Title

Use of highway underpasses by large mammals and other wildlife in Virginia and factors influencing their effectiveness

Permalink

https://escholarship.org/uc/item/0t36v00w

Author

Donaldson, Bridget M.

Publication Date

2005-08-29

Use of Highway Underpasses by Large Mammals and Other Wildlife in Virginia and Factors Influencing Their Effectiveness

Bridget M. Donaldson (Phone: 434-293-1922, Email: bridget.donaldson@vdot.virginia.gov), Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, VA 22903

Abstract: The rapid increase in animal-vehicle collisions on U.S. roadways is a growing concern in terms of human safety, property damage and injury costs, and viability of wildlife populations. Wildlife crossing structures are gaining national recognition by transportation agencies as effective measures to reduce animal-vehicle collisions and connect wildlife habitats across transportation corridors. In Virginia, white-tailed deer and black bear pose the highest risk. This one-year study was conducted to monitor various underpass structures in Virginia to determine the structural and location attributes that make a crossing successful in terms of use by large mammals. The underpasses, most of which were not specifically designed as wildlife crossings, consist of box culverts and bridges of varying sizes.

Remote cameras installed at seven underpass sites in Virginia have recorded more than 2,700 wildlife photographs and documented 1,107 white-tailed deer crossings in the most heavily used structures. Underpasses with a minimum height of 12 ft were successful at facilitating deer passage. Such structures were also heavily used by a variety of wildlife species, including coyote, red fox, raccoon, groundhog, and opossum. Structures with drainages that mimic natural waterways can encourage use by a diversity of terrestrial, semi-aquatic, and aquatic species.

This report provides guidance in choosing cost-effective underpass design and location features that are necessary to consider to increase motorist safety and habitat connectivity. The findings also demonstrate that if only a minimal number of deer-vehicle collisions is prevented by an effective underpass, the savings in property damage alone can outweigh the construction costs of the structure.

Introduction

The increasing frequency of animal-vehicle collisions in the United States is taking an enormous toll in terms of wildlife viability and driver safety. For species that commonly attempt to cross roads, the numbers of animals killed can have a devastating effect on their populations. Roads and highways act as barriers for other species, isolating populations and increasing the chance of local extinction. For humans, more than $1.1 billion in vehicle damage is caused in the United States from an estimated 1.5 million traffic accidents involving deer alone (Hedlund et al. 2003). In Virginia, the white-tailed deer (*Odocoileus virginianus*) population has increased 400 percent since 1968, and Virginia's human population has increased 61 percent. As a result of these drastic increases, the number of reported deer-vehicle collisions (DVCs) in the state has increased nearly eight-fold in the last 35 years.

In areas where black bear attempt to cross roads, road-mortality has significantly affected black bear (*Ursus americanus*) populations in the southern Appalachians. As roads are upgraded to accommodate greater traffic volumes, the rate of successful black bear crossings in the Appalachians decreases significantly, and black bears become reluctant to cross roads (Brody and Pelton 1989, Virginia Dept. of Game and Inland Fisheries 2002). This avoidance of roads can isolate wildlife populations, and ultimately reduce biodiversity and genetic variability.

Wildlife crossings, or passages beneath or above a roadway, are a form of mitigation designed to facilitate safe wildlife movement across a transportation corridor. In a literature review of 16 mitigative techniques to reduce DVCs, the only measures consistently found to achieve DVC reductions were the installations of exclusionary fencing and wildlife crossing structures (Knapp et al. 2004). Similarly, the 2003 report issued by the Insurance Institute for Highway Safety regarding methods to reduce DVCs concluded: "Fencing, combined with underpasses and overpasses as appropriate, is the only broadly accepted method that is theoretically sound and proven to be effective" (Hedlund et al. 2003, p. 14).

Because many states have relatively few structures designed to facilitate wildlife passage, monitoring for wildlife use is often limited to underpasses that were designed for other purposes. Structures such as bridges or culverts that were constructed to span streams and rivers, to protect wetlands, or to provide access for farm animals or equipment may function as wildlife crossings. Virginia has multiple structures throughout its roadway system that are likely used by wildlife. The Virginia Department of Transportation (VDOT) has constructed two structures designed for large mammal passage in northern Virginia, and others are currently under construction on Route 17 through the Great Dismal Swamp National Wildlife Refuge. However, VDOT has no information regarding the performance of any of its structures in terms of facilitating animal movement.

The purpose of this study was (1) to determine the effectiveness of VDOT's existing large mammal crossings, (2) to determine the design and location attributes that make a wildlife crossing successful in terms of use by Virginia's large mammals and the associated influence on animal-vehicle collisions, and (3) to analyze the costs of wildlife crossing construction relative to the potential savings in property damage resulting from a reduction in animal-vehicle collisions.

Methods

Underpass study sites
Seven underpass structures were monitored over a 12-month period, from June 1, 2004, to May 31, 2005. These sites were chosen in order to obtain a representative sample of structures beneath Virginia roadways that potentially function as deer and black bear crossings. Five of the structures (Sites 1, 2, 4, 5, and 6) were not constructed for the purpose of wildlife movement, and two structures (Sites 3A and 3B) were installed specifically for animal passage. Because most of the structures were not designed as wildlife crossings, study sites are generally referred to as

"underpasses" or "structures" rather than wildlife crossings in this report. Sites 3A and 3B were constructed with a section of grating 45 ft by 10 ft (18 m by 3 m) centered in the ceilings (in the highway median above) to allow in sunlight. Most structures convey water (generally a narrow stream or creek) but also offer ample space for animal movement.

