

Using Video Surveillance to Estimate Wildlife Use of a Highway Underpass

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ABSTRACT Roads pose many threats to wildlife including wildlife–vehicle collisions, which are a danger to humans as well as wildlife. Bridges built with provisions for wildlife can function as important corridors for wildlife passage. We used video surveillance to record wildlife passage under a bridge near Durham, North Carolina, USA, to determine whether it functioned as a wildlife underpass. This is particularly important for white-tailed deer (*Odocoileus virginianus*) because forests associated with the bridge created a corridor between 2 natural areas. We calculated detection probabilities and estimated the number of crossings as observed crossings divided by detection probability. We observed 126 crossings by >10 species of mammals. Detection probability was 42%; therefore, an estimated 299 wildlife crossings occurred. We observed 75 deer: 17 deer approached the underpass and retreated. We estimated sighting 40% of deer crossings and 92% of deer approaches. Thus, an estimated 185 deer crossings and 18 approaches occurred. As an index of road mortality, we conducted weekly surveys of vehicle-killed animals on a 1.8-km section containing the underpass. We discovered only 5 incidences of animals killed by vehicles. The size and design of the bridge promoted wildlife use of the underpass, providing landscape connectivity between habitats on opposite sides of the highway and likely increasing motorist safety. Thus, bridges in the appropriate landscape context and with a design conducive to wildlife use, can function as a corridor to reduce the effects of fragmentation. (JOURNAL OF WILDLIFE MANAGEMENT 71(8):2792–2800; 2007)

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Roads pose numerous threats to humans and wildlife throughout the world. Roads act as barriers to wildlife movements, thereby fragmenting populations, increasing mortality of individuals from vehicle collisions, and increasing human access and, therefore, disturbance, into previously remote areas (Forman 2000). In the United States alone, roads and vehicular traffic directly affect approximately 20% of the land (Forman 2000). Conover et al. (1995) estimated that >1 million deer–vehicle collisions (DVCs) occur annually in the United States. Human injuries often result from animal–vehicle collisions (AVCs), but fatalities are rare (Allen and McCullough 1976). In 2001–2002, 26,647 injuries resulted in the United States from accidents involving animals, 85% of which involved large mammals (Centers for Disease Control and Prevention 2004). In addition, approximately 200 human deaths are reported annually in the United States as resulting from collisions involving animals (Centers for Disease Control and Prevention 2004).

Underpasses that allow passage of animals under roads might be the most effective method of decreasing AVCs and reducing the barrier effects of roads (Forman 2000). Underpasses provide connectivity between habitats separated by roads, thereby permitting gene flow between populations and maintaining the integrity of wildlife travel routes.

The structural design of underpasses may influence

wildlife use. Reed (1981:542) suggested that structural dimensions of underpasses are important factors in underpass design, because the height, width, and length of underpasses determined the appearance of an underpass, "...which is the primary stimulus to approaching deer." Clevenger and Waltho (2000, 2005) found that structural variables most significantly influenced ungulate use of underpasses and were most closely correlated with crossing structure use by large mammals, including carnivores and ungulates. Although much research has been conducted on design of underpasses that incorporate wildlife concerns, few studies evaluate the efficacy of such structures in terms of intensity of wildlife use and reduction of AVCs (Spellerberg 1998).

Our objectives were to 1) document wildlife use and human activity near the New Hope Creek (NHC) underpass; 2) examine deer responses to the underpass for signs of reluctant or hesitant behaviors; and 3) estimate effectiveness of the current NHC underpass by estimating road mortality through roadkill surveys and records of deer-related vehicle collisions on the 1.8-km section of Highway 15/501 containing the NHC bridge.

STUDY AREA

We monitored white-tailed deer (*Odocoileus virginianus*) and other wildlife use of the NHC bridge on United States Highway 15/501, which ran northeast and southwest, between Durham and Chapel Hill, North Carolina, USA. The NHC underpass was important as a wildlife passage, especially for white-tailed deer, because forests associated with NHC created a corridor between 2 natural areas: Duke

