



An Evaluation of Roadside Activity and Behavior of Deer and Black Bear to Determine Mitigation Strategies for Animal-Vehicle Collisions

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16. Abstract: <p>Virginia is consistently among the top 10 states with the highest number of deer-vehicle collisions (DVCs), with more than 56,000 DVCs per year since 2007. The Virginia Department of Transportation has targeted a section of I-64 on and near Afton Mountain for safety and mobility improvements because of a high number of crashes and traffic stoppages. DVCs are a primary driver safety concern in the area, and vehicle collisions with black bears are also relatively frequent. Mitigation strategies are needed to address this issue.</p> <p>The purpose of this study was to evaluate white-tailed deer activity and behavior along (1) an interstate roadside adjacent to unfenced isolated underpasses used by deer and (2) a stream corridor / highway intersection with no viable underpass for deer. Although not a primary focus, black bear and other wildlife activity was also evaluated. Two years of camera data and animal carcass removal data were analyzed to gain a better understanding of deer and black bear activity and behavior relative to the two road and landscape features.</p> <p>Cameras were installed at a large bridge underpass and a box culvert (both used by deer to cross beneath the highway) and along the adjoining 0.5-mile roadside on both sides of the underpasses. Despite frequent use of the underpasses by deer (1,187 per year), there was high deer activity along the adjacent roadside (1,182 per year). A statistically significant relationship was found between roadside deer activity and DVCs (i.e., as deer activity increased, DVCs increased), and this relationship was strongest in October and November. Although highway crossing attempts comprised a low proportion of deer behavioral responses (n = 100 crossing attempts), crossing attempts resulted in 7.5 DVCs per year on the 1-mile highway segments adjacent to each unfenced underpass. Deer along the roadside exhibited relatively low responsiveness (or vigilance) to the interstate; predominant behaviors included walking along the roadside and feeding.</p> <p>At the stream corridor / highway intersection, cameras were installed at the intersection and extended along the adjoining 0.25-mile roadside on both sides of the intersection. Bear were more active along the roadside near the stream corridor than at the underpass sites. The stream corridor and associated topography were found to concentrate deer movement toward a relatively short section of highway; deer activity was statistically higher nearest the stream corridor / highway intersection and decreased farther away from this intersection. DVCs were statistically correlated with roadside deer activity and were significantly higher during October and November than during the other months of the year.</p> <p>Study recommendations include (1) the installation of fencing along the roadside adjacent to existing large underpasses, and (2) an animal advisory message on the dynamic message signs along I-64 in the Afton Mountain area. Messages should be displayed from dusk through dawn from October through November (to correspond with periods of higher deer activity and DVCs). Fencing both sides of just one underpass is expected to result in a savings in costs associated with DVCs of \$501,473 over its service life. A planned post-mitigation study may find that these low-cost forms of mitigation could have a substantial impact on drivers and wildlife, particularly if implemented on a larger scale.</p>					
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FINAL REPORT

**AN EVALUATION OF ROADSIDE ACTIVITY AND BEHAVIOR OF DEER
AND BLACK BEAR TO DETERMINE MITIGATION STRATEGIES
FOR ANIMAL-VEHICLE COLLISIONS**

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ABSTRACT

Virginia is consistently among the top 10 states with the highest number of deer-vehicle collisions (DVCs), with more than 56,000 DVCs per year since 2007. The Virginia Department of Transportation has targeted a section of I-64 on and near Afton Mountain for safety and mobility improvements because of a high number of crashes and traffic stoppages. DVCs are a primary driver safety concern in the area, and vehicle collisions with black bears are also relatively frequent. Mitigation strategies are needed to address this issue.

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Cameras were installed at a large bridge underpass and a box culvert (both used by deer to cross beneath the highway) and along the adjoining 0.5-mile roadside on both sides of the underpasses. Despite frequent use of the underpasses by deer (1,187 per year), there was high deer activity along the adjacent roadside (1,182 per year). A statistically significant relationship was found between roadside deer activity and DVCs (i.e., as deer activity increased, DVCs increased), and this relationship was strongest in October and November. Although highway crossing attempts comprised a low proportion of deer behavioral responses (n = 100 crossing attempts), crossing attempts resulted in 7.5 DVCs per year on the 1-mile highway segments adjacent to each unfenced underpass. Deer along the roadside exhibited relatively low responsiveness (or vigilance) to the interstate; predominant behaviors included walking along the roadside and feeding.

At the stream corridor / highway intersection, cameras were installed at the intersection and extended along the adjoining 0.25-mile roadside on both sides of the intersection. Bear were more active along the roadside near the stream corridor than at the underpass sites. The stream corridor and associated topography were found to concentrate deer movement toward a relatively short section of highway; deer activity was statistically higher nearest the stream corridor / highway intersection and decreased farther away from this intersection. DVCs were statistically correlated with roadside deer activity and were significantly higher during October and November than during the other months of the year.

Study recommendations include (1) the installation of fencing along the roadside adjacent to existing large underpasses, and (2) an animal advisory message on the dynamic message signs along I-64 in the Afton Mountain area. Messages should be displayed from dusk through dawn from October through November (to correspond with periods of higher deer activity and DVCs). Fencing both sides of just one underpass is expected to result in a savings in costs associated with DVCs of \$501,473 over its service life. A planned post-mitigation study may find that these low-cost forms of mitigation could have a substantial impact on drivers and wildlife, particularly if implemented on a larger scale.

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INTRODUCTION

The Virginia Department of Transportation (VDOT) has targeted a section of I-64 for safety and mobility improvements because of a high number of vehicle crashes and traffic stoppages. The safety improvement area includes a segment of I-64 from mile marker (MM) 97 to MM 105 (passing through Augusta, Nelson, and Albemarle counties). Deer-vehicle collisions (DVCs) are the third most frequent type of crash reported by the Virginia State Police in this area (VDOT, unpublished data, 2013). Vehicle collisions with black bears are also frequently reported in this area, as the mountains intersected by the interstate serve as a significant travel corridor for wildlife. Thirteen black bears were killed in October 2013 alone (VDOT, unpublished data, 2013). VDOT is considering mitigation options to reduce animal-vehicle collisions (AVCs) and asked the Virginia Transportation Research Council (VTRC) to identify strategic locations for mitigation. Because improving driver safety is the priority in this area, VDOT's primary goal is to reduce DVCs, but a reduction in vehicle collisions with black bear and other wildlife is also desired.

DVCs are a problem throughout Virginia. According to State Farm Insurance claims data, Virginia is consistently among the top 10 states with the highest number of DVCs, with more than 56,000 DVCs per year since 2007 (Lafon, 2013; Miles, 2014). DVCs represented 17% (or 1 in 6) of the insurance claims in Virginia in 2014 (Miles, 2014). DVCs in Virginia can involve numerous vehicles and fatalities ("Churchville," 2013; NBC12 Newsroom, 2013a, 2013b). Bear-vehicle collisions are also common on certain road segments, particularly in years with scarce food supplies (Kocka, 2013).

Successful AVC Countermeasures

The most successful types of mitigation with regard to AVCs have been well documented over the past two decades. These measures can be grouped into those designed to influence

driver behavior, such as deer signs and driver warning systems, and those designed to influence animal behavior, such as roadside deer reflectors and wildlife crossings (overpasses or underpasses used by wildlife to cross over or under a road). An extensive literature review conducted as part of a report to the U.S. Congress on AVC mitigation (Huijser et al., 2008) noted that more than 40 mitigation methods have been tested and/or implemented in the last decade to reduce AVCs. Currently, the most effective methods are (1) certain types of driver warning systems, and (2) wildlife crossings used in conjunction with fencing.

Driver Warning Systems

Animal detection systems sense large animals as they approach the roadway. The system is activated once an animal's body blocks or reduces the signal received by the receiver (Huijser et al., 2006b). Once detection is verified, a warning system can be used to alert drivers to the danger, resulting in a reduction in vehicle speed and stopping distance (Huijser et al., 2006b). A study in Arizona found a 91% DVC reduction following the installation of a system (Dodd and Gagnon, 2008).

Most animal detection systems contain either above-ground area-cover sensors or break-the-beam sensors (Figure 1). In their recently completed study of a buried cable animal detection system installed along a test road (closed to public traffic), Druta and Alden (2015) found that with proper installation and calibration, the system detected large animals with more than 95% reliability, even when the cable was covered with up to 3 feet of snow (a factor that can block the sensors of other detection systems). Buried cable detection systems offer numerous apparent advantages over above-ground detection technologies when environmental variables such as precipitation and vegetation and site-specific characteristics such as topology, subsidence, and road curvature are considered (Huijser et al., 2006b). However, additional research is needed to determine the system's effectiveness at reducing DVCs on a Virginia road.

Dynamic, or "changeable," message signs are another option used to reduce DVCs, particularly if applied only seasonally to reduce driver habituation effects (Figure 1).



Figure 1. Driver Warning Systems. Buried cable animal detection system during installation (*left*); flashing warning system that can be connected to a detection system (*center*); dynamic message sign (*right*).

However, studies show mixed results with regard to their effectiveness at DVC reduction, and more research is required to determine their effectiveness (Huijser et al., 2008).

Wildlife Crossings With Fencing

The effectiveness of properly designed wildlife crossings at reducing vehicle collisions with deer and other ungulates (hoofed mammals) is well established (Forman et al., 2003; Huijser et al., 2008; McCollister and Van Manen, 2010). When combined with fencing, which helps funnel the animals toward the crossings, these structures have been found to reduce vehicle collisions with these species by more than 80% (Bissonette and Rosa, 2012; Clevenger et al., 2001; Dodd and Gagnon, 2008).

Wildlife crossings with fencing are substantially more beneficial to wildlife populations than fencing alone because of the habitat connectivity that wildlife crossings provide. Wildlife crossings allow wildlife to pass unharmed beneath or above a road to access important habitat. This connection also helps prevent the isolation of wildlife populations, which can increase the risk of eventual extirpation or local extinction (Foresman, 2004; Forman et al., 2003).

Similar to many roads in the United States, I-64 includes several bridge and culvert underpasses that are large enough to facilitate passage of large animals. Because these structures were constructed for drainage or other purposes unrelated to wildlife passage, they are typically spaced miles apart and have no fencing. Although Virginia has very few underpass structures that were specifically designed for large animals, deer using box culverts with openings as small as 6 by 10 feet have been documented (Donaldson, 2007). Larger underpasses, such as large culverts or bridges spanning rivers or wetlands, receive substantially more use by deer and other wildlife (Donaldson, 2007; Donaldson and Schaus, 2009) (Figure 2).



Figure 2. Bridge Underpass Beneath U.S. Highway 17 (left); Large Box Culvert Beneath Fairfax County Parkway (right). Both are used frequently by deer and other wildlife (Donaldson, 2007; Donaldson and Schaus, 2009).

Preliminary Evaluations

Given the established effectiveness of underpasses with fencing and certain driver warning systems, VTRC researchers conducted preliminary evaluations in 2012 to determine whether the installation of these measures was feasible in the Afton Mountain Safety Improvement Area and to identify specific locations where they would be most applicable. It was established early in these evaluations that although constructing new wildlife underpasses was not entirely excluded from consideration by VDOT, its high costs and disruption to vehicular travel on a major interstate would be problematic. Costs for underpasses are substantially higher if the underpasses are constructed after a road is in place because installation may necessitate removing a section of road. VDOT's preferred mitigation in this area would therefore not entail such costly and disruptive measures.

