest 50m from the roadway. For the last part of the 2006 field season and the entire 2007 field season, this first transect was moved closer to the roadway to align with the forest edge (~ 35m from the roadway). Traps were set at 25m intervals along each transect, except for the 50m-wide area directly adjacent to the crossing structure where we placed traps 10m apart during trapping periods.

With four sets of trap transects (one on each side of the two crossing structures), we attempted to trap for two to three nights in each set of transects monthly depending on weather conditions. We chose this long interval between trap sessions within a set of transects to reduce the potential for “trap-happy” or “trap-shy” animals (Sheppe 1967, Renzulli et al. 1980, Menkens and Anderson 1988).

We baited traps with peanut butter and supplied cotton for nesting material, and placed them at habitat features (i.e. logs, trees, burrows) within 1m of each trapping point in the late afternoon. Captured animals are identified, sexed, aged, marked with metal ear tag (if unmarked), tag number and station number were recorded, and the animal released at the capture location. We were unable to reliably distinguish between deer mice

(*Peromyscus maniculatus*) and white-footed mice (*Peromyscus leucopus*) in the field, thus we recorded these two species as *Peromyscus* spp. Similarly, we were unable to identify the species of jumping mice captured, so they were recorded as *Zapodidae*. Traps were checked daily (mornings) and traps containing animals were re-baited. All traps were collected at the end of each trapping session to reduce habituation to traps.

WE calculated distance traveled by calculating distances between recaptures. For animals with multiple recaptures we used the longest distance traveled of all recaptures. We also evaluated the effect of time on distance traveled by grouping recaptures into one of five "time between capture" categories: < 1 week, 1 – 2 weeks, 2 – 4 weeks, > 4 weeks, and > 1 year. We used the Pearson correlation to test for a relationship between time and distance traveled.

Results

We trapped and tagged 690 small mammals over 48 trapping sessions during the 2006 (n = 28 sessions, 31 May – 17 Oct) and 2007 (n = 20 sessions, 8 Jun – 17 Oct) field seasons (Table 5.1). *Peromyscus* spp. were captured most frequently (92%) followed by southern red-backed voles (*Clethrionomys gapperi*)(6%), eastern chipmunks (*Tamias striatus*) (1%) jumping mice (family *Zapodidae*)(< 1%) and meadow vole (*Microtus pennsylvanicus*)(< 1%) . Several other small mammal species were captured including, northern short-tailed shrews (*Blarina brevicauda*)(n = 127), red squirrels (*Tamiasciurus hudsonicus*)(n = 6), long-tailed weasels (*Mustela frenata*)(n = 5) and ermine (*Mustela erminea*)(n = 4). Of the 690 animals tagged, 55% (n = 378) were recaptured at least once. The recapture rate was slightly higher in 2006 (57%) than in 2007 (52%). On average, recaptured animals were trapped 2.74 times, totaling 1,043 recaptures with average recapture numbers slightly higher in 2007 (3.02) than in 2006 (2.62).

We detected 26 structure crossings by 13 individual *Peromyscus* spp. for the two field seasons, 18 at WAB and 8 at EAB (Table 5.1), and one road crossing by a *Peromyscus* spp. Based upon the longest distance traveled for each individual recaptured, over 36% of *Peromyscus* spp. (n = 138) moved distances ≥ 65m, the minimum distance needed to move between the two adjacent forest edges through one of the crossing structures. The 13 animals detected moving through the crossing structures represent 4.7% of recaptured animals. There was strong positive correlation between distance traveled and time between recaptures for all small mammals in 2006 ($r = 0.239$, $n = 232$, $p = < 0.001$) and 2007 ($r = 0.326$, $n = 149$, $p = < 0.001$) (Table 5.2).

Discussion

The road as a barrier to movement

The numbers of small mammals crossing the roadway through the crossing structures (n = 13) or across the roadway (n = 1) is small when compared to the 138 small mammals that moved ≥ 65m during the two field seasons. These low crossing numbers suggest that the roadway poses a barrier to *Peromyscus* spp. movements. However, it is important to consider that animals moving through crossing structures must move in a specific direction, encompassing an arc of approximately 40°. This contrasts with animals recaptured within interior portions of our trap grid that can move in any direction. Thus, the recapture probability is lower for animals moving from the periphery of the trap grid.

