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Enhancing Existing Isolated Underpasses With Fencing to Decrease Wildlife Crashes and Increase Habitat Connectivity

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BRIDGET M. DONALDSON
Associate Principal Research Scientist

KAITLYN E.M. ELLIOTT
Research Assistant

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VIRGINIA TRANSPORTATION RESEARCH COUNCIL
530 Edgemont Road, Charlottesville, VA 22903-2454
vtrc.virginiadot.org

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16. Abstract:

The impact of wildlife-vehicle collisions on drivers and wildlife populations has been gaining increasing attention in the United States. Given the established success of wildlife crossings with fencing in reducing wildlife crashes and connecting habitat, a growing number of states, including Virginia, have enacted wildlife corridor legislation, some of which encourages or requires the construction of wildlife crossings along identified wildlife corridors and/or high-crash areas. Because of the growing interest in wildlife crossing measures, research is needed on cost-effective means of implementation for departments of transportation.

When wildlife crossings are constructed, they are often built into new road construction projects as a series of two or more underpasses and/or overpass structures connected by exclusionary fencing. Given limited transportation budgets, enhancing existing underpasses on previously constructed roads has also been recognized as a cost-effective mitigation opportunity. More research is needed, however, on the effects of adding fencing to existing underpasses, particularly those that are too far from one another to be connected with contiguous fencing.

The purpose of this study was to determine the effectiveness of enhancing existing isolated underpasses with wildlife fencing. One mile of 8-ft-high wildlife fencing was added to a large bridge underpass and a large box culvert 5 mi apart on Virginia's I-64. Effectiveness was determined by conducting a 2-year post-fencing camera monitoring study and comparing the findings with those from a 2-year pre-fencing study with regard to the frequency of deer-vehicle collisions (DVCs); the use of the underpasses by deer and other wildlife; and roadside deer activity. The study also used deer behavior and activity data to make comparisons among different fence end designs and jumpout designs applied at the study sites.

The study found that the addition of wildlife fencing to certain existing isolated underpasses can be a highly cost-effective means of increasing driver safety and enhancing habitat connectivity for wildlife. After fencing installation, DVCs were reduced by 92% on average (96.5% and 88% at the box culvert and bridge underpass, respectively). Deer crossings increased 410% at the box culvert and 71% at the bridge underpass. Use of the culvert and bridge underpasses by other mammals increased 81% and 165%, respectively. DVCs did not increase at the fence ends, but there was high deer activity at the ends that did not tie into a feature such as right-of-way fencing.

At the study sites, the benefits from crash reduction exceeded the fencing costs in 1.8 years, and fencing resulted in an average savings of more than $2.3 million per site. The findings from this study should be considered when DVC mitigation and/or wildlife connectivity measures are needed. Wildlife crossing and fencing guidelines will be developed to provide the Virginia Department of Transportation with a resource for the cost-effective implementation of this wildlife crash mitigation measure.

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FINAL REPORT

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Bridget M. Donaldson
Associate Principal Research Scientist

Kaitlyn E.M. Elliott
Research Assistant

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ABSTRACT

The impact of wildlife-vehicle collisions on drivers and wildlife populations has been gaining increasing attention in the United States. Given the established success of wildlife crossings with fencing in reducing wildlife crashes and connecting habitat, a growing number of states, including Virginia, have enacted wildlife corridor legislation, some of which encourages or requires the construction of wildlife crossings along identified wildlife corridors and/or high-crash areas. Because of the growing interest in wildlife crossing measures, research is needed on cost-effective means of implementation for departments of transportation.

When wildlife crossings are constructed, they are often built into new road construction projects as a series of two or more underpasses and/or overpass structures connected by exclusionary fencing. Given limited transportation budgets, enhancing existing underpasses on previously constructed roads has also been recognized as a cost-effective mitigation opportunity. More research is needed, however, on the effects of adding fencing to existing underpasses, particularly those that are too far from one another to be connected with contiguous fencing.

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The study found that the addition of wildlife fencing to certain existing isolated underpasses can be a highly cost-effective means of increasing driver safety and enhancing habitat connectivity for wildlife. After fencing installation, DVCs were reduced by 92% on average (96.5% and 88% at the box culvert and bridge underpass, respectively). Deer crossings increased 410% at the box culvert and 71% at the bridge underpass. Use of the culvert and bridge underpasses by other mammals increased 81% and 165%, respectively. DVCs did not increase at the fence ends, but there was high deer activity at the ends that did not tie into a feature such as right-of-way fencing.

At the study sites, the benefits from crash reduction exceeded the fencing costs in 1.8 years, and fencing resulted in an average savings of more than $2.3 million per site. The findings from this study should be considered when DVC mitigation and/or wildlife connectivity measures are needed. Wildlife crossing and fencing guidelines will be developed to provide the Virginia Department of Transportation with a resource for the cost-effective implementation of this wildlife crash mitigation measure.

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INTRODUCTION

Background on Deer-Vehicle Collisions and Wildlife Crossings

The impact of wildlife-vehicle collisions on drivers and wildlife populations has been gaining increasing attention in the United States in recent decades (Vartan, 2016). Because driver safety is a priority to departments of transportation (DOTs), mitigation efforts often focus on reducing collisions with large hooved mammals such as deer. According to State Farm auto insurance industry estimates from 2019-2020, U.S. motorists have a 1 in 116 chance of colliding with a deer, elk, or moose. Virginia is considered a high-risk state, with a 1 in 74 chance of a motorist in Virginia striking a deer (State Farm, 2020). Deer-vehicle collisions (DVCs) in Virginia increased 25% from 2005-2017, and more than 60,000 have occurred per year since 2015 (Miles, unpublished data). These incidents in Virginia were found to correlate with traffic volume, road type, and volume of housing developments (McShea et al., 2008). Given their high volume, DVCs are estimated to be among the costliest collision types in Virginia, averaging more than $533 million per year (Donaldson, 2017).

Although insurance claim estimates provide an indication of the scale of the DVC problem, the locations of these crashes are not available for use by DOTs. The Virginia Department of Transportation (VDOT) uses police report data for project planning and safety evaluations; however, police-reported DVCs represented 9.4% of insurance claim estimates for DVCs from 2010-2017. Deer carcass removal records provide a more accurate indication of DVC frequencies and locations (Donaldson, 2017; Donaldson and Lafon, 2010), but these records are not systematically collected in Virginia.

Perhaps because the crash data used in Virginia do not accurately reflect the magnitude and hotspots of DVCs, mitigation to reduce these crashes is uncommon in the state. One successful mitigation project includes a wildlife underpass constructed in 2005 near the Great Dismal Swamp National Wildlife Refuge. This bridge underpass spans a wetland and includes berms to serve as dry areas for black bear, deer, and other wildlife to cross beneath the highway. Two miles of wildlife fencing was also constructed to keep wildlife off the highway and funnel them to the bridge underpass. A camera monitoring study established that this wildlife crossing project was successful not only at connecting important wildlife habitat for bear and many other

species, but, as deer represented 30% of the crossings, also at reducing the risk of DVCs (Donaldson and Schaus, 2009).

The success of such wildlife crossings (overpasses or underpasses) with fencing has been well established in recent decades (Clevenger and Huijser, 2011; Dodd et al., 2007; Gagnon et al., 2010; Kintsch et al., 2020), resulting in a substantial increase in their construction in the United States (Vartan, 2020). These structures are typically located where roads intersect with identified wildlife corridors and/or wildlife crash hotspots. The reduction in vehicle collisions with deer and elk as a result of these measures is typically greater than 80% (Clevenger et al., 2001; Sawyer et al., 2012) and was 90% or more in several studies (Bissonette and Rosa, 2012; Kintsch et al., 2020; Parker et al., 2011; Woods, 1990).