During the preliminary evaluations, it became evident that there were potential mitigation opportunities within and several miles beyond the Afton Mountain Safety Improvement Area. The project area was therefore expanded to include the 23-mile segment of interstate between Waynesboro and Charlottesville (MM 95 to MM 118). The evaluations within the project area included (1) a review of existing crash records, (2) a review of VDOT's structures database to identify underpasses in the project area that were potentially suitable for deer and black bear passage, and (3) a series of field visits. The field visit group included VTRC researchers, VDOT staff (from the Staunton and Culpeper districts), wildlife biologists from the Virginia Department of Game and Inland Fisheries, and a former university professor and black bear expert. The findings from these evaluations were documented and conveyed to the staff of VDOT's Staunton District in 2012 (Donaldson, 2012a, 2012b).

At the conclusion of these evaluations, Donaldson (2012b) recommended that specific sites in the project area be more closely evaluated to determine whether mitigation measures would have a high probability of success at reducing DVCs. These sites included two unfenced underpasses that were known from a previous study to facilitate deer passage and one stream corridor / highway intersection (Donaldson, 2007).

Unfenced Underpasses

The two underpasses evaluated previously included a box culvert (10 by 12 by 189 feet) and a large bridge (307 feet long) spanning a river. Because they were not constructed for the purpose of wildlife movement, they did not have fencing. Although deer used both structures, the large bridge underpass was more heavily used than the box culvert (Donaldson, 2007). Donaldson (2012b) suggested that adding fencing might increase the use of these structures and decrease collisions with deer and black bear along the adjoining sections of interstate. However, more data were needed before it could be recommended that VDOT invest in fencing at these and other unfenced underpasses used by wildlife.

These underpasses and their adjoining sections of highway were chosen as sites for further evaluation (Sites 1 and 2, Figure 3). The 5-mile separation between the sites is too large to accommodate wildlife passage at both structures by the same individuals but is small enough that the surrounding habitat is similar in terms of topography and vegetation. Because the

underpasses differed greatly by size and wildlife use, they allowed a useful comparison with regard to adjacent roadside deer activity and DVCs.

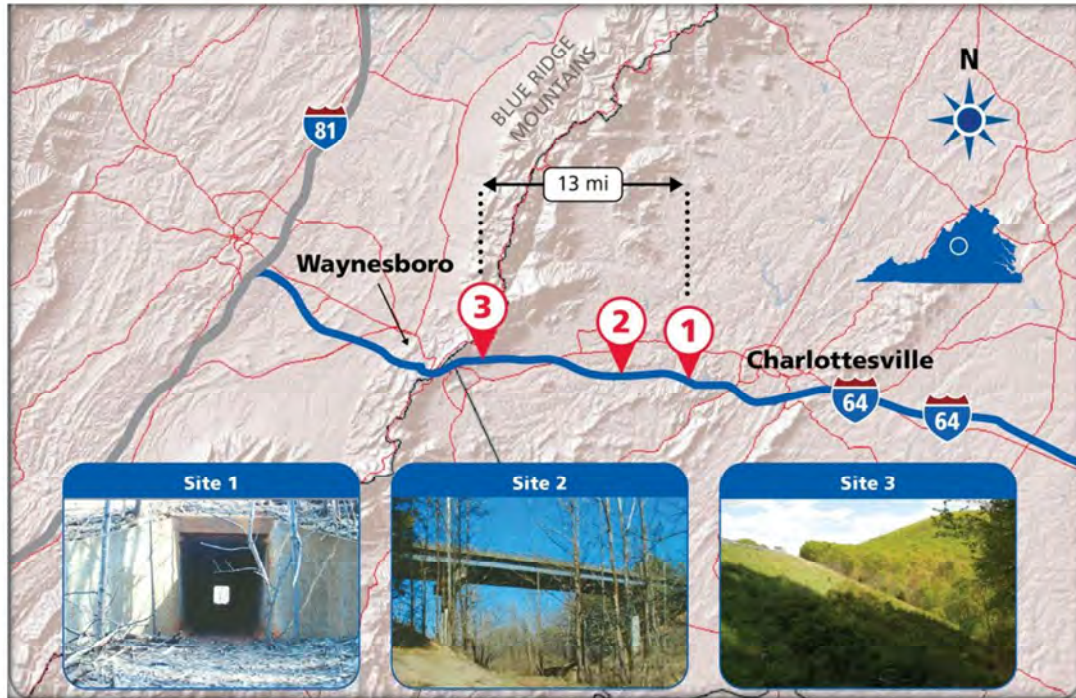


Figure 3. Study Sites Within the 23-Mile Project Area. Sites 1 and 2 are underpasses used by deer, and Site 3 is a stream corridor / highway intersection.

Stream Corridor / Highway Intersection

Forest edges and stream corridors are among the most preferred habitats for deer (Clements et al., 2011; Compton et al., 1988). Landscape features, and road alignment with major drainages in particular, strongly influence the movement of deer and other ungulates toward roadways (Bellis and Graves, 1971; Carbaugh et al., 1975; Feldhammer et al., 1986). Correspondingly, areas where drainages, or stream corridors, intersect with highways are often associated with higher probabilities of DVCs (Huijser et al., 2006a; Huijser et al., 2008; Rogers, 2004). Although DVC data can be useful in determining the general area for mitigation, animal movement and habitat preferences should also be considered in determining optimal placement (Barnum, 2003; Clevenger et al., 2002).

For these reasons, Donaldson hypothesized that a driver warning system might be an effective DVC mitigation option at stream corridor / highway intersections (Donaldson, 2012a, 2012b). However, additional information was needed regarding deer and black bear activity in these drainage areas. A stream corridor / highway intersection along Afton Mountain was selected for further evaluation (Site 3, Figure 3).

Camera Monitoring to Inform Mitigation Decisions

VDOT and other departments of transportation (DOTs) need research-based evidence to support the strategic and cost-effective implementation of AVC mitigation. Inadequate information is available regarding species' movements near and across roads (Forman et al., 2003), an important factor in mitigation decisions.

Wildlife crossing research has shown that using fencing to connect a *series* of newly constructed wildlife underpasses with fencing and associated components decreases vehicle collisions with elk by 97% (Dodd and Gagnon, 2008). However, research is needed to establish how retrofitting an *individual* existing underpass with fencing affects AVCs and the use of the structure by deer. Underpasses that were not constructed for wildlife (and therefore have no fencing) but that are nonetheless used by wildlife are numerous throughout the United States (Forman et al., 2003). The U.S. road system includes more than 582,000 bridges longer than 20 feet, 480,000 of which are over waterways (Forman et al., 2003). The road system also includes millions of smaller structures, many of which serve as passageways for wildlife (Forman et al., 2003). There are no published studies that evaluate the movement and behavior of wildlife that move toward and potentially cross a road passing over an unfenced underpass rather than use the underpass. If adding fencing to existing underpasses used by wildlife would increase the use of the structures and reduce AVCs, this could have a substantial impact on drivers and wildlife, particularly if implemented on a large scale.

Targeting certain stream corridor / highway intersections for driver warning systems may also be a successful strategic means of focusing mitigation efforts. Deer trails in the project area indicated travel to and from stream corridors and their intersections with I-64 (Donaldson, 2012b). Evaluating deer and black bear activity and behavior at these intersections might help determine whether driver warning systems could potentially enhance driver safety.

Studies that use trail and video cameras to document the use of wildlife underpasses are not uncommon (Clevenger and Waltho, 2000; Cramer, 2013; Dodd et al., 2006; Donaldson; 2007; Huijser et al., 2011; Smith, 2003). However, information is needed on deer use of the roadside environment, particularly with regard to whether deer activity on the roadside is correlated with DVCs or whether deer activity and behavior are unrelated to deer road crossing attempts and crashes. Using cameras to photograph deer behavior and their interactions with the interstate would help decision makers in making mitigation decisions. In order to provide evidence-based mitigation recommendations, additional information was needed with regard to deer activity and behavior at unfenced underpasses and stream corridor / highway intersections.

PURPOSE AND SCOPE

The purpose of this study was to evaluate white-tailed deer activity and behavior along (1) an interstate roadside adjacent to unfenced isolated underpasses, and (2) a stream corridor / highway intersection. Although not a primary focus, black bear and other wildlife activity was also evaluated.

Study sites included a large bridge underpass and a box culvert that were known to be used by deer and a stream corridor / highway intersection (Figure 3). Because the underpasses differed greatly in size and wildlife use, they allowed a useful comparison with regard to adjacent roadside deer activity and DVCs. Sites were monitored with trail cameras for 2 years. Two years of carcass removal data provided a context for the evaluations.

If the findings of the study supported the installation of fencing at the underpass sites and a driver warning system at the stream corridor / highway intersection, the baseline data collected in the study were to be used in a comparison post-mitigation camera monitoring study to determine the effectiveness of the two mitigation measures.

METHODS

Four tasks were conducted to achieve the study objectives.

1. Obtain, document, and analyze deer and black bear carcass removal data provided by a VDOT contractor.
2. Determine strategic camera placement at two underpass sites within the study area, and install cameras to capture deer and bear activity and behavior.
3. Analyze the carcass removal and camera data at the two underpass sites to compare underpass use with adjacent roadside activity and to determine whether roadside activity and behavior correlate with DVCs.
4. Analyze the carcass removal and camera data at the stream corridor / highway intersection to assess roadside activity and behavior relative to the stream corridor, determine whether there are seasonal and temporal variations in deer activity, and determine whether activity and behavior correlate with DVCs.

Carcass Removal Data Collection

VDOT's contractor for interstate maintenance was asked to document animal carcass removals and provide the documentation to the researchers on a monthly basis over a 3-year period (April 2013 through March 2015). Within the 23-mile project area (Figure 3, MM 95 to MM 118), the contractor documented the date, the species, and the location of the species to the nearest 0.1-mile using posted mile marker signs. (Devices for recording geographical location were not available to the contracted maintenance staff.)

For the underpass sites (Sites 1 and 2), carcass removal data were evaluated within an 11-mile study area (MM 107 to MM 118) extending from 3 miles to the east of the Site 1 box culvert to 3 miles to the west of the Site 2 underpass and encompassing 5 miles of interstate between the underpasses. For the stream corridor / highway intersection (Site 3), carcass

removal data were evaluated from a 3-mile highway segment to the east of the stream corridor / highway intersection to a 3-mile highway segment to the west of the intersection (for a study area totaling 6 miles, from MM 99.4 to MM 105.4).

In summary, carcass removal data were organized for analyses in three groupings:

1. a 23-mile project area
2. an 11-mile study area for Sites 1 and 2
3. a 6-mile study area for Site 3.

Camera Placement and Installation

A total of 54 Reconyx Hyperfire (Reconyx, Inc.) digital trail cameras were installed at the study sites. Cameras were operative over a 2-year period (March 2013 through February 2015). The cameras use motion sensors to detect the presence of an animal and are programmed to take three pictures per triggered event with a 5-second interval between pictures. The cameras use undetectable infrared illumination rather than a flash at night and have a night range up to 50 feet and a day range up to 100 feet.

