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UTILIZING A MULTI-TECHNIQUE, MULTI-TAXA APPROACH TO MONITORING WILDLIFE PASSAGEWAYS IN SOUTHERN VERMONT

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ABSTRACT

Roadways affect wildlife habitat disproportionate to the area of land they occupy, impacting wildlife through the loss and fragmentation of habitat, road mortality and disruption of movement. A variety of strategies have been used with mixed success to mitigate the impacts of transportation systems on wildlife. Through 2008, nearly 700 terrestrial and 10,700 aquatic crossing structures have been identified throughout North America but only a small portion of these crossings had monitoring incorporated into their project design. Building on prior studies, this project takes a broad, multi-taxa approach to monitoring crossing structures on a newly constructed highway (the Bennington Bypass) in southern Vermont. We used a variety of techniques to assess movements of an array of species at two passage structures associated with the highway as well as in the surrounding landscape. Techniques used in our study include: track beds/plates, remote camera sensing, small mammal trapping, snow-tracking and road kill surveys. Our data suggest that the concurrent use of track beds and camera traps provide excellent tools for determining an index of passage use but are limited in their ability to monitor individual use of structures. Six hundred and ninety small mammals were ear tagged over two field seasons, with 15 individuals successfully moving through the crossing structures and one individual crossing the road, suggesting that the road serves as a barrier to movement and the structures may only minimally mitigate those effects. Snow-tracking is an excellent tool for detecting movement of animals in and around structures but is limited seasonally and similar to track beds/cameras, cannot discern individuals. Road kill surveys showed a minimal number of deer hit by vehicles but revealed high mortality on amphibians, reinforcing our suggestion that monitoring should take a multi-taxa approach. By monitoring a wide variety of animal movements rather than focusing exclusively on the use of passages by wildlife, we believe we can more accurately assess the effectiveness of the mitigation structures.
Keywords: Animal movement; highways; mitigation, monitoring; wildlife crossings.

RESUMO

O USO DE UMA ABORDAGEM COM MÚLTIPLAS TÉCNICAS E MÚLTIPLOS TAXA PARA O MONITORAMENTO DE PASSAGENS PARA A VIDA SILVESTRE NA REGIÃO SUL DE VERMONT. Estradas afetam os habitats de maneira desproporcional à área da superfície terrestre que ocupam, impactando a vida silvestre através da perda e fragmentação de habitat, mortalidade nas estradas, e distúrbios na movimentação. Diversas estratégias têm sido usadas, com diferentes níveis de sucesso, na mitigação dos impactos dos sistemas de transporte sobre a vida silvestre. Durante o ano de 2008, quase 700 estruturas de passagem terrestres e 10.700 aquáticas foram identificadas na América do Norte, mas apenas uma pequena parte destas passagens apresenta o monitoramento incorporado à concepção de seus projetos. Baseando-se em estudos anteriores, este projeto adota uma ampla abordagem, considerando múltiplos taxa, para monitorar estruturas de passagem em uma estrada recentemente construída no sul de Vermont (Bennington Bypass). Utilizou-se diversas técnicas para avaliar a movimentação de uma gama de espécies em duas estruturas de passagem associadas à estrada, bem como à paisagem circundante. As técnicas usadas nesse estudo incluem: parcelas de areia, câmera com disparo remoto, captura de pequenos mamíferos, rastreamento na neve, e

avaliação de mortes por atropelamento. Nossos dados sugerem que o uso concomitante de parcelas de areia e armadilhas fotográficas é uma excelente ferramenta para determinar um índice de utilização da passagem, mas são limitados em sua capacidade de monitorar o uso individual das estruturas. Seiscentos e noventa pequenos mamíferos foram marcados na orelha durante duas campanhas, tendo 15 indivíduos atravessado com sucesso a estrutura de passagem, e um indivíduo atravessado pela estrada, o que sugere que esta age como uma barreira para o movimento, e que as estruturas de passagem podem apenas mitigar minimamente tais efeitos. O rastreamento na neve é uma ferramenta excelente para detectar a movimentação de animais nas estruturas e seu entorno, mas é limitado sazonalmente e, de modo similar às parcelas de areia e às câmeras, não é capaz de discernir indivíduos. As avaliações de atropelamentos mostraram um número mínimo de colisões entre veados e automóveis, mas revelaram alta mortalidade de anfíbios, reforçando a nossa sugestão de que o monitoramento deve levar em conta uma abordagem de múltiplos taxa. Ao monitorar uma variedade de movimentos animais, ao invés de focar exclusivamente no uso das passagens pela vida silvestre, acreditamos que se pode avaliar a eficácia das estruturas de mitigação de maneira mais acurada.
Palavras-chave: Movimentação animal; estradas; mitigação; monitoramento; passagem para animais.

RESUMEN

USO DE UN ABORDAJE CON VARIAS TÉCNICAS Y PARA MÚLTIPLES TAXONES PARA EL MONITOREO DE CORREDORES PARA FAUNA SILVESTRE EN EL SUR DE VERMONT. Las carreteras afectan el hábitat de la vida silvestre de manera desproporcional al área que ocupan, a través de la pérdida y fragmentación de hábitat, la mortalidad en carreteras y la disrupción del movimiento. Diversas estrategias han sido usadas, con diferentes grados de éxito, para mitigar el impacto de los sistemas de transporte sobre la vida silvestre. Hasta 2008, cerca de 700 estructuras terrestres y 10700 estructuras acuáticas han sido identificadas a lo largo de Norteamérica pero solo una pequeña porción de estos proyectos de pasajes incluían el monitoreo en su diseño. A partir de estudios anteriores, este proyecto aborda el monitoreo de las estructuras de paso desde una perspectiva amplia, para múltiples taxones, en una carretera recién construida (el Bennington Bypass) en el sur de Vermont. Usamos una variedad de técnicas para evaluar los movimientos de un grupo de especies por dos pasajes asociados con la carretera y con el paisaje alrededor. Las técnicas utilizadas en nuestro estudio incluyeron: parcelas de arena, cámaras con obturador remoto, captura de mamíferos pequeños, rastreo en la nieve y evaluación de muertes por atropellamiento. Nuestros datos sugieren que el uso concomitante de parcelas de arena y trampas fotográficas es una herramienta excelente para determinar un índice de uso de un pasaje, pero tienen capacidad limitada de monitorar el uso individual de las estructuras. Seiscientos noventa pequeños mamíferos fueron marcados em la oreja durante dos campañas, de los cuales 15 individuos usaron con éxito las estructuras de paso y uno cruzó la carretera. Esto sugiere que la carretera sirve de barrera al movimiento y las estructuras pueden mitigar de forma mínima estos efectos. El rastreo en la nieve es una herramienta excelente para detectar el movimiento de animales dentro y alrededor de las estructuras, pero está limitado estacionalmente y al igual que las cajas de arena y las cámaras, no puede discernir entre individuos. El levantamiento de muertes por atropellamiento mostró un número mínimo de choques entre ciervos y automóviles, pero revelaron una mortalidad alta de anfibios, lo que refuerza nuestra sugerencia de que el monitoreo debe incluir diferentes taxones. Creemos que monitorear una amplia variedad de movimientos en vez de enfocarnos exclusivamente en el uso de pasajes por la vida silvestre nos permite evaluar con mayor precisión la efectividad de las estructuras de mitigación.
Palabras clave: Flujos de fauna; carreteras; mitigación; monitoreo; pasajes para animales.