Support for the increasing efforts to identify wildlife corridors and construct wildlife crossings is reflected in a series of wildlife corridor programs and legislation passed in the United States in recent years. The recognized need for wildlife to travel in response to climate change is bolstering these efforts (Guarino, 2020). In 2019, the U.S. Senate approved a 50-year, $287 billion highway bill (America's Transportation Infrastructure Act), which provides $250 million for a new grant program for projects designed to reduce wildlife-vehicle collisions. The bill also adds new funding eligibilities for the construction of wildlife crossing structures and prioritizes the research and development of animal detection systems to reduce the number of wildlife-vehicle collisions (Guarino, 2020; Senate Environment and Public Works Committee, 2019). Nine states have passed wildlife corridor bills, many of which direct the DOT to construct wildlife crossings in areas with a high risk of wildlife crashes and/or where roads transect identified wildlife corridors (Fisher, 2020). Virginia is the most recent state to pass such legislation. In 2020, Virginia's General Assembly passed legislation titled the "Wildlife Corridor Action Plan," which directs the Virginia Department of Game and Inland Fisheries, in collaboration with VDOT and the Virginia Department of Conservation and Recreation, to identify wildlife corridors and areas with a high risk of wildlife-vehicle collisions in Virginia. In areas where road projects may affect identified wildlife corridors and/or wildlife crash hotspots, the bill directs VDOT to "consider measures for the mitigation of harm caused by such road to terrestrial and aquatic wildlife" (SB 1004, 2020 Reg. Sess., Virginia 2020).

Given the success of wildlife crossings and the associated increased demand for these measures, research is needed on cost-effective means of implementation for DOTs. Wildlife crossings are typically constructed as a series of two or more underpass and/or overpass structures connected by exclusionary fencing (Clevenger et al., 2001; Dodd et al., 2007; Forman et al., 2003; Gagnon et al., 2010; Huijser et al., 2009). Although the costs for these structures can represent a relatively small portion of the overall project budget when incorporated into a new road project, the costs can be high when they are constructed on roads that have already been built. For these roads, enhancing existing underpasses that were not designed for wildlife but may be used by them to cross beneath the road is being recognized as a cost-effective mitigation opportunity. Although published research is limited, some studies in the southwestern United States have shown that the addition of fencing to connect existing underpasses used by wildlife (regardless of whether the underpasses were designed for wildlife) is an effective means of crash reduction (Dodd et al., 2007; Ward, 1982). Elk-vehicle collisions were reduced by 85% to 97% in Arizona after fencing was constructed to connect wildlife crossing structures (Dodd et al., 2007, Gagnon et al., 2010). Similarly, elk-vehicle collisions decreased 97% after the height

of 3-ft fencing was increased to 8 ft between two large bridges and interchanges along Arizona's Highway 17. The use of these bridges by elk increased by 217% and 54% (Gagnon et al., 2015).

Underpasses that were not constructed for wildlife but that are nonetheless used by them are numerous throughout the United States (Forman et al., 2003). The U.S. road system includes more than 582,000 bridges longer than 20 ft, 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). In a camera monitoring study of existing underpasses in Virginia, cameras documented that white-tailed deer occasionally used structures with openings as small as 10 ft wide by 6 ft high, but larger structures were much more effective at facilitating deer passage (Donaldson, 2007).

Potential opportunities to enhance existing underpasses with fencing are plentiful along Virginia roads, but there is little research on the effects of adding fencing to structures that are isolated (i.e., too far from another underpass to be connected with contiguous fencing). Existing underpasses that may be viable for wildlife passage are often too far apart to be connected with fencing. The longer the fencing, the less likely it is that all animals can reach the underpass (McCollister and Van Manen, 2010). Without an accessible underpass, fencing can adversely affect populations that need access to resources on both sides of the road (Jaeger and Fahrig, 2003). Understanding the effectiveness of adding fencing to isolated structures (rather than connecting two or more distant structures) is therefore needed, particularly if such measures are to be implemented on a larger scale.

For this approach, the design of the ends of a fence is of particular importance to minimize "end runs," whereby an animal circumvents the fencing by traveling from the habitat side of the fence end to the traffic side. Clevenger et al. (2001) found an increase in ungulate-vehicle collisions within 1 km of fence ends, although the authors concluded that major drainages near the fence ends likely influenced these occurrences. Conversely, Gagnon et al. (2015) and Bissonette and Rosa (2012) found no increases in wildlife-vehicle collisions at fence ends. The risk of end runs can be minimized by tying the fence ends into areas of steep topography or other obstacles that create difficulty for the animal to circumvent the fence end (Huijser et al., 2015; Jared et al., 2017).

Pre-Fencing Underpass Study

VDOT targeted a section of I-64 near the Afton Mountain area for safety and mobility improvements because of a high number of vehicle crashes and traffic stoppages. This east-west segment of interstate ranges in annual average daily traffic between 27,000 and 49,000. The highway is predominantly surrounded by oak-hickory forest interspersed with patches of agricultural land. According to police reports, DVCs were the third most frequent type of crash in the area. A subsequent analysis of deer carcass removal records, however, indicated that the number of DVCs was up to 8.5 times greater than those in police reports and DVCs were the most frequent type of collision compared to other reported crash types (Donaldson et al., 2016). 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 bears and other wildlife.

To provide VDOT with mitigation options to reduce DVCs, researchers at the Virginia Transportation Research Council (VTRC) conducted a study that evaluated the activity and behavior of white-tailed deer and other wildlife near two existing unfenced underpasses along I-64 (between Charlottesville and Crozet, Figure 1) (Donaldson et al., 2016). Because wildlife were known to use certain existing underpasses to cross beneath roadways, the study included an analysis of DVCs near these structures and 2 years of camera monitoring to evaluate wildlife use of the underpasses and deer activity along the adjoining (unfenced) roadside.

The underpass at Site 1 is a single-barrel box culvert with 10 ft by 12 ft openings and a length of 189 ft. The Site 2 underpass is a large bridge 5 mi west of Site 1. The bridge is 307 ft long (or wide, from the perspective of an animal crossing beneath it) and spans the Mechum River. The river width is approximately 45 ft, with approximately 10-ft-wide grassy strips on each side to allow the passage of farm vehicles. The remaining area beneath the bridge is sloped with sandy substrate, also passable by wildlife.

Cameras were placed on the roadside above each underpass, and the extent of camera placement was based on the distance that deer could be expected to travel to the underpass. The home range size for white-tailed deer was used to determine this distance (Bissonette and Adair, 2008). Male white-tailed deer in Virginia have an average home range of approximately 1 mi^2; females have a smaller home range (Batts, 2008; Hewitt, 2011). In general, a deer situated at any point along the extent of camera placement (or future fencing) would therefore be able to reach the underpass.

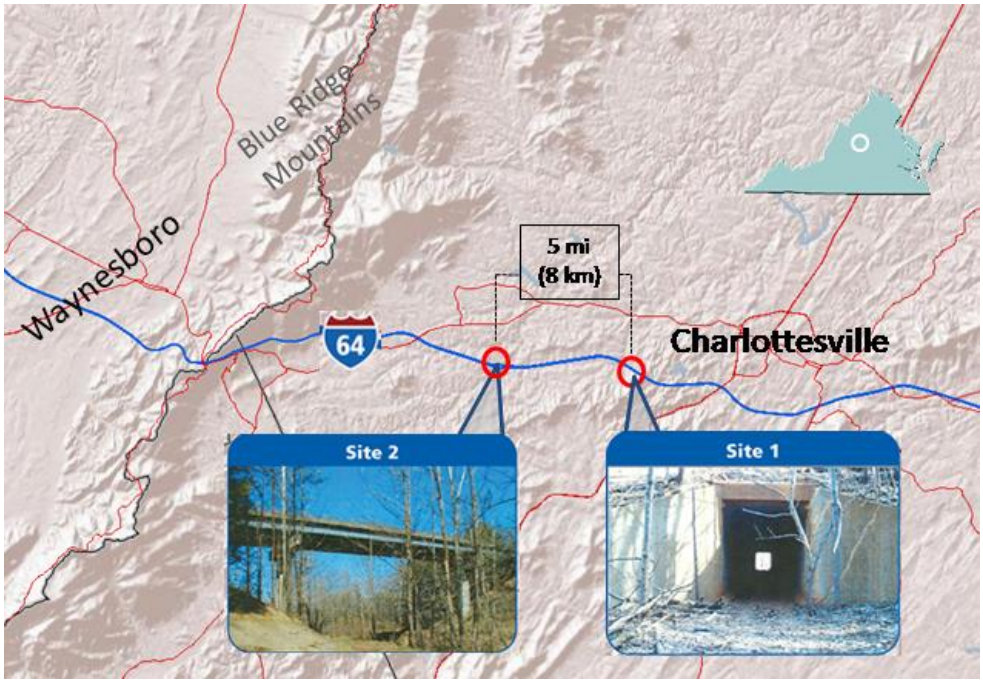


Figure 1. Locations of Existing Underpass Study Sites (Donaldson et al., 2016)

Cameras were evenly spaced in 0.1-mi intervals in the east and west directions from the underpasses and up to 0.5 mi on each side of the Site 1 and Site 2 underpasses. With this placement, cameras captured the activity and behavior of deer that used the underpasses and those that had access to the underpasses but that traveled up to and potentially across the highway. At the box culvert (Site 1), one camera was also placed at each of the two entrances to the box culvert. Four cameras were placed beneath the bridge underpass (Site 2) to capture the areas on both sides of the river.