As detailed later, cameras were installed at underpasses and along the interstate roadside. Cameras along the roadside were positioned within 2 feet of the paved shoulder and mounted on poles that were inserted in the ground or attached to a guardrail. Cameras were angled such that the area of detection included the entire width of the shoulder to the area approximately 30 feet off the shoulder at the extent of the camera range (Figure 4). Cameras at underpasses were mounted on trees at the entrances of the box culvert and beneath the bridge underpass. Researchers visited the cameras once every 2 months to replace the Secure Digital (SD) cards that stored the images. Batteries were replaced as needed.



Figure 4. Camera Placement Along Highway (*left*); Angle of View (*right*)

Sites 1 and 2: Unfenced Underpasses

Cameras were placed on the roadside above each underpass, and camera placement extended to the maximum distance that deer could be expected to travel to the underpass. The

radius of the home range size for deer was used to determine the extent of camera placement (Bissonette and Adair, 2008; Huijser et al., 2015). Male white-tailed deer in Virginia have an average home range of approximately 1 square mile (N. Lafon, personal communication). With a deer's home range (hypothetically) centered on an underpass, a deer can be expected to travel only as far as the radius of the home range (0.5 mile, assuming a circular home range).

Cameras were therefore positioned to extend up to 0.5 mile on either side of the Site 1 and Site 2 underpasses. With this placement, cameras would capture the activity and behavior of deer that used the underpass and those that had access to the underpass but that traveled up to and potentially across the highway. Cameras at each site were positioned to face toward the underpass.

Site 1: Box Culvert

The underpass at Site 1 is a single-barrel box culvert that measures 10 by 12 by 189 feet. It was installed during the construction of I-64 in 1968 so that cattle and farm equipment could access both sides of the highway. The floor of the culvert is covered with a layer of dirt, which becomes muddy with heavy rain. The surrounding habitat is heavily forested (Figure 5), with an abandoned dirt road (now covered with leaf litter and emergent vegetation) extending from both ends of the crossing.

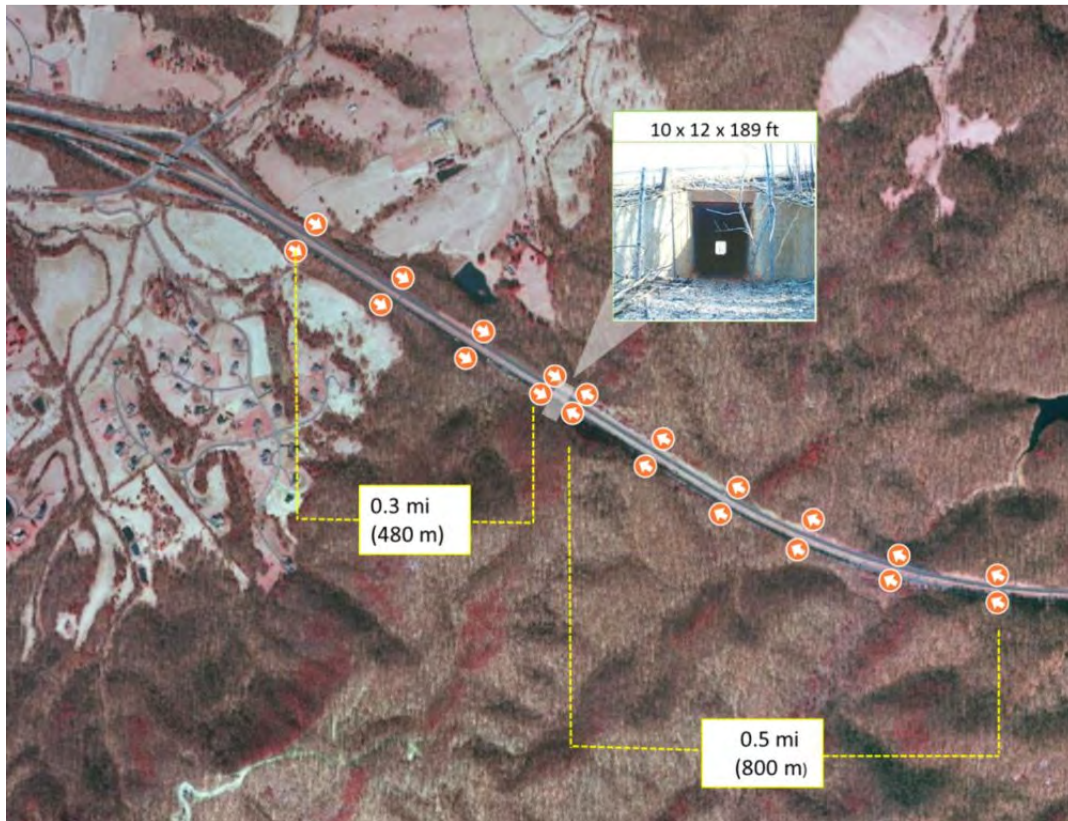


Figure 5. Camera Placement Along Roadside at Site 1. Cameras (represented by circles with arrows indicating the direction the camera faces) are centered above the underpasses and extend up to 0.3 mile to the west and 0.5 mile to the east.

At Site 1, 20 cameras were divided between the eastbound and westbound lanes (Figure 5). One camera was also placed at each of the two entrances to the box culvert. Cameras were placed along the shoulder of the highway directly above the underpass entrances to capture the deer that did not use the underpass and traveled directly up to the highway. Cameras were evenly spaced in 0.1-mile intervals in the east and west directions from the cameras centered above the underpass. Camera placement extended 0.5 mile on the east side of the underpass and 0.3 mile on the west side, for a combined length of 0.8 mile. Immediately beyond 0.3 mile west of the underpass, the ground drops off the paved shoulder next to the eastbound and westbound lanes, creating a steep slope that likely precludes deer movement (and negates the need for cameras).

Site 2: Bridge Underpass

The underpass at Site 2 is a bridge along the eastbound lane of I-64, 5 miles west of Site 1. A wide median separates the eastbound and westbound lanes. The bridge is 307 feet long (or wide, from the perspective of an animal crossing beneath it) and was constructed in 1969 to span the Mechum River. The river width is approximately 45 feet, with approximately 10-foot-wide grassy strips on each side to allow the passage of farm vehicles. The remaining area beneath the bridge is sloped with sandy substrate, which is also heavily traversed by wildlife (Donaldson, 2007). The surrounding habitat comprises a mixture of trees and open farmland. Sixteen cameras were placed along a 1-mile segment of the eastbound lanes at Site 2, with the bridge underpass at the center (Figure 6).



Figure 6. Camera Placement Along Roadside at Site 2. Cameras (represented by circles with arrows indicating the direction the camera faces) are centered above the underpasses and extend 0.5 mile to the east and west.

Given the number of available cameras, placing them along only the eastbound lanes allowed for more coverage of the highway corridor at Site 1 (where cameras were placed in pairs along the eastbound/westbound lanes across the highway). In addition, because of the wide median between lanes, placing cameras in pairs across the eastbound and westbound lanes would have made inferences about deer and bear crossing the full highway problematic. For the analyses and reported results for Sites 1 and 2, data from each eastbound and westbound camera pair at Site 1 were averaged. This allowed for comparisons of roadside deer activity between Sites 1 and 2. Cameras along the highway were positioned immediately above and on either side of the bridge and spaced at 0.1-mile intervals in the east and west directions along the highway. Four cameras were placed beneath the bridge underpass (two cameras were positioned on both sides of the river) in order to capture the entire area of dry land beneath the bridge.

Site 3: Stream Corridor / Highway Intersection

Site 3 is situated within a forested riparian corridor of the Blue Ridge Mountains. The small stream at Site 3 originates on Afton Mountain and travels south, where it passes beneath the interstate through a drainage culvert that is too small to facilitate passage by large animals.

The primary consideration in determining camera placement at Site 3 was the surrounding landscape features that might influence deer and black bear movement (see Figure 7).



Figure 7. Camera Placement Along Roadside at Site 3. The shaded area highlights the contours of the landscape; the steep topography creates a saddle that may help funnel wildlife toward this section of the interstate. Cameras (represented by circles with arrows indicating the direction the camera faces) are centered on the stream corridor and extend along the highway 0.25 mile to the east and west.

The steeply sloped topography on the north side of the interstate appears to create a saddle that potentially serves as a funnel for wildlife movement. The funnel narrows, or forms a “bottleneck,” just north of the corridor intersection with the northern (westbound) lanes of the interstate, which may result in an area of concentrated wildlife activity.

Data Documentation and Analyses

Carcass removal data (represented as DVCs in this report) and camera data were analyzed. Because some deer struck by vehicles leave the right of way, carcass removals do not account for all DVCs but do provide for a useful index of DVCs. Carcass removal data were analyzed in two ways: (1) 3 years of carcass removal records over a 23-mile project area (MM 95 to MM 118) were evaluated, and (2) 2 years of carcass removal records that corresponded with the 2 years of camera data were evaluated by site.

Site-specific carcass removal records were evaluated for an 11-mile study area for Sites 1 and 2. Camera data for Sites 1 and 2 represented the 0.8-mile and 1-mile highway segments, respectively, illustrated in Figures 5 and 6, respectively.

Site-specific carcass removal records were also evaluated for a 6-mile study area for Site 3. Analyses were conducted to determine whether DVCs in the 6-mile study area were predominantly concentrated at the stream corridor / highway intersection. Camera data for Site 3 represented the 0.5-mile highway segment illustrated in Figure 7.

Activity Data

Data documented from photographs included date, time, species, number of individuals, and direction of travel. Each photograph of wildlife along the road was evaluated for “activity,” which was determined by the number of animals in a detection event. A *detection event* was defined as one or more animals captured by the camera and separated from the prior detection of the same species by at least 15 minutes. This reduced instances of the same animal being counted more than once and provided an indication of the general density of animals using the roadside. Although the activity data for all wildlife species captured by cameras were analyzed, the analyses focused on deer and black bear with regard to the categories listed in Table 1.

At underpass sites, the number of completed passages through the underpasses by deer and bear was compared to the number of turn-around events (approaches to an underpass with an incomplete crossing). Hesitancy behaviors by deer (indicated by muzzles lowered to the ground) (Gordon and Anderson, 2003; Reed et al., 1975) were also documented.

Table 1. Camera Data Analyses Conducted at Study Sites With Regard to Deer and Black Bear

Camera Data Analysis		Sites 1 and 2	Site 3
Activity	Roadside activity	✓	✓
	Relationships between roadside activity and DVCs	✓	✓
	Roadside activity relative to distance from feature (underpass for Sites 1 and 2, stream corridor / highway intersection for Site 3)	✓	✓
	Seasonal differences in activity	✓	✓
	Use of the underpasses	✓	–
Behavior	Underpass hesitancy behaviors	✓	–
	Behavioral response to highway (responsive versus unresponsive)	✓	✓
	Attempt to cross the highway	✓	✓
	Relationships between the behaviors and DVCs	✓	✓

DVC = deer-vehicle collision.

Behavior Data

Behavioral data were grouped into two categories (Table 1). The first was the deer’s behavioral response (Chester, 1976; Hardy, 2001) to the highway and/or traffic (i.e., responsive versus unresponsive). Responsive behaviors included vigilance (indicated by head held high in the direction of the highway or a vehicle) (Chester, 1976; Hardy, 2001) and flight from a vehicle. Unresponsive behaviors included daily activity behaviors (i.e., feeding; walking along the roadside; not exhibiting vigilant or responsive behavior; bedding; mating; and sparring or fighting).