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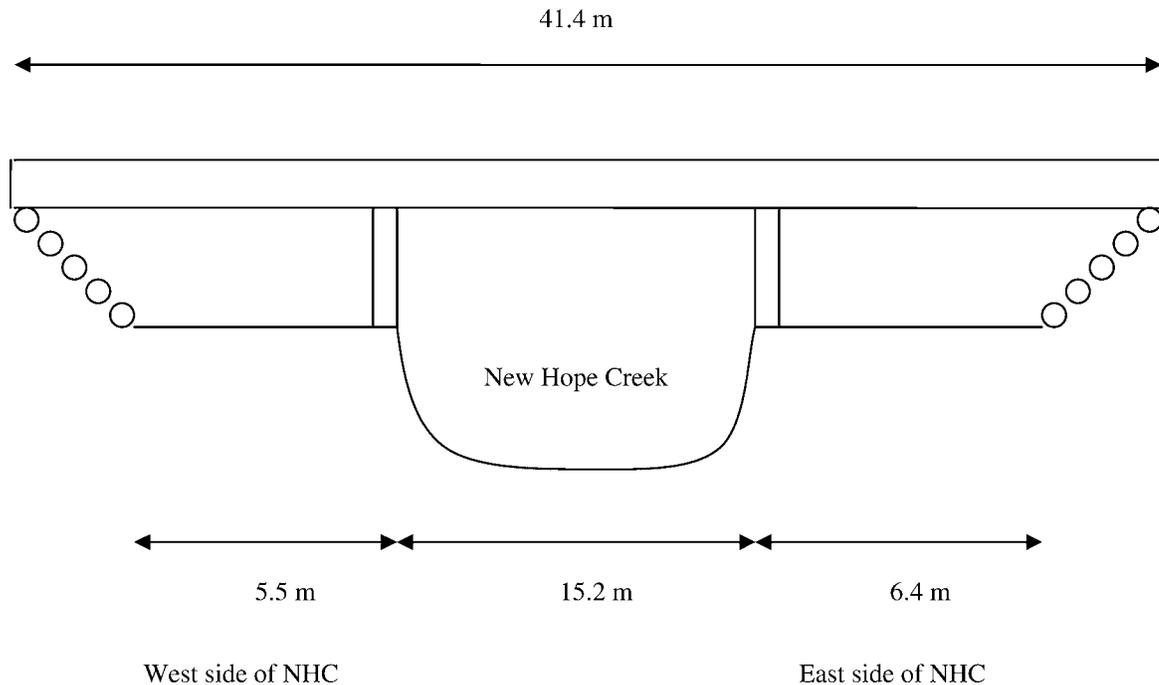


Figure 1. Diagram of the Highway 15/501 bridge over New Hope Creek (NHC), Durham County, North Carolina, USA (North Carolina Department of Transportation 2001); we filmed wildlife use of the underpass from December 2003 through May 2005.

Forest to the north and New Hope Game Lands located north of B. Everett Jordan Lake to the south (Hall and Sutter 1999). In addition, the NHC corridor provided wildlife habitat and recreational opportunities for humans in an area with increasing urbanization; shopping centers were located 0.48 km northeast and 1.29 km southwest of the NHC underpass along Highway 15/501, and a parcel of land adjacent to the NHC corridor was available for purchase for future development during the study period. Thus, the importance of the NHC corridor as wildlife habitat and landscape linkage will likely increase as development continues.

The NHC underpass, a dual bridge with 2 lanes of traffic on each bridge and an open median, was 41.1 m long and crossed over New Hope Creek, which is approximately 15.2 m wide (Fig. 1). The width of each dual bridge was 6.5 m, and the width of the open median was 6.1 m (North Carolina Department of Transportation [NCDOT] 2001). Horizontal clearance on the east and west sides of the creek was approximately 6.4 m and 5.5 m, respectively, through which wildlife could cross. Soil and sparse vegetation comprised the floor of the underpass, which could be underwater approximately 16 days per year after periods of heavy rainfall (Garrett 2001). The underpass had a vertical clearance of 2.4–3.0 m. The southbound bridge was built in 1951, and the northbound bridge was added in 1955. The section of Highway 15/501 that included the NHC bridge was built on extensive fill, which created a steep slope approximately 3–4.6 m high leading up to the road. The current bridge had an openness ratio of approximately 3.4 m ([2.4 m high \times 27.1 m wide between slope walls]/19.2 m long including the median).

Vegetation near and under the bridges reflected a disturbed early successional community (NCDOT Division of Highways 2002). Hall and Sutter (1999) classified the forest to the north of the NHC bridge, which flooded frequently, as Piedmont Alluvial Forest, based on categorizations of Schafale and Weakley (1990). Hall and Sutter (1999) classified forests south of the site as Dry-Mesic Oak-Hickory Forest, based on categorizations of Schafale and Weakley (1990). Regularly maintained power line and sewer corridors were located adjacent to Highway 15/501 (Fig. 2).

METHODS

Wildlife and Human Use

We installed 2 digital ultra low-light cameras (Sentinel 5 System; Sandpiper Technologies, Inc., Manteca, CA) and infrared light emitting diode spotlights for collection of night data that continuously recorded 2 underpass entrances and exits on the north side of the southbound bridge. We recorded video data from December 2003 through May 2005 onto a 40-gigabyte disk cartridge using a digital video recorder housed in a waterproof box located on top of a cement cap of a bridge support pillar. From December 2003 until February 2005, 2–3 12-V deep-cycle marine batteries powered the camera system, which allowed 4–7 days of continuous recording. From February 2005 through May 2005, 2 123-W solar panels powered the cameras, which permitted continuous recording with minimal interruptions.