Several factors may be restricting small mammal movements across the road surface, including: steep embankments along the roadway, grassy vegetative communities in the 50m-wide right-of-way (ROW) on both sides of the roadway, and the wide expanse of asphalt where northern hardwood forests once occurred. However, Adams and Geiss (1983) reported higher densities of small mammals in grassy ROWs, but increased instances of road-killed animals along roadways. In our study area, the grassy ROW probably provided more favorable habitat for meadow voles but would be an atypical habitat for white-footed mice (Grant 1971, Choate 1973, Kaufman and Flaherty 1974). Kozel and Fleharty (1979) reported that white-footed mice were reluctant to venture onto road surfaces when distances between forest edges exceeded 20m. Although deer mice are known to occupy the grassy habitats similar to that created by ROWs, they generally prefer bushy areas and woodlands (King 1968). Further, the extremely large openness ratios (structure width x height/length) (EAB $\geq$ 97.4, WAB $\geq$ 86.3) of the two crossing structures we studied may inhibit small mammal movements. Openness ratio recommendations for mule deer (0.6) and Florida panther (*Puma concolor pumyi*) (0.92) are substantially smaller for these two large mammals (Reed and Ward 1985, Foster and Humphrey 1995). McDonald and St. Clair (2004*b*) found that small mammals, including three of the species found in our study area (deer mouse, meadow and red-backed voles), had much higher success moving through smaller than larger crossing structures which they attributed to greater overhead cover in the smaller structures. Further, the entrances to the two crossing structures in our study had limited natural vegetation, another factor limiting crossing structure use in the report by McDonald and St. Clair (2004*b*).

Impacts of trapping grid arrangement and intensity on small mammal movements

We believe that our trap grid design using multiple long transects (500m) provides an optimal design for recording small mammal movements associated with roadways and crossing structures. Further, the strong positive correlation between time and distance moved in our study suggests that trapping periods need to be long to capture the full extent of dispersal movements.

Literature Cited

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.

Bennett, A.F. 1991. Roads, roadsides, and wildlife conservation: a review. Pp. 99-118 *In* D.A. Saunders and R.J. Hobbs, editors. Nature Conservation 2: The Role of Corridors. Surrey Beatty & Sons, London, UK.

Carey, A. B. and M. L. Johnson. 1995. Small mammals in managed, naturally young and old growth forests. Ecological Applications 5:336-352.

Choate, J. R.. 1973. Identification and recent distribution of white-footed mice (*Peromyscus leucopus*) in New England. Journal of Mammalogy 54:41-49.

Clark, B. K., B. S. Clark, L. A. Johnson, and M. T. Haynes. 2001. Influence of roads on movements of small mammals. The Southwestern Naturalist 46:338-344.

Conrey, R. C., and L. S. Mills. 2001. Do highways fragment small mammal populations? Pages 448-457 *in* Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-28 September 2001, Keystone, CO, USA.

De Santo, R.S. and D.G. Smith. 1993. Environmental auditing: an introduction to issues of habitat fragmentation relative to transportation corridors with special reference to high-speed rail (HSR). Environmental Management 17:111-114.

Dickman, C. R., and C. P. Doncaster. 1987. The ecology of small mammals in urban habitats. I. Populations in a patchy environment. The Journal of Animal Ecology 56:629-640.

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

Foresman, K. R. 2004. The Effects of Highways on Fragmentation of Small Mammal Populations and Modifications of Crossing Structures to Mitigate Such Impacts. Final Technical Report for Montana Department of Transportation.

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 Jr., T., and W. G. Bradley. 1984. Effects of a highway on Mojave desert rodent populations. The American Midland Naturalist 111:47-56.

Grant, P. R.. 1971. The habitat preference of *Microtus pennsylvanicus*, and its relevance to the distribution of this species on islands. Journal of Mammalogy 52:351-361.

Jackson, S.D. 1999. Overview of transportation related wildlife problems. Pages 1-4 *in* Proceedings of the Third International Conference on Wildlife Ecology and Transportation. Center for Transportation and the Environment. 13-16 September 1999, Missoula, MT, USA.

Kaufman, D. W. and E. D. Fleharty. 1974. Habitat selection by nine species of rodents in north-central Kansas. Southwestern Naturalist 18:443-452.

King, J. A. 1968. Biology of Peromyscus (Rodentia). First Edition. The American Society of Mammalogists, Stillwater, Oklahoma.

Kozel, R. M. and E. D. Fleherty. 1979. Movements of rodents across roads. The Southwestern Naturalist 24:239-248.

Linden, P.J.H. 1997. A wall of tree stumps as a fauna-corridor. Pages 409-417 *in* Habitat Structure and Infrastructure, Proceedings of the International Conference on Habitat Fragmentation, Infrastructure and the Role of Ecological Engineering. Ministry of Transport, Public Works and Water Management. Delft, The Netherlands.

McDonald, W., and C. C. St. Clair. 2004*a*. The effects of artificial and natural barriers on the movement of small mammals in Banff National Park, Canada. Oikos105:397-407.

McDonald, W., and C. C. St. Clair. 2004*b*. Elements that promote highway crossing structure use by small mammals in Banff National Park. Journal of Applied Ecology 41:82-93.

Menkens Jr., G. E., and S. H. Anderson. 1988. Estimations of small-mammal population size. Ecology 69:1952-1959.

Oxley, D.J., M.B. Fenton, and G.R. Carmody. 1973. The effects of roads on populations of small mammals. Journal of Applied Ecology 11:51-59.