The second behavioral category was related to a deer’s attempt to cross the highway. Behaviors considered a “crossing attempt” included walking or running onto a lane of the highway. The camera view prevented determination of whether a crossing was successful. Behaviors considered a “potential crossing attempt” included standing on the paved shoulder of the highway while facing the opposite side of the highway and appearing vigilant. All other behaviors were considered “no crossing attempt.”

Statistical Analyses

Differences between sites with regard to deer activity and behavior were evaluated with a *t*-test. *P*-values less than 0.05 were considered significant. Negative binomial and Poisson regressions were used to evaluate the relationship, if any, between DVCs in the study areas and deer activity and behavior variables along the roadside. For the regression analyses, seasonal effects were also accounted for using month-group variables.

On some occasions, cameras were not operational for short periods because the battery power depleted before the battery was replaced or the SD card reached maximum storage capacity. Differences in camera operative days were accounted for in all analyses. To account for site differences in the number of cameras along the roadside, an activity index was calculated by dividing the activity for each species by the number of roadside cameras at each site.

RESULTS AND DISCUSSION

DVCs and Bear-Vehicle Collisions: All Study Sites

There were 474 DVCs and 14 bear-vehicle collisions documented between MM 95 and MM 118 over 3 years, an average of 158 deer and 5 bear per year. This is an average of nearly 7 DVCs per mile per year. Figure 8 illustrates the location of these collisions relative to the study sites. Nine of the 14 bear deaths occurred between MM 96 and MM 99 on Afton Mountain. The 0.5-mile section with the most DVCs was situated between Sites 1 and 2, with 54 DVCs during the 3-year data collection period (an average of 18 DVCs per year in this 0.5-mile section).

Figure 9 illustrates the monthly number of vehicle collisions with deer and black bear over the 3-year data collection period.

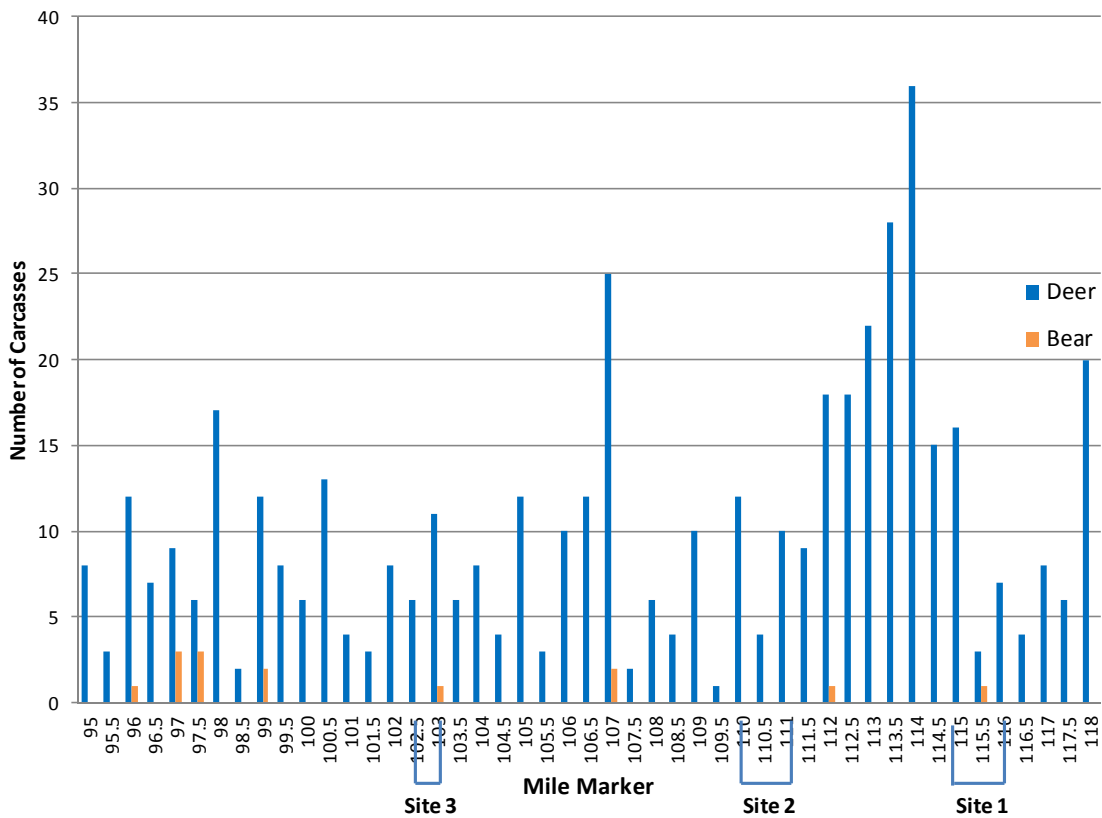


Figure 8. Cumulative Deer and Bear Carcass Removals From MM 95 to MM 118 Over 3-Year Period (April 2012–March 2015). Grouped in 0.5-mile intervals.

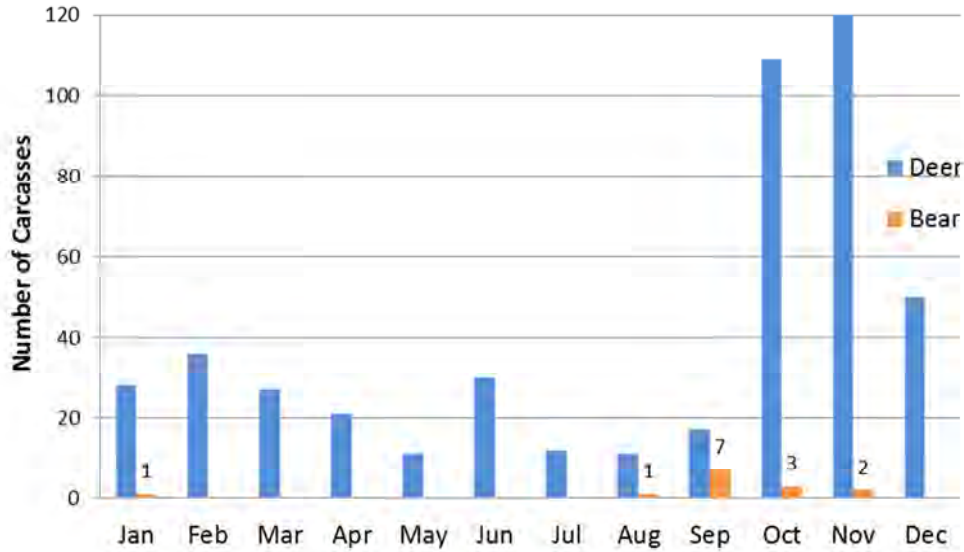


Figure 9. Monthly Vehicle Collisions With Deer and Bear Over 3-Year Period (April 2012–March 2015)

Sites 1 and 2

DVCs and Bear-Vehicle Collisions

There were 202 DVCs and 4 bear-vehicle collisions documented in the 11-mile study area of Sites 1 and 2 over 2 years. This is an average of 101 DVCs per year, or 9.2 DVCs per mile per year in the study area. At Site 1 (i.e., a 1-mile segment with Site 1 at its center), there were 15 DVCs, or 7.5 DVCs per mile per year, and 1 bear carcass over the 2-year monitoring period. There were 7.5 DVCs per mile per year at Site 2's 1-mile highway segment, but there were no bear carcasses.

The highest frequencies of DVCs occurred in October and November. More than one half occurred in the combined months of October (24%) and November (28%). All three bear-vehicle collisions occurred in September ($n = 1$) and October ($n = 2$). These peaks correspond to deer breeding season and intense feeding by bears before denning (N. Lafon, personal communication).

Camera Data

Site 1 Deer and Bear Activity (Box Culvert and Adjacent Roadside)

Cameras were operative an average of 705 days, or 96.5% of the 2-year monitoring period. Deer represented 89% of photographed wildlife.

Deer activity at Site 1 totaled 2,229, most of which were along the roadside. A total of 506 deer used the underpass (253 per year). Deer activity along the adjacent roadside was more than 3 times greater ($n = 1,723$, or 861.5 per year) (Figure 10). There was a high degree of reluctance by deer to enter the culvert underpass at Site 1. Hesitancy behavior was exhibited by

43% of deer that approached the underpass, and 18% of approaches by deer resulted in a turning back rather than a crossing through. Photographs from the roadside cameras directly above the underpass frequently documented deer traveling up the hillside from the direction of the underpass entrance.

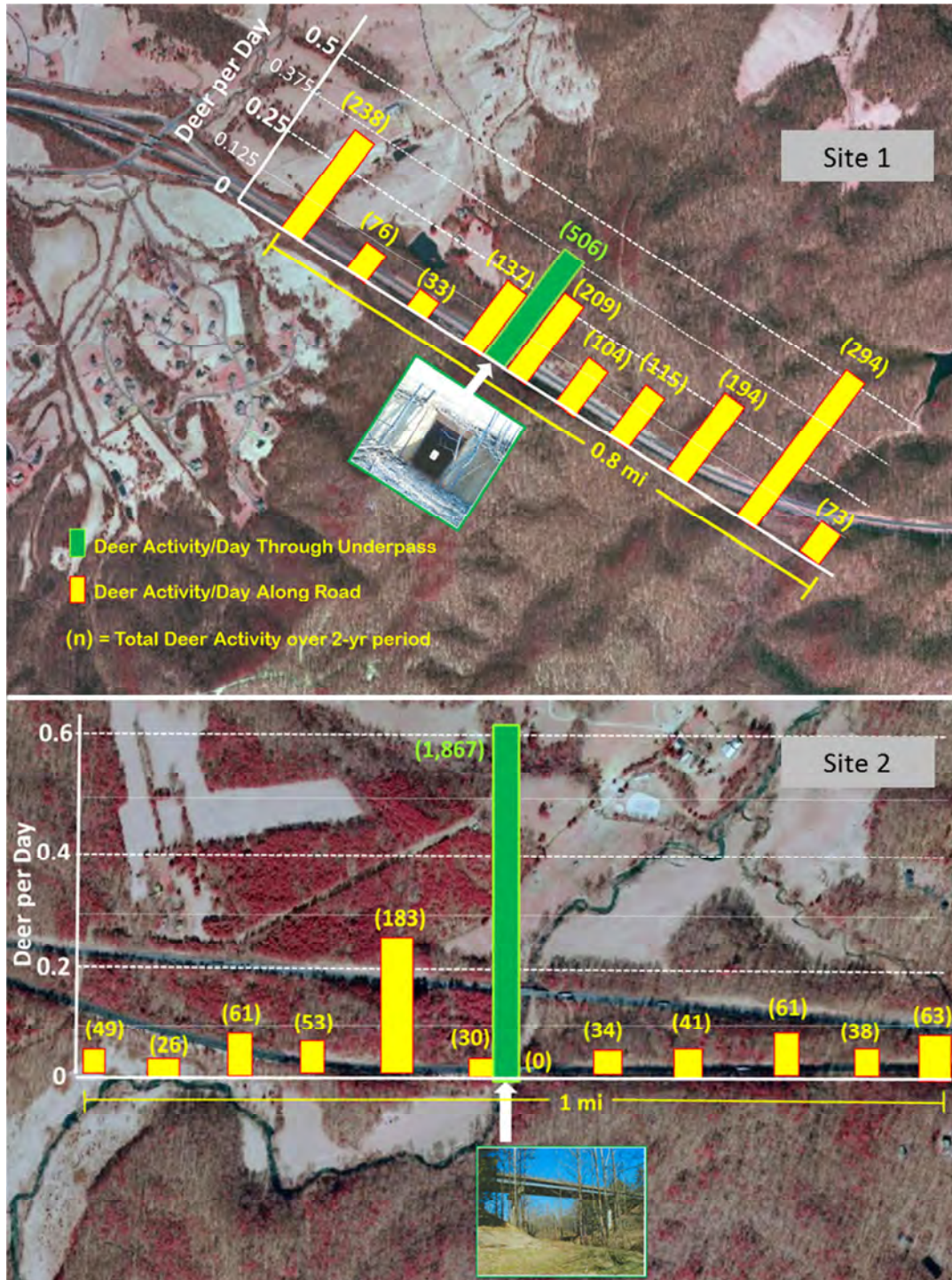


Figure 10. Deer Activity Along Interstate and Through Underpasses at Site 1 (top) and Site 2 (bottom). Bars are positioned at camera locations. Data from corresponding north and south cameras were averaged for Site 1.