We reviewed video recordings with iMovie software on a PowerMac G5 computer (Apple, Inc., Cupertino, CA). Because of the large amount of video data, we sampled the first second of each minute. We further reviewed inconsistencies from one minute to the next by examining the

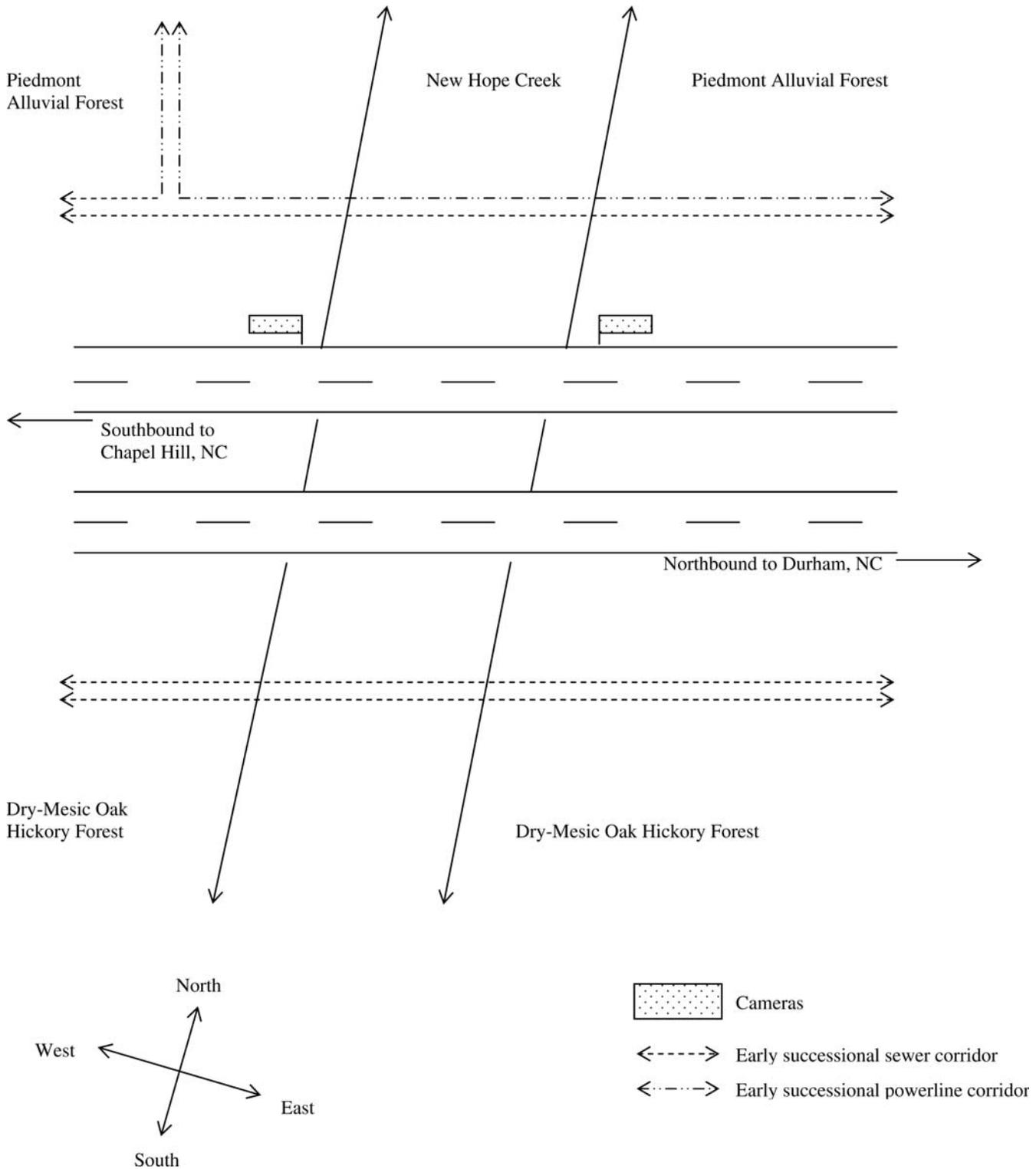


Figure 2. Locations of the video cameras filming wildlife crossings through the northeast and northwest corners of the New Hope Creek underpass from December 2003 through May 2005, Durham County, North Carolina, USA; Hall and Sutter (1999) classified habitats on the north and south sides of the underpass as Piedmont Alluvial Forest and Dry-Mesic Oak-Hickory Forest, respectively, based on categorizations by Schafale and Weakley (1990).

data in real- or double-time. We recorded animal activity on a standardized form documenting details of each animal crossing and a detailed account of each animal's behavior, including duration of each behavior.

We estimated the probability that events involving wildlife

use of the underpass would be detected by the minute-to-minute sampling technique. To determine the probability that an event (i.e., the instance in which we observed ≥ 1 animal in the video footage) would be detected with the sampling technique, we recorded the duration of each event (sec)

occurring for <1 minute divided by 59 seconds. We detected an event occurring for <1 minute only if an animal was within view of the cameras during the first second of each minute. Detection probability for events occurring for ≥ 1 minute was 1.0, because we observed the beginning of each minute in the sample. To estimate detection probabilities:

$$\begin{aligned} p_i &= d_i/59 && \text{if } d_i \text{ was } \leq 59 \text{ sec} \\ p_i &= 1 && \text{if } d_i \text{ was } > 59 \text{ sec,} \end{aligned}$$

where p_i = probability of detection for each event, and d_i = duration of event (sec).

The estimated number of animals was the sum of the number of animals per event divided by each event-specific detection probability, or

$$\hat{N} = \sum (\text{no. of animals per event} / p_i),$$

where \hat{N} = estimated number of animals. Overall detection probability for crossings was the actual number of observed animals divided by the estimated number of animals, or:

$$\hat{p}_{\text{detection}} = n / \hat{N},$$

where n = actual number of animals observed in the sample of video data.