Eleven variables including structural, landscape, and human activity attributes were measured at each site (table 1). The openness factor, a structural variable used as a measurement of ambient light in a structure, was calculated by the equation (width x height)/length. Openness has been found to be a significant factor in determining relative effectiveness of structures in terms of use by deer and other species (Reed et al. 1975). Other attributes, including structure ground covering and frequency of human visits to the structures, were also recorded. The description of the deer habitat suitability indices are described below.

Table 1. Attributes of underpass structures in Virginia monitored from May 2004 through May 2005

Attributes	Structure						
	1 Box Culvert	2 Bridge	3A Box Culvert	3B Box Culvert	4 Triple Box Culvert	5 Double Box Culvert	6 Bridge
Structural							
Width, ft (m)	10 (3.0)	32 (9.8)	20 (6.1)	10 (3.0)	6 (1.8)	8 (2.4)	44 (13.4)
Height, ft (m)	12 (3.7)	45 (13.7)	15 (4.6)	6 (1.8)	6 (1.8)	8 (2.4)	15 (4.6)
Length, ft (m)	189 (57.6)	307 (93.6)	192 (58.5)	105 (32.0)	68 (20.7)	260 (79.2)	59 (18.0)
Openness (metric) [a]	0.19	1.43	0.64[b]	0.17[b]	0.16	0.07	3.42
Structure floor	Natural	Natural	Natural	Concrete	Concrete	Concrete	Natural
Fencing, ft (m)	5200 (1,585)	None	40 (12)	40 (12)	None	None	None
Landscape (distance to)							
Forest cover, ft (m)	0	15 (4.6)	12 (3.7)	5 (1.5)	7 (2.1)	0	50 (15.2)
Drainage, ft (m)	320 (97.5)	0	0	0	0	0	0
Human activity							
Human use	3	17	10	5	1	1	2
Traffic intensity[c]	H	H	H	H	M	H	H
Deer habitat suitability index[d]	72.20	74.15	65.68	67.91	72.41	62.56	64.40

[a] Openness was determined by calculating (height x width)/length (Reed et al., 1975).
[b] Because the ceilings of structures 3A and 3B have a grated center section that allows in light, the openness value was calculated using ¾ of the length.
[c] Based on average annual daily traffic of High (10,000-49,999), Medium (1,000-9,999), and Low (0-999).
[d] Based on a scale of 1 to 100. Land use was similar in the immediate surroundings of study sites, reflected by the proximities of the indices.

Underpass monitoring
Data from monitoring animal movements were obtained from Game-Vu (Nature Vision, Inc.) and Stealth Cam® digital scouting cameras. These remote cameras photograph images based on infrared heat and motion sensors. Game-Vu Digital Trail cameras use undetectable infrared illumination at night rather than a flash and were, therefore, installed at sites where human visitation was a concern. Stealth Cam® cameras were used at the other sites because of their slightly longer range at night. Two cameras were installed at each site. For box culvert monitoring, one camera was attached to a tree, to a wooden post, or near the ground at both of the structure entrances. For bridge monitoring, two cameras were attached to trees on either end of the bridge. Because cameras could not capture the entire range beneath the Site 2 bridge, sand beds at each end of the bridge were checked weekly for large mammal tracks to supplement camera monitoring.

Structures were visited once every week during the 12-month period to download photographs from the cameras and to replace batteries. Data recorded from photographs at each site included the date, time, number of photographs of each species, and direction of travel. The number of complete passages through the structure by deer and black bears, the number of turn-around events (approaches to an underpass with incomplete crossings), and the number of hesitancy behaviors by deer (indicated by muzzles lowered to the ground) were determined (Reed et al. 1975, Gordon and Anderson, 2003).

On some occasions, camera battery power depleted one to two days prior to replacement. In order to account for site differences in camera operative days, crossing frequency indices were calculated by dividing the number of crossings by deer and black bears at each site by the respective number of camera operative days.

Development of deer habitat suitability indices
In order to make valid comparisons of underpass use by deer, it was necessary to quantify either deer population or deer habitat suitability in the vicinity of each underpass. Given the spatial and geographic variation among the seven sites, it could not be assumed that deer populations and habitat suitability were uniformly distributed around the sites. Because the size of the deer population immediately surrounding each site was unavailable, deer habitat suitability indices were developed. The higher the index, the higher the relative deer habitat suitability was surrounding the underpasses. These indices were later used in the statistical analyses of underpass use.

A geographic information system (GIS) is a widely used tool for modeling habitat suitability for a variety of applications. Much of the development of deer habitat suitability indices for this study was adapted from the work of Clevenger et al. (2002) and Clevenger and Waltho (2005). They found that a GIS-generated model, using habitat information derived from expert literature to perform pairwise comparisons, most closely approximated an empirical model for identifying black bear habitat. For the development of the deer habitat suitability indices for this study, a similar methodology was applied with the use of ArcGIS® (Environmental Research Institute, Redlands, California) and a pairwise comparison matrix (Saaty 1977).