Although cameras documented regular use of the underpasses by deer and other wildlife, there was also a high degree of deer activity along the adjacent roadside and an associated high frequency of DVCs (Donaldson et al., 2016). The study findings indicated that the threat to driver safety that deer posed was apparent even on roads near suitable underpasses if those underpasses had no fencing. The study therefore recommended the installation of up to 1 mi of 8-ft-high exclusionary fencing along eastbound and westbound lanes at both study sites. This was expected to help guide deer and other wildlife toward the underpasses and prevent them from attempting to cross the highway (Donaldson et al., 2016).

PURPOSE AND SCOPE

The purpose of this study was to determine the effectiveness of enhancing existing isolated underpasses with wildlife fencing. Effectiveness was determined by conducting a post-fencing camera monitoring study and comparing the findings with data collected during the Donaldson et al. (2016) pre-fencing study. Pre-fencing findings were compared with post-fencing findings with regard to (1) the frequency of DVCs, (2) the use of the underpasses by deer and other wildlife, and (3) roadside deer activity.

The study also used deer behavior and activity data to make comparisons among the different fence end designs and jumpout designs applied at the study sites. Finally, a cost analysis was conducted to compare the costs of the fencing with the savings from any DVC reductions at the study sites.

For the DVC evaluations, several years of pre-fencing deer carcass removal records were compared to 3 and 2 years of post-fencing records for Sites 1 and 2, respectively. For evaluations of roadside and underpass activity by deer and other wildlife, 2 years of pre-fencing camera data were compared with 2 years of post-fencing camera data. In the subsequent sections, "DVCs" indicates data collected from deer carcass removal records. Deer-related vehicle collisions from police records are referred to as "police-reported DVCs."

METHODS

This study included several tasks, beginning with the design and construction of fencing and jumpout structures. Subsequent tasks repeated most of the methods used in the pre-fencing study, including camera placement, deer carcass data collection and analyses, and analyses of

camera data. This allowed for a comparison of post-fencing findings with those from the pre-fencing study.

Other tasks included comparing fence end designs with regard to deer activity and DVCs. Similarly, deer behavior at the jumpouts was monitored to compare among designs.

Fencing and Jumpout Design and Construction

Fencing and Fence End Treatments

The installation of approximately 23,000 linear feet of fencing (approximately 1 mi at each site, on both sides of the interstate) was initiated in 2016. Fencing extended from each of the two underpasses (0.5 mi of fencing extending along the roadside east and west from the underpasses). The fencing length decision was based on the same rationale as described previously for the extent of camera placement (i.e., based on a deer's home range size). Although one study suggested that fencing lengths of at least 5 km (3.1 mi) can maximize DVC reductions (Huijser et al., 2016), another study found no detectable association between fence length and average effect sizes (Rytwinski et al., 2016). For this study, a length of no greater than approximately 1 mi was selected to allow any deer and other species that approached the fence to be able to reach the underpass rather than to have a situation where the fencing created a complete barrier for species with smaller home ranges.

The fence constructed was an 8-ft-high woven wire fence designed to prevent wildlife from entering the roadway and to guide them toward the underpasses (Figure 2). The spacing between the horizontal wires gradually decreased farther down the fence to prevent smaller animals from passing through.

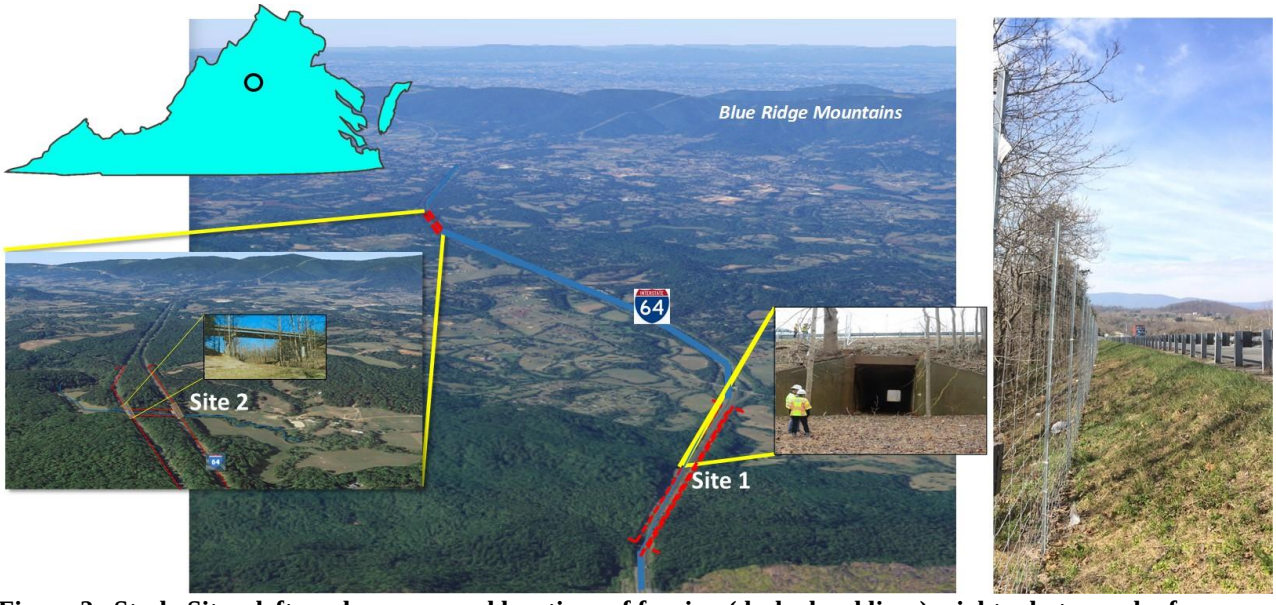


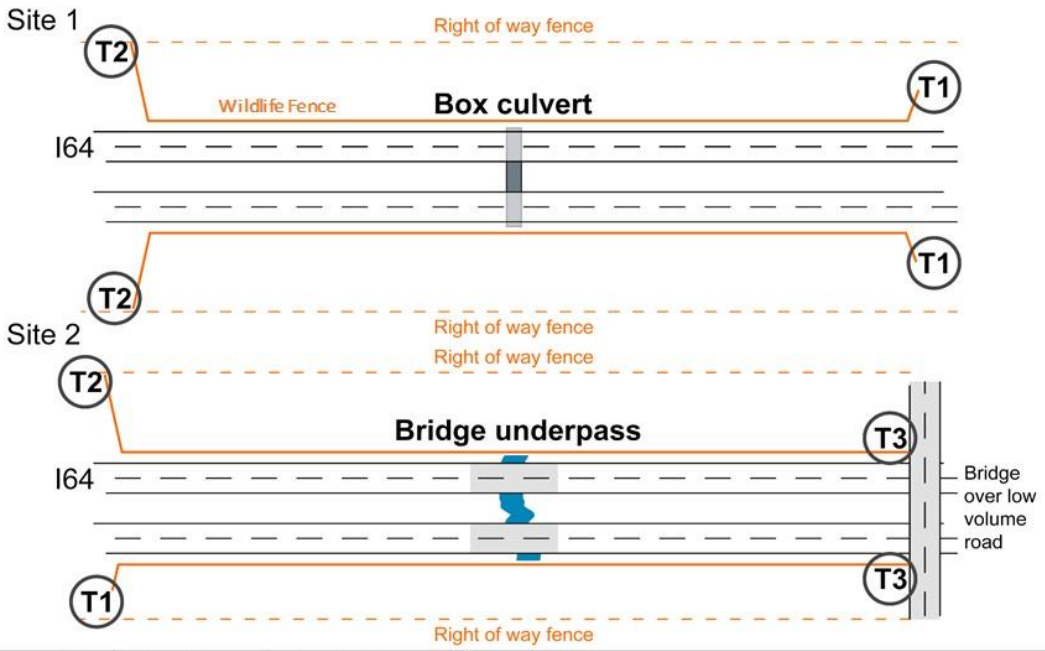
Figure 2. Study Sites: left, underpasses and locations of fencing (dashed red lines); right, photograph of fencing

Fencing was constructed at the edge of the tree line, which varied from several feet to approximately 40 ft from the highway shoulder. This design allowed maintenance staff access to the grassy areas off the roadside to perform routine maintenance activities. Fencing was completed at the Site 1 box culvert underpass in February 2017 and at the Site 2 bridge underpass in January 2018.