INTRODUCTION

As long linear features on the landscape, roads and highways (roadways) impact wildlife and their habitats over areas that are disproportionate to the land they occupy. Roadways affect wildlife through direct loss and fragmentation of habitats, as a source of additive mortality for wildlife and by disrupting animal movements (Jaeger *et al*. 2005). Through isolation of wildlife populations, roadways can also disrupt gene flow and metapopulation dynamics (Jackson 1999, Trombulak & Frissell 2000, Corlatti *et al*. 2009, Flesch *et al.* 2010).

A variety of strategies have been used with mixed success to mitigate the impacts of transportation systems on wildlife (Clevenger & Waltho 2005, Mata *et al.* 2008, Olson & Widen 2008, Glista *et al.* 2009). Underpasses are commonly used to facilitate movement of wildlife across roadways in Europe, Australia, Canada and the US. However, the effectiveness of these underpasses depends on the management goal (to facilitate wildlife movement or reduce road kill) and on a number of variables, including: size, proximity to natural wildlife corridors, noise levels, substrate, vegetative cover, moisture, temperature, light, and human disturbance (Grilo *et al*. 2008, Glista *et al*. 2009). For example, installation of shelves in culverts (Foresman 2003) and stump rows through underpasses (van Bohemen 2005) facilitated small mammal movements. However, passage systems designed for use by a single species may act as barriers for other species with different requirements (Glista *et al*. 2009).

As of 2008, there were nearly 700 terrestrial crossing and 10,700 aquatic crossing structures documented in North America (Cramer & Bissonette 2008); yet, relatively few of these structures had been monitored for effectiveness. Those that were monitored typically used tracking beds, cameras, and counters to determine whether animals used the structures, but these methods provided little information on species or individuals that failed to use a structure. A sampling of 21 studies revealed that on average four species are monitored per study, with larger carnivores and ungulates the taxa groups most frequently targeted. Some studies focused on a single species (Kaye *et al*. 2005, Gagnon *et al*. 2007, Braden *et al*. 2008), while most studies recorded general use of structures. Further, radio-tracking and mark-recapture studies provide information about movements of individuals, but typically not where they cross roads. In contrast, track bed and camera trap studies provide information about use of crossing structures but not with reference to particular individuals. Thus, to fully assess the effectiveness of crossing structures for wildlife, a combination of monitoring techniques are needed to evaluate structure use and the extent to which transportation systems affect animal movements at the landscape scale (Jackson 1999).

To evaluate the effectiveness of wildlife passage structures, it is important to define the criteria for success (how much wildlife passage is enough to achieve a stated goal). Wildlife use of passage structures has to be assessed relative to some baseline level of passage determined either by 1) data on pre-construction wildlife movements in the area, or b) an evaluation of the extent to which the highway (including passage structures) inhibits wildlife movement through the area. Thus, in the absence of pre-construction data, post-construction monitoring strategies need to evaluate passage use as well as other wildlife movements that indicate the degree to which wildlife are failing to use the passage structures.

Understanding movement patterns relative to the roadway and passage structures are important elements in gaining a better understanding of effectiveness of mitigation strategies. By incorporating a variety of monitoring techniques, the ability to evaluate effectiveness may be improved. The Bennington Bypass study in Vermont, USA incorporated an array of monitoring techniques in an attempt to understand movement patterns of various taxa ranging from small mammals to ungulates. In this study, our aim is to summarize the key findings for a variety of monitoring techniques (track beds/plates, remote camera sensing, small mammal trapping, snow-tracking and road kill surveys) used in an assessment of a particular highway mitigation project and present a general approach to multi-technique, multi-taxa monitoring of wildlife passage structures. Specifically, our objectives were to:

1) evaluate passageways use by wildlife through track beds and camera traps;
2) analyze wildlife movements in the study area using snow-tracking and small mammal trapping; and
3) assess road mortality.

CONCEPTUAL MODEL

A variety of techniques are used to assess wildlife passageway effectiveness (Abson & Lawrence 2003). A sampling of passageway studies revealed that the most prevalent techniques used are remote camera sensing and track beds (Krawchuk *et al*. 2005, Clevenger & Waltho 2005, Gagnon *et al.* 2007, Olson & Widen 2008, McCollister & Van Menen 2010, Allen 2011). In many studies, cameras were used in conjunction with track beds to verify crossing occurrences; however, these techniques primarily provided information only on the use of structures by wildlife. Yet, there are a number of other potential animal movements that need to be considered when designing and evaluating roadways and crossing structures. We developed a conceptual model depicted in Figure 1 to illustrate the possible animal movements in relation to a roadway and crossing structure, including: (a) moves across the road surface from one side of a road to the other without getting hit by a car; (b) attempts to cross the road but is hit by a vehicle; (c) approaches lead fencing of a crossing structure (or highway fencing) and moves away from the crossing structure, subsequently crossing the road or getting hit by a vehicle; (d) approaches the fencing and is deflected away from the road, neither crossing the road or moving through the crossing structure; (e) approaches fencing and is guided towards the crossing structure and passes through successfully; (f) approaches the crossing structure directly and passes through successfully; (g) approaches the crossing structure directly but moves away from the structure rather than pass through; (h) animal is in the vicinity of the highway but moves away from the road; (i) an animal that approaches the road but, upon encountering it, moves away from it. Our study evaluated these potential movements for carnivores, mesopredators and small mammals using a multi-technique monitoring approach. We use the categories of movements in the model to facilitate comparisons among results from different techniques.

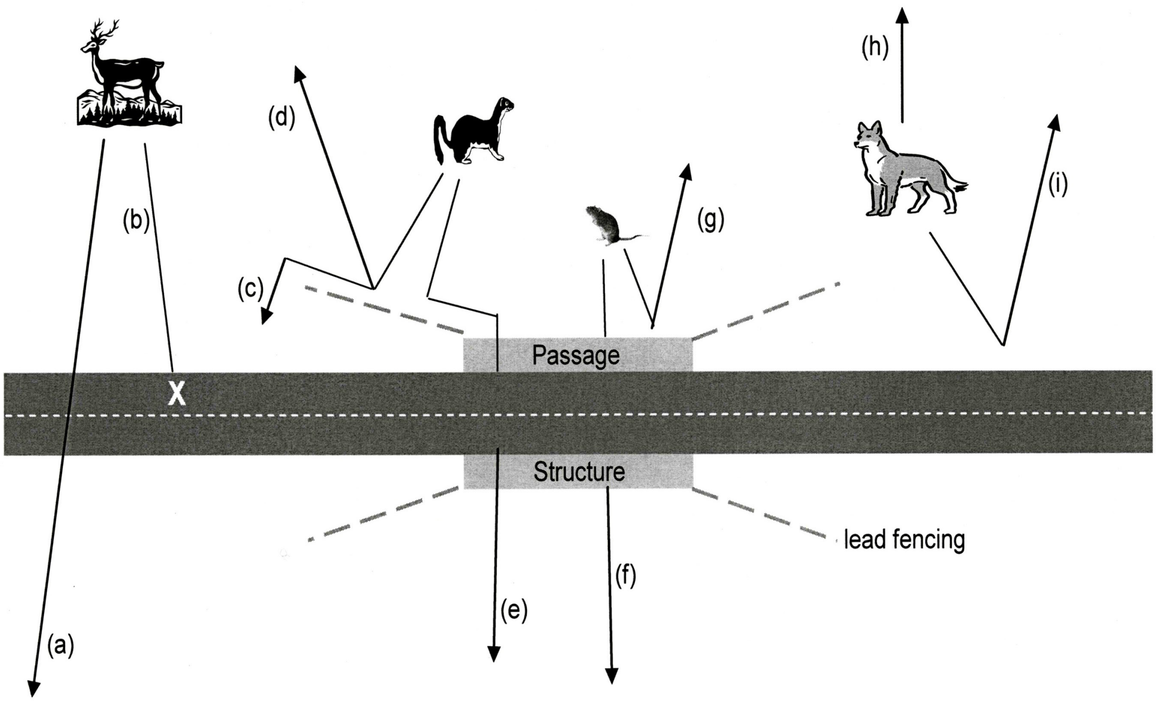

Figure 1. Potential wildlife movement relative to roadway and passage structure. (a) Move successfully across the roadway, (b) animal-vehicle collision, (c) approach lead fencing, moving away from passageway around lead fencing, (d) approach lead fencing and move away from roadway, (e) approach lead fencing and move successfully through passageway, (f) move through passageway unaided by fencing, (g) approach and avoid passageway, (h) avoid roadway and (i) approach and avoid roadway.