National land cover data were obtained from the U.S. Geological Survey and imported into ArcGIS®. This dataset included 13 habitat types within the areas surrounding the underpass sites. Because the home range of deer is generally no larger than one mile (Severinghaus and Cheatum 1956), a one-mile buffer was generated around each of the seven underpass sites. The ArcGIS® Spatial Analyst extension was then used to determine the percentage of each habitat type within each one-mile radius.

For the pairwise comparison, each of the 13 habitat types was rated against the other in terms of relative importance of the habitat for white-tailed deer. Ratings were based on a nine-point continuous scale: 9, extremely more important; 7, very strongly more important; 5, strongly more important; 3, moderately more important; 1, equally more important; 1/3, moderately less important; 1/5, strongly less important; 1/7, very strongly less important; and 1/9, extremely less important (Saaty 1977). Information on which to base deer habitat ratings was obtained from four sources of information (Harlow 1984, Newson 1984, Shrauder 1984, Whittington 1984); the latter three were directly relevant to deer in Virginia. Two individuals, including the author, used the information from these sources to complete the pairwise comparison matrix. The completed pairwise comparisons resulted in weights for each habitat type. A consistency ratio was calculated to ensure consistency in rating development. Pairwise comparison matrices with consistency ratios greater than 1.0 were reevaluated (Saaty 1977). The percentage of each habitat type (derived from the GIS analyses) within the one-mile radius of each site was then multiplied by its weight (derived from the pairwise comparison). The weighted values for the site were summed to derive a deer habitat suitability index. This method was repeated with each of the seven underpass sites. Indices are listed in table 1.

Underpass evaluations
The numbers of deer and black bear crossings, turn-arounds, and hesitancy behaviors were compared among all underpass sites. Sites 3A and 3B are located approximately 0.25 mi (400 m) from one another and potentially facilitate the movement of the same animal populations. Because they primarily differ in structural attributes, the use of these structures by all species was compared to help provide valuable information on animal preferences for crossing structures.

Data analyses
Multiple regression analyses were performed to determine the influence of underpass attributes on deer crossing frequency, adjusting for differences in deer habitat suitability between sites. Statistical analyses were performed with the assumption that the crossing frequency was a measure of the quality of the underpass as sensed by wildlife. For all analyses, differences were considered statistically significant when $p < 0.05$.

Criteria for success
In order to evaluate an underpass in terms of its effectiveness in reducing the barrier effect of roads and reducing animal-vehicle collisions, it was necessary to specify the criteria for success. Goals and criteria, adapted from those of Forman et al. (2003), include (1) maintain habitat connectivity (determined by a minimum passage of animals detected), (2) maintain genetic interchange (determined by a passage of adults), and (3) allow for dispersal (determined by passage of juveniles).

Determination of deer-vehicle collisions relative to underpass locations
Using available information obtained from Virginia's Highway Traffic Records Information System and Fairfax County police records, the number and locations of DVCs reported from 1997 through 2001 and 1995 through 2004, respectively, were recorded within several miles of each monitored site used by deer. Because only reported collisions are included in these records, however, a potentially large percentage of the actual collisions that occurred was unavailable for analysis.

Cost analysis

To transportation agencies, cost is often the largest deterrent to constructing wildlife crossings. Because there are currently no regulatory directives or guidelines pertaining to wildlife crossings, the decision by transportation agencies to construct them is often based on the expected return in investment. This may be in the form of ecological benefits and increased driver safety. Ecological benefits include the creation of wildlife corridors, reduced effects of fragmentation (Forman et al. 2003), and reduced road mortality. Driver safety includes a reduction in animal-vehicle collisions and the corresponding reduction in deaths, injuries, and property damage, which translates into savings for taxpayers. With regard to taxpayer savings, one human fatality from a DVC can result in a loss of millions of dollars in damage, hospital costs, and lost wages. Property damage costs alone comprise a substantial taxpayer cost. Since assigning a monetary value to the ecological benefits is difficult, the economic benefits solely in terms of a reduction in property damage were analyzed. Property damage values were derived from the 2003 average cost in property damage from DVCs in Virginia ($2,530).

Construction costs for two effective underpasses in this study, Sites 1 and 3A, were used for the analyses. Annualized costs, or the equivalent uniform annual costs, were calculated for these underpasses for comparison with annual DVC incidents. Annualized costs in these examples are the yearly costs of an underpass as if they were uniform throughout the service life of the structure (estimated at 70 years; Blackwell and Yin 2002). Although these sites do not have fencing designed to funnel animals toward the structures, fencing prices ($125,000 for each structure) were added to the underpass construction costs to represent more realistic examples of wildlife crossing scenarios.

Results

Deer and black bear activity
A total of 2,702 photographs of wildlife were captured at the seven sites over the 12-month period (fig. 1). Six of these photographs were of black bear, and 1,040 were of white-tailed deer.

Figure 1. Black bear approaching entrance of Site 1 (A), deer in Site 1 (B), red fox in Site 3A (C).

Black bears
No black bears crossed through any of the monitored underpasses, although they approached the northern entrance of Site 1 on three occasions. On two occasions, a bear remained facing the culvert entrance for two minutes before turning and leaving the area. On September 20, a bear approached the entrance a second time 38 minutes after the first approach.