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

Renzulli, C. B., J. F. Flowers, and R. H. Tamarin. 1980. The effects of trapping design on demographic estimates in the meadow vole, Microtus pennsylvanicus. The American Midland Naturalist 104:397-401.

Sheppe, W.. 1967. The effect of livetrapping on the movements of Peromyscus. The American Midland Naturalist 78:471-480.

Trombulak S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

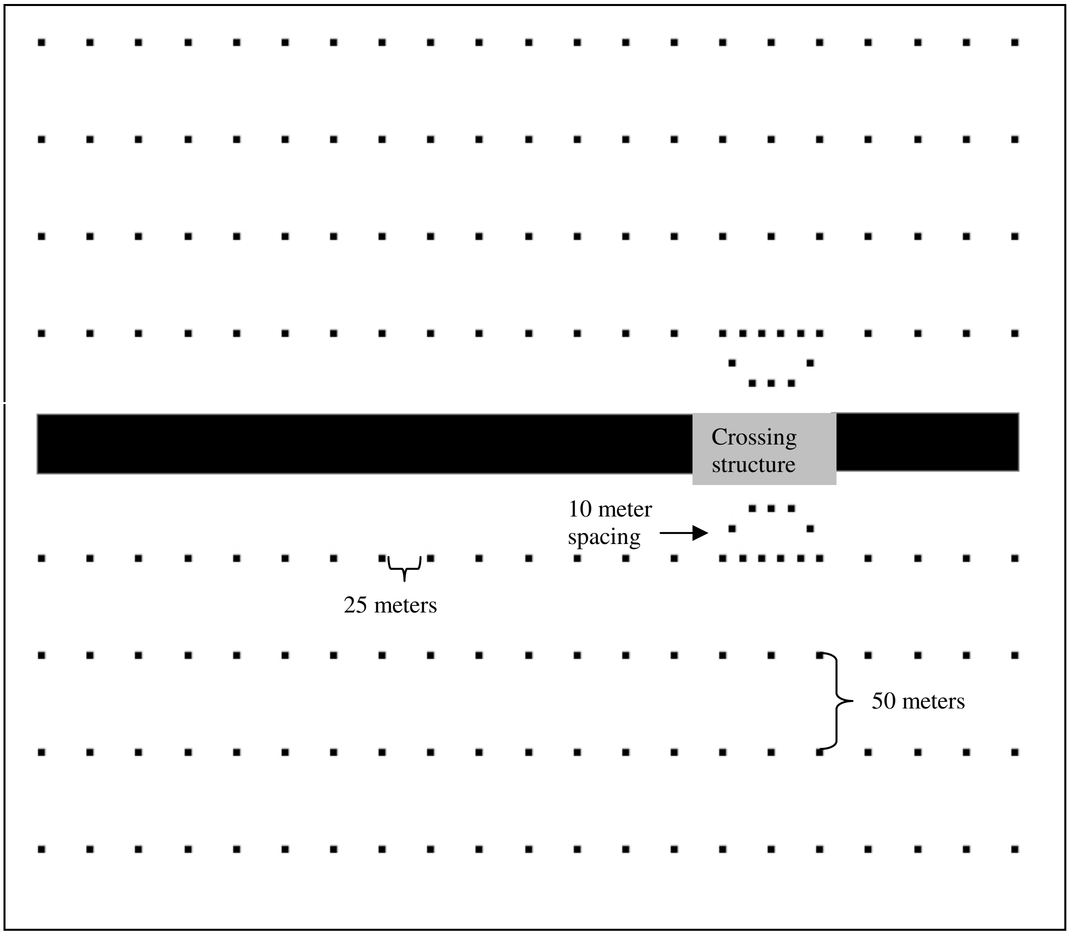

Figure 5.1. Small mammal trapping grid. Bennington, VT. Small squares = trap locations.

Table 5.1. Number of small mammals captured, marked, recaptured in addition to number of passage and road crossings at West Airport Brook (WAB) and East Airport Brook (EAB) crossing structures. Highway 279, Bennington, VT, 2006 - 2007.

	2006		2007		
	WAB	EAB	WAB	EAB	Totals
Species	# individuals tagged				
Peromyscus	251	154	108	122	635
Red back vole	12	15	1	12	40
Eastern chipmunk	4	0	1	2	7
Zapodidae	2	0	0	0	2
Meadow vole	3	2	1	0	6
	272	171	111	136	690
	# individuals recaptured				
Peromyscus	143	92	59	65	359
Red back vole	7	4	0	4	15
Eastern chipmunk	2	0	0	0	2
Zapodidae	2	0	0	0	2
	154	96	59	69	378
% recaptured	57%	57%	53%	51%	55%
	Total number of recaptures				
Peromyscus	452	183	213	163	1011
Red back vole	7	5	0	4	16
Eastern chipmunk	3	0	0	0	3
Zapodidae	6	0	0	0	6
	468	188	213	174	1043
recapture rate[a]	3.12	1.98	3.61	2.52	2.74
	# passage crossings				
Peromyscus	11	4	7	4	26
(# individuals)	(4)	(2)	(5)	(2)	(13)
	# road crossings				
Peromyscus	0	0	0	1	1

[a] = calculated for recaptured animals only.