STUDY AREA

The Bennington Bypass (Highway 279) is a 7km-long highway connecting New York Route 7 in Hoosick Falls, New York, to Vermont Route 7 in Bennington, Vermont. It is a two-lane highway with several three-lane areas designed as passing zones. Highway 279 is the first part of a three-phase highway project that will circumvent downtown Bennington. This western phase of the highway opened in October 2004 and included two wildlife passage structures and a large culvert that had potential to serve as a crossing structure. For the three years of our study, average daily traffic (ADT) on the Bennington Bypass ranged from 4,290 to 7,578 vehicles, with the highest volumes in summer (June-August). The two passage structures are ‘extended bridges’, meaning they were slated as smaller stream crossing bridges but were widened under the guidance of state wildlife biologists to accommodate wildlife passage along the stream banks. Whereas, the primary purpose of the large culvert was for water conveyance. The location of the two wildlife passages and single culvert, along with the adjacent landscape, are shown in Figure 2.

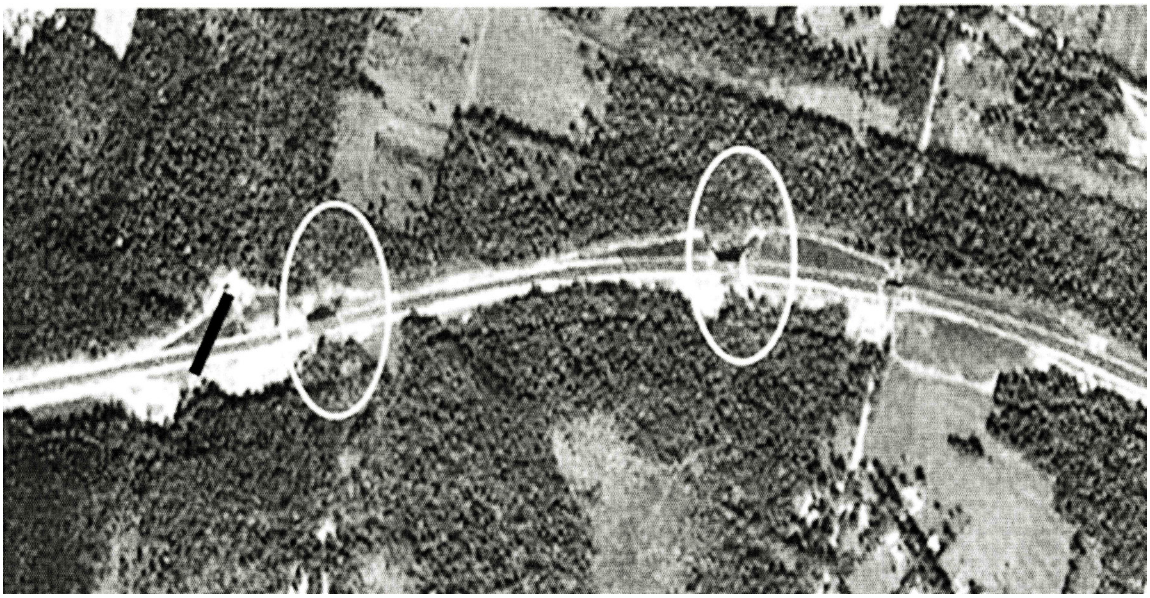

Figure 2. Location of 7 km-long Highway 279 and primary study area with locations of passage structures (white circles) and drainage culvert (black line to west of structures). Passage structures are 0.6 km apart.

Both bridges were constructed as overpasses over two streams, East Airport Brook (EAB) and West Airport Brook (WAB). The two streams are separated by 0.6km and both occur in the eastern half of the 7km-long bypass. They both flow south to north into the Walloomsac River. East Airport Brook is a 2m-wide intermittent stream, whereas the similar-sized West Airport Brook is perennial. The brooks within both passageways run off center of the overpasses, closer to the western edges of the openings.

The extended bridge over the EAB is 43.3m long, 8m wide and 18m above the terrain directly below it. The bridge over WAB is 56.55m long, 8m wide and 12.17m above the terrain directly below it. The length and height of both bridges create relatively large passageways underneath the highway. Lead fencing was installed on both sides of each entrance of the crossings with 4 lead fences per crossing. The lead fencing was 2.5m high chain link and extended out 61m from each side of each crossing entrance at a 45 degree angle. It was initially covered with black tarp material to minimize animals’ field of vision when approaching the structures, but winter weather damaged most of the tarp material over time. The drainage culvert is located approximately 200m west of West Airport Brook. The 1.65m wide, 124m long culvert connects two retention ponds located on each side of the highway.

The vegetative community adjacent to the bypass is a Northern hardwoods broad leaf complex dominated by American Beech (*Fagus grandfolia*), Maple (*Acer* spp.) and Eastern hemlock (*Tsuga canadensis*). Much of the under story is dominated by Canada honeysuckle (*Lonicera canadensis*). A 15m mowed right-of-way, buffering the road from the forest, occurs along both sides of the roadway. The topography of the study area is rolling hills and located approximately 4km west of the Green Mountains. The adjacent landscape is residential with sparsely spaced houses. Except for the right-of-way, all fieldwork occurred on private land.

METHODS

Our monitoring approaches focused on four general categories: monitoring of wildlife use of the mitigation structures (track beds and camera traps), wildlife movements in the broader study area (snow-tracking), small mammal trapping to examine their movements, and road kill surveys.

PASSAGEWAYS USE BY WILDLIFE THROUGH TRACK BEDS AND CAMERA TRAPS

To monitor animal movement within the passageways, we used track beds and motion-sensing camera traps to obtain information for large- and medium-sized mammals, including: white-tailed deer (*Odocoileus virginianus*), moose (*Alces alces*), black bear (*Ursus americanus*), bobcat (*Lynx rufus*), red fox (*Vulpes vulpes*), coyote (*Canis latrans*), North American river otter (*Lutra canadensis*), raccoon (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*), striped skunk (*Mephitis mephitis*), long-tailed weasels (*Mustela frenata*), ermine (*Mustela erminea*), fisher (*Martes pennanti*), American mink (*Neovison vison*), and woodchuck (*Marmota monax*). Track beds were located in the center of each crossing and 1-3 cameras were placed within the crossing structures. We also periodically used cameras in the surrounding area to confirm use of game trails by animals. In addition, the culvert passage structure was monitored with track plates and cameras to confirm use by animals. Track plates differed from track beds, consisting of a $1m^2$ aluminum sheet sooted with a propane torch with a piece of white contact paper 30cm wide in the middle of the aluminum sheet (Zielinski 1995).