Deer
A total of 1,107 deer crossings occurred through four of the seven underpass sites in the 12-month period (x= 277, N = 4). Sites 1, 2, and 3A received the heaviest use, and Site 3B the least. There were no crossings or visits by deer in Sites 4, 5, and 6. Although Site 1 received relatively high use by deer, it was associated with the highest number of turn-around events and hesitancy behaviors (fig. 2).
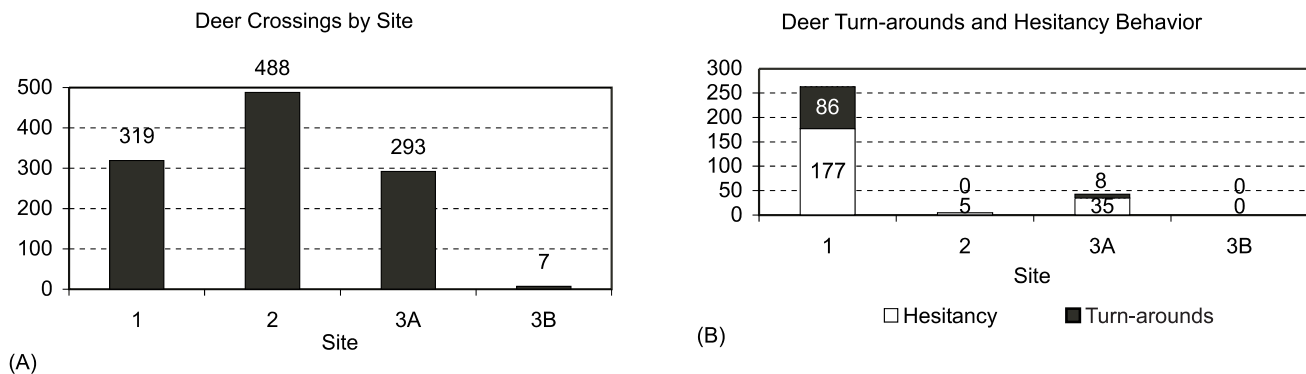

(A)

(B)

Figure 2. Number of white-tailed deer crossings (A) and number of turn-arounds and hesitancy behaviors (B) for underpasses visited by deer from June 2004 through May 2005.

The crossing frequency index was highest and most consistent at Site 2, with 1.34 crossings per day. Site 1 averaged 1.1 crossings per day, Site 3A averaged 0.91 crossing per day, and Site 3B received relatively little use, at 0.02 crossing per day. The monthly crossing frequency indices at each site were highest in the autumn months, dropped steeply in winter, and rose in late spring. During the period of heaviest activity in the fall, Site 1 received the heaviest use, reaching an average of 4.7 crossings per day in September (fig. 3).
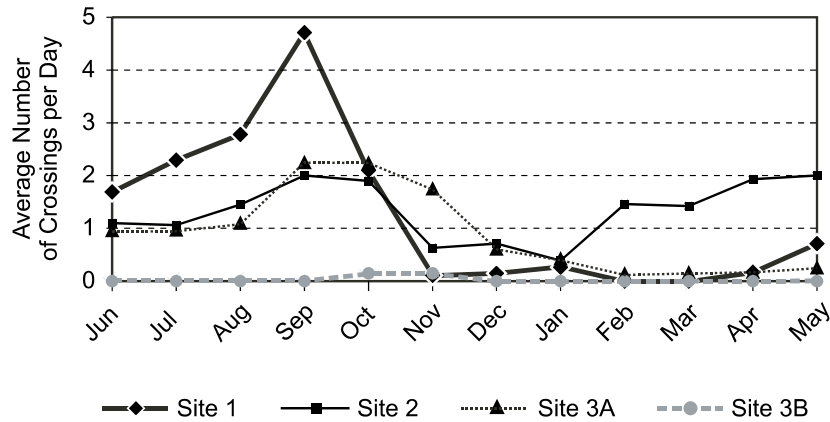
Figure 3. Average number of white-tailed deer crossings per day each month, from June 2004 through May 2005.

Other wildlife activity

Although the focus of this project was large mammal use of underpasses, the number and species of other wildlife were also recorded. Each underpass site was used by a minimum of two species. Other species detected included opossum, squirrel, house cat, bobcat, red fox, coyote, raccoon, groundhog, mice species, amphibian species (southern leopard frog and American toad), black rat snake, at least two bird species (songbird and great blue heron), and fish species. Because amphibian, reptile, mouse, and fish use of the underpasses was observed but not detected by cameras, these species were not included in the analyses. Nocturnal species used the underpasses between dusk and dawn, with daytime use generally limited to deer and groundhog. Cameras at Site 3A photographed a coyote with a small mammal in its mouth (species cannot be determined).