At the Site 1 box culvert, fencing extended continuously along the interstate above the culvert. At the Site 2 bridge underpass, the fence was designed to tie into each bridge abutment and leave a 3-ft opening to serve as a jumpout for deer or other wildlife that might become trapped on the traffic side of the fence (Figure 3). These sections of the abutment are approximately 4 ft high, making it possible for deer to jump down but unlikely for deer beneath the bridge to jump up to the traffic side of the fence. Fencing then extended just below the bridge abutments, continued downhill and beneath the bridge, and tied into the abutment on the other side of the interstate. Extending the fence beneath the bridge prevented animals below the bridge from entering the median of the interstate.

Although fence ends should ideally be designed to end at (or tie into) a landscape feature such as steep topography or another natural barrier to prevent deer from circumventing the fence ends, there were no such natural features at the study sites. The ends of the fencing were designed in three different treatments that allowed for a comparison with regard to deer activity and DVCs near the fence ends. Fence ends were designed either to angle away from the road, extend 10 to 20 ft, and end without tying into a feature (Treatment 1); to angle away from the road and tie into the existing 4-ft right-of-way (ROW) fencing (which ran parallel to and approximately 50 ft from the interstate) (Treatment 2); or to remain parallel to the road and tie into a bridge underpass that spanned a low volume gravel road with a low posted speed limit (Treatment 3, Figure 4).

Figure 3. Fence at Site 2 Underpass. The gap between the fencing and the bridge was designed to serve as a jumpout to allow wildlife on the traffic side of the fence to access the underpass below.



Fence End Treatment	Site (No. of fence ends)	Description
T1	1 (2 ends) 2 (1 end)	No tie-in. Fence end angles away from road, extends 20 to 30 ft, and does not tie into any structure or landscape feature
T2	1 (2 ends) 2 (1 end)	Ties in with right-of-way fencing. Fence end angles away from road and ties in with 4-ft high right-of-way fencing
T3	2 (2 ends)	Ties in with a bridge underpass. Fence ends on top of bridge abutment of a bridge that spans a low volume gravel road.

Figure 4. Fence End Treatments at the Two Study Sites

Jumpouts

In addition to the gaps that served as jumpouts at the Site 2 bridge abutments (Figure 3), four jumpouts were incorporated at each site approximately halfway between the underpass and each fence end. These features consisted of shorter sections of fencing to allow escape for any wildlife trapped within the roadway and to prevent animals from entering the roadway through the jumpout.

Each jumpout comprised a 4-ft-high 8-ft-wide section of fencing but varied according to whether it (1) was in line with the fencing or funneled farther back from the road, and (2) had a top-mounted angled attachment (Figure 5). Five jumpouts were set back from the road, and the fencing functioned as a short funnel to guide deer to the jumpout. Three jumpouts were in line with the fencing. Three of the jumpouts had a top-mounted angled attachment (a design described in Jared et al. [2017]). The outrigger attachments were used for jumpouts on a level ground and were angled toward the habitat side of the fence, making it unlikely for deer on the habitat side of the fence to jump over them (Jared et al., 2017). The attachments were not used on jumpouts located on a downhill grade. On downhill grades, the height that a deer on the downslope habitat side of the fence would have to jump was deemed too great (i.e., over 4 ft) for such a jump to be a likely occurrence.

Figure 5. Jumpout Designs at Study Sites: left, jumpout set farther back from the road and on a downslope (with no angled attachment); center, jumpout in line with the fence and on a downslope (with no angled attachment); right, jumpout set farther back from the road on level ground (with the angled attachment)

Camera Placement

A total of 43 Reconyx Hyperfire (Reconyx, Inc.) digital trail cameras in steel enclosures were installed at the study sites within 1 week after fencing installation at each site. Cameras were placed in the same underpass and roadside locations and were the same models as those installed for the pre-fencing evaluation (Donaldson et al., 2016). Cameras were installed at the eight jumpouts (four at each site) and each of the fence ends. The cameras use motion sensors to detect the presence of an animal and were 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 ft and a day range up to 100 ft.

Cameras along the roadside were attached to the guardrail or mounted on poles positioned approximately 5 ft from the paved shoulder. Cameras were angled such that the area of detection included the traffic side of the fence (i.e., the area between the highway shoulder and the fencing) and a portion of the habitat side of the fence that predominantly comprises oak-hickory forest. Cameras were mounted on trees at the entrances of the box culvert (one camera at each entrance), and four cameras were placed beneath the bridge underpass to capture the entire area beneath the bridge.

Carcass Data Collection and Analyses

Deer carcass removal data were obtained from hand-written records collected by VDOT's contractor for interstate maintenance. These data have been collected on a monthly basis since 2013. The contractor documented the date, the species, and the location of the species to the nearest 0.1 mi using posted mile marker signs. (Devices for recording geographical location were not available to the contracted maintenance staff.)

At both study sites, 4 years of DVCs pre-fencing were compared with DVCs post-fencing. Three years of post-fencing DVCs were available for Site 1 (2013-2016). Because the fencing at Site 2 was completed 1 year after the Site 1 fencing, 2 years of post-fencing DVCs were available for Site 2 (2018-2019).

To determine whether DVCs increased near the fence ends, pre-fencing DVCs (over the 3- and 4-year period of pre-fencing DVC analyses) were compared to post-fencing DVCs within 0.3 mi and 0.5 mi of the fence ends. Differences between pre- and post-fencing DVCs were evaluated as a whole (combining the DVC data from all of the fence ends) and according to the specific fence end treatments. Differences between pre-fencing and post-fencing DVCs were evaluated with *t*-tests. *P*-values less than 0.05 were considered significant.

Camera Data Collection and Analyses

Methods for camera data documentation and analyses were the same as those for the pre-fencing study (Donaldson et al., 2016). 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 in each camera and provided an indication of the general density of animals using the roadside.

On some occasions, cameras were not operational for short periods because the battery power depleted before the batteries were replaced or the secure digital card reached maximum storage capacity. Differences in camera operative days were accounted for in all analyses. Any results that were reported as the yearly total (e.g., the number of wildlife using the underpasses per year) were calculated by multiplying the average number of wildlife per camera operative day by 365. This allowed for a more balanced comparison, given differences in camera operative days between sites.

Wildlife crossings through each underpass were grouped by month and evaluated with the Mann-Whitney U Test to test the null hypothesis that there were no statistically significant differences in the number of crossings by deer pre- and post-fencing. Hesitancy behavior by deer was also documented as deer approached the underpass; this behavior is indicated by muzzles lowered to the ground (Gordon and Anderson, 2003; Reed et al., 1975). The 2 Proportion Z Test was used to test the null hypothesis that the proportion of deer that exhibited hesitancy behavior upon approaching the underpass before fencing installation was not statistically different than the proportion of deer that exhibited hesitancy behavior upon approaching the underpass after fencing installation. The 2 Proportion Z Test was also used to test the null hypothesis that the proportion of deer approaches to the underpass that resulted in crossings rather than retreats was not statistically different before fencing as compared to after fencing. A 0.05 level of significance was used for both statistical tests.