We constructed track beds along the midline of each crossing structure 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, primarily rainy, windy weather. 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 daily during three field seasons (2005-2007) but only data from 2006 and 2007 was utilized. The 2005 field season was viewed as a trial period in which we experimented with various methods before settling on methods used throughout the remainder of the study. The track beds were monitored a total of 128 track nights in 2007 and 84 track nights in 2008. The reason for the relatively high variation in track nights was due to weather conditions where 2008 experienced more windy, rainy days that made the track beds unreadable. Each track set was recorded as a track bed crossing, not a structure crossing, since we were unable to confirm that an animal that crossed the track bed passed all the way through the structure. We considered numbers of track sets to be an index of structure use and compared this index between structures and years by species.

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 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. This camera was set to record 10 images/trigger and mounted on a wooden post, approximately 1m above the ground. The camera was in place continuously for 143 days during the 2006 field season and 133 days during the 2007 field season. However, this camera ran out of film sporadically (approximately 6 days per field season) and on a few occasions (n<10 days per field season) the triggering mechanism seemed unresponsive.

The second type of camera used at 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 the first two field seasons 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. Cameras were mounted on wooden posts, approximately 1m above the ground. We checked/downloaded images from the cameras weekly using MapView Image Management™ (Reconyx, LLP, Holmen, WI).

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. These cameras were used to identify species moving through the structures in areas not covered by track beds. These cameras were in place continuously for 143 days during the 2006 field season and 133 days during the 2007 field season. In both cases battery failure occurred only rarely. We compared camera trap records to track bed crossings only for dates when both cameras and track beds were operational to account for animals missed by the track beds.

ANALYSIS OF WILDLIFE MOVEMENTS IN THE STUDY AREA

Snow-tracking

Snow-tracking during winter provides the opportunity to 1) evaluate animal movements relative to the roadway and passageways, and 2) document the presence of animals in the study area not detected by track beds/plates. For example, data from track beds/plates and camera traps during 2005 documented the occurrence of woodchucks, raccoons, white-tailed deer, mink and muskrat (*Ondatra zibethicus*) within the passageways. However, species such as bobcat, coyote, fisher, otter, North American porcupine (*Erithizon dorsatum*) and American beaver (*Castor canadensis*) were not detected, yet occur in the area. We assumed that snow-tracking would capture movement/crossings of these animals.

The grid design for snow-tracking consisted of four transects parallel to the highway and 6 transects perpendicular to the highway (Figure 3). The grid began 500m to the east of the East Airport Brook passageway and ended 500m to the west of West Airport Brook passageway. The parallel transects included two pair of transects at the highway's edge and two more 100m into the forest on each side of the highway in order to capture all the types of movement depicted in Figure 1. Two of the 6 perpendicular transects were located at the far ends of the grid (500m from each of the large passage structures); the remaining 4 perpendicular transects were clustered around the two large passage structures (2 transects per structure, 50m apart) in order to detect movements of animals near the structures. During each snow-tracking day, we also checked the passageways for evidence of movement through the structures.

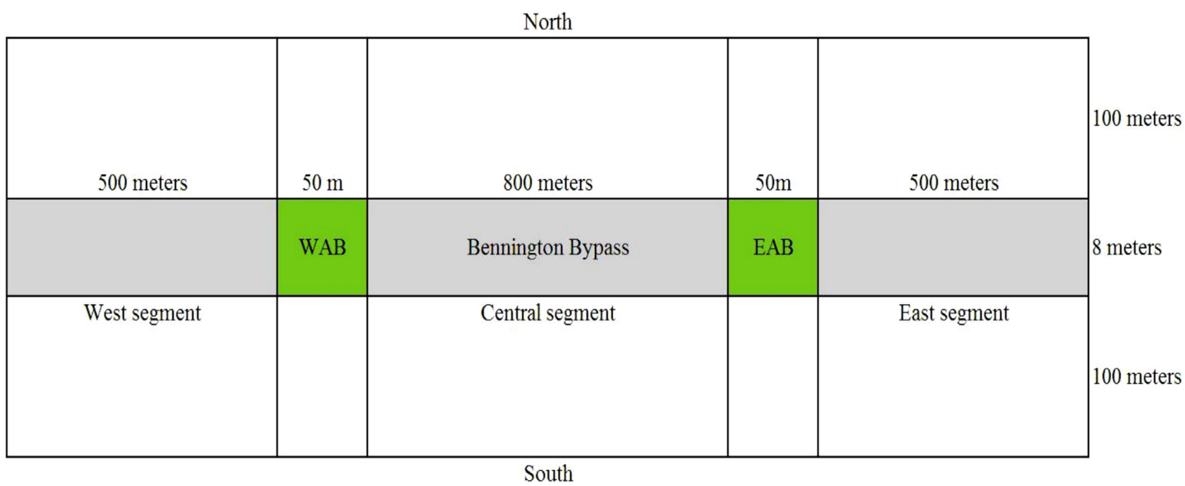

Figure 3. Snow-tracking grid. Black lines represent transects

We conducted snow-tracking sessions 48 hours after snowfalls of ≥1.3cm. We used Palm Pilots with Cybertracker software integrated with GPS to record species, track and gait measurements, gait pattern, direction of movement, markings (scat, scent marking), highway crossing locations, weather (temperature and cloud cover), days since last snowfall, snow depth, date and time. The order of transect coverage was reversed on each successive tracking session. During the 2005/06 and 2006/07 snow-tracking seasons, we frequently were not able to walk the entire grid in a single day. When this occurred, we initiated tracking the following day from the last point covered the previous day, weather permitting. For our analysis, we categorized each recorded movement using the model depicted in Figure 1 and classified the movements as road crossings, passage crossings and non-crossings. We then compared the proportions of crossings for each species detected for each type of crossing.

Small mammal movements

Considering roads can limit movements of small mammals (Oxley *et al*. 1973), which may lead to local extinctions, social disturbance and morphological divergence (Dickman & Doncaster 1987), we used a mark/recapture study to assess small mammal movements relative to the roadway and the passageways.

We captured small mammals adjacent to the two crossing structures using Sherman live traps (n=226) following guidelines outlined by American Society of Mammalogists (Gannon & Sikes 2007). Figure 4 represents our trapping grid at each crossing. At WAB, eight 750m-long transects were established parallel to the roadway with four transects on each side of the road/crossing structure with 50m between transects. At EAB, four 750m-long transects were established on the north side of the roadway and three on the south side with 50m between transects. The reason for only three on the south side was a wetland area on the southeast edge of the study area that was not available for trapping. In addition to the 750m transects parallel to the road, a single 50m transect was established at the opening of either side of both crossing structures, which is represented by the short black line near the wildlife crossing seen in Figure 4. Traps were set at 25m intervals along the 750m transects, except for the 50m transects directly adjacent to the crossing structure where we placed traps 10m apart. Traps were placed closer together in these areas to improve the chances of capturing small mammals crossing through the structure.

With four sets of trap transects (one on each side of the two crossing structures), we trapped 2-3 nights in each set of transects per month, 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 & Anderson 1988). We baited traps with peanut butter and supplied cotton for nesting material, and placed them at habitat features (as logs, trees, burrows) within 1m of each trapping point in the late afternoon. Captured animals were 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 and recorded both as *Peromyscus* spp. Similarly, we were unable to identify the species of jumping mice captured, and recorded these as *Zapodidae*. Traps that contained animals were re-baited and reset for the duration of the trapping session. All traps were collected at the end of each trapping session to reduce habituation to traps. We calculated distance traveled by calculating straight-line distances between recaptures.

Road-kill surveys

Wildlife passageways can potentially reduce vehicle/wildlife collisions by minimizing road crossings, thereby also reducing animal mortality. The null hypothesis for this segment of the study was that road kill rates will not vary at differing distances from the crossing structures. If the passageways were effective we would expect lower road kill rates near the structures assuming fewer animals are exposed to vehicle traffic here, and conversely, road kill rates should be higher in areas farther from the passageways.