Table 5.2. Average distances moved by time period from mark/recapture study of 684 small mammals adjacent to two crossing structures along Highway 279, Bennington, VT in 2006 and 2007.

	2006		2007	
Time Period	N	distance (m)	N	distance (m)
< 1 week	75	43.1	35	43.3
1 - 2 weeks	34	60.1	14	86.6
2 - 4 weeks	78	76.2	36	63.5

BIBLIOGRAPHY

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

Allen, C.H., R.L. Marchinton, and W. M. Lentz. 1985. Movement, habitat use and denning of opossums in the Georgia piedmont. American Midland Naturalist 113:408-412.

Alexander, S. M., P. C. Pacquet, T. B. Logan, and D. J. Saher. 2005*a*. Snow-tracking versus radiotelemetry for predicting wolf-environment relationships in the Rocky Mountains of Canada. Wildlife Society Bulletin 33:1216-1224.

Alexander, S. M., N. M. Waters, and P.C. Paquet. 2005*b*. Traffic volume and highway permeability for a mammalian community in the Canadian Rocky Mountains. The Canadian Geographer 49:321-331.

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 *in* Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-28 September 2001, Keystone, CO, USA.

Austin J. M., K. Viani, F. Hammond, and C. Slesar. 2006. A GIS-based identification of potentially significant wildlife habitats associated with roads in Vermont . Pages 185-196 *in* Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 29 August – 2 September 2005, San Diego, CA, USA.

Badyaev, A. V., W. J. Etges, and T. E. Martin. 1996. Ecological and behavioral correlates of variation in seasonal home ranges of wild turkeys. Journal of Wildlife Management 60:154-164.

Bailey, E. D.. 1965*a*. Seasonal changes in metabolic activity of non-hibernating woodchucks. Canadian Journal of Zoology 43:905-909.

Bailey, E. D.. 1965*b*. The influence of social interaction and season on weight changes in woodchucks. Journal of Mammalogy 46:438-445.

Baofa, Y., H. Huyin, Z. Yili, Z. Le, and W. Wanhong. 2006. Influence of the Qinghai-Tibetan railway and highway activities of wild animals. Acta Ecologica Sinica 26:3917-3923.

Barnum S. 2004. Identifying the best locations to provide safe highway crossing opportunities for wildlife. Pages 246-252 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-29 August, Lake Placid, NY, USA.

Barrette, C., and F. Messier. 1980. Scent marking in free ranging coyotes, *Canis latrans*. Animal Behaviour 28:814-819.

Battin, J.. 2004. When good animals love bad habitats: Ecological traps and the conservation of animal populations. Conservation Biology 18:1482-1491.

Beauvais, G. P., and S. W. Buskirk. 1999. An Improved Estimate of Trail Detectability for Snow-Trail Surveys. Wildlife Society Bulletin 27:32-38.

Bennett, A.F. 1991. Roads, roadsides, and wildlife conservation: a review. Pp. 99-118 *In* D.A. Saunders and R.J. Hobbs, editors. Nature Conservation 2: The Role of Corridors. Surrey Beatty & Sons, London, UK.

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

Bellis, E. D., and H. B. Graves. 1971. Deer mortality on a Pennsylvania interstate highway. The Journal of Wildlife Management 35:232-237.

Bennett, A.F. 1991. Roads, roadsides, and wildlife conservation: a review. Pp. 99-118 *In* D.A. Saunders and R.J. Hobbs (eds.) Nature Conservation 2: The Role of Corridors. Surrey Beatty & Sons, London.

Beyer, H. L. 2004. Hawth's Analysis Tools for ArcGIS. Available at http://www.spatialecology.com/htools

Bixler, A., and J. L. Gittleman. 2000. Variation in home range and use of habitat in the striped skunk (*Mephitis mephitis*). Journal of Zoology 251:525-533.

Bonesi, L., and D. W. Macdonald. 2004. Differential habitat use promotes sustainable coexistence between the specialist otter and the generalist mink. Oikos 106:509-519.

Brody, A. J., and M. R. Pelton. 1989. Effects of roads on black bear movements in western North Carolina. Wildlife Society Bulletin 17:5-10.

Brudin, C. O.. 2004. Wildlife use of existing culverts and bridges in north central Pennsylvania. Pages 344-352 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24 – 29 August 2003, Lake Placid, NY, USA.

Burgess, S. A., and J. R. Bider. 1980. Effects of stream habitat improvements on invertebrates, trout populations, and mink activity. Journal of Wildlife Management 44:871-880.