There was no significant relationship between deer activity along the roadside and distance from the underpass (according to the final negative binomial regression); as distance from the underpass increased, there was no statistical trend of increased or decreased deer activity. Activity was relatively high 0.4 mile to the east of the underpass (where $n = 294$). At this location, a stream corridor that leads to a lake on the north side of the interstate likely influenced deer movement toward the interstate. At the western end of Site 1 (where $n = 238$), deer activity was high next to the relatively open area scattered with fragments of forest, a preferred habitat for white-tailed deer (Figure 10).

There were no bears captured by photographs at the culvert or along the roadside at Site 1, although one bear was killed by a vehicle 0.2 mile from the underpass. Evidence varies on the underpass sizes black bears will use, from smaller constricted crossings (Clevenger and Waltho, 2005) to bridge underpasses (Kintsch and Cramer, 2011).

Site 2 Deer and Bear Activity (Bridge Underpass and Adjacent Roadside)

Instances of deer activity at Site 2 totaled 2,506, and most of this activity occurred beneath the bridge underpass ($n = 933.5$ per year) rather than along the roadside ($n = 319.5$ per year) (Figure 11). The high frequency of deer crossings beneath the underpass was attributed not only to the large size of the underpass but also because the underpass spans an ideal travel corridor for deer (i.e., a riparian corridor with a mixture of open areas and forest). Unlike at Site 1, no deer exhibited behavior indicating reluctance to use the underpass.

Along the roadside, there was relatively low deer activity compared with the activity at the underpass. Nevertheless, the 7.5 DVCs per mile per year at Site 2 indicated that deer still attempted to cross the interstate despite their access to the underpass. Similar to Site 1, there was no significant relationship between deer activity along the roadside and distance from the underpass (according to the final negative binomial regression).

Bear activity data indicated that when bears had access to a large bridge underpass, they used the underpass rather than cross the highway. There were 18 bear crossings through the underpass and no roadside bear activity or bear-vehicle collisions.

Both Sites

Wildlife Activity. Figure 11 illustrates a comparison of the detected wildlife crossings through the Site 1 and 2 underpasses and the activity per camera along adjacent roadside sections. Other than deer and bear, cameras captured 674 individuals of mammalian species at the study sites. A greater number of small to medium-sized wildlife crossed through the Site 1 box culvert than passed beneath the Site 2 bridge. This corresponded with the lower activity of these species along the roadside at Site 1 than at the roadside at Site 2 (Figure 11). Deer activity at both sites was substantially higher than that of other wildlife.

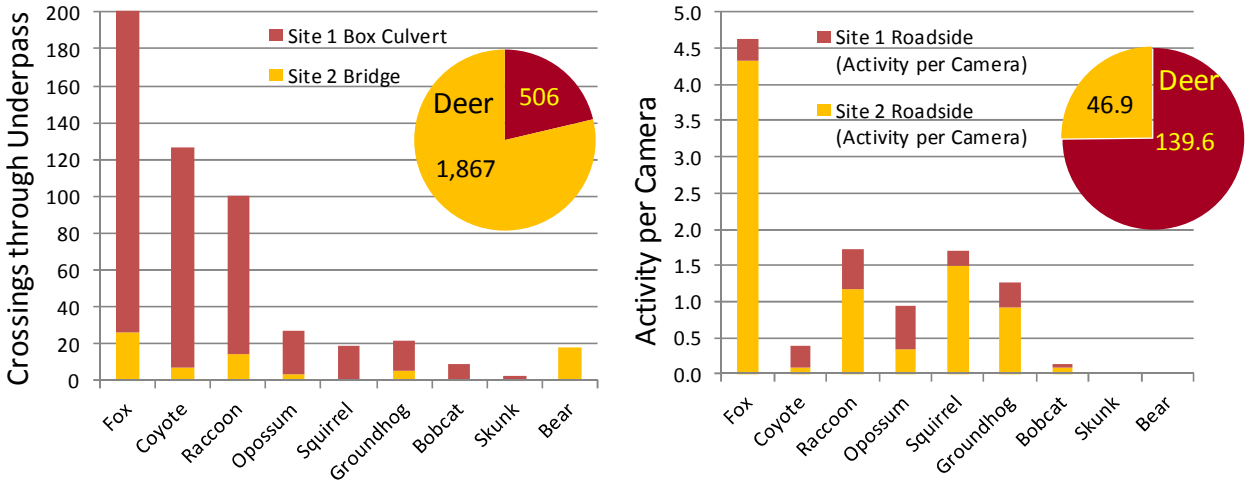


Figure 11. Comparisons of Wildlife Activity at Sites 1 and 2. Wildlife crossings through underpasses (left) and activity per camera along roadside (right) over the 2-year monitoring period.

Deer Activity and Behavior. Deer activity along the roadside at Sites 1 and 2 peaked in September (Figure 12). This suggests that deer may use roadsides as foraging habitat during the late summer when herbaceous vegetation is still succulent and before acorns have fallen in the more heavily forested areas adjacent to the road (N. Lafon, personal communication).

A statistically significant relationship was found between monthly roadside deer activity at the study sites and DVCs in the 11-mile project area (i.e., as roadside deer activity increased, DVCs increased) (Figure 12). Figure 12, *bottom*, which was created based on predictions from the final negative binomial regression, illustrates this positive correlation, which was strongest in October and November, and illustrates that (for example) with a deer activity of 0.3 deer per day (or approximately 10 per month) along the evaluated study sites (which have a combined roadside length of 1.8 miles), approximately 28 DVCs per month were predicted within the 11-mile study area.

Although the weekly use of the Site 2 bridge underpass by deer was significantly higher than at Site 1 ($p < 0.05$) (Table 2), both underpasses provided high connectivity for deer (according to previously established criteria) (Donaldson, 2007; P. Cramer, unpublished data). Weekly deer activity along the roadside at Site 2 was significantly lower than at Site 1 ($p < 0.05$), which corresponds with the more frequent use of the larger Site 2 underpass. Despite the differences in roadside activity, the DVCs were equal at each site (7.5 per mile per year).

There were no significant differences between Sites 1 and 2 with regard to the evaluated behaviors ($p > 0.05$). Given the similarities between Sites 1 and 2 with regard to deer behavior (Table 2), roadway factors (sight distance, vehicle speed, etc.) may play a role in the high number of DVCs at Site 2 relative to deer activity. Figure 13 illustrates some of the behaviors listed in Table 2.

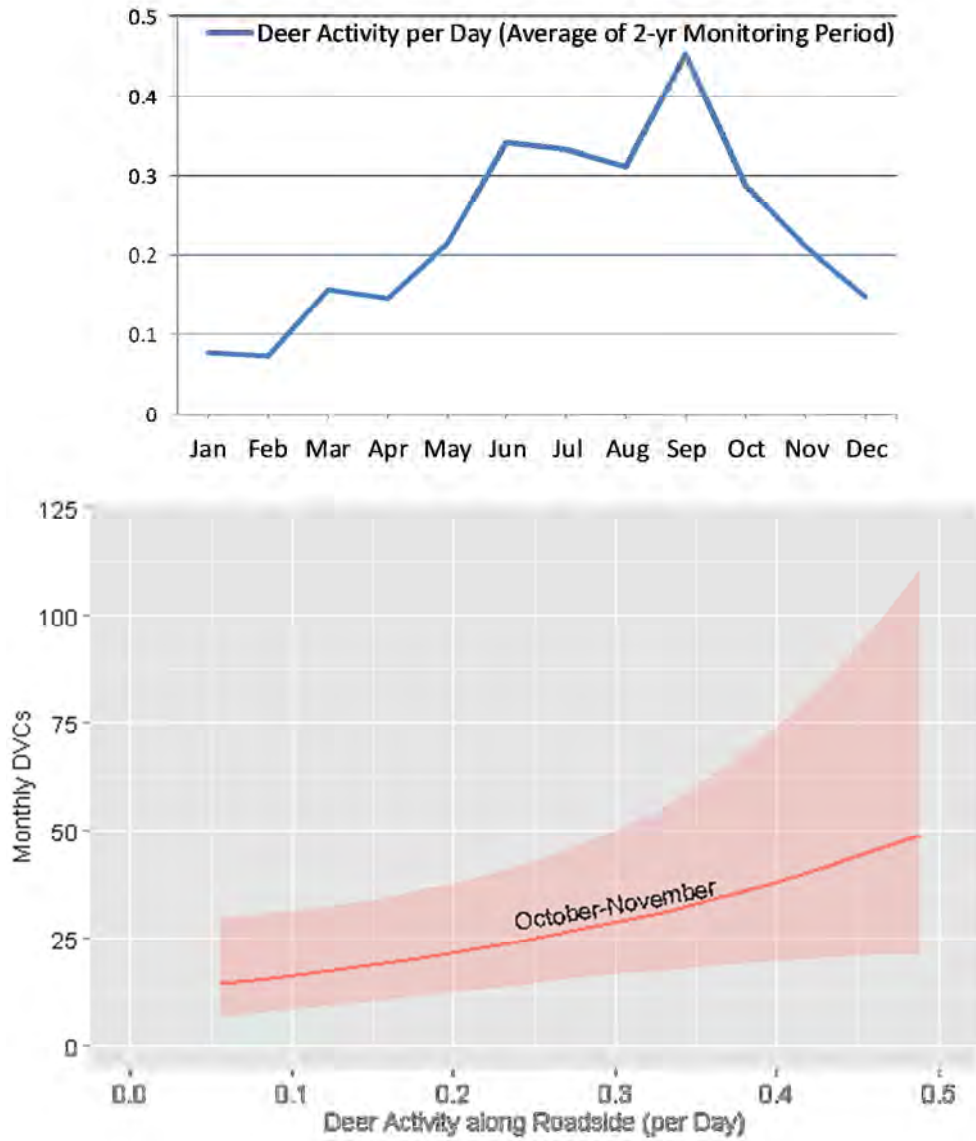


Figure 12. Daily Roadside Deer Activity per Month at Combined Sites 1 and 2 (*top*) and Relationship Between Deer Activity and DVCs (*bottom*). The bottom figure illustrates the positive correlation between monthly DVCs in the 11-mile study area and roadside deer activity at the study sites, which was strongest in October and November. In the bottom figure, the solid line represents a mean prediction curve and the band surrounding the curve represents a 95% confidence prediction limit.