We conducted road kill surveys between 1500-1800hrs 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 (paved area including shoulder) was scanned continuously, noting all animal carcasses. Some larger animals (such as deer) hit by vehicles were found in the right of way beyond the paved shoulder, and we included these in our counts. For each carcass we found, we recorded the species (or at best taxa), 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 size, and large animals to be white-tailed deer 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. To avoid double counting we circled counted road kill with colored spray paint.

We conducted two analyses for road kill. The first is an index that reflects the number of road kills per survey for each of the three groupings (small, medium, large). These data provide an overview of the number/type/size of animal that were killed by vehicles during the study. The second analysis depicts road kill rates at varying distances from the crossing structures, with the hypothesis that road kill rates should decrease at farther distances from the structures.

RESULTS

PASSAGEWAYS USE BY WILDLIFE THROUGH TRACK BEDS AND CAMERA TRAPS

We recorded 786 sets of animal tracks on track beds over 349 track nights for the three field seasons, representing at least 26 taxa. One hundred-ten of the

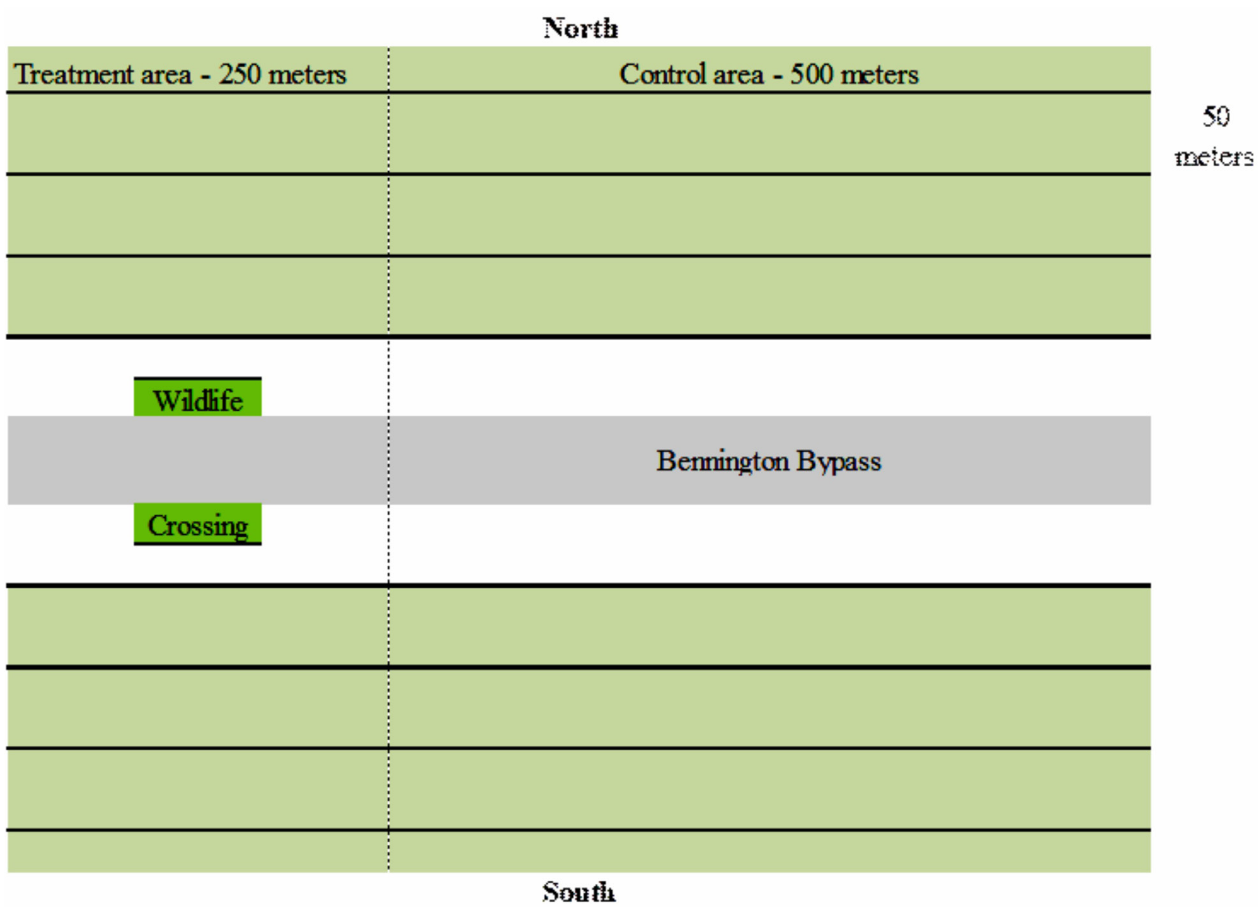

Figure 4. Small mammal trapping grid. 1) Large shaded area depicts forest, 2) black lines = transects. Traps were spaced 25m apart except along short transects at forest edge in front of passageways where traps were spaced 10m apart. This figure represents the grid at West Airport Brook. East Airport Brook was similar but had only three transects on the south side due to a wetland present.

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), *Canidae* (n=3), *Felidae* (n=4), *Zapodidae* (n=12), and *Peromyscus* (n=41). As can be observed in Table 1, 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 (*Meleagris gallopavo*, n=12), bobcat (n=9), raccoon (n=9), woodchuck (n=6) and domestic cat (*Felis silvestris catus*. n=1). Of the 90 total crossings, 57 took place at EAB and 33 at WAB. The majority of the difference in crossing data between the two structures can be explained by white-tailed deer (n=36 at EAB, n=17 at WAB). When camera crossing 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, white-tailed deer, and wild turkey accounting for the majority of these increases

Table 1. Structure use (number of crossings) by six species detected by track beds and cameras in two wildlife crossing structures, Bennington, VT.

	2006 (128 track nights, 143 camera trap nights)						**2007** (84 track nights, 133 camera trap 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	50	8	15	23	25	1	26
Woodchuck	10	1	11	48	4	52	8	1	9	22	0	22
Raccoon	5	2	7	4	2	6	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

ANALYSIS OF WILDLIFE MOVEMENTS IN THE STUDY AREA

Snow-tracking

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, river otter, gray fox (*Urocyon cinereoargenteus*), and raccoon. Because tracks for white-tailed deer and domestic cat were so numerous and difficult to differentiate individual movements, we focused our analysis for these species on road and passage crossings.

Over the two field seasons, we detected 57 passage crossings (movements e and f in Figure 1) and 68 road crossings (movements a and c in Figure 1) as seen in Table 2. Nine of the 10 species detected via snow-tracking used the structures, and 7 of the 10 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 that used the crossing structures in 2006-07 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). Mink had the highest proportion of structure versus road crossings (9/0) and coyote had the lowest (8/31).

Table 2. Number of movements of each type (conceptual model, Figure 1) detected for each species representing two winter field seasons (January 2006 to February 2007) in Bennington, VT. 'Road crossings' are movements a and c, 'passageway crossings' are e and f. All other movement types are 'non-crossings.' Deer and domestic cat are listed separately because only crossing data were collected for these species. NI = Pattern Not Identifiable.