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

Carey, A. B. and M. L. Johnson. 1995. Small mammals in managed, naturally young and old growth forests. Ecological Applications 5:336-352.

Caro, T. M., J. A. Shargel and C. J. Stoner. 2000. Frequency of medium-sized mammal road kills in an agricultural landscape in California. American Midland Naturalist 144:362-369.

Carr, L. W., and L. Fahrig. 2001. Effect of road traffic on two amphibian species of differing vagility. Conservation Biology 15:1071-1078.

Case, R. M.. 1978. Interstate highway road-killed animals: a data source for biologists. Wildlife Society Bulletin 6:8-13.

Chamberlain, M. J., and B. D. Leopold. Overlap in space use among bobcats (Lynx rufus), coyotes (Canis latrans) and gray foxes (*Urocyon cinereoargenteus*). The American Midland Naturalist 153:171-179.

Choate, J. R.. 1973. Identification and recent distribution of white-footed mice (*Peromyscus leucopus*) in New England. Journal of Mammalogy 54:41-49.

Clark, B. K., B. S. Clark, L. A. Johnson, and M. T. Haynes. 2001. Influence of roads on movements of small mammals. The Southwestern Naturalist 46:338-344.

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 263-277 *in* Proceedings of the Third International Conference on Wildlife Ecology and Transportation. Center for Transportation and the Environment. 13-16 September 1999, Missoula, MT, USA.

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.E. Gunson. 2001*a*. Drainage culverts as habitat linkages and factors affecting passage by mammals. Journal of Applied Ecology 38:1340-1349.

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

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., B. Chruszcz, and K. E. Gunson. 2003. Spatial patterns and factors influencing small mammal vertebrate fauna road-kill aggregations. Biological Conservation 109:15-26.

Clevenger, A.P., and N. Waltho. 2004. Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies. Pages 293-302 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24 – 29 August 2003, Lake Placid, NY, USA.

Clevenger, A. P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation 121:453-464.

Conover, M. R., W. C. Pitt, K. K. Kessler, T. J. DuBow,, and W. A. Sanborn. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. Wildlife Society Bulletin 23:407-414.

Conover, M. R. 1997. Monetary and intangible valuation of deer in the United States. Wildlife Society Bulletin 25:298-305.

Conrey, R. C., and L. S. Mills. 2001. Do highways fragment small mammal populations? Pages 448-457 *in* Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24-28 September 2001, Keystone, CO, USA.

Cramer, P.C., and J. A. Bissonette. 2006. Wildlife crossings in North America: the state of the science and practice. Pages 442-447 *in* Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 29 August – 2 September 2005, San Diego, CA, USA.

DeGraaf, R. M., and M. Yamasaki. 2001. New England Wildlife: Habitat, Natural History and Distribution. University Press of New England, Lebanon, NH.

De Santo, R.S. and D.G. Smith. 1993. Environmental auditing: an introduction to issues of habitat fragmentation relative to transportation corridors with special reference to high-speed rail (HSR). Environmental Management 17:111-114.

DeVos, A. 1958. Summer observations on moose behavior in Ontario. Journal of Mammalogy 39:128-139.

Dickman, C. R., and C. P. Doncaster. 1987. The ecology of small mammals in urban habitats. I. Populations in a patchy environment. The Journal of Animal Ecology 56:629-640.

Dodd, Jr., C. K., W. J. Barichivich., and L. L. Smith. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation 118:619-631.

Dodd, N. L., J. W. Gagnon, S. Boe, and R. E. Schweinsburg. 2007. Assessment of elk highway permeability by using global positioning system telemetry. Journal of Wildlife Management 71:1107-1117.

Doncaster, C. P., and D. W. Macdonald. 1991. Drifting territoriality in the red fox *Vulpes vulpes*. The Journal of Animal Ecology 60:423-439.

Drews, C.. 1995. Road kills of animals by public traffic in Mikumi National Park, Tanzania, with notes on baboon mortality. African Journal of Ecology 33:89-100.

Ellis, J. E., and J. B. Lewis.. 1967. Mobility and annual range of wild turkeys in Missouri. Journal of Wildlife Management 31:568-581.

Erlinge, S.. 1969. Food habits of the otter Lutra lutra L. and the mink Mustela vison schreber in a trout water in southern Sweden. Oikos 20:1-7.

Fahrig, L., and G. Merriam. 1985. Habitat patch connectivity and population survival. Ecology 66:1762-1768.

Fahrig, L., J. H. Pedlar, S. E. Pope, P. D. Taylor, and J. F. Wagner. 1995. Effect of road traffic on amphibian density. Biological Conservation 73:177-182.

Faison, E. K., and D. R. Houston. 2004. Black bear foraging in response to beech bark disease in northern Vermont. Northeastern Naturalist 11:387-394.

Fall, M. W.. 1971. Seasonal Variations in the Food Consumption of Woodchucks (*Marmota monax*). Journal of Mammalogy 52:370-375.