Because of the proximity and similar landscape attributes of Sites 3A and 3B, the sites were useful for comparing use by species. Activity was greater for all species in Site 3A, with 1,177 photographs compared to the 708 photographs at Site 3B (fig. 4).
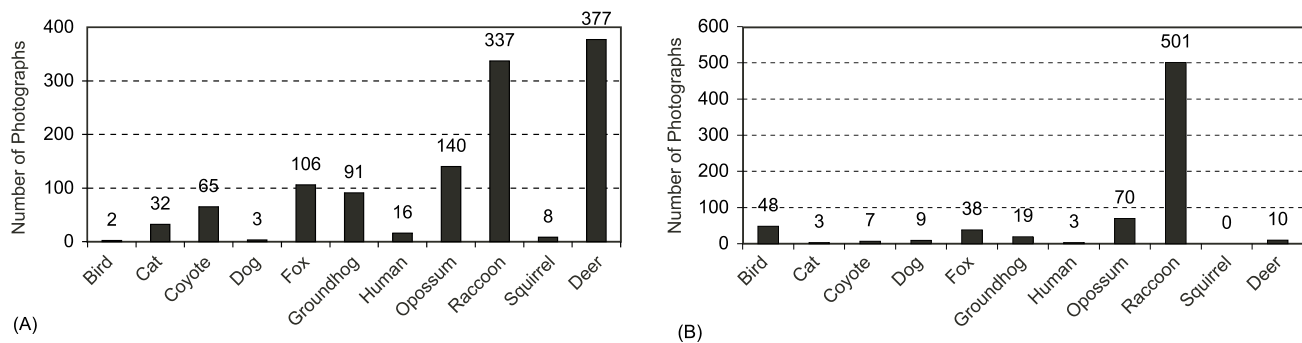

Figure 4. Number of photographs in Site 3A (A) and 3B (B) taken by two cameras at each site.

Underpass evaluations

Data analysis
A large discrepancy in deer crossing frequency was apparent between structures with a height greater than or equal to 12 ft (3.7 m) and those with a height less than 12 ft. To represent this distinction, height values were differentiated into these height groupings. Adjusting for deer habitat suitability at each site, an underpass height greater than 12 ft was significantly correlated to crossing frequency (Beta = 0.78 ± 0.20, P = 0.047). Landscape and human activity variables were not significantly correlated to crossing frequency.

Criteria for success
Underpasses were evaluated according to whether they met the predefined goals (table 2). Because no black bears crossed during the monitoring period, evaluations were based solely on white-tailed deer. In terms of meeting all three underpass goals for deer, Sites 1, 2, and 3A were determined to be effective overall.

Table 2. Goals and successes (in terms of white-tailed deer use) of seven underpasses monitored from June 2004 through May 2005

Goals	Criteria for Success	Site						
		1	2	3A	3B	4	5	6
1. Maintain habitat connectivity	Minimum passage of deer detected	Yes 319	Yes 488	Yes 293	No[a] 7	No 0	No 0	No 0
2. Maintain genetic interchange	Passage by adults (primarily males in breeding season)	Yes	Yes	Yes	Yes	No	No	No
3. Allow for dispersal	Evidence of juvenile passage	Yes	Yes	Yes	No	No	No	No

[a]Based on a comparison of the number of crossings at Site 3B relative to that at Sites 1, 2, and 3A, it is unlikely that 7 crossings over a 1-year period adequately met the goal of maintaining habitat connectivity. It is possible that the proximity of 3B to 3A influenced the crossing frequency at 3B.

Deer-vehicle collisions relative to underpass locations

Small sample sizes restricted the statistical analyses of the number of DVCs immediately surrounding the underpasses relative to segments with no underpasses. These data were, therefore, depicted graphically to illustrate the number of DVCs adjacent to underpass locations (fig. 5). For Site 1, there were no reported DVCs 0.75 mi to the west and 1.25 mi to the east of the underpass within a five-year period (1997-2001) for which data were available. At the section east of the underpass, a high ridge prevents deer from entering the highway. Within the 2.5-mile road segment (flanked by two perpendicular roads) under which Sites 3A and 3B lie, there were five DVCs within a 10-year period (1995 through 2004).
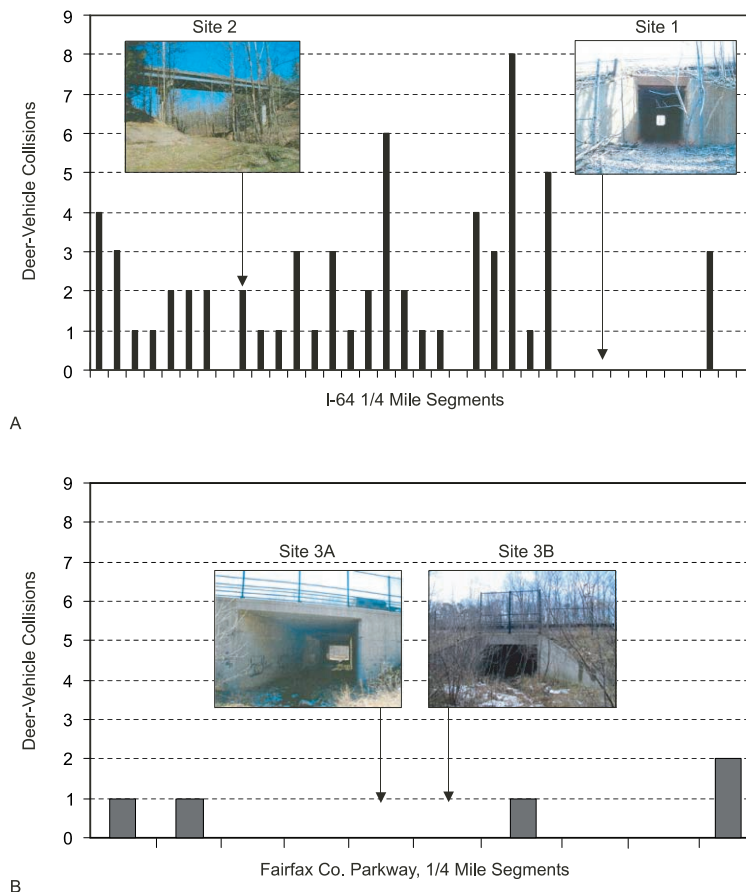

Figure 5. Reported deer-vehicle collisions in relation to location of underpasses used by white-tailed deer. DVC data for I-64 (A) include a 5-year period (1997-2001), and data for the Fairfax County Parkway include a 10-year period (1995-2004).