For camera data collected along the roadside, 2 years of roadside deer activity collected prior to fencing construction was compared to 2 years of deer activity on the traffic side of the fencing after fencing construction. Camera data collected at the fence ends were evaluated to determine if there were detectable differences in deer activity among fence end designs. At the jumpouts, the number of approaches and attempts at using these features to cross from one side of the fence to the other was documented

Cost Analysis

A cost analysis was conducted to compare the costs of the fencing (including site preparation and maintenance costs) with the savings from any DVC reductions at the study sites. Each DVC at the study site (as determined by a deer carcass removal) was attributed a dollar value based on collision severity (Table 1). This approach was based on valuations used by traffic engineers in evaluating applications for the VDOT Highway Safety Improvement Program, in which dollar values are attributed based on the type and severity of the collision. These costs were developed from a crash costs estimates report by Council et al. (2005). From Virginia's Traffic Records Electronic Data System (an online database of police-reported crashes), the most recent 4 years of available deer crash data were evaluated to determine the collision severity of police-reported DVCs in the project area.

The annual fencing maintenance cost and the annual crash cost savings at the fenced interstate segments were expressed as a present discounted value. The present discounted value measures the worth of a future amount of money in today's dollars adjusted for interest and inflation. This allowed the annual fencing maintenance and annual crash cost savings to be tabulated with the one-time fencing installation costs. Finally, the minimum number of deer crash reductions needed to offset the costs of fencing was determined.

Table 1. Costs of an Animal-Vehicle Collision According to Collision Severity

Collision Severity	Cost
Fatal	$5,912,317
Serious Injury	$364,362
Minor Injury	$93,177
Property Damage Only	$8,008

Source: VDOT valuations developed from Council et al. (2005).

RESULTS

DVCs and Bear-Vehicle Collisions

On average, DVCs decreased 92% over the 2 and 3 years post-fencing at Site 2 and Site 1, respectively, for an average reduction of 8.4 DVCs per mile per year (Figure 6). In the 4 years pre-fencing at Site 1, the 1-mi interstate segment averaged 9.5 DVCs per year. In the 3 years post-fencing, there was an average of 0.3 DVCs per year (1 DVC occurred the first year post-fencing), representing a 96.5% reduction in DVCs.

In the 4 years pre-fencing at Site 2, the 1-mi interstate segment averaged 8.5 DVCs per year. In the 2 years post-fencing, there was an average of 1 DVC per year (2 DVCs occurred the second year post-fencing), representing an 88% reduction in DVCs at Site 2. These reductions were statistically significant at each site ($p < 0.05$).

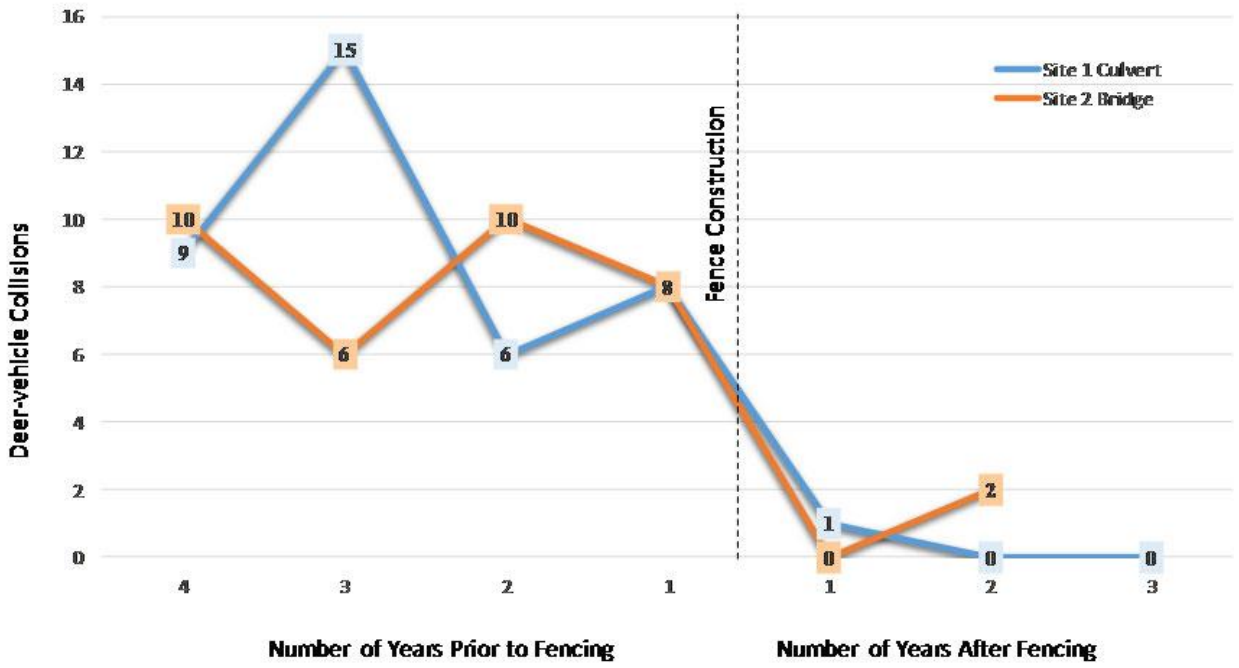


Figure 6. Deer-Vehicle Collisions Pre- and Post-Fencing at Site 1 and Site 2

There are approximately 5 mi of interstate between the study sites, 3 mi of which have no fencing or any underpasses large enough for use by deer. The average number of DVCs per mile per year remained relatively constant in this unfenced area pre- and post-fencing at the study sites, with 13.4 DVCs per mile per year in the 4 years pre-fencing and 13.0 DVCs per mile per year over the 3 years post-fencing at the study sites.

No black bears were killed by vehicles at Site 1 pre- or post-fencing. At Site 2, one bear was killed by a vehicle 2 years pre-fencing and no bears were killed post-fencing.

With regard to pre-fencing DVCs vs. post-fencing DVCs at the fence ends as a whole (combining DVC data from all fence ends), there were no statistically significant differences within 0.3 and 0.5 mi beyond the ends. In addition, there were no statistically significant differences in pre- and post-fencing DVCs according to fence end treatments. Differences in deer activity among the fence end treatments are discussed in a subsequent section.

Use of Underpasses

Over the 2-yr camera monitoring period at each site, cameras were operative an average of 661 days for the post-fencing study (91% of the 2-yr monitoring period) compared to an average of 705 days for the pre-fencing study (97% of the 2-yr monitoring period). Camera operative days post-fencing were slightly lower at Site 1 (639 days) than at Site 2 (683 days).

Deer

Deer crossings through the underpasses per day were statistically significantly higher at both sites in the 2 years post-fencing (Table 2). The greatest increase in crossings post-fencing was at the box culvert, where the daily average increased 410%, from 0.40 crossings per day pre-fencing to 2.04 per day post-fencing. Table 2 also provides the average crossings per year. These values were calculated by multiplying the average crossings per camera operative day by 365 to account for differences in camera operative days between the sites. Because cameras were operational for more than 90% of the study period, these values closely reflect the actual number of crossings documented by cameras. Post-fencing at Site 2, deer crossings beneath the underpass increased 71%, from an average of 2.60 crossings per day pre-fencing to 4.44 crossings per day post-fencing.

In addition to the increase in the number of crossings, there was a significantly greater proportion of approaches to the Site 1 box culvert that resulted in crossings (rather than retreats) post-fencing (80%) than pre-fencing (54%) ($z = -11.5$, $p < 0.05$). This is consistent with the decrease in deer hesitancy behavior post-fencing; the proportion of deer that hesitated upon approaching the box culvert post-fencing (30%) was significantly less than pre-fencing (43%) ($z = -3.8$, $p < 0.05$).

With the larger Site 2 bridge underpass, deer that approached the bridge underpass rarely retreated or hesitated pre- or post- fencing. Greater than 92% of approaches resulted in crossings both pre- and post-fencing. There were no significant differences in the proportions of approaches that resulted in retreats or hesitancy behavior pre-fencing compared with post-fencing.

Figure 7 illustrates deer use of the Site 1 box culvert over the course of the 2-yr pre-fencing and 2-yr post-fencing camera monitoring studies. As evident by the steeper slopes in the post-fencing graphs, which signify the cumulative number of deer crossings over time, deer use substantially increased approximately 3 to 4 months post-fencing.