Farias, V., T. K. Fuller, R. K. Wayne, and R. M. Sauvajot. 2005. Survival and cause-specific mortality of gray foxes (*Urocyon cinereoargenteus*) in southern California. Journal of Zoology 266:249-354.

Fedak, M., P. Lovell, B. McConnell, and C. Hunter. 2002. Overcoming the constraints of long range radio telemetry from animals: Getting more useful data from smaller packages. Integrative and Comparative Biology 42:3-10.

Foresman, K. R., and D. E. Pearson. 1998. Comparison of proposed survey procedures for detection of forest carnivores. Journal of Wildlife Management 62:1217-1226.

Foresman, K. R., 2004. Small mammal use of modified culverts on the Lolo south project of western Montana – an update. Pages 342-343 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24 – 29 August 2003, Lake Placid, NY, USA.

Foresman, K. R.. 2004. The effects of highways fragmentation of small mammal populations and modifications of crossing structures to mitigate such impacts. Final report for Montana Department of Transportation. Helena, MT.

Forman, T. T. and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecological Systems 29:207-231.

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

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 Jr., T., and W. G. Bradley. 1984. Effects of a highway on Mojave desert rodent populations. The American Midland Naturalist 111:47-56.

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.

Gordon, K. M., and S. H. Anderson. 2004. Mule deer use of underpasses in western and southeastern Wyoming. Pages 309-318 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24 – 29 August 2003, Lake Placid, NY, USA.

Grant, P. R.. 1971. The habitat preference of *Microtus pennsylvanicus*, and its relevance to the distribution of this species on islands. Journal of Mammalogy 52:351-361.

Grinder, M.I., and P.R. Krausman. 2001. Home range, habitat use, and nocturnal activity of coyotes in an urban environment. The Journal of Wildlife Management 65:887-898.

Hardy, A., A. P. Clevenger, and M. Huijser. 2004. An overview of methods and approaches for evaluating the effectiveness of wildlife crossing structures: Emphasizing the science in applied sciences. Pages 319-330 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24 – 29 August 2003, Lake Placid, NY, USA

Harrison, R. L.. 1997. A comparison of gray fox ecology between residential and undeveloped rural landscapes. Journal of Wildlife Management 61:112-122.

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.

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

Jackson, S.D. and T.F. Tyning. 1989. Effectiveness of drift fences and tunnels for moving spotted salamanders *Ambystoma maculatum* under roads. pp. 93-99 *in* Amphibians and Roads, Proceedings of the Toad Tunnel Conference. ACO Polymer Products, Shefford, England.

Jackson, S.D. and C.R. Griffin. 1998. Toward a practical strategy for mitigating highway impacts on wildlife. Pages 17-22 *in* Proceedings of the International Conference on Wildlife Ecology and Transportation. Center for Transportation and the Environment. 9–12 February 1998, Fort Myers, FL, USA.

Jackson, S.D. 1999. Overview of transportation related wildlife problems. Pages 1-4 *in* Proceedings of the Third International Conference on Wildlife Ecology and Transportation. Center for Transportation and the Environment. 13-16 September 1999, Missoula, MT, USA.

Jackson, S. D., and C. R. Griffin. 2000. A strategy for mitigating highway impacts on wildlife. Wildlife and Highways: Seeking solutions to an ecological and socio-economic dilemma. The Wildlife Society Bethesda, MD.

Jackson, S. D.. 2004. Ecological Considerations in the Design of River and Stream Crossings. Pages 20-29 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24 – 29 August 2003, Lake Placid, NY, USA

Kaufman, D. W. and E. D. Fleharty. 1974. Habitat selection by nine species of rodents in north-central Kansas. Southwestern Naturalist 18:443-452.

Kaye, D. R. J., Walsh, K. M. and C. C. Ross. 2006. Spotted turtle use of a culvert under relocated Route 44 in Carver, Massachusetts. Pages 426-432 *in* Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 29 August – 2 September 2005, San Diego, CA, USA.

King, J. A. 1968. Biology of Peromyscus (Rodentia). First Edition. The American Society of Mammalogists, Stillwater, Oklahoma.

King, C. M. 1989. The advantages and disadvantages of small size to weasels, Mustela species. In Gittleman, J.L., editor, Carnivore behavior, ecology, and evolution, Ithaca, NY: Comstock Publishing Associates, pp 302-334.

Kozel, R. M. and E. D. Fleherty. 1979. Movements of rodents across roads. The Southwestern Naturalist 24:239-248.

Kucera, T. E., and R. H. Barrett. 1993. The Trailmaster® camera system for detecting wildlife. Wildlife Society Bulletin 21:505-508.

Land, D., and M. Lotz. 1996. Wildlife crossing designs and use by Florida panthers and other wildlife in southwest Florida. *In* Evink, G.L., P. Garrett and D. Zeigler, (eds), highways and movement of wildlife: improving habitat connections and wildlife crossing structures across highway corridors. Florida Department of Transportation, Tallahassee, FL. pp 323-328.