We calculated overall detection probabilities separately for 1) wildlife crossings, including all entrances and exits; 2) deer crossings, including all entrances, exits, and approaches that occurred when deer moved toward and then retreated from the underpass; and 3) human activities occurring near the underpass. We calculated estimated numbers of wildlife crossings, deer crossings and approaches, and humans active near the underpass. We used Wilcoxon rank sum tests in SAS V.8 (SAS Institute, Cary, NC) to identify pairwise differences in detection probabilities between wildlife entrances and exits and deer entrances and exits.

Deer Behavior

We carefully reviewed video of deer as they approached, entered, or exited the underpass. We documented reluctant behaviors of deer approaching or entering the underpass, described by Reed et al. (1975) as evident in the look-up, muzzle-to-ground, and tail-up behaviors. Because the muzzle-to-ground behavior might have been confounded by deer feeding near the underpass during all seasons, we did not interpret this behavior as indicative of hesitation or reluctance. We also documented reluctant or hesitant behaviors as deer exited the underpass. As described by Reed (1981), these behaviors include trotting, bounding, and hesitating near the underpass exit. To indicate the willingness of deer to use the underpass, we compared the number of deer that approached but did not enter the underpass with the number of deer that entered and exited the underpass.

Road Mortality and Animal-Related Vehicle Collisions

As an index of road mortality, we conducted surveys of vehicle-killed animals at least once a week by driving north and south along the 1.8-km section of Highway 15/501

containing the underpass. We recorded species, date, and location of all vehicle-killed animals. Additionally, we obtained records of date, time, vehicle speed, total damages, and injuries of AVCs on that section of Highway 15/501 from NCDOT. This information, along with the information gathered by roadkill surveys, provided an index to the number of AVCs that occurred on the 1.8-km section of Highway 15/501 containing the underpass.

RESULTS

Wildlife and Human Use

From 11 December 2003 through 31 May 2005, we recorded 458 days (24 hr), which was 85% of total possible days. The proportion of days recorded (100%) was highest ($P < 0.05$) in spring 2005, after the installation of solar panels, and lowest (79%) during winter 2003–2004 and 2004–2005. Few animals were recorded at night because the spotlights did not illuminate the entire width of the underpass entrances. Because we sampled from all the recorded video data, observed animals and events represent a minimum of all activity at the NHC underpass; we estimated total activity from detection probabilities.

Wildlife crossings.—We observed 126 crossings in the sample of video data, including 81 entrances and 45 exits, by ≥ 10 species during 102 events (Table 1). Because we could not individually recognize animals, total crossings could have consisted of multiple crossings by the same individuals. Median duration of crossing events for all species observed was 1.31 minutes. Based on our sampling protocol, we detected 42% of all wildlife crossings, including 47% of entrances and 35% of exits. Detection probabilities for wildlife entrances and exits were not significantly different ($P > 0.05$). Thus, an estimated 299 wildlife crossings occurred (172 entrances and 127 exits). The highest and lowest rates of wildlife use of the underpass ($P < 0.05$) occurred during the summer of 2004 and autumn of 2004, respectively (Fig. 3). A primary peak in wildlife crossings occurred about sunrise, whereas a secondary peak occurred about sunset (Fig. 4).

Human activity near the underpass.—We observed 146 human activities, of which 77 were work-related and 69 were recreational. Work-related activities included work by NCDOT personnel or contractors. Recreational activities included walking or hiking, fishing, and off-road vehicle (ORV) use. We observed 60 people walking or hiking near the underpass, 7 people fishing, and 2 people riding ORVs. We estimated 81% of all human activity was detected, including 92% of work-related and 71% of recreational activities. Detection probabilities were significantly different for work-related and recreational activities ($P < 0.05$). Thus, an estimated 181 human activities occurred, including 84 work-related and 97 recreational activities. All human activity observed in the sample occurred between 0600 hours and 1800 hours (Fig. 4). Estimated recreational activities were highest ($P < 0.05$) during winter of 2003–2004 and lowest during the winter of 2004–2005, whereas estimated

Table 1. Species observed crossing through the New Hope Creek underpass, Durham County, North Carolina, USA, 2003–2005.

Species ^a	Entrances	Exits	Total	Proportion of total
Domestic dog or coyote	1	0	1	0.008
Domestic cat	0	1	1	0.008
Red or gray fox	0	2	2	0.016
Woodchuck	9	5	14	0.111
White-tailed deer	54	21	75	0.595
Muskrat	0	1	1	0.008
Raccoon	2	3	5	0.040
Gray squirrel	2	0	2	0.016
Hispid cotton rat	0	1	1	0.008
Chipmunk	2	4	6	0.048
Unidentifiable medium mammal	8	5	13	0.103
Unidentifiable small mammal	3	2	5	0.040
Total	81	45	126	1.000

^a Red fox, *Vulpes vulpes*; gray fox, *Urocyon cinereoargenteus*; muskrat, *Ondatra zibethicus*; hispid cotton rat, *Sigmodon hispidus*; eastern chipmunk, *Tamias striatus*.

work-related activities were highest ($P < 0.05$) during the spring of 2004 and lowest during the winter of 2003–2004.