Table 2. Comparison of Number of Deer Crossings Pre- and Post-Fencing at the Study Sites

	Site 1 Box Culvert[a]			Site 2 Bridge Underpass[b]		
Unit	Pre-Fencing	Post-Fencing	Increase Post-Fencing	Pre-Fencing	Post-Fencing	Increase Post-Fencing
Average per day[c]	0.40	2.04	410%	2.60	4.44	71%
Average per year	145	745		949	1,620	

[a] Site 1 post-fencing average crossings per day were significantly greater (median = 1.90, n = 26) than pre-fencing crossings (median = 0.23, n = 25), U = 95, $p < 0.05$).

[b] Site 2 post-fencing average crossings per day were significantly greater (median = 0.95, n = 24) than pre-fencing crossings (median = 0.59, n = 25), U = 145, $p < 0.05$).

[c] Per camera operative day.

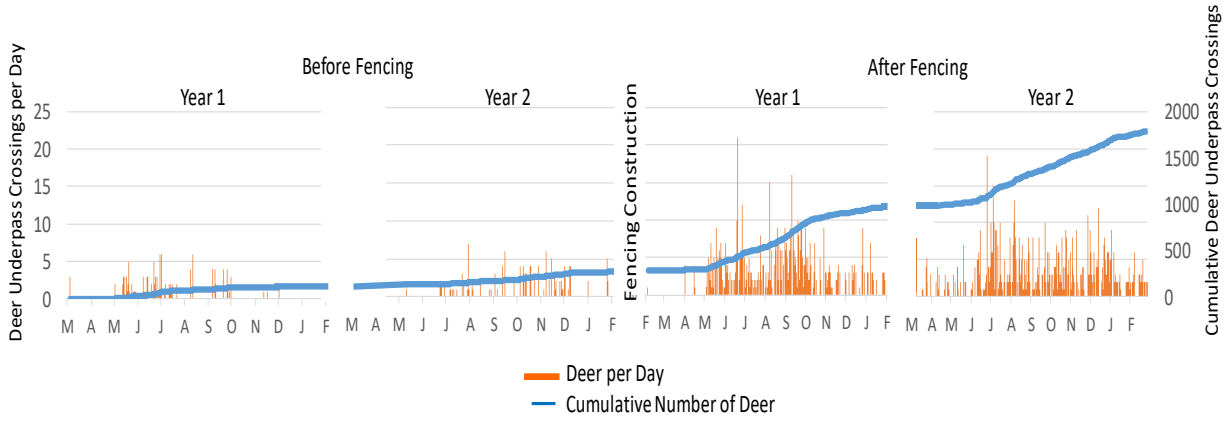


Figure 7. Deer per Day and Cumulative Number of Deer at Site 1. Deer per day (represented by the y axis on the left) and cumulative number of deer (represented by the y axis on the right) over the 2-yr pre-fencing and 2-yr post-fencing monitoring studies at the Site 1 box culvert. Months in each graph are represented on the x axes, beginning the month camera monitoring was initiated in the pre- and post-fencing studies.

Other Wildlife

The number of wildlife crossings through the underpasses increased post-fencing for most species (i.e., black bear, bobcat, fox, opossum, and skunk). For species smaller than deer, there was more use of the Site 1 box culvert than the Site 2 bridge underpass both pre- and post-fencing (Figure 8).

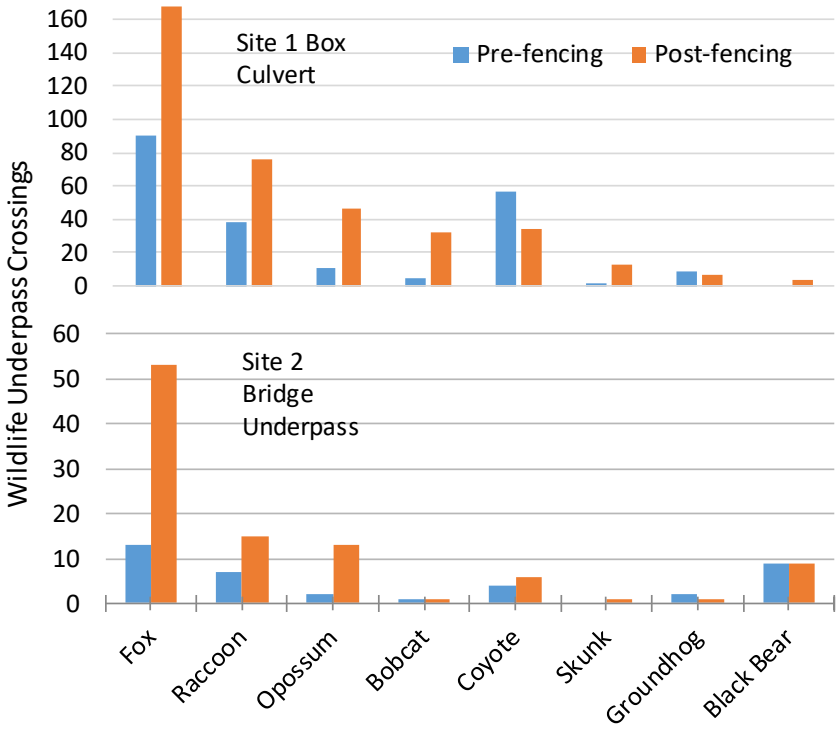


Figure 8. Wildlife Crossings per Year Pre- and Post-Fencing at Site 1 and Site 2 Underpasses. Note that different scales are used for each site.

Post-fencing at the box culvert, the number of wildlife crossings by species other than deer increased 81% (from 210 crossings per year pre-fencing to 381 per year post-fencing). Post-fencing at the Site 2 bridge underpass, the average number of wildlife crossings increased 165% (from an equivalent of 37 crossings per year pre-fencing to 98 per year post-fencing).

Black bears crossed through the culvert on eight occasions over the 2-yr post-fencing monitoring period. This is noteworthy given the fact that they had neither approached nor crossed through the box culvert during the pre-fencing study (Donaldson et al., 2016) and they had approached the box culvert and retreated (rather than crossing through) on three occasions during an earlier 1-yr monitoring study (Donaldson, 2007). Numerous crossings by deer, coyote, and bobcats occurred by adults with their young, though the numbers of these instances were not calculated given the difficulty in distinguishing between offspring and unrelated young adults in some cases (Figure 9).

Figure 9. Camera Images of Deer and Bear Behind the Fence and Crossing Through the Site 1 Box Culvert. Also illustrated are coyote (top right), bobcat and bobcat kittens (center right and bottom right), and bear cub (bottom center).

Deer Roadside Activity

With regard to deer roadside activity pre-fencing and post-fencing on the traffic side of the fence at both study sites, there was an average reduction of 72% (Figure 10). It is important to note that deer activity numbers in Figure 10 do not indicate the number of individual deer; it is likely that deer were captured by more than one camera as they traveled along the roadside. The highest activity on the traffic side of the fence occurred at the fence ends that did not tie into any

feature or ROW fencing (T1 treatments; see the caption of Figure 10 for treatment descriptions). At Site 1, which had a 58% reduction in roadside deer activity, more than one-half (55%) of the post-fencing roadside activity occurred at the eastern fence ends (both of which were T1 treatments that did not tie into any feature). At Site 2, where three of the four fence ends tied into ROW fencing or another bridge underpass, roadside deer activity was reduced 87% after fencing installation. Despite the high deer activity at Site 1's TI treatments (approximately 180 per year), deer activity at the underpass was much greater, with 745 crossings per year.

As mentioned previously, there was not a significant increase in DVCs within 0.5 km or 0.8 km of these ends despite the higher deer activity. Deer activity counts at the T1, T2, and T3 fence ends were 124 per year, 11.8 per year, and 3.6 per year, respectively.