	Movement Type										
Species	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**NI**	**Totals**
Coyote	29	0	2	2	2	6	1	8	4	18	72
Bobcat	6	0	2	0	0	3	0	4	1	9	25
Mink	0	0	0	0	1	8	0	0	0	6	15
Fisher	1	0	1	0	1	1	0	3	0	3	10
Long-tailed weasel	2	0	0	0	0	2	0	0	0	4	8
River otter	0	0	0	0	0	3	0	0	0	3	6
Gray fox	0	0	0	0	0	0	1	0	1	2	4
Raccoon	1	0	0	0	0	2	0	0	0	0	3
	39	**0**	**5**	**2**	**4**	**25**	**2**	**15**	**6**	**45**	**143**
White-tailed deer	11					33					
Domestic cat	2					6					

Small Mammal Movements

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. *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 (n=5) and ermine (n=4). Of the 690 animals tagged, 55% (n=378) were recaptured at least once. We detected 26 structure crossings by 15 individual *Peromyscus* spp. for the two field seasons, 18 at WAB and 8 at EAB, and one possible 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. No other species were recorded crossing through the structures or over the road.

Road-kill Surveys

Table 3 shows that we recorded a total of 1,289 road-killed animals (movement b in Figure 1) 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 species level, so we created three categories for road kill, 1) small (rabbit or smaller), 2) medium (rabbit to coyote size), and 3) large (white-tailed deer). Seventy five percent of the road kill was categorized as small animal, with 69% of those unidentifiable, even to taxa. However, we were able to identify 31% of the small animals to the family Anura. Average monthly traffic volume increased each year of the study (2005=4,412, 2006=4,989, 2007=5,795) as well as the average monthly road kill index (number of road kills/number surveys) each year (2005=6.67, 2006=7.20, 2007=11.50).

Table 3. Number of monthly road kills and indices for species groups during 2005/06/07 field seasons. Index=number of road kills/number of surveys. ADT=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		4.437		4.509						
	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		

Table 4 characterizes the amount of road kill at varying distances from the crossing structures. In order to normalize data, an index (number of road kills/number of surveys) was used. If the wildlife crossings were clearly mitigating the impacts of the road we would expect more road kill at farther distances from the crossings. There was no correlation between distance and road kill (Pearson's correlation, r=-0.644, p=0.167). It should be noted that sample size is quite small for large animals.

Table 4. Number of road kills and indices for each species group at varying distances for 2005/06/07 field seasons. Index=number of road kills/number of surveys. Within year comparisons calculated on raw data (same number of surveys), across years on normalized data (indices) to account for between year differences in the number of surveys, a=rabbit or smaller, b=rabbit to coyote size, c=white-tailed deer. Data were recorded in Bennington, VT, using automobile odometer which was in miles. 1 mi=1.60934km.

		Distance from crossing structures (miles)												
		0 - 0.2		0.3 - 0.4		0.5 - 0.6		0.7 - 0.8		0.9 - 1.0		1.1 -1.2		
Size	Year	Index	#	Index	#	Index	#	Index	#	Index	#	Index	#	*P*
Small animal[a]	2005	0,50	9	1,17	21	0,94	17	1,28	23	0,56	10	0,28	5	0,733
	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
Medium animal[b]	2005	0,00	0	0,06	1	0,00	0	0,06	1	0,00	0	0,06	1	0,503
	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
Large animal[c]	2005	0,00	0	0,00	0	0,00	0	0,06	1	0,00	0	0,06	1	1,000
	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

DISCUSSION

TRACK BEDS AND CAMERA TRAPS

The actual number of wildlife crossings through the structures, depicted as movements e and f in Figure 1, would have been greatly underestimated without the use of the stream cameras. Stream cameras recorded the occurrence of much fewer taxa (n=6) than track beds (n=26) for the monitoring periods that both were operational, yet, these cameras provided important information on animal crossings through the structures in areas not monitored by track beds. These camera observations were critical for recording the use of structures by bobcats and several other species, especially through EAB. These camera data also underscore the importance of using cameras in areas within structures that cannot be monitored by track beds.

Each method has its advantages and disadvantages. Advantages of track beds include: 1) low cost, 2) round the clock 'monitoring', 3) simplicity, leading to less down time, and 4) easy coverage of broad areas. Disadvantages include: 1) the relatively high need for maintenance, 2) their vulnerability to weather, 3) frequent difficulty of differentiating species, 4) inability to differentiate individuals, and 5) need for a flat surface. Advantages of camera traps include their ability to 1) clearly identify species, 2) capture behavior (via video or rapid fire), 3) be situated in uneven terrain, 4) be easily repositioned, and 5) low maintenance (digital). Disadvantages of cameras include their 1) high cost, especially to cover a broad area, 2) potential for theft/vandalism, and 3) potential lack of consistency due to mechanical malfunction. Findings from our study were similar to those found by Hardy *et al.* (2003) in which the authors recommend using a combination of monitoring methods.

Regarding species, it is important to note that deer sometimes avoided the track beds (for example on East Airport Brook passage in 2006, Table 1) but were captured via remote camera. This information was important to the Vermon Department of Transportation (VTrans) since one of their major objectives was to minimize vehicle collisions with larger animals. Using only track beds would have underestimated deer use of the structures. The track beds appeared to be most effective in capturing medium size animals that did not have the capacity to jump over the beds such as woodchucks and raccoons. They proved problematic for detecting passage by small mammals. It was difficult to differentiate a true movement across the track bed because in many instances the small mammals (primarily mice) moved up and down the track bed making it difficult to discern true crossings. Our study appears to support research by Ford *et al.* (2009) in which they found cameras a more effective method for ungulates and track beds more suitable for medium size animals such as coyote.

While both track beds and camera traps 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 (as we did for small mammals) and telemetry monitoring may be necessary.

SNOW-TRACKING

Snow-tracking provides a tool for detecting behavior of animals in the broader landscape around crossing structures. A major benefit of snow-tracking is the ability to monitor a large number of continuous sets of animal tracks and therefore a large number of movements (a-i in Figure 1). 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 moderately large for snow-tracking, relative to the effort required for a similar sample size for a telemetry study. Although it was not possible in our study, pre-construction monitoring using telemetry and snow-tracking would be particularly useful for evaluating how construction of roadways may be affecting the movement and behavior of animals. One limitation of snow-tracking is that it provides only winter movement of animals, which may differ from movements during other times of the year.

During our two snow-tracking seasons seen in Table 2, we observed a higher use of the wildlife crossings than we did crossings of the road for white-tailed deer and a 75% (2005, n=12; 2006, n=21) increase from the first winter field season to the second, even with fewer track nights (2005, n=30; 2006, n=17). Thus, these data are consistent with studies suggesting that ungulates adapt to the use of wildlife crossings (Forman *et al*. 2003, Ruediger 2007, Olson & Widen 2008). The large size of the Bennington Bypass structures appears to be conducive for movement of ungulates. Only 17% (25/143) of animals that encountered the crossing structures moved away from them (movements d, g, h and i in Figure 1).

Contrary to deer, coyote appear to be primarily using the road for crossing (n=29) rather than the structures (n=8). This is similar to findings from Tigas *et al.* (2002) who found coyotes moving more readily across a highway versus an available culvert. While coyotes utilized the road for crossing they also exhibited aversive behavior to the road. Fifteen coyote tracks (out of a total 54 confirmed movements) showed animals moving away from the road or crossing structures (movements d, g, h and i in Figure 1), which was unexpected given the relative high proportion of coyotes crossing the highway in our study and other studies such as Singleton & Lehmkuhl (2000) and Donaldson (2005). A still higher proportion of coyotes were found moving across the highway (movements e and f in Figure 1). The coyotes avoiding the road might have been influenced by human activity. Fisher also both crossed over the highway (n=4) and avoided the highway (n=3), but our small sample size makes it difficult to make strong inferences about fisher movements in relation to roads.