Table 2. Deer Activity and Behavior at Sites 1 and 2

Site No.	Deer Activity (Mean and Standard Deviation per Week)		Deer Behavior Along Roadside (2-Year Total)				
	Underpass	Roadside	Responsive ^a	Unresponsive ^b	No. of Crossing Attempts	No. of Potential Crossing Attempts	No. of No Crossing Attempts
1	4.8 ± 5.9	15.1 ± 11.7	160 (10.2%)	1,412 (89.8%)	61 (3.9%)	34 (2.2%)	1,477 (93.9%)
2	17.7 ± 12.0	6.1 ± 7.5	123 (19.2%)	516 (80.8%)	39 (6.1%)	26 (4.1%)	547 (89.8%)

^a Responsive behavior included vigilance (indicated by head held high in the direction of the highway or a vehicle) and flight from a vehicle.

^b Unresponsive (non-vigilant) behavior included feeding (51.3%), walking along the roadside (48.4%), bedding (0.16%), and 1 occasion each of mating (0.05%) and sparring (0.05%).



Figure 13. Behavior Considered Responsive to Interstate (left top and bottom), Crossing Attempt (top right), and Unresponsive Feeding Behavior (bottom right)

There were 100 deer crossing attempts captured by cameras and 30 DVCs within the combined 1.8 miles of highway at the study sites. Although the proportion of deer that attempted to cross the highway at the sites was relatively low (more than 90% did not attempt to cross), the findings indicate that relatively few crossing attempts can result in a large number of DVCs. Highway crossings have also been found to be performed by a relatively small number of deer (Stickles, 2014). More than 90% of more than 1,400 highway crossings by white-tailed deer fitted with GPS collars were performed by 7 deer within 1 year. The majority of these crossings (n = 919) was done by one female (Stickles, 2014).

Deer were predominantly unresponsive to the highway, an indication of their habituation to the highway. Feeding represented the largest proportion of the unresponsive behaviors (51.3%, Table 2), but it was not found to be significantly associated with DVCs. However, walking along the roadside, which represented 48.4% of the unresponsive behaviors (Table 2), was statistically correlated with DVCs when controlling for seasonal effects. In the months of October and November, detections of deer walking along the roadside at the study sites were significantly associated with DVCs. DVCs increased as deer roadside walking increased. This suggests that many deer were likely searching for a suitable location to cross. Earlier studies have found that ungulates tend to travel parallel to roads before crossing (Puglisi et al., 1974; Romin and Bissonette, 1996).

The relationship between roadside walking and DVCs underscores the potential value of fencing in reducing deer roadside activity and directing deer to a nearby underpass. Installing fencing would likely reduce DVCs throughout the year and would have the greatest impact on driver safety during the fall deer mating season when deer walking (or movement) escalates (Beier and McCullough, 1990).

Site 3: Stream Corridor / Highway Intersection

DVCs

There were no vehicle collisions with black bear within the 6-mile study area of Site 3 over the 2-year monitoring period. There were 74 DVCs, or 6.2 DVCs per mile per year, in the study area. In the 1-mile highway segment centered on the Site 3 stream corridor / highway intersection, there was an average of 6.5 DVCs per year. The drainage or stream corridor at Site 3 is one of five that originate on Afton Mountain and intersect the highway within the 6-mile study area. Likely because of the proximity of the other drainages and associated landscape features that play a role in directing deer movement, there was no clear distinction between DVC frequencies at Site 3 compared to those along other highway segments in the study area. Each 1-mile segment within the 6-mile study area encompassing Site 3 ranged from 5.5 to 6.5 DVCs per year. This suggests that animal detection driver warning systems, which are typically installed along a relatively short segment of highway (for cost and feasibility purposes), may not be effective at reducing overall DVCs on Afton Mountain if the installations are limited to a single stream corridor / highway intersection.

Similar to the underpass sites, DVCs were significantly higher in October and November than in the other months ($p < 0.05$). DVCs in these months accounted for 46% of the annual DVCs. This is an important consideration with regard to the potential application of a dynamic message sign (another type of driver warning system). These signs, which provide advisory messages for a general area as opposed to the site-specific warnings of an animal detection driver warning system, may be most effective when applied seasonally (and even limited to certain times of day) to reduce the potential for drivers to habituate to year-round warnings (Hardy et al., 2006).

Camera Data

Wildlife Activity

Wildlife activity totaled 3,370 for deer and 275 for non-deer species along the Site 3 roadside over the 2-year monitoring period (Figures 14 and 15). Bears visited the roadside 20 times. Other than deer, coyotes were the most common species photographed along the roadside.

Analyses of deer activity and behavior relative to the landscape features at Site 3 indicated that the topography influenced deer movement and associated DVCs along the highway. This was signified by (1) the proportion of roadside deer activity on the northern side of the highway versus that on the southern side; (2) the relationship between deer activity and the distance from the stream corridor / highway intersection; and (3) the locations of the crossing attempts (detailed here).

Figure 17 illustrates deer activity at the camera locations. Ninety percent of the deer roadside activity illustrated in Figure 17 occurred on the northern side, or westbound lanes, of the highway, where the drainage was saddled by steep slopes. Deer roadside activity was statistically correlated with the distance from the stream corridor (according to the final negative binomial regression) (Figure 18). Specifically, deer activity was highest at the stream corridor / highway intersection and decreased farther away from this intersection where the roadside topography was impassable. These findings show that deer movement was influenced by the stream corridor and the associated steep topography to the north of the highway. The landscape in this area serves as a funnel that concentrates deer in a relatively short section of highway.

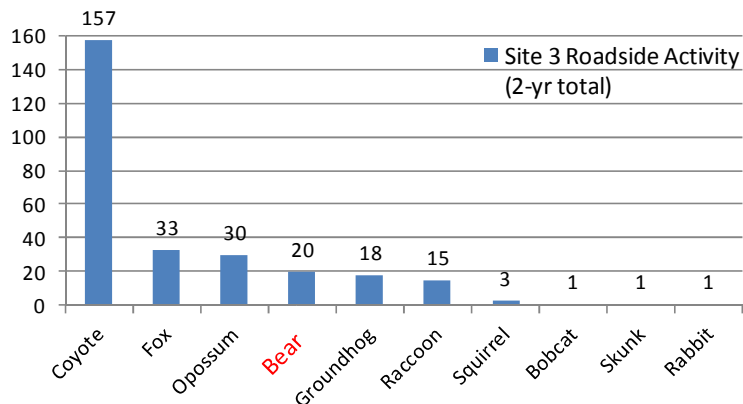


Figure 14. Wildlife Activity at Site 3 Over the 2-Year Monitoring Period



Figure 15. Photographs of Deer, Black Bear, a Coyote (*top left*), and a Fox (*bottom right*) Along Roadside at Site 3

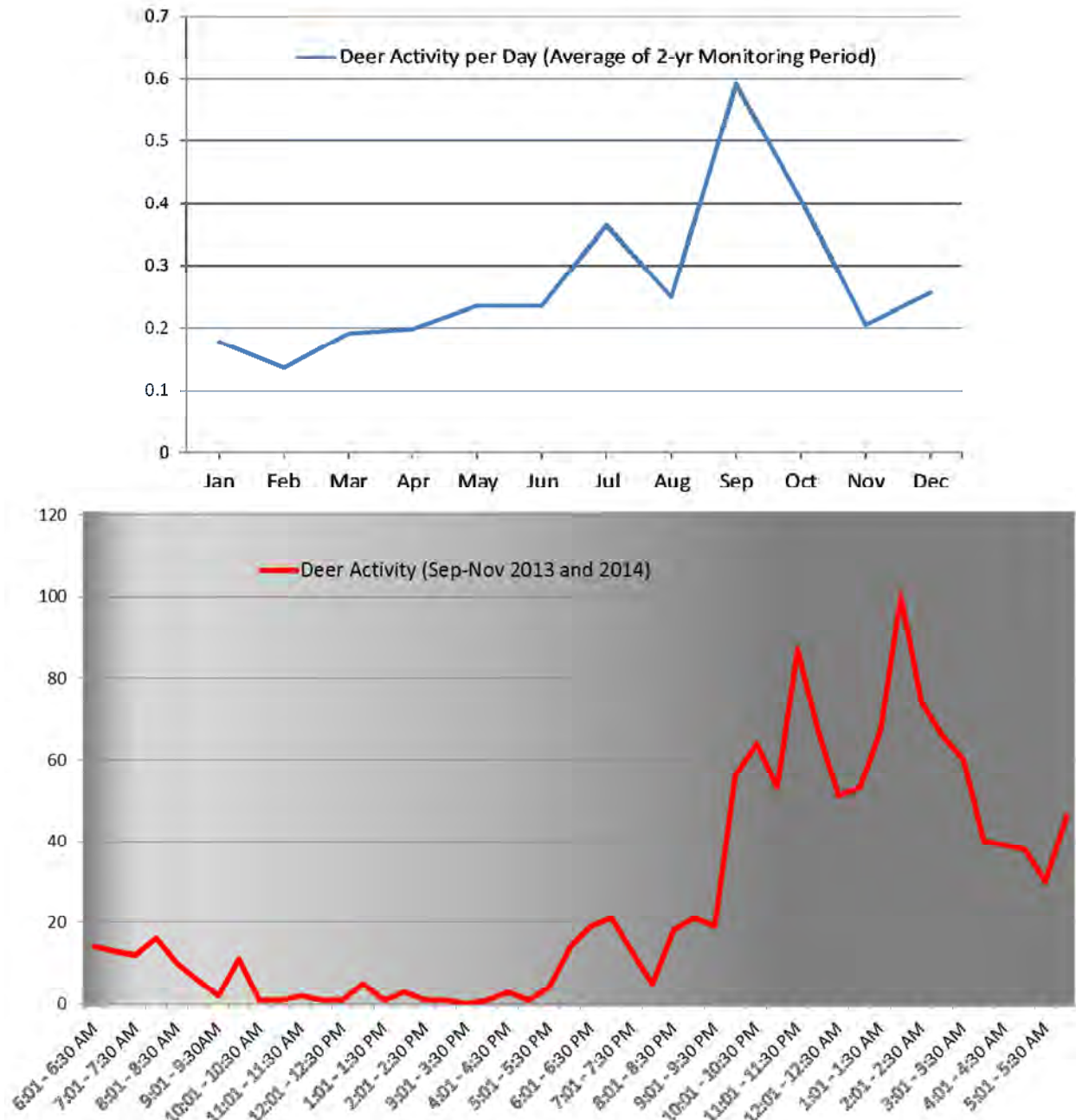


Figure 16. Daily Roadside Deer Activity per Month (*top*) and Deer Activity by Time of Day: September-November (*bottom*). Lighter shades correspond with daylight hours during fall months in Virginia.