Deer Use and Behavior

Deer crossings.—From 11 December 2003 through 31 May 2005, we recorded 75 deer crossing through the underpass during 53 events. Fifty-four deer entered and 21 deer exited the underpass. We estimated that we detected 40% of all deer crossing events, including 42% involving entrances and 36% involving exits. We detected no significant difference ($P > 0.05$) between detection

probabilities for deer entrances and exits. An estimated 185 deer crossings occurred (127 entrances and 58 exits).

We recorded 17 deer approaching and retreating from the underpass during 15 events. We estimated 92% of approaches were detected. Thus, an estimated 18 deer approaches occurred.

The lowest and highest ($P < 0.05$) crossing rates by deer occurred during the autumn of 2004 and spring 2005, respectively (Fig. 5). Two hourly peaks in deer crossings occurred, the primary peak near dawn and a secondary peak near sunset. Of deer crossings and approaches, 86% occurred within 2 hours of sunrise and sunset. Solitary individuals accounted for 72% of crossings; whereas, 19% of crossings involved 2 deer, 5% involved 3 deer, and 4% involved 4 deer.

Deer behavior.—We recorded 25 hesitation behaviors by deer, 9 of which were associated with exits and 16 with entrances and approaches. On 2 occasions heads of deer were not visible to observe the look-up behavior, and on 13 occasions tails were not visible to observe the tail-up behavior. We observed hesitation behaviors during 27% of crossings and approaches. Look-up behavior occurred during 14% of all crossings and approaches, and hesitation while exiting occurred during 4%, bounding while exiting and tail-up each occurred during 3%, and trotting while exiting occurred during 2% of all crossings and approaches.

Road Mortality, Road Approaches, and Animal-Related Vehicle Collisions

From December 2003 through June 2005, we found 5 road-killed animals (raccoon [*Procyon lotor*], Virginia opossum

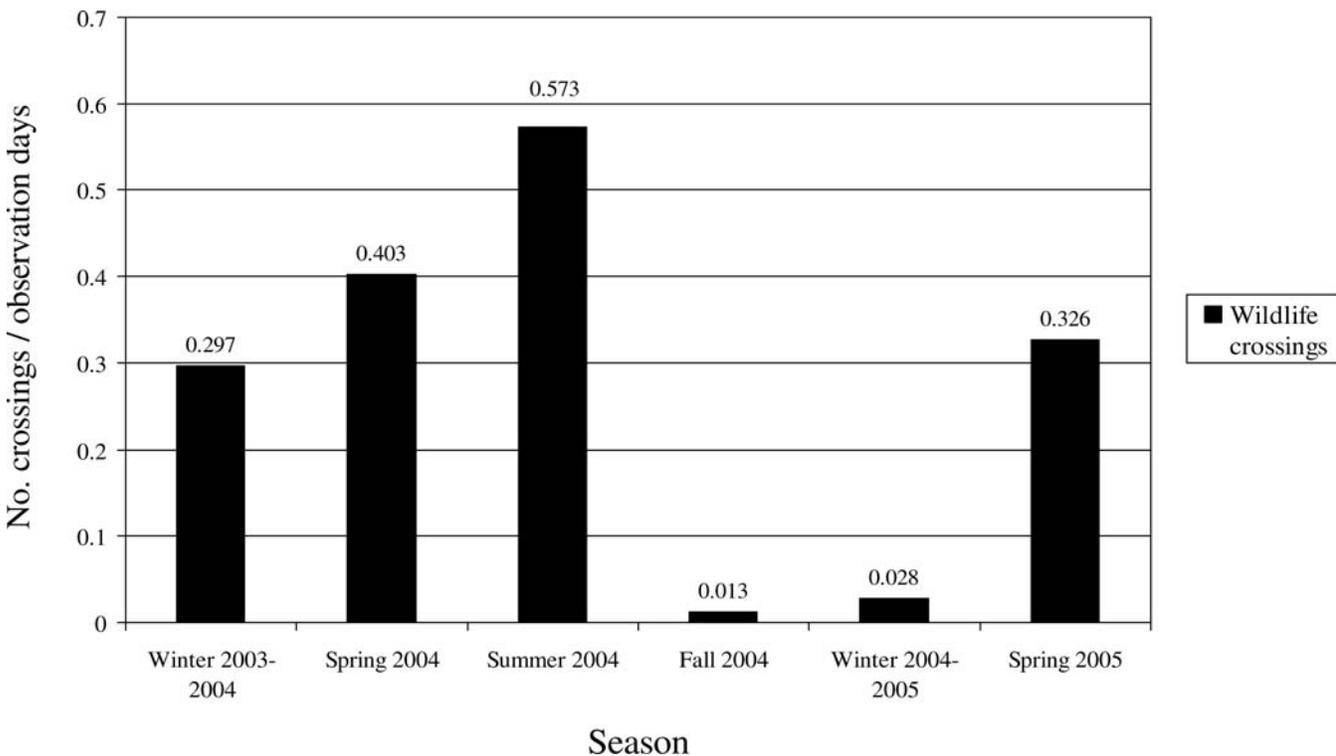


Figure 3. Number of wildlife crossings observed in the sample of video data per days recorded by season at the New Hope Creek underpass from December 2003 through May 2005, Durham County, North Carolina, USA.