Cost analysis

The annualized costs were $6,600 for Site 1 and $23,000 for Site 3A (based on total costs of $257,000 and $585,000, respectively). Underpasses at these prices are cost-effective in terms of property damage savings when they prevent a minimum of 2.6 DVCs per year and 9.1 DVCs per year, respectively (fig. 6).

Because the Site 1 and Site 3A underpasses were constructed when the road was constructed, pre-construction DVC data are unavailable. However, considering that the numbers of deer crossings in Site 1 and Site 3A were 319 and 293, respectively, it is probable that more than 2.6 and 9.1 DVCs, respectively, were prevented that year. If this was the case, then the savings in property damage alone outweighed the annualized cost of the underpasses.
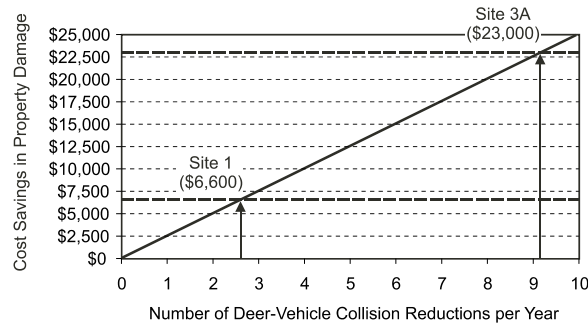

Figure 6. Cost savings in property damage resulting from reduction in deer-vehicle collisions.

Discussion

The results of this research concur with those of studies that have found that properly sized and located structures receive heavy use by wildlife (Foster and Humphrey 1995, Clevenger and Waltho 2005, Mata et al. 2005), thereby reducing the ecological effect of roads and reducing animal-vehicle collisions. For large mammals in Virginia, appropriate structure design is essential for maximizing the benefit from wildlife crossing construction.

Sites 1, 2, and 3A were determined to be effective road-crossing mechanisms for deer. Crossing frequencies were highest during late summer and fall. Crossing use reflected seasonal activity, with deer averaging nearly five crossings per day at Site 1 in the fall months. This corresponds to greater periods of movement associated with mating and feeding activities.

The other sites were ineffective in terms of facilitating deer passage. For most sites, this was a result of the structure's small size and corresponding low openness factor. For the bridge of Site 6, this was not the case. At this site, the structure size was adequate, but the uneven approach and lack of visibility from one end to the other likely discouraged large mammal use. At the western opening of this bridge, a four-foot ledge slightly impeded access to the area beneath the bridge, and the ledge and a rock cliff obstructed views of the habitat on the far side of each entrance. Effective underpasses were easily accessible with level approaches and had clear lines of site to the habitats on the far side.

Black bears approached but did not cross through any of the underpass sites. Because of annual fluctuations in food availability, environmental conditions, and inter- and intra-specific interactions, however, one year of data collection is insufficient to allow the conclusion that the structures are unsuitable for bears (Manen and Pelton 1995).

Attributes of effective underpasses

White-tailed Deer
Underpasses with a minimum height of 12 ft (3.7 m) were significant determinants of deer crossing frequency. The bridge (Site 2) had the highest deer passage rate and lowest number of incidents of hesitancy behavior and turn-arounds. This was expected because of its large size and lack of walls, unlike the Site 1 and 3A box culverts. Although the second highest number of crossings was at Site 1, 19 percent of the approaches to Site 1 were associated with turn-arounds. The high number of crossings at this site was likely influenced by the structure's position in the landscape. The southeastern borders along the underpass openings slope to a high ridge. This ridge functioned as a barrier to deer movement across the highway (as evidenced by no DVCs within 1.25 mi [2,012 m] east of the underpass), and the surrounding hillsides served as a guideway for deer toward the underpass (fig. 7). Although the optimal placement of Site 1 undoubtedly contributed to its high use by deer, the high number of incidents of hesitation and turn-arounds is likely explained by its relatively low openness index (0.19).
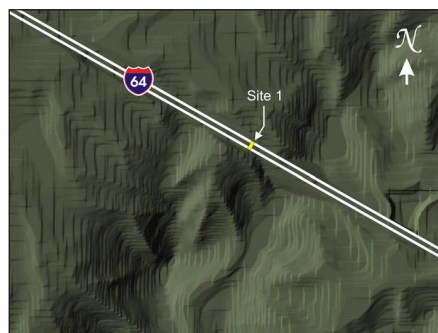

Figure 7. Aerial view of topographic features surrounding Site 1.

Conversely, the larger structure (Site 3A) had an openness index of 0.64 and had a low number of hesitancy behavior and turn-arounds (3%). Despite the lower deer habitat suitability rating of Site 3A (65.68) compared to Site 1 (72.20), Site 3A had only 26 fewer crossings than did Site 1 throughout the year. In addition, crossing frequency at Site 3A was more consistent throughout the year than that at Site 1. The size dimensions, presence of a creek, and ceiling grating of Site 3A are, therefore, thought to be more appropriate features for encouraging deer passage than those (or the lack thereof) at Site 1.