Lariviere, S., and F. Messier. 1997. Seasonal and daily activity patterns of striped skunks (*Mephitis mephitis*) in the Canadian prairies. Journal of Zoology 243:255-262.

Lavsund, S., F. Sandegren. 1991. Moose-vehicle relations in Sweden: a review. Alces 27:118-126.

Linden, P.J.H. 1997. A wall of tree stumps as a fauna-corridor. Pages 409-417 *in* Habitat Structure and Infrastructure, Proceedings of the International Conference on Habitat Fragmentation, Infrastructure and the Role of Ecological Engineering. Ministry of Transport, Public Works and Water Management. Delft, The Netherlands.

Litvaitis, J. A., J. T. Major, and J. A. Sherburne. 1987. Influence of season and human-induced mortality on spatial organization of bobcats (*Felis rufus*) in Maine. Journal of Mammalogy 68:100-106.

Lovallo, M. J., and E. M. Anderson. 1996. Bobcat movements and home ranges relative to roads in Wisconsin. Wildlife Society Bulletin 24:71-76.

Madison, D. M., R. W. Fitzgerald, and W. J. McShea. 1984. Dynamics of social nesting in overwintering meadow voles (*Microtus pennsylvanicus*): possible consequences for population cycling. Behavioral Ecology and Sociobiology 15:9-17.

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.

Mata, C., I. Hervas, J. Herranz, F. Suarez, and J. E. Malo. 2004. Effectiveness of wildlife crossing structures and adapted culverts in a highway in northwest Spain. Pages 265-276 *in* Proceedings of the 2003 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 24 – 29 August 2003, Lake Placid, NY, USA

McCoy, K.. 2005. Effects of transportation and development on black bear movement, mortality, and use of the Highway 93 corridor in NW Montana. Masters Thesis. University of Montana, Missoula. 142 pp.

McDonald, W., and C. C. St. Clair. 2004^{a}. The effects of artificial and natural barriers on the movement of small mammals in Banff National Park, Canada. Oikos 105:397-407.

McDonald, W., and C. C. St. Clair. 2004 ^{b}. Elements that promote highway crossing structure use by small mammals in Banff National Park. Journal of Applied Ecology 41:82-93.

McManus, J.J. 1974. "Didelphis virginiana." Mammalian Species. The American Society of Mammalogists. No. 40:1-6.

Melquist, W. E., and M. G. Hornocker. 1983. Ecology of river otters in west central Idaho. Wildlife Monographs. 60p.

Menkens Jr., G. E., and S. H. Anderson. 1988. Estimations of small-mammal population size. Ecology 69:1952-1959.

Merriam, H. G.. 1966. Temporal Distribution of Woodchuck Interburrow Movements. Journal of Mammalogy 47:103-110.

Naiman, R. J., H. Decamps, and M. Pollock. 1993. The Role of Riparian Corridors in Maintaining Regional Biodiversity. Ecological Applications 3:209-212.

Ng, S. J., J. W. Dole, R. M. Sauvajot, S. P. D. Riley and T. Valone. 2004. Use of highway undercrossings by wildlife in southern California. Biological Conservation 115:499-507.

Norman, T., and A. Finegan. 1998. The role of fauna underpasses in New South Wales. Pages 195-208 *in* Proceedings of the international Conference on Wildlife Ecology and Transportation. Center for Transportation and the Environment 9 – 12 February 1998, Fort Myers, FL, USA.

Noss, R. F., and A. Y. Cooperider. 1994. Saving Nature's Legacy. Island Press, Washington, D. C..

Oxley, D.J., M.B. Fenton, and G.R. Carmody. 1973. The effects of roads on populations of small mammals. Journal of Applied Ecology 11:51-59.

Parker, G. R., and J. W. Maxwell. 1989. Seasonal movements and winter ecology of the coyote, *Canis latrans*, in northern New Brunswick. Canadian Field-Naturalist 103:1-11.

Powell, R. A.. 1994. Effects of Scale on Habitat Selection and Foraging Behavior of Fishers in Winter. Journal of Mammalogy 75:349-356.

Prange, S., S. D. Gehrt, and E. P. Wiggers. Demographic Factors Contributing to High Raccoon Densities in Urban Landscapes. Journal of Wildlife Management 67:324-333.

Puky, M.. 2006. Amphibian road kills: a global perspective. Pages 325-338 *in* Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment. 29 August – 2 September 2005, San Diego, CA, USA.

Pulliam, H. R.. 1988. Sources, sinks, and population regulation. The American Naturalist 132:652-661.

Putman, R. J.. 1997. Deer and road traffic accidents: Options for management. Journal of Environmental Management 51:43-57.

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.

Reed, D. F., T. D. I. Beck, and T. N. Woodard. 1982. Methods of Reducing Deer-Vehicle Accidents: Benefit-Cost Analysis. Wildlife Society Bulletin 10:349-354.