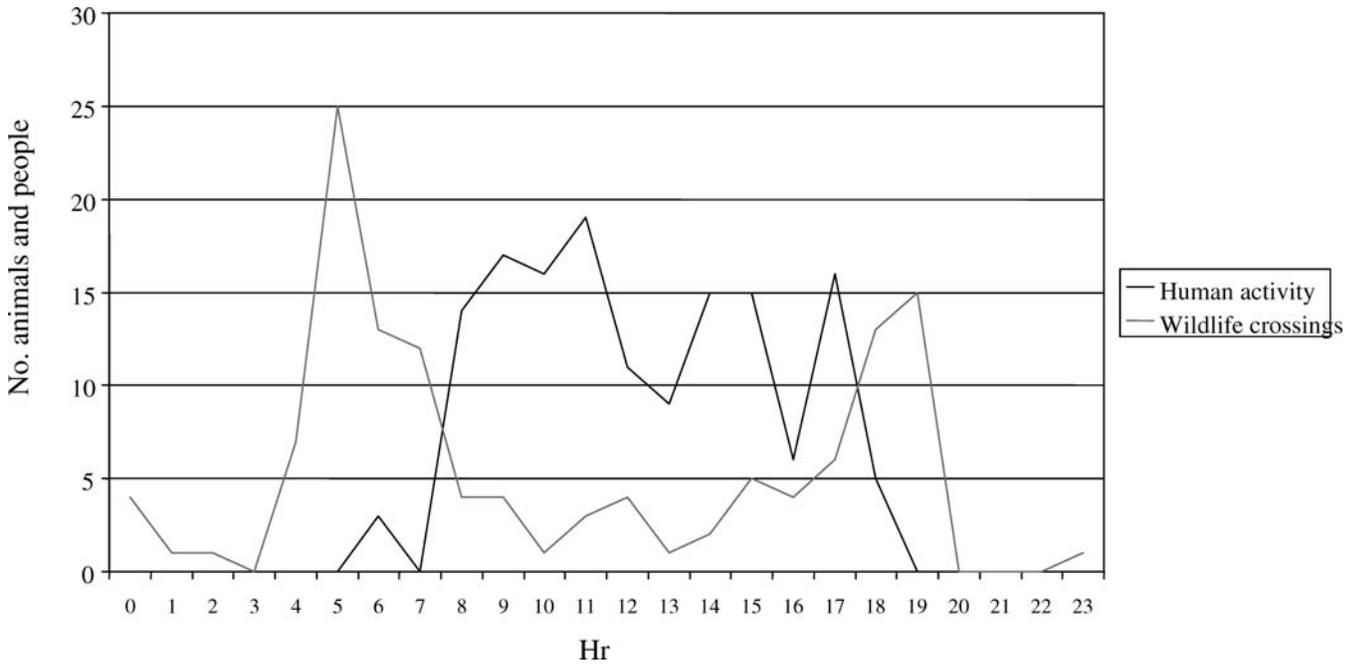


Figure 4. Hourly wildlife crossings and human activity at the New Hope Creek underpass observed in the sample of video data from December 2003 through May 2005, Durham County, North Carolina, USA.

[*Didelphis virginiana*], woodchuck [*Marmota monax*], wild turkey [*Meleagris gallopavo*], and an unidentifiable medium-sized mammal) on the 1.8-km section of Highway 15/501 containing the underpass.

From December 2003 through May 2005, we recorded 8 road approaches, including 5 by deer and 3 by small mammals. Of the deer, we observed 3 of 5 individuals

approaching and later retreating from the road. All 3 road approaches by small mammals could potentially have been road crossings, as we observed the animals approaching the road but did not later observe them in the video footage.

We found no evidence of DVCs during the driving survey for vehicle-killed animals on the 1.8-km section of Highway 15/501 containing the underpass. The NCDOT recorded