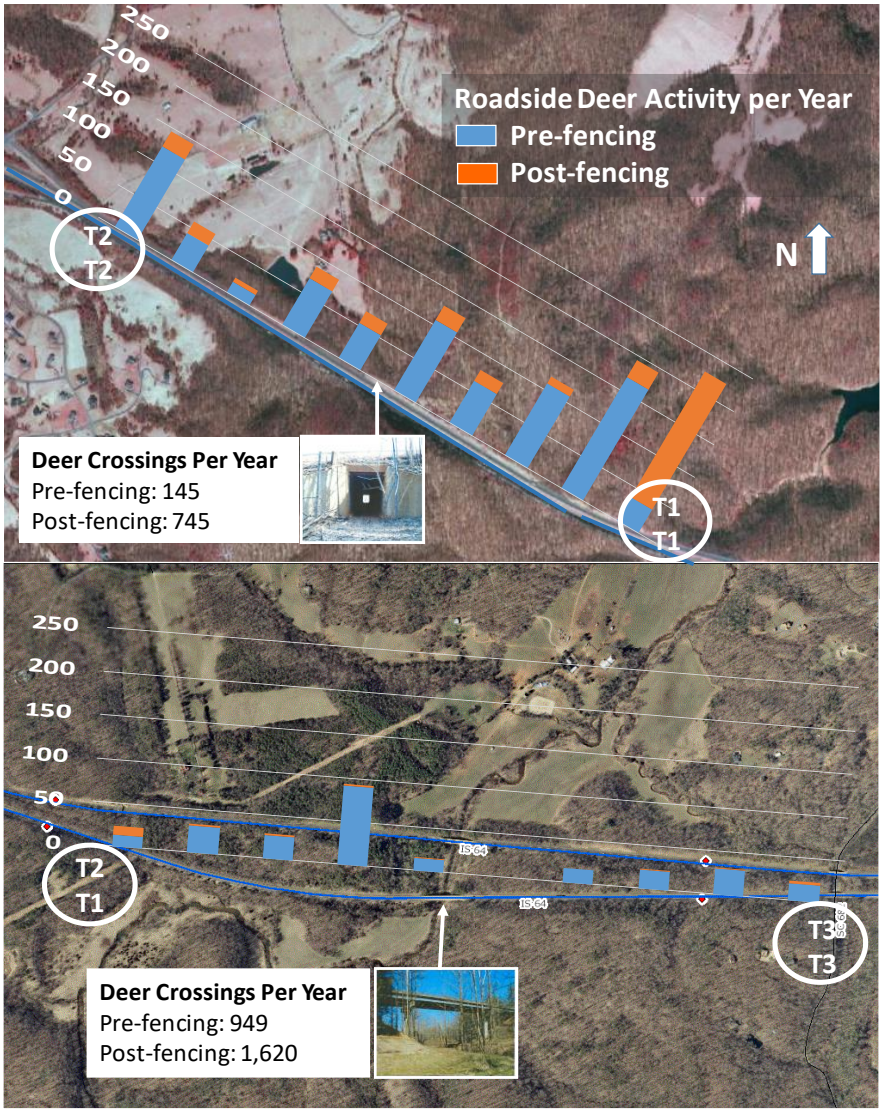


Figure 10. Roadside Deer Activity per Year. Roadside deer activity per year at camera locations (blue and orange bars), fence end treatments (white circles), and deer crossings per year through the underpasses. T1 = fence end does not tie into any structure or landscape feature (n = 3, average deer activity/yr = 124); T2 = fence end ties in with right-of-way fence (n = 3, average deer activity/yr = 11.8); T3 = fence end ties in with a bridge underpass that spans a low volume road (n = 2, average deer activity/yr = 3.6).

At both sites, damage to the fence occurred from vehicle crashes (one at each site), resulting in a 10- to 20-ft damaged sections of fence through which deer could travel to and from the roadside. Although the number of breaches through the fence could not be determined since cameras were not situated at these damaged sections, deer activity on the traffic side of the fence increased over the several-week period before the fencing was repaired.

Jumpouts

At the eight jumpouts (four at each study site), there were 32 approaches by deer from the traffic side of the fence. Seventeen of these approaches (53%) resulted in successful clearing of the jumpouts. Ten of the 15 unsuccessful attempts occurred at jumpouts with an angled attachment. With each of these attempts, deer ran up to the jumpout and stopped before jumping. After the first year of the study, the angled attachments were shortened, which reduced the frequency of unsuccessful jumpout attempts. After these modifications, however, there were not enough approaches to these jumpouts to determine the effectiveness of the shortened attachment design. At the Site 2 bridge underpass or the bridge spanning the low volume road at the terminus of the Site 2 fencing, no attempts were made by deer to jump up or down between the gaps left between the fencing and the bridge abutments.

All of the approaches that resulted in deer successfully scaling the jumpouts occurred at those that were set back from the road, where the fencing functioned as a short funnel that guided deer to the jumpout. Whereas the jumpouts that were in line with the fence tended to be unnoticed by deer as they walked by, the jumpouts that were at the end of the short funneled section of fencing appeared to be more easily detected (perhaps perceived by deer as a break in the fence). In addition, the funnel design provided space for deer to get the running start that was occasionally needed to scale the jumpout.

Jumpouts on a downhill grade (which had no top-mounted angled attachments) appeared to be an effective design that allowed escape from the traffic side to the habitat side but did not allow access to the traffic side. There was only one attempt by deer to scale a jumpout from the habitat side of the fence to the traffic side, and it was unsuccessful.

Cost Analysis

Fencing and Associated Expenses

A different contractor installed the fencing at each of the two study sites. There was a large discrepancy in cost per linear foot ($12 and $29) charged by the contractors. The costs of the fencing alone differed by nearly $200,000 ($335,600 at one site and $137,088 at the other). Neither contractor charged an additional amount for jumpout construction. The total cost per site, including associated expenses, averaged $265,409 (Table 3).

Table 3. Average Costs of Fencing and Associated Expenses

Expense	Average Cost per Site[a]
Site Preparation	$11,350
Traffic Control	$16,860
Fencing	$236,344 (average $20.5/linear foot)
Maintenance	$1,035
Total	$265,409

[a] Fencing length was approximately 2 mi at each site (1 mi on both sides of the interstate) for a total of approximately 11,500 linear feet.

Fencing maintenance was needed approximately once per year at each site to repair damage from fallen tree limbs and once per site to repair damage from vehicle crashes. Routine mowing and spraying costs were not included in the cost analysis because these activities were not changed by the presence of the fence.

Savings From a Reduction of DVCs

A DVC was valued at $8,936, which is slightly higher than the $8,008 "property damage only" value used by VDOT's Highway Safety Improvement Program. This number was calculated by classifying 99% of the deer carcass removals as property damage only crashes and 1% as minor injury crashes. These percentages were based on the findings that injuries from police-reported DVCs over the previous 4 years in the study area represented 1% of the number of deer carcass removals during that same time period.

Reflecting a fencing service life of 25 years and a discount rate of 0.03 (to adjust for inflation), the following summarizes the findings from the present discounted value calculations:

1. The total savings from deer crash reduction at the study sites were $2,524,870 and $2,171,959 (depending on the fencing contractor), for an average savings per site of $2,348,415.

2. Economic benefits from crash reductions would exceed fencing costs if deer crashes were reduced by an average of 9.4%, or less than 1 deer crash per site per year (0.85). In this study, these numbers were greatly exceeded, with an average DVC reduction of 92% (8.5 per site per year).

3. The economic benefits from deer crash reductions, predominantly in the form of property damage savings to drivers, begin exceeding fencing costs in an average of 1.8 years.

DISCUSSION

For existing roads where new wildlife crossing construction may not be an affordable option for DOTs, the DVC reductions found in this study suggest that enhancing certain existing isolated underpasses with fencing is a valuable opportunity to reduce crashes considerably while maintaining habitat connections for wildlife. Although white-tailed deer appear to be ubiquitous in many eastern states, they do not travel randomly throughout the landscape; their movements in

the environment and across roads are influenced by habitat features and resource availability, among other factors (Clevenger et al., 2001; Long et al., 2005; Webb et al. 2009). The addition of fencing to strategically selected underpasses can alter the movements of deer and other wildlife to the benefit of driver safety without compromising the ability of wildlife to access needed resources.

In this study, deer traveled more frequently and purposefully toward the box culvert once fencing was constructed, as evident by the significant reduction in retreats and hesitancy behavior. Their awareness of the fencing barrier likely increased their willingness to travel out of their way toward the structure in order to access habitat across the interstate. Once these routes are established, it becomes intergenerational knowledge (Vartan, 2016). Adults traveling through the crossings with their young were frequent occurrences by multiple species in this study; this type of learning behavior likely explains the growth in use of crossing structures over time (Beckmann et al., 2010; Vartan, 2016).

Similar to other studies that have found that different species select for different crossing structure designs (Ford et al., 2017; Mata et al., 2005), crossing frequency by species differed between the underpasses evaluated in this study. Although deer and black bear preferred the large bridge underpass, there were more crossings by medium and small mammals through the box culvert. The number of crossings at both structures increased for most species post-fencing, indicating that fencing did not benefit some species at the expense of others (Huijser et al., 2016; Jakes et al., 2018).