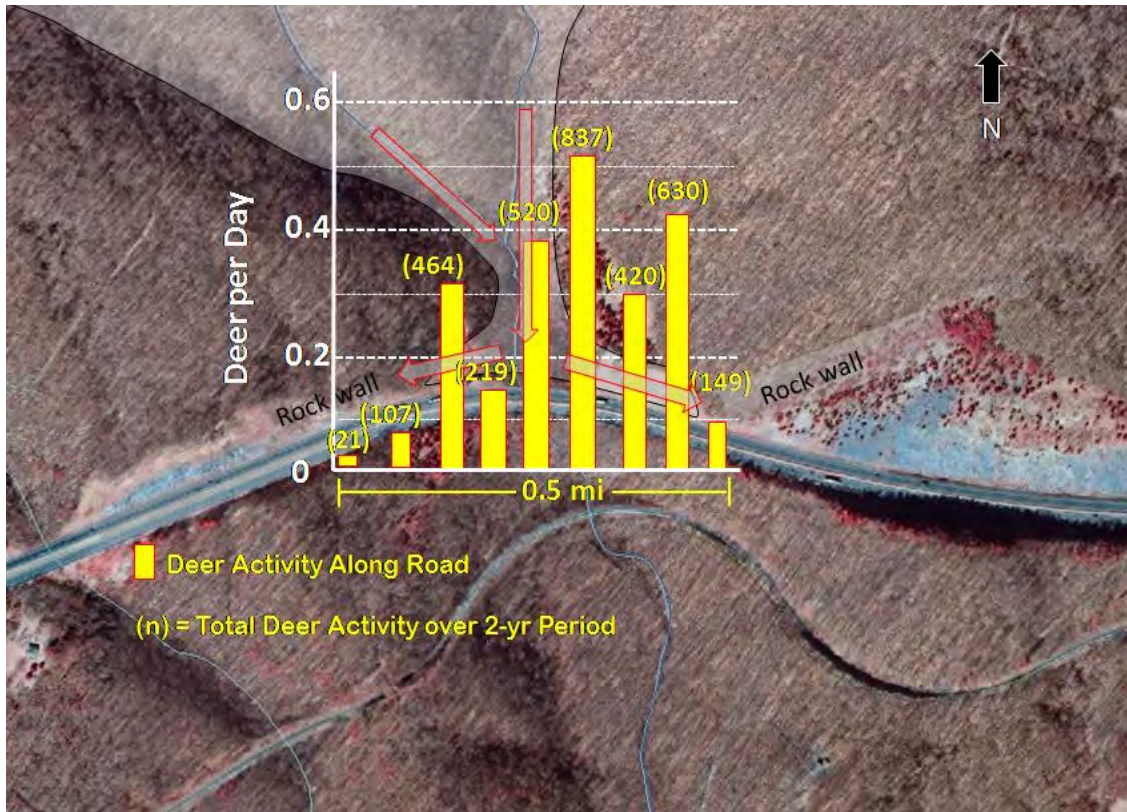


Figure 17. Deer Activity Along Interstate at Site 3. Bars are positioned at camera locations and illustrate activity from corresponding north and south cameras. The shaded area highlights the contours of the landscape and the saddle shape created by the steep topography. The arrows represent likely deer movement along the stream corridor toward and along the roadside (as indicated by camera data).

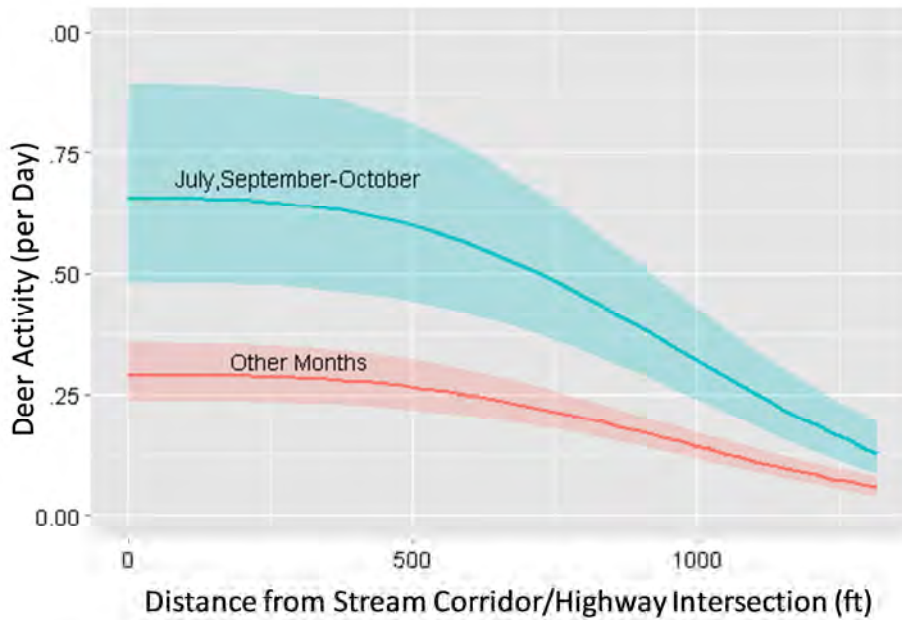


Figure 18. Graph Illustrating Statistically Significant Decrease in Daily Deer Activity As Distance From Stream Corridor / Highway Intersection Increases. The solid line represents a mean prediction curve, and the band surrounding the curve represents a 95% confidence prediction limit in the bottom graph. The months with the highest deer activity (July, September-October) are separated from the other months to highlight the stronger statistical relationship during those months.

Table 3 lists deer and bear behavior at Site 3. One camera (of the 18 total) captured the largest proportion (41%) of the 176 deer crossing attempts and potential crossing attempts. This camera was positioned at an area of roadside where grass groundcover transitions to a rock wall; this location is represented by the bar in Figure 17 with the second highest level of deer activity (n = 630). This indicates that as deer traveled east along the roadside away from the stream corridor / highway intersection, they either turned back or attempted to cross the interstate just before the rock wall inhibited their movement.

Similar to their roadside behavior at the underpass sites, deer were predominantly unresponsive to the highway (Table 3). Feeding (44.9%) and walking along the roadside (54.6%) represented the largest proportion of unresponsive behaviors. In October and November, feeding and walking were each significantly correlated with DVCs in the 6-mile study area. As more deer feed and walk along the roadside during these months (behaviors that are likely associated with fall rutting activities), DVCs can be expected to increase.

The proportion of bears responsive to the highway was higher than for deer (Table 3). Bears also exhibited more interest than deer in crossing the highway (50%) than in walking or feeding along the roadside. These findings indicate that deer use roadsides as foraging habitat more than bears and could suggest that bears are less habituated to the highways compared to deer.

Camera data analyses from Site 3 corresponded with earlier research that found topography strongly influences deer movement (Bellis and Graves, 1971; Carbaugh et al., 1975; Feldhammer et al., 1986). These findings are useful for determining effective mitigation strategies in areas with landscape features similar to those at Site 3. Carcass removal data indicate that vehicle collisions with deer and bear along Afton Mountain are not limited to isolated “hotspots” but rather have a more uniform distribution that is likely influenced by the several drainage corridors that intersect Afton Mountain. Whereas animal detection driver warning systems are typically installed along discrete DVC hotspots, dynamic message signs to warn motorists can apply to a larger area. Application of a deer advisory message on Afton Mountain’s dynamic message signs would therefore be a more feasible mitigation option in this area and may be most effective if applied seasonally from dusk through the end of the dawn hours (so reduce the likelihood of driver habituation to the message).

Table 3. Deer and Bear Roadside Behavior at Site 3

Species	Responsiveness to Highway		Highway Crossings		
	Responsive ^a	Unresponsive ^b	No. of Crossing Attempts	No. of Potential Crossing Attempts	No. of No Crossing Attempts
Deer	479 (14.2%)	2,884 (85.8%)	95 (2.8%)	81 (2.4%)	1,477 (94.8%)
Black Bear	11 (55%)	9 (45%)	3 (15%)	7 (35%)	10 (50%)

^a Responsive deer and black bear behavior included vigilance (indicated by head held high in the direction of the highway or a vehicle) and flight from a vehicle.

^b Unresponsive (non-vigilant) deer behavior included walking along the roadside (54.6%), feeding (44.9%), and bedding (14 instances, 0.5%). Unresponsive black bear behavior included walking along the roadside (100%).

Future construction or maintenance projects in this area of I-64 may provide opportunities to improve wildlife connectivity and reduce DVCs. In the event that increasing the size of existing drainage culverts (which are situated at ideal locations for wildlife movement) or constructing new wildlife underpasses with fencing becomes a feasible option along Afton Mountain, doing so is expected to reduce vehicle collisions with deer and black bear substantially in the Afton Mountain area.

SUMMARY OF FINDINGS

Sites 1 and 2: Unfenced Underpasses

- *Deer used the culvert underpass to cross beneath the highway (n = 506 crossings in 2 years) but were often reluctant to do so (as indicated by a high proportion of hesitancy behaviors [43%] and approaches that did not result in full crossings [18%]). Deer were more active along the roadside adjacent to the box culvert (n = 1,723 in 2 years) than they were along the roadside adjacent to the bridge underpass (n = 641 in 2 years).*
- *The large bridge underpass was heavily used by deer (n = 1,867 crossings in 2 years), but deer were also active along the roadside adjacent to the underpass (n = 639 in 2 years). Although deer activity along the adjoining roadside was lower than at Site 1, there was an equal number of DVCs at each site.*
- *Deer activity along the roadside was significantly associated with DVCs (i.e., as deer activity on the roadside increased, DVCs increased), and these relationships were strongest in October and November (when the fall mating season is associated with increased deer movement). The findings that deer activity along the roadside was greatest during September suggests that deer may use roadsides as foraging habitat during the late summer when herbaceous vegetation is still succulent and before acorns have fallen in the more heavily forested areas adjacent to the road.*
- *Although the highway crossing attempts and potential crossing attempts documented by cameras were low (n = 160) compared to other behaviors, crossing attempts resulted in relatively frequent DVCs at both study sites. DVCs at both study sites averaged 7.5 per mile per year.*
- *Deer exhibited relatively low responsiveness to the interstate (n = 283 responsive behaviors, or 15.3%). Unresponsive behavior predominantly included feeding on grass next to the shoulder (48.4%) and walking along the roadside (51.3%).*

Site 3: Stream Corridor / Highway Intersection

- *There were 74 DVCs (6.2 DVCs per mile per year) in the 6-mile study area of Site 3, and DVCs were significantly correlated with roadside deer activity (i.e., DVCs increased as deer*

activity on the roadside increased). There was little difference between DVC frequencies at Site 3 and along other segments in the larger study area, likely because the other nearby drainage corridors on Afton Mountain influence deer movement toward the interstate.