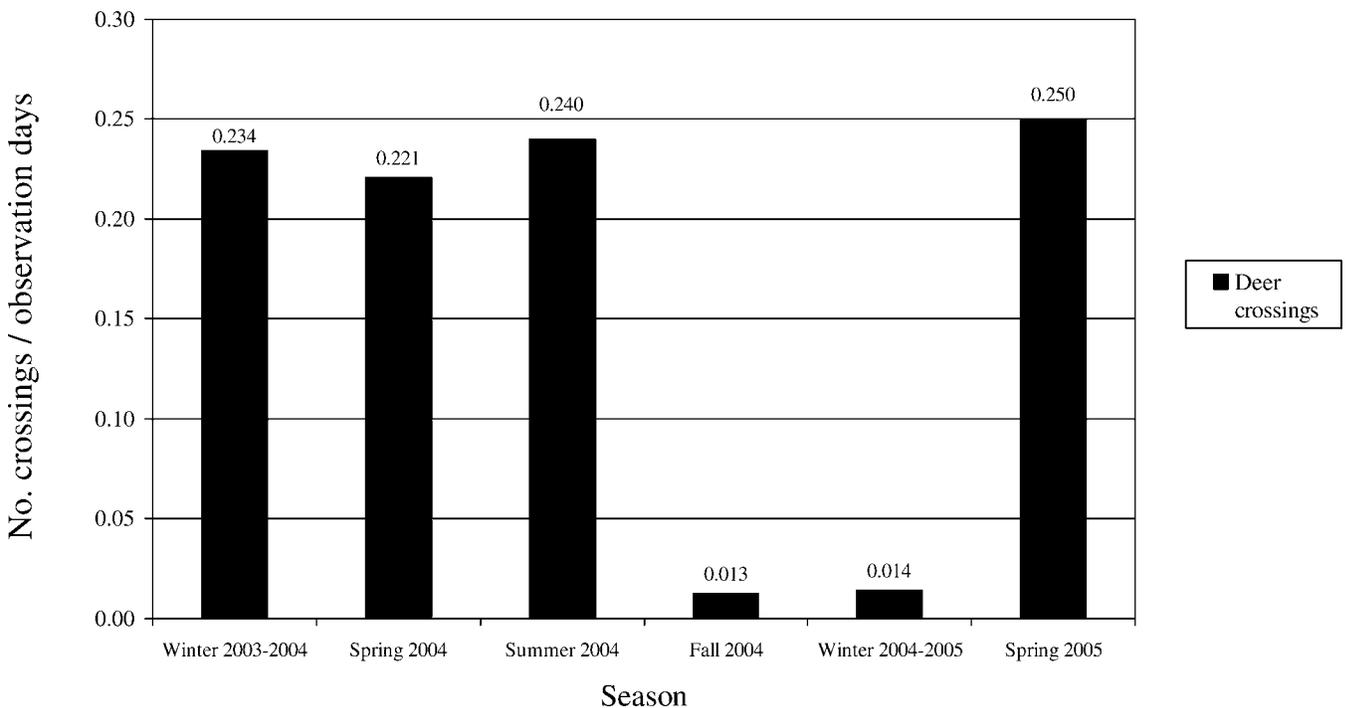


Figure 5. Number of white-tailed deer crossings observed in sample of video data per days recorded by season at the New Hope Creek underpass from December 2003 through May 2005, Durham County, North Carolina, USA.

16 deer-related vehicle collisions between 1 January 1990 and 30 October 2004. No injuries were reported. Average vehicular speed was 74.4 km/hour (46.25 miles/hr), ranging from 48 km/hour to 88 km/hour (30–55 miles/hr). Average damage estimate was \$2,184, ranging from \$650 to \$4,000. There was no significant correlation between vehicle speed and damages ($r = 0.02$, $P > 0.05$).

DISCUSSION

Deer Use and Behavior at the NHC Underpass

Based on the estimated detection probability, of 185 deer crossing through the underpass, 18 approached then retreated without crossing. Thus, for every deer estimated to have approached and retreated from the underpass, about 10 deer crossed through. Reed et al. (1975) studied mule deer use of a 3.05-m-tall \times 3.05-m-wide \times 30.48-m-long concrete box culvert and observed an approach-per-crossing ratio of 2.56, indicating that fewer deer entered the underpass than approached and retreated. In our study deer apparently had adapted to using the underpass to avoid crossing Highway 15/501 and were willing to use an underpass of such size and design. However, although the proportion crossing in our study was higher than in Reed et al. (1975), the estimated number of deer using the underpass in Reed et al. (1975) was much higher than in our study.

We expected deer use of the underpass to increase during the autumn and early winter as a result of increased movement during the rut—a period of high activity and movements (Puglisi et al. 1974, Allen and McCullough 1976). However, the lowest number of deer crossings through the NHC underpass occurred during this time. Decreased use during the autumn of 2004 and winter of 2004–2005 might have been influenced by the coincidence of deer hunting season, which is permitted in the southern portions of the corridor. Sage et al. (1983) reported decreased deer observability during and following deer hunting season.

We expected deer moving north and south along the NHC corridor, as reflected by the number of underpass exits and entrances, respectively, to be similar; however, about twice as many deer entered the underpass as exited. One explanation is that more deer moved south along the NHC corridor toward Jordan Lake than moved north along the corridor toward Duke Forest. Under this scenario, Duke Forest, where hunting is prohibited, was a source of deer, whereas the New Hope Game Lands, where hunting is permitted, was a sink.

The small overall proportion of deer exhibiting hesitation behaviors at the NHC underpass suggested that deer were readily willing to use the underpass to cross under Highway 15/501. Of all deer observed crossing through or approaching the NHC underpass in the sample, 27% exhibited hesitation behaviors; 22% of deer entering or approaching the underpass and 43% of deer exiting the underpass exhibited reluctant behaviors. Reed et al. (1975) observed that 24% of mule deer approaching or entering a 3.05-m-tall \times 3.05-m-wide \times 30.48-m-long, concrete-box culvert

exhibited the look-up behavior and few exhibited the tail-up behavior. Reed (1981) found that trotting, bounding, or hesitating near the underpass exit was observed in 75% of exiting mule deer, suggesting that most observed deer were cautious or hesitant. We observed a smaller proportion of deer exhibiting hesitation behaviors at the NHC underpass than that observed by Reed et al. (1975) and Reed (1981), suggesting that deer would likely show less hesitation and, thus, be more willing to use a structure of similar size and design as the NHC underpass, than an underpass similar to the one studied by Reed et al. (1975) and Reed (1981). Estimated numbers of deer in Reed et al. (1975) and Reed (1981) were much higher than in our study, however. The willingness of deer to use the underpass and small proportion of hesitation behaviors we observed could be associated with the age of the bridge. Built in the 1950s, the bridge structure has offered ≥ 5 –10 generations of deer an alternate route for reaching the opposite side of the highway.