Although overall, more animals used the crossing structures (n=68) than used the road (n=57) to cross the highway, the relatively high number of road crossings suggest that the structures may not be providing sufficient mitigation for this highway. This might be attributed to the lack of high fencing along the highway, a critical component of most successful wildlife crossing systems (Gloyne & Clevenger 2001, Braden *et al*. 2008, Olson & Widen 2008).

SMALL MAMMALS

For small mammals, both the road and the crossing structures appeared to exert some restriction on movement. Yet, the crossing structures provided at least some degree of connectivity between populations on opposite sides of the road, whereas small mammals rarely crossed over the highway

ROAD KILL

For larger species such as deer, the road kill index (N=number of road kills/road kill surveys) remained relatively low over the three years of our study (2005, N=0.05; 2006, N=0.07; 2007, N=.06), especially when considering the high numbers of deer observed in the area during other portions of our study. Since this was a new highway there were no pre-construction data to compare with our data. To put this in perspective, the road kill index over the three years for small animals was N=6.72, N=4.40 and N=8.89. 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 deer are successfully crossing the road, despite the medium to high traffic volumes along the Bypass. Similarly, Carbaugh *et al.* (1975) found that a high proportion of deer successfully crossed Interstate 80 in Pennsylvania when directly moving across the highway, but became more vulnerable when using the right of way for feeding. Based on our snow-tracking data we found that deer were mostly crossing at points along the highway where patch to patch distance was relatively short, a factor strongly supported by several other studies (Finder *et al*. 1999, Barnum 2003, Glista *et al*. 2009). These findings suggest that in areas where fencing (or wildlife crossings) is limited, landscape structure may the most important factor for successful deer crossings.

Our study appears to support research by Glista *et al*. (2008) that reported road mortality is highest for amphibians. We found that at least 31% of the road kills were anurans, and this number is likely higher considering only 69% of our small animals were identifiable. This reinforces the need for a multi species approach to wildlife crossing studies; few studies focus on herpetofauna. Overall roadkill rates did not decrease as distances increased from the crossing structures. This suggests that the passage structures may not have been particularly effective for reducing wildlife-vehicle collisions. These data combined with our snow-tracking data showing relatively high use of the road for crossing, reinforces the need for highway fencing if the goal of a project is to avoid wildlife-vehicle collisions and enhance the use of the crossing structures.

CONCLUSIONS

Using a combination of approaches, targeting multiple taxa, we conclude that the Bennington Bypass crossing structures are used frequently and by many species. However, this finding is tempered by continued crossings over the road (movements a and c in Figure 1), putting animals in danger of collision (movement b). Bobcat and coyote, for example, 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. The large size of the structures likely make them conducive to use by medium and large animals, especially deer, but the large size may also inhibit movement of smaller mammals because of the reduced vegetation cover (Rodriguez *et al.* 1996, Clevenger & Waltho 1999, Foresman 2003). Over time when the area revegetates, this dynamic may change and enhance movement of small mammals in the area. The crossing structures span riparian areas, thereby encompassing some of the most diverse, dynamic and complex biophysical habitats in terrestrial zones, benefitting species such as mink and otter (Naiman *et al.* 1993).

Our study underscores the importance of developing objectives when planning mitigation projects. If the objective is to minimize the number of potential collisions (movements a, b, and c) (moose, elk *Cervus canadensis*, Florida panthers *Puma concolor*), the criteria for success would be to minimize the number of these movements. In this case, continued use of the roadway by wildlife (movements a and c) or ongoing road-kill (b-type movement) would indicate that the mitigation has not been successful. Where the objective is to reduce but not necessarily eliminate road-kill (amphibians on a causeway through extensive areas of habitat), then the tolerance for movements a, b, and c would be higher. In the case of the Bennington Bypass, if the goal was to prevent animals' exposure to vehicle collisions, our data suggest these crossing structures are not fully effective. If, alternatively, the primary goal was to enhance permeability of the roadway, allowing a portion of each species' population to cross (movements a, c, e, and f), then these structures appear to be effective for some of the species we detected, specifically deer and mink. Track bed, remote camera and snow-tracking data suggest that the roadway was permeable for most species, especially deer, bobcat, coyote and mink, but this does not necessarily mean they are all passing through the structures, and many species are still vulnerable to vehicle collisions. Additional information on the demographics and population trends of particular species are needed, to identify the number of crossings per species to maintain population viability and likely effects of road-kill on population persistence. Monitoring projects such as this one, that evaluate a broad range of wildlife movements (Figure 1), can serve as a reasonable approach to evaluating mitigation success, particularly when combined with population modeling.

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REFERENCES

ABSON, R.N. & LAWRENCE, R.E. 2003. Monitoring the use of the Slaty Creek wildlife underpass, Calder Freeway, Black Forest, Macedon, Victoria, Australia. Pp. 303-308. *In:* Proceedings of the International Conference on Ecology and Transportation, NY, USA.

ALLEN, T.D.H. 2011. The use of wildlife underpasses and the barrier effect of wildlife guards for deer and black bear. *MSc Thesis*. Montana State University. Bozeman, MT, USA. 82p.

BARNUM, S. 2003. Identifying the best locations to provide safe highway crossing opportunities for wildlife. Pp. 246-252. *In*: Proceedings of the International Conference on Wildlife Ecology and Transportation, NY, USA.

BRADEN, A.W.; LOPEZ, R.R.; ROBERTS, C.W.; SILVY, N.J.; OWEN, C.B. & FRANK, P.A. 2008. Florida Key deer *Odocoileus virginianus clavium* underpass use and movements along a highway corridor. *Wildlife Biology*, 14: 155-163, http://dx.doi.org/10.2981/0909-6396(2008)14[155:FKDOVC]2.0.CO;2

CARBAUGH, B.; VAUGHAN, J.P.; BELLIS, E.D. & GRAVES, H.B. 1975. Distribution and activity of white-tailed deer along an interstate highway. Journal of Wildlife Management, 39: 570-581, http://dx.doi.org/10.2307/3800400

CLEVENGER, A.P. & WALTHO, N. 1999. Dry drainage culvert use and design considerations for small and medium sized mammal movement across a major transportation corridor. Pp. 263-277 *In:* Proceedings of the Third International Conference on Wildlife Ecology and Transportation, MT, USA.

CLEVENGER, A.P. & WALTHO, N. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation*, 121: 453-464, http://dx.doi.org/10.1016/j.biocon.2004.04.025

CORLATTI, L.; HACKLANDER, K. & FREY-ROOS, F. 2009. Ability of wildlife overpasses to provide connectivity and prevent genetic isolation. *Conservation Biology*, 23: 548-556, http://dx.doi.org/10.1111/j.1523-1739.2008.01162.x

CRAMER, P.C. & BISSONETTE, J.A. 2008. *National Cooperative Highway Research Program - Report 615 -.Evaluation of the use and effectiveness of wildlife crossings*. 161 p.

DICKMAN, C.R. & DONCASTER, C.P. 1987. The ecology of small mammals in urban habitats. *The Journal of Animal Ecology*, 56: 629-640, http://dx.doi.org/10.2307/5073

DONALDSON, B.M. 2005. *Report VTRC 06-R2 – The use of highway underpasses by large mammals in Virginia and factors influencing their effectiveness*. 37p.