Previous studies on deer and other ungulates found that they preferred underpasses at least 23 ft (7 m) wide and 8 ft (2.4 m) high (Carsignol et al. 1993, Foster and Humphrey 1995), which is substantially wider (and likely costlier) than what was necessary to achieve a high crossing frequency in this study. Successful underpasses dimensions for white-tailed deer in this study concur with Smith's (2003) minimum height recommendation of 12 ft (3.7 m), and a minimum width of 10 ft (3 m). The length should be short enough to result in an openness index of at least 0.25 to discourage the high percentage of turn-arounds at Site 1. Lower structures may also be successful if the structure is wide and short (in length) enough to result in a high openness index.

Black bears
Research results on black bear size preferences for underpasses are conflicting. Clevenger and Waltho (2005) found that black bears prefer more constricted crossing structures with low heights and narrow widths. Other research has shown bears to use underpasses with larger, more open dimensions, such as bridges and a culvert 25-ft by 8-ft by 47-ft (7.6-m by 2.4-m by 14.3-m; Land and Lotz 1996). The presence of herbaceous vegetation at structure entrances was found to be important in bear underpass use (Smith 2003), and distance to nearest drainage was found to be positively correlated with black bear use (Clevenger and Waltho 2005). The fact that black bears approached Site 1 on three occasions, remaining at the entrance up to 38 minutes but not crossing through, may indicate that its structural dimensions are unsuitable for black bears. Further studies on black bear wildlife crossing preferences are needed.

Other wildlife
Structures that were effective for deer were also used heavily by other species. With the exceptions of Sites 3A and 3B, cameras were positioned to maximize the likelihood of deer and bear photographs and were, therefore, not optimally placed for capturing photographs of smaller animals. Because of the low camera positioning and the sites' proximity to one another, Sites 3A and 3B were useful for comparing use by small and medium species. Compared to Site 3B, Site 3A received the most use in terms of both number of photographs and number of species using the structure. Other than structure size differences, the only perceptible difference between these sites was the structure floor. Site 3A had an open bottom with a creek passing between two areas of dry land, whereas Site 3B had a concrete bottom that remained dry the majority of the year. In addition to the larger size and natural bottom of Site 3A, the presence of various-sized rocks in the underpass (for cover for small species) also likely influenced underpass use.

For some animals, the habitat within the underpasses appeared to be a center of activity within their home range. Many of the smaller mammals entered the underpass in one entrance, remained for several minutes to hours, and left from the same entrance. Animals, including deer, raccoon, red fox, and a great blue heron, were photographed drinking and/or foraging from the creek in Site 3A on multiple occasions. For medium and large animals, the underpasses generally appeared to be a means to access habitat on either side of the road. The photograph of a coyote with a small mammal in its mouth may suggest that carnivores use underpasses for catching prey. Although the coyote may have been carrying the prey from one side of the road to the other, there is some evidence that crossing structures have been used for hunting (Foster and Humphrey 1995).

Location and placement
Views differ regarding the most effective placement of wildlife crossings and whether structural features or location and landscape features are more important in determining a structure's success. Some studies have attributed success to placement, based on optimal location features or placement along actual travel routes, rather than the dimensions of a structure (Beier and Loe 1992, Foster and Humphrey 1995). Topography and watercourses can affect animal movement across a road. Barnum (2003) found that linear guideways, including ridgelines, drainages, and sharp breaks in cover type, correlate with road-crossing hotspots.

Other research has found structural attributes to be more important determinants of a structure's success for deer (Clevenger and Waltho 2005). In this study, height was the most important determinant of deer crossing frequency, although placement was also important. The hilly topography around Site 1, for example, seemed to serve as a natural guide for deer toward the underpass (fig. 7), and all sites used by deer were surrounded by suitable deer habitat on either side of the structures. Deer have likely altered their movement patterns over the years to cross through structures that meet the minimum size requirements, as it is unlikely that the heavily used underpasses (1,107 deer crossings in 1 year) were coincidentally placed immediately along deer travel routes. Studies suggest that wildlife passage increases as animals learn a structure's location and become accustomed to it over time (Land and Lotz 1996, Walker and Baber 2003).

Savings in property damage
Sites 1 and 3A are cost-effective in terms of property damage savings alone when they prevent a minimum of 2.6 and 9.1 DVCs per year, respectively. Considering the number of deer crossings in Site 1 and Site 3A (319 and 293, respectively), it is probable that those numbers are achieved annually.

Although the bridge of Site 2 received the heaviest use by deer, structures this size are likely not the most cost-effective if constructed primarily to facilitate deer passage. Multiple culverts, designed to serve the dual purpose of drainage, and fencing may provide more passage and reduce more DVCs for the same cost as a large bridge.

Biographical Sketch: Bridget Donaldson completed her bachelor's degree in biology from University of Colorado, and received a master's of science degree in ecology and evolutionary biology from University of Tennessee in 2001. She has nine years of experience in ecology and conservation; her work has included research on terrestrial animals throughout the southeastern U.S., the Gulf of Mexico, Queensland Australia, and Grand Cayman Island. In her current position as a research scientist with Virginia Transportation Research Council (a component of Virginia Department of Transportation) in Charlottesville, VA, her work involves research in the field of ecology and transportation.