Road Mortality and Animal-Related Vehicle Collisions

Road mortality.—All potential road crossings observed in the video footage represented animals approaching or attempting to cross Highway 15/501 at the bridge site. Although more road approaches likely occurred outside of the view of the cameras, the number of road approaches and potential road crossings was low, considering the level of wildlife activity at the bridge site. Only 3% of the animals observed crossing through or approaching the NHC underpass in the sample potentially crossed Highway 15/501, indicating that the underpass likely played a role in diverting animals from the road.

Deer-related vehicle collisions.—In a 15-year period NCDOT recorded 16 deer-related vehicle collisions in the 1.8-km section of Highway 15/501 containing the underpass; 81% occurred between 1800 hours and 0600 hours. Of DVCs near the NHC underpass, 81% occurred during autumn and winter. Allen and McCullough (1976) and Puglisi et al. (1974) observed a high occurrence of DVCs during autumn and winter, which they attributed to increases in activity during the rut. Fritzen et al. (1995) found that road crossings by deer in Florida occurred most frequently between 2 hours after sunset to 2 hours before sunrise.

In an area with a large population of deer, as occurs in the broader areas surrounding the NHC bridge, 16 deer-related accidents over 15 years is a low collision rate. In a study of cost-effectiveness of fencing in reducing DVCs, fencing was installed along study areas with an average prefencing mortality rate of 8.9–34.8 deer mortalities per 1.6 km per year (Reed et al. 1982), which is substantially higher than the average 1.1 DVCs per 1.8-km section of Highway 15/501 containing the underpass per year. However, Romin (1994) estimated that only about 50% of DVCs are reported or documented, so the number of actual DVCs might be higher than the number reported. Although many factors might account for the low rate of DVCs along the section of Highway 15/501 containing the NHC bridge, the

presence of the underpass coupled with early successional power line and sewer corridors might reduce the need of deer to approach and cross the highway. The underpass provides deer with an alternate route for accessing habitat on the opposite side of the highway, and the early successional habitat in utility corridors provides deer with foraging opportunities away from the road. Thus, there might be little incentive for deer to approach the roadway on this section of Highway 15/501. In addition, the steep grade leading up to the highway created by fill might help to funnel deer toward the underpass. Although the steep slopes are in no way barriers to deer movement, decreased visibility past the top of the slopes, which may be intensified by the presence of guardrails at the top of the slopes, might deter deer from crossing the road. Carbaugh et al. (1975) suggested that guardrails could act as visual barriers to deer when located on top of inclines.

The importance of the NHC underpass lies in its location along a wildlife travel route between 2 natural areas in a region of increasing urbanization, where formerly wooded areas and fields adjacent to the NHC corridor are being converted to commercial and residential developments. The high level of wildlife use of the NHC underpass emphasizes the role of underpasses in maintaining habitat connectivity in the greater context of large-scale habitat fragmentation (i.e., habitat loss resulting from development) apart from the fragmentation created by the road itself. Development of former natural areas is a common occurrence throughout the United States, and wildlife is often pushed into smaller habitats, such as the forests surrounding New Hope Creek. Underpasses can be integrated into road design near remaining habitat patches in areas where such development and consequent habitat loss is occurring to maintain habitat connectivity and reduce animal-vehicle collisions.

MANAGEMENT IMPLICATIONS

Hubbard et al. (2000) suggested that creating bridges that function as wildlife underpasses could mitigate DVCs. The 15/501 bridge over New Hope Creek, although not designed to facilitate wildlife movement under the highway, does function as a wildlife underpass.

The detection probabilities we used to estimate total wildlife use of the underpass could be more widely applied to wildlife research using video surveillance. This technique allows large volumes of data to be sampled while having the benefit of calculating how well a sample represents a population by estimating the probability of an event being detected; thus, this technique allows researchers to estimate the total population of interest, rather than rely solely on the results of the sample.

According to Forman and Deblinger (2000:45), "Road ecology is one of the great frontiers awaiting science and technology." As with the Highway 15/501 bridge over New Hope Creek, much of this country's road system was constructed before consideration was given to the ecological effects that roads have on natural resources. As knowledge of the ecological effects of roads continues to increase and

many older roads require renovations, ecological and transportation research communities and transportation engineers will be given opportunities to work together to create roads that lessen the negative impacts roads have on natural resources while likely increasing motorist safety. Furthermore, wildlife underpasses help maintain landscape connectivity and reduce the number of animals killed by vehicles. Future research is required to evaluate proper design of underpasses to ensure that resources are not wasted constructing improperly designed underpasses that will not be used by wildlife.

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