- *DVCs were significantly higher during October and November than during the other months of the year and represented 46% of the annual DVCs.*
- *Occurrences of deer activity along the 0.5-mile monitored roadside segment totaled 3,370 and that of other wildlife species totaled 275 over the 2-year monitoring period. That deer activity along the roadside was greatest from July through October suggests that deer may use roadsides as foraging habitat during the late summer when herbaceous vegetation is still succulent and before acorns have fallen in the more heavily forested areas adjacent to the road.*
- *During the fall months with high deer activity, deer were most active along the roadside at night. Smaller peaks of activity occurred during dawn and dusk.*
- *Deer activity was significantly higher nearest the stream corridor / highway intersection and decreased farther away from this intersection. Deer activity data and the concentration of crossing attempts indicate that as deer traveled along the roadside away from the stream corridor / highway intersection, they either turned back or attempted to cross the interstate just before a rock wall along the shoulder inhibited their movement.*
- *Similar to deer roadside behavior at the underpass sites, deer were predominantly unresponsive to the highway (85.8%). Feeding (44.9%) and walking along the roadside (54.6%) represented the largest proportion of the unresponsive behaviors and were significantly correlated with DVCs in October and November.*
- *Bears were more active along the roadside at Site 3 (n = 20) than at the underpass sites. Bears either walked alongside the highway (possibly seeking a suitable crossing location) or attempted to cross the highway rather than use the roadside for feeding.*

CONCLUSIONS

Sites 1 and 2: Unfenced Underpasses

- *In this study, the threat to driver safety that deer posed was apparent even on roads near suitable underpasses if those underpasses had no fencing. The attempted at-grade crossings by deer and the high frequency of DVCs in the evaluated highway segments indicate that many deer crossed the easily accessible interstate rather than use a nearby underpass, particularly when the underpass was smaller than what deer typically seem to prefer (Clevenger and Huijser, 2011; Donaldson, 2007).*

- *Just as DVCs statistically increased with deer roadside activity, a significant reduction in roadside deer activity is expected to reduce DVCs significantly. This is an important consideration for DVC mitigation decisions.*
- *Fencing installation along the roadside adjacent to the underpasses is expected to guide deer to the underpass and reduce roadside deer activity and associated DVCs. The addition of fencing may also increase use of the underpasses by bear and other wildlife.*
- *Deer were active along the full extent (up to 0.5 mile) of the monitored roadside sections on both sides of the underpasses; there was no significant relationship between deer activity along the roadside and distance from the underpass.*

Site 3: Stream Corridor / Highway Intersection

- *The stream corridor and topography at Site 3 strongly influences deer movement along the highway in two predominant ways:*
 - *The steep landscape features to the north of the interstate have a funneling effect on deer and concentrate their movements toward a relatively short section of highway.*
 - *An area with vertical rock walls along the highway shoulder inhibits deer movement and is associated with a relatively high number of crossing attempts where the rock wall begins.*
- *Because there are several stream corridor / highway intersections on Afton Mountain that have DVC frequencies similar to those at Site 3, the number of animal detection driver warning systems that would be needed to reduce DVCs on Afton Mountain may be impractical. These systems would be more cost-effective along highway sections that have a marked spike in DVC frequencies.*
- *Given the higher proportion of DVCs on Afton Mountain in October and November than in the other months of the year, the use of a dynamic message sign (which would apply to the general Afton Mountain area) to warn drivers of high deer activity may be effective during those months and would reduce the potential for drivers to become habituated to year-round warnings. Messages could be further limited to the hours between dusk and dawn, when deer are most active.*

RECOMMENDATIONS

1. *VDOT's Culpeper District Maintenance Engineer should install deer fencing at the evaluated bridge underpass and culvert sites as a DVC countermeasure. Fencing should extend up to 0.5-mile on both sides of the underpass (or as far as a topographic feature that obstructs deer movement).*

2. *VDOT's Northwest Regional Operations Director should coordinate with the State Operations Engineer to display an animal crossing advisory message on the changeable message signs on I-64 in the Afton Mountain area. The message should be displayed in October and November, from dusk through dawn hours, to correspond with periods of higher deer activity and DVCs.*
3. *VDOT's Traffic Engineering Division should evaluate AVC locations along all Virginia interstates to determine whether there are other areas with high AVC frequencies. If the Traffic Engineering Division finds high frequencies of animal-related crashes, the Traffic Engineering Division and VDOT's five operations regions should coordinate with VDOT's Operations Division to display animal advisory messages each fall in those areas to encourage driver vigilance during these seasonal periods of greater deer movement.*
4. *Upon the installation of fencing and the display of animal advisory messages, VTTC should conduct a post-mitigation study to compare the data collected in that study with the baseline data collected in this study. Driver speed and DVCs should be monitored to determine the effectiveness of the dynamic message sign, and deer activity (as captured by cameras) and DVCs should be evaluated to determine the effectiveness of fencing.*

BENEFITS AND IMPLEMENTATION

Benefits of DVC Reduction

Cost/Benefit Analysis for Fencing

There are numerous benefits from reducing DVCs, and placing a value on this benefit allows a comparison with the costs of the mitigation applied. In July 2015, VDOT began the installation of dynamic message signs on Afton Mountain. These signs are used for a variety of safety messages, and the decision to install them was made prior to this study. There is therefore no cost associated with posting a deer advisory message on these signs. Any reduction in DVCs resulting from the message would provide a savings in costs associated with human injury, human fatality, vehicle repair, towing and investigation, the monetary value of the animal (i.e., economic value associated with hunting and recreational wildlife viewing), and carcass removal and disposal.

The installation of fencing, however, will require VDOT expenditures. Annualized costs, or the equivalent uniform annual costs, were calculated for fencing and associated escape structures (i.e., jump-outs, which provide an exit for wildlife trapped between the fences) for comparison with the savings from a reduction in DVCs. Annualized costs in this example are the yearly costs of fencing and escape structures as if they were uniform throughout its service life. For this analysis, costs were estimated for the installation of 1 mile of roadside fencing (0.5 mile on both sides of an underpass) on both sides of the highway and four jump-out structures.

The annualized cost (AC) for fencing with jump-outs was calculated by the formula

$$AC_{F+J} = (C_F \times r) / (1 - (1 + r)^{-T_F}) + (C_J \times r) / (1 - (1 + r)^{-T_J})$$

where

AC_F = annualized cost of fencing
 AC_J = annualized cost of jump-outs
 C_F = cost for 1 mile of fencing
 r = interest rate (estimated at 0.05)
 T_F = service life for the fencing
 C_J = cost for the jump-outs
 T_J = service life for the jump-outs.

Fencing costs vary depending on the type chosen and the road section concerned. The fencing and jump-out costs and service life estimates used for this calculation were provided by Huijser et al. (2009). Fencing costs were based on the median value of 8-foot-high wildlife fencing costs (in 2015 U.S. dollars) along U.S. Highway 93 in Montana. The service life of fencing was estimated at 25 years (Huijser et al., 2009). The cost of one jump-out was estimated at \$9,813 and the service life was estimated at 75 years (Huijser et al., 2009). A DVC was valued at \$6,617; this value was derived from the cost/benefit analysis of AVC mitigation measures conducted by Huijser et al. (2009). This cost is based on the items listed previously (i.e., human injury, human fatality, vehicle repair, towing and investigation, the monetary value of the animal, and carcass removal and disposal costs [\$50]).

The cost/benefit analysis resulted in the following findings for one underpass site at which fencing and jump-outs are installed (as illustrated in Figure 19):

- The annualized costs of fencing and jump-outs are \$6,328 (based on a total cost of \$100,052).
- Fencing with jump-outs is cost-effective in terms of savings from DVC reduction when it prevents a minimum of 1 DVC per mile per year.
- With an expected 86% reduction in DVCs after fencing installation (Huijser et al., 2009), 6.45 DVCs would be avoided per mile per year. This results in a savings of approximately \$43,000 per mile per year.
- Over the 25-year service life of the fencing, the total savings would be \$501,473.

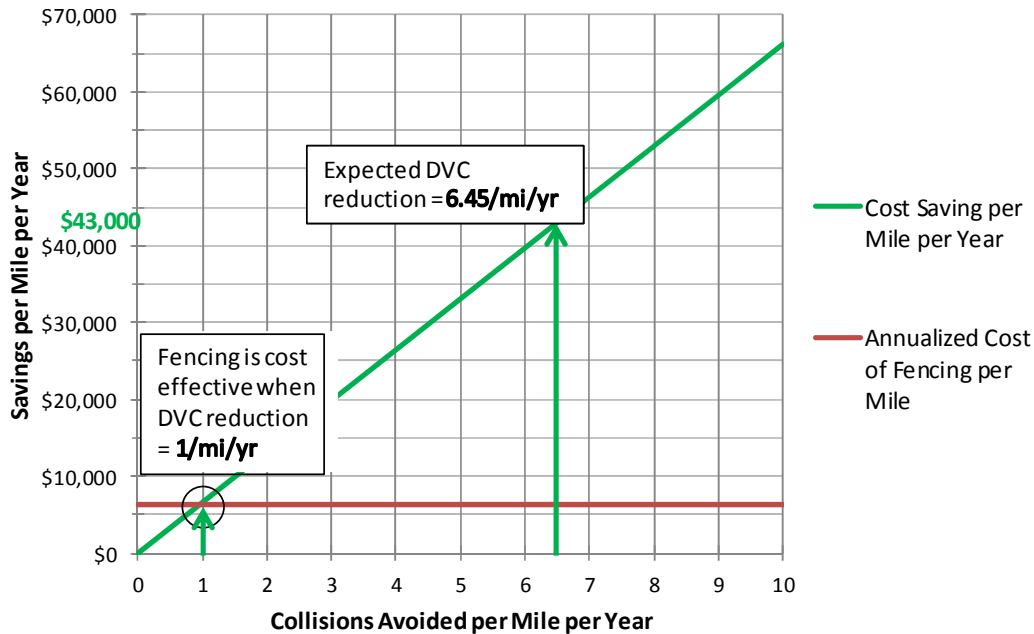


Figure 19. Cost Savings From Reduction in DVCs As Result of Installation of Fencing and Escape Structures

Implementation

VTRC researchers and the VTRC Implementation Coordinator have begun discussions with staff of VDOT’s Staunton and Culpeper districts with regard to implementation of the recommended mitigation measures. The VTRC Implementation Coordinator and VTRC researchers will provide technical assistance to VDOT’s Culpeper District Maintenance Engineer with regard to fencing placement decisions, methods to install escape structures, and effective ways to end the fencing. For example, tying fence ends into transitional areas (e.g., steep terrain or areas with a change in habitat or land use) is thought to decrease the probability of collisions at fence ends (Clevenger et al., 2001; Hardy et al., 2001). A recent report titled *Construction Guidelines for Wildlife Fencing and Associated Escape and Lateral Access Control Measures* (Huijser et al., 2015) will be referenced for fencing guidelines. Fencing installation is expected to be complete by January 2016.

VTRC researchers are working with the State Operations Engineer and the Operations Director of the Northwest Region to post a seasonal animal advisory message on VDOT’s changeable message signs. The messages will be displayed on signs in the Afton Mountain area. Messages will be deployed in the fall months (October and November) between 5 P.M. and 9 A.M. VDOT’s Traffic Engineering Division is also evaluating animal-related crashes along all Virginia interstates. Depending on the findings, the animal advisory messages will be displayed in other areas of Virginia to promote the need for additional driver vigilance because of the increased DVC risk each autumn. VDOT routinely informs the public every fall of this seasonal driving hazard. This fall, information about the display of the deer advisory messages will be incorporated in its outreach. Finally, VDOT’s operations staff is adding a wildlife warning safety section to VDOT’s guidelines for changeable message signs; the safety section is currently in draft form.

VTRC will conduct a post-mitigation study to determine the effectiveness of the fencing and the animal advisory message. VTRC is also initiating a project that will investigate the development of a programmatic approach for reducing AVCs in Virginia. The project will evaluate means to apply the findings from this study to other areas in Virginia; address issues such as improved documentation of VDOT's animal carcass removals; discuss funding options for AVC mitigation; and suggest ways VDOT can make use of available information and resources (i.e., Virginia wildlife corridor maps and AVC reduction initiatives by other DOTs).

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