FINDER, R.A.; ROSEBERRY, J.L. & WOOLF, A. 1999. Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. *Landscape and Urban Planning*, 44: 77-85, http://dx.doi.org/10.1016/S0169-2046(99)00006-7

FLESCH, A.D.; EPPS, C.W. & CAIN, J.W. 2010. Potential effects of the United States-Mexico border fence on wildlife. *Conservation Biology*, 24: 171-181, http://dx.doi.org/10.1111/j.1523-1739.2009.01277.x

FORD, A.T.; CLEVENGER, A.P. & BENNETT, A. 2009. Comparison of methods of monitoring wildlife crossing-structures on highways. *The Journal of Wildlife Management*, 73: 1213-1222, http://dx.doi.org/10.2193/2008-387

FORESMAN, K.R. 2003. Small mammal use of modified culverts on the Lolo south project of western Montana – an update. Pp. 342-343 *In*: Proceedings of the International Conference on Wildlife Ecology and Transportation, NY, USA.

FORMAN, R.T.T.; SPERLING, D.; BISSONETTE, J.A.; CLEVENGER, A.P.; CUTSHALL, C.D.; DALE, V.H.; FAHRIG, L.; FRANCE, R.L.; GOLDMAN, C.R.; HEANUE, K.; JONES, J.; SWANSON, F.; TURRENTINE, T. & WINTER, T.C. 2003. *Road Ecology: Science and Solutions*. Island Press, Washington, D.C. 483p.

GAGNON, J.W.; THEIMER, T.C.; DODD, N.L.; MANZO, A.L. & SCHWEINSBURG, R.E. 2007. Effects of traffic on elk use of wildlife underpasses in Arizona. *Journal of Wildlife Management*, 71: 2324-2328, http://dx.doi.org/10.2193/2006-445

GANNON, W. & SIKES, L.R. 2007. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. *Journal of Mammalogy*, 88: 809-823, http://dx.doi.org/10.1644/06-MAMM-F-185R1.1

GLISTA, D.J.; DEVAULT, T.L. & DEWOODY, J.A. 2008. Vertebrate road mortality predominantly impacts amphibians. *Herpetological Conservation and Biology*, 3: 77-87.

GLISTA, D.J.; DEVAULT, T.L. & DEWOODY, J.A. 2009. A review of mitigation measures for reducing wildlife mortality on roadways. *Biological Conservation*, 91: 1-7.

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

GRILO, C.; BISSONETTE, J.A. & SANTOS-REIS, M. 2008. Response of carnivores to existing highway culverts and underpasses: implications for road planning and mitigation. *Biodiversity and Conservation*, 17: 1685-1699, http://dx.doi.org/10.1007/s10531-008-9374-8

HARDY, A.; CLEVENGER, A.P.; HUIJSER, M. & NEALE, G. 2003. An overview of methods and approaches for evaluating the effectiveness of wildlife crossing structures: emphasizing the science in applied science. Pp. 319-330. *In:* Proceedings of the International Conference on Ecology and Transportation, NY, USA.

JACKSON, S.D. 1999. Overview of transportation related wildlife problems, Pp. 1-4. *In*: Proceedings of the Third International Conference on Wildlife Ecology and Transportation, FL, USA.

JAEGER, J.A.; BOWMAN, G.J.; BRENNAN, J.; FAHRIG, L.; BERT, D.; BOUCHARD, J.; CHARBONNEAU, N.; FRANK, K.; GRUBER, B. & VON TOSCHANOWITZ, K.T. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. *Ecological Modelling*, 185: 329-348, http://dx.doi.org/10.1016/j.ecolmodel.2004.12.015

KAYE, D.R.J.; WALSH, K.M. & ROSS, C.C. 2005. Spotted turtle use of a culvert under relocated Route 44 in Carver, Massachusetts. Pp. 426-432 *In*: Proceedings of the International Conference on Ecology and Transportation, CA, USA.

KRAWCHUK, A.; LARSEN, K.W.; WEIR, R.D. & DAVIS, H. 2005. Passage through a small drainage culvert by mule deer, *Odocoileus hemionus*, and other mammals. *The Canadian Field-Naturalist*, 119: 296-298.

MATA, C.; HERVAS, I.; HERRANZ, J.; SUAREZ, F. & MALO, J.E. 2008. Are motorway wildlife passages worth building? Vertebrate use of road-crossing structures on a Spanish motorway. *Journal of Environmental Management*, 88: 407-415, http://dx.doi.org/10.1016/j.jenvman.2007.03.014

MCCOLLISTER, M.F. & VAN MANEN, F.T. 2010. Effectiveness of wildlife underpasses and fencing to reduce wildlife-vehicle collisions. *Journal of Wildlife Management*, 74: 1722-1731, http://dx.doi.org/10.2193/2009-535

MENKENS JR., G.E. & ANDERSON, S.H. 1988. Estimations of small-mammal population size. *Ecology*, 69: 1952-1959, http://dx.doi.org/10.2307/1941172

NAIMAN, R.J.; DECAMPS, H. & POLLOCK, M. 1993. The Role of Riparian Corridors in Maintaining Regional Biodiversity. *Ecological Applications*, 3: 209-212, http://dx.doi.org/10.2307/1941822

OLSON, M.P.O. & WIDEN, P. 2008. Effects of highway fencing and wildlife crossings on moose *Alces alces* movements and space use in southwestern Sweden. *Wildlife Biology*, 14: 111-117, http://dx.doi.org/10.2981/0909-6396(2008)14[111:EOHFAW]2.0.CO;2

OXLEY, D.J.; FENTON, M.B. & CARMODY, G.R. 1973. The effects of roads on populations of small mammals. *Journal of Applied Ecology*, 11: 51-59, http://dx.doi.org/10.2307/2402004

RENZULLI, C.B.; FLOWERS, J.F. & TAMARIN, R.H. 1980. The effects of trapping design on demographic estimates in the meadow vole, *Microtus pennsylvanicus*. *The American Midland Naturalist*, 104: 397-401, http://dx.doi.org/10.2307/2424887

RODRIGUEZ, A.; CREMA, G. & DELIBES, M. 1996. Use of non-wildlife passages across a high speed railway by terrestrial vertebrates. *The Journal of Applied Ecology*, 33: 1527-1540, http://dx.doi.org/10.2307/2404791

RUEDIGER, B. 2007. Management Considerations for Designing Carnivore Highway Crossings. Pp. 546-555. *In*: Proceedings of the International Conference on Ecology and Transportation, AR, USA.

SHEPPE, W. 1967. The effect of livetrapping on the movements of Peromyscus. *The American Midland Naturalist*, 78: 471-480, http://dx.doi.org/10.2307/2485244

SINGLETON, P.H., & LEHMKUHL, J.F. 2000. I-90 Snoqualmie Pass wildlife habitat linkage assessment. 106p.

TIGAS, L.A.; VAN VUREN, D.H. & SAUVAJOT, R.M. 2002. Behavioral responses of bobcats and coyotes to habitat fragmentation and corridors in an urban environment. *Biological Conservation*, 108: 299-306, http://dx.doi.org/10.1016/S0006-3207(02)00120-9

TROMBULAK S.C. & FRISSELL, C.A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology*, 14: 18-30, http://dx.doi.org/10.1046/j.1523-1739.2000.99084.x

VAN BOHEMEN, H.D. 2005. *Ecological Engineering*. Boxtel, The Netherlands. 401p.

YANES, M.; VELASCO, J.M. & SUAREZ, F. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. *Biological Conservation*, 71: 217-222, http://dx.doi.org/10.1016/0006-3207(94)00028-O

ZIELINSKI, W.J. 1995. Track Plates. Pp 67-89. *In*: W.J. Zielinski & T.E. Kucera (eds.). USDA Forest Service General Technical Report PSW GTR-157 – American Marten, Fisher, Lynx, and Wolverine: Survey Methods for Thair Detection. 164p.

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