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

Reed, R. A., J. Johnson-Barnard and W. L. Baker. 1996. Contribution of roads to forest fragmentation in the Rocky Mountains. Conservation Biology 10:1098-1106.

Renzulli, C. B., J. F. Flowers, and R. H. Tamarin. 1980. The effects of trapping design on demographic estimates in the meadow vole, Microtus pennsylvanicus. The American Midland Naturalist 104:397-401.

Riley, S. P. D., J. P. Pollinger, R. M. Sauvajot, E. C. York, C. Bromley, T. K. Fuller and R. K. Wayne.. 2006. A southern California freeway is a physical and social barrier to gene flow in carnivores. Molecular Ecology 15:1733-1741.

Rodda, G. H.. 1990. Highway madness revisited: Roadkilled *Iguana iguana* in the Llanos of Venezuela. Journal of Herpetology 24:209-211.

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

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.

Rolley, R. E., and L. E. Lehman. 1992. Relationships among raccoon road-kill surveys, harvests, and traffic. Wildlife Society Bulletin 20:313-318.

Romin, L. A., and J. A. Bissonette. 1996. Temporal and spatial distribution of highway mortality of mule deer on newly constructed roads at Jordanelle reservoir, Utah. Great Basin Naturalist 56:1-11.

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.

Rondinini, C., and C. P. Doncaster. 2002. Roads as barrier to movement for hedgehogs. Functional Ecology 16:504-509.

Samson, C., and J. Huot. 1998. Movements of female black bears in relation to landscape vegetation type in southern Quebec. Journal of Wildlife Management 62:718-727.

Sanderson, E. W., K. H. Redford, A. Vedder, P. B. Coppolillo, and S. E. Ward. 2002. A conceptual model for conservation planning based on landscape species requirements. Landscape and Urban Planning 58:41-56.

Schauster, E.R., E.M. Gese, and A.M. Kitchen. 2002. An evaluation of survey methods for monitoring swift fox abundance. Wildlife Society Bulletin 30:464-477.

Semlitsch, R. D.. 2007. Differentiating migration and dispersal processes for pond-breeding amphibians. Journal of Wildlife Management 72:260-267.

Sheppe, W.. 1967. The effect of livetrapping on the movements of Peromyscus. The American Midland Naturalist 78:471-480.

Silveira, L., A. T. A. Jacomo, A. Alexandre, and F. Diniz-Filho. 2003. Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation 114:351-355.

Singleton, P.H., and Lehmkuhl, J. F.. 1999. Assessing wildlife habitat connectivity in the Interstate 90 Snoqualmie Pass corridor, Washington. Pages 75-84 *in* Proceedings of the Third International Conference on Wildlife Ecology and Transportation. Center for Transportation and the Environment. 13-16 September 1999, Missoula, MT, USA.

Spackman, S. C., and J. W. Hughes. 1995. Assessment of minimum stream corridor width for biological conservation: Species richness and distribution along mid-order streams in Vermont, USA. Biological Conservation 71:325-332.

Stoner, D. 1936. Wildlife casualties on the highways. Wilson Bulletin 48:276-283.

Swihart, R. K.. 1992. Home-Range Attributes and Spatial Structure of Woodchuck Populations. Journal of Mammalogy 73:604-618.

Tierson, W. C., G. F. Mattfield, R. W. Sage Jr., and D. F. Bahrend. Seasonal movements and home ranges of white-tailed deer in the Adirondacks. Journal of Wildlife Management 49:760-769.

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

Trombulak S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

Veenbaas, G., and J. Brandjes. 1999. Use of fauna passages along waterways under highways. Pages 253-258 *in* Proceedings of the Third International Conference on Wildlife Ecology and Transportation. Center for Transportation and the Environment. 13-16 September 1999, Missoula, MT, USA.

Vermont Agency of Transportation (VTrans). 2004. Traffic Data Electronic Publications. <http://www.aot.state.vt.us/Planning/Documents/TrafResearch/Publications/pub.htm>. Accessed 29 March 2008.

Voight, D. R., and B. D. Earle. 1983. Avoidance of coyotes by red fox families. Journal of Wildlife Management 47:852-857.

Weckerly, F.W., and M.A., Ricca. 2000. Using presence of sign to measure habitats used by Roosevelt elk. Wildlife Society Bulletin 28:146-153.

White, P. A.. 2007. *Getting up to Speed*: A conservationist's guide to wildlife and highways. Defenders of Wildlife, Washington, D. C..

Witmer, G. W., S. K. Martin, and R. D. Sayler. 1998. Forest carnivore conservation and management in the interior Columbia basin: issues and environmental correlates. Gen. Tech. Rep. PNW-GTR-420. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 51 p. (Quigley, Thomas M., ed.; Interior Columbia Basin Ecosystem Management Project: scientific assessment).

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.