References

Barnum, S.A. *Identifying the Best Locations Along Highways to Provide Safe Crossing Opportunities for Wildlife.* Report Number CDOT-DTD-UCD-2003-9. Colorado Department of Transportation Research Branch, Denver, 2003.

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

Blackwell, M.R. and X. Yin. Installation and initial performance of 60" ADS N-12HC® HDPE pip3w. Report RDT02-007/RI01-037. Missouri Department of Transportation, Jefferson City, Missouri, 2002.

Brody, A.L., and M.R. Pelton. Effects of Roads on Black Bear Movements in Western North Carolina. *Wildlife Society Bulletin*, Vol. 17, 1989, pp. 5-10.

Carsignol, J. *Passages pour la grande faune.* Service d'Etudes Techniques des Routes et Autoroutes, Centre de la Securite et des Techniques Routieres, Bagneaux, France, 1993.

Clevenger, A.P., and N. Waltho. Performance Indices to Identify Attributes of Highway Crossing Structures Facilitating Movement of Large Mammals. *Conservation Biology*, Vol. 121, 2005, pp. 453-464.

Clevenger, A.P., J. Wierzchowski, B. Chruszcz, and K. Gunson. GIS-Generated Expert Based Models for Identifying Wildlife Habitat Linkages and Mitigation Passage Planning. *Conservation Biology*, Vol. 16, 2002, pp. 503-514.

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

Foster, M.L., and S.R. Humphrey. Use of Highway Underpasses by Florida Panthers and Other Wildlife. *Wildlife Society Bulletin*, Vol. 23, No. 1, 1995, pp. 95-100.

Gordon, K.M., and S.H. Anderson. Mule Deer Use of Underpass in Western and Southeastern Wyoming. In *Proceedings of the International Conference on Ecology and Transportation*. Center for Transportation and the Environment, Lake Placid, N.Y., 2003.

Harlow, R.F. Habitat Evaluation. In L.K. Halls, Ed., *White-Tailed Deer: Ecology and Management*. Stackpole Books, Harrisburg, Pa., 1984, pp. 601-628.

Hedlund, J.H., P.D. Curtis, G. Curtis, and A.F. Williams. *Methods to Reduce Traffic Crashes Involving Deer: What Works and What Does Not.* Insurance Institute for Highway Safety, Arlington, Va., 2003.

Knapp, K.K. *Deer Vehicle Crash Countermeasure Toolbox: A Decision and Choice Resource.* Report DVCIC-02. Wisconsin Department of Transportation, Madison, 2004.

Land, D., and M. Lotz. Wildlife Crossing Designs and Use by Florida Panthers and Other Wildlife in Southwest Florida. In *Trends in Addressing Wildlife Mortality: Proceedings of the Transportation Related Wildlife Mortality Seminar.* FL-ER-58-96. Florida Department of Transportation, Tallahassee, 1996, pp. 379-386.

Manen, F.T., A.B. Coley, and M.R. Pelton. *Use of Interstate Passageways by Black Bears.* Report TN-RES1058. Tennessee Department of Transportation, Nashville, 1995.

Mata, C., I. Hervás, J. Herranz, F. Suárez, and J.E. Malo. Complementary Use by Vertebrates of Crossing Structures Along a Fenced Spanish Motorway. *Biological Conservation*, Vol. 124, No. 3, August 2005, pp. 397-405.

Newson, J.D. Coastal Plain. In L.K. Halls, Ed., *White-Tailed Deer: Ecology and Management*. Stackpole Books, Harrisburg, Pa., 1984, pp. 367-380.

Reed, D.F., T.N. Woodward, and T.M. Pojar. Behavioral Response of Mule Deer to a Highway Underpass. *Journal of Wildlife Management*, Vol. 39, 1975, pp. 361-167.

Saaty, T.L. A Scaling Method for Priorities in Hierarchical Structures. *Journal of Mathematical Psychology*, Vol. 15, 1977, pp. 234-281.

Severinghaus, C.W., and E.L. Cheatum. Life and Times of the White-Tailed Deer. In W.P. Taylor, Ed., *The Deer of North America*. The Stackpole Co., Harrisburg, Pa., 1956, pp. 157-186.

Shrauder, P.A. Appalachian Mountains. In L.K. Halls, Ed., *White-Tailed Deer: Ecology and Management*. Stackpole Books, Harrisburg, Pa., 1984, pp. 331-344.

Smith, D.J. *Monitoring Wildlife Use and Determining Standards for Culvert Design.* Report BC354-34. Florida Department of Transportation, Tallahassee, 2003.

Virginia Department of Game and Inland Fisheries. *Virginia Black Bear Management Plan (2001-2010).* Richmond, 2002.

Walker, G., and J. Baber. *Wildlife Use and Interaction With Structures Constructed to Minimize Vehicle Collisions and Animal Mortality Along State Road 46, Lake County, Florida.* Report BD-162. Florida Department of Transportation, Tallahassee, 2003.

Whittington, R.W. Piedmont Plateau. In L.K. Halls, Ed., *White-Tailed Deer: Ecology and Management*. Stackpole Books, Harrisburg, Pa., 1984, pp. 355-366.