For white-tailed deer, the structures evaluated in this study fall near the opposite ends of the range of underpasses that they will comfortably use (Donaldson, 2007). Although deer crossed beneath the large bridge underpass without hesitation, the size attributes of the long enclosed box culvert were close to the lower limit of what deer would consistently use pre-fencing (Donaldson et al., 2016). Although fencing increased the use of both underpasses by wildlife, the addition of fencing to the culvert had the greatest impact on use by deer and black bears. Culvert crossings by bears began to occur only after the fencing was constructed. The large increase in culvert crossings by deer (410%) and the significant decrease in hesitancy behavior and retreats suggest that deer become less reluctant to use structures that are smaller (and/or longer) than what they prefer if they are otherwise restricted from accessing habitat across the highway.

It should not be assumed, however, that fencing will increase the use of all large culverts by wildlife. Identifying existing structures that may be suitable for fencing retrofits involves several considerations, including location, structural attributes, and evidence of use by wildlife (Clevenger and Huijser, 2011). The degree of openness, or "openness factor," (i.e., [height x width]/length) of a structure has also been found to influence structure use by deer and other species (Reed et al., 1975). Openness is largely a measure of ambient light in the passage; the larger the factor, the less tunnel-like the appearance of the structure. Given that 30% of deer in this study hesitated at the box culvert entrance even after fencing was installed, the addition of lighting in the culvert is an additional opportunity to enhance its suitability for wildlife and reduce reluctance to enter the structure.

Post-fencing, the difference in roadside deer activity among the fence end treatments that did and did not tie into any features underscores the importance of proper fence end design in minimizing DVC risk. In the pre-fencing study, a statistically significant relationship was found between roadside deer activity and DVCs; DVCs increased as roadside activity increased (Donaldson et al., 2016). Although DVCs did not increase at any of the fence ends in the post-fencing study, there was a high degree of deer activity at the ends that did not tie into a feature. Extending these ends in order to tie them into ROW fencing or another suitable feature would reduce roadside deer activity and the associated risk of DVCs in these areas. In the absence of a tie-in feature, extending fencing beyond wildlife crash hotspots has also been found to decrease the risk of collisions at fence ends (Bissonette and Rosa, 2012).

Although no DVCs occurred during the occasions that vehicles or downed tree limbs damaged sections of fencing, fence maintenance was an important component in minimizing the ability of deer to access the traffic side of the fence. Fencing repair was needed 1 or 2 times per year at each site as a result of fallen tree limbs or vehicle crashes. For a relatively minimal cost of approximately $1,000 per year at each site, repairing damage quickly will help ensure the effectiveness of the fencing in funneling deer to the underpasses and restricting them from the roadside.

Summary of Findings

- DVC reductions after fencing installation were 96.5% at the box culvert site and 88% at the bridge underpass site (an average of 92%, or 8.4 DVCs per mile per year).

- Deer use of the box culvert, which deer used reluctantly prior to fencing, increased 410% after fencing installation. Deer use of the bridge underpass increased 71% after fencing.

- Culvert and bridge underpass crossings by other wildlife (including black bear, bobcat, opossum, skunk, raccoon, and fox species) increased after fencing construction by 81% and 165%, respectively.

- Although DVCs did not increase at any of the fence ends, there was high roadside deer activity near the ends that did not tie into a feature. Deer activity was minimal at the ends that tied into ROW fencing or into a bridge underpass that spanned a low volume road.

- Jumpouts at the end of a funneled section of fencing appeared to be more easily detected and successfully used by deer than designs that were in line with the fence. Although more information is needed, deer appeared to prefer jumpouts that were funneled away from the road and consisted of shortened sections of fence on downslopes with no angled attachment.

- Less than 1 DVC reduction per year (a 9.4% reduction) was needed for the economic benefits to exceed the fencing costs at each site, and an average of 8.4 reductions per year (92%) were achieved. The benefits from DVC reductions exceeded fencing costs in an average of 1.8 years, and fencing was estimated to result in an average savings of more than $2.3 million per site over the lifetime of the fence.

CONCLUSIONS

- *The addition of exclusionary fencing to certain existing isolated underpasses used by wildlife can be a highly cost-effective form of DVC mitigation that requires a minimal number of crash reductions for the economic benefits to exceed the costs of the fence.*

- *The addition of exclusionary fencing can significantly increase the use of certain existing isolated underpasses by white-tailed deer, black bear, and other wildlife species.*

- *Fence end design plays a large role in minimizing deer access to the traffic side of the fence.* DVC risk is minimized by tying fence ends into features or obstacles that will create difficulty for deer attempting to circumvent the ends.

- *Jumpouts at the end of a funneled section of fencing appear to be more easily detected and successfully used by deer than designs that are in line with the fence*.

RECOMMENDATIONS

1. *VDOT's Traffic Engineering Division, district traffic engineers, and residency administrators should utilize the findings of this study when mitigation is needed in areas with high volumes of deer crashes and/or when there is a need to increase habitat connectivity for wildlife populations.*

2. *VTRC should extend the three "open" fence ends described in this study to tie them into ROW fencing in order to minimize the risk of DVCs in those areas.*

3. *VTRC should conduct and monitor an implementation project to determine the effectiveness of adding lighting to the Site 1 box culvert.* Researchers should determine the most cost-effective type of lighting that increases the number of crossings in the box culvert and reduces the proportion of retreats by deer.

IMPLEMENTATION AND BENEFITS

Implementation

With regard to Recommendation 1, the development of wildlife crossing and fencing guidelines would be the most efficient means of consolidating the findings of this study and providing a resource for VDOT when deer crash mitigation and/or wildlife connectivity measures are needed. By August 1, 2020, VTRC researchers (with the VDOT Northwest Region Operations Director as project champion) will initiate meetings with relevant VDOT divisions to present the results of this study and determine the next steps for developing and adopting guidelines accessible to VDOT staff. The guidelines will be developed using the findings of this study and existing national and state guidelines and will include detail drawings of wildlife crossing elements such as fencing and jumpouts.

With regard to Recommendation 2, VTRC researchers will work with the VTRC Implementation Coordinator to obtain a cost estimate for extending the three open fence ends at Sites 1 and 2. The timeline for securing a contract for the work will depend on the availability of funding and is expected to be completed by December 1, 2021.

With regard to Recommendation 3, VTRC researchers will work with the VTRC Implementation Coordinator to obtain cost quotations for lighting products. Types of lighting products that have been found effective in similar wildlife crossing projects will be considered. This project and its timeline will depend on the availability of funding. VTRC researchers will coordinate with the VTRC Implementation Coordinator by January 15, 2021, to determine whether funding is available to begin the project in FY 21.

Benefits

Implementing Recommendation 1 will provide VDOT a resource when considering mitigation for wildlife crash problem areas and/or a means to connect habitat in specific locations. It can also serve as a resource for VDOT when considering mitigation or connectivity measures for projects identified in the Wildlife Corridor Action Plan (SB 1004, 2020 Reg. Sess., Virginia 2020).

Implementing Recommendation 1 is also expected to result in substantial cost benefits if the guidelines lead to additional sites with fencing enhancements. A minimal number of deer crash reductions is required for the benefits of fencing to exceed installation and maintenance expenses. In this study, a reduction of less than 1 deer crash per site per year (9.4%) was needed to offset fencing costs, and this study had an average DVC reduction of 92% (8.5 per site per year). These benefits offset fencing costs in approximately 1.8 years, and there was an average savings per fenced site of more than $2.3 million.

Implementing Recommendation 2 is expected to decrease the volume of roadside deer activity at the three fence ends that do not tie into a feature or ROW fencing. Decreasing deer activity at these fence ends will decrease the risk of DVCs in these areas.

Implementing Recommendation 3, which will include a small-scale lighting implementation project at Site 1, is expected to increase further the use of the Site 1 box culvert by deer. Because 30% of the approaches to the culvert did not result in crossings after the addition of fencing, adding lighting will likely decrease the number of deer that potentially seek another means to cross the interstate. This study will also inform decisions on the most cost-effective means of enhancing other existing culverts with lighting to increase their use.

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