ABSTRACT

KLEIST, ANDREA MARGARET. New Hope Creek Bridge as a Wildlife Underpass. (Under the direction of Richard A. Lancia and Phil Doerr)

Roads pose many threats to wildlife. One such threat, wildlife-vehicle collisions, is a danger to humans as well as wildlife. Bridges built to facilitate movement of wildlife under roads may reduce threats that exist when large mammals attempt to cross roadways. My study is the first phase of a two-stage investigation of whether a bridge designed to function as a wildlife underpass influences wildlife use of the U.S. Highway 15/501 bridge over New Hope Creek (NHC) near Durham, North Carolina. This underpass is important as a wildlife passage, particularly for white-tailed deer (*Odocoileus virginianus*), because the forests associated with NHC create a corridor between two natural areas: Duke Forest to the north and B. Everett Jordan Lake to the south. Phase One involves monitoring wildlife use of the current bridge structure using video cameras. In 2007, a longer bridge will be constructed. Phase Two will be the replication of my study upon completion of the new bridge. Wildlife use of the current and future underpass will be compared to determine whether underpass dimensions influence wildlife use of the underpass. Wildlife use of the NHC underpass was recorded continuously from December 2003 through May 2005. During the study period, 126 crossings were observed in the sample of video data by the following species: white-tailed deer, woodchuck (*Marmota monax)*, chipmunk (*Tamias striatus*), raccoon (*Procyon lotor)*, red or gray fox (*Vulpes vulpes* or *Urocyon cinereoargenteus*), gray squirrel (*Sciurus carolinensis*), domestic dog or coyote (*Canis* spp.), domestic cat (*Felis catus*), muskrat (*Ondatra zibethicus*), hispid cotton rat (*Sigmodon hispidis*), and unidentifiable small and medium-sized mammals. Based on the sampling technique, 42.2% of wildlife crossings were observed. Thus, an estimated 299 wildlife crossings occurred throughout the study period. Seventy-five deer were observed in the sample of video data using the underpass, while 17 deer approached and retreated. Using the sampling technique, 40.5% of deer crossings and 92.1% of deer approaches were observed. Thus, an estimated 185 deer crossings and 18 approaches occurred during the study period. One-hundred forty-six people were observed

near the underpass in the sample of video data. Based on the sample, 80.8% of human activity near the underpass was detected. Thus, an estimated 181 people were observed near the underpass during the study period. Five potential road crossings, including three by small mammals and two by deer, were observed in the sample of video footage. As an index of road mortality near the NHC underpass, weekly surveys of vehicle-killed animals were conducted while driving north and south on the 1.8 km section of Highway 15/501 containing the underpass from December 2003 through June 2005. The surveys revealed that five individuals were killed by vehicle collisions, including raccoon, opossum (*Didelphus virginiana*), woodchuck, wild turkey (*Meleagris gallapavo*), and one unidentifiable mammal. North Carolina Department of Transportation records of wildlife collisions occurring from January 1, 1990 through October 30, 2004 revealed that deer-vehicle collisions on the section of Highway 15/501 containing the NHC underpass were infrequent, with 16 deer-related vehicle collisions occurring. Because several years will separate the current study from the future study of the expanded NHC underpass, a deer abundance index was developed using counts of deer observed during a driving route along roads west and north of the NHC underpass. From March 23, 2004 through May 31, 2005, 205 deer were observed during 53 driving counts. These data suggest that the Highway 15/501 underpass provides landscape connectivity between habitats on opposite sides of the highway and likely increases motorist safety by providing deer and other wildlife with an alternate route for reaching habitat on the far side of the highway without crossing onto the road.

New Hope Creek Bridge as a Wildlife Underpass

by

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Approved by:

Chair of Advisory Committee

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DEDICATION

To all who helped me along the way…

BIOGRAPHY

Andrea Kleist was born in 1981 in LaPorte, Indiana to Norm and Karen Kleist and sister, Katherine. Andrea graduated as Valedictorian of LaPorte High School in 1999. She then continued on to college. Her undergraduate career began at Purdue University North Central after receiving a scholarship. Her educational endeavors then led her to Indiana University to study Animal Behavior, where she graduated in 2003 with highest distinction and a Bachelor of Science degree in Psychology, with minors in Biology and Animal Behavior. During the summers of 2002 and 2003, Andrea held two positions at Hoosier National Forest in southern Indiana. During the summer of 2003, she became crew leader of the first wilderness survey crew in the Hoosier, hiking cross-country through the Charles C. Deam Wilderness to collect data on the environmental conditions of campsites, locate archeological sites, and maintain trails within the wilderness area. In order to combine her passions for conservation of natural resources and animal behavior, she decided to pursue a career in wildlife. Andrea began graduate work in the Fisheries and Wildlife Sciences Program at North Carolina State University in August of 2003. She will be receiving a Master of Science degree in Fisheries and Wildlife Sciences in December of 2005.

Andrea's professional interests lie in incorporating the behavior of large mammals into management plans to increase the efficacy of management programs. In addition, she feels that public education is a vital step in the struggle for coexistence of wildlife and humans, since a person cannot treasure what he or she does not understand. Andrea's personal interests lie in music, primarily guitar, piano, and mandolin; outdoor activities, primarily backpacking and canoeing; spending time with her nephew, Kurt, and niece, Victoria; and spoiling her dog, Delilah, and cat, Ziggy.

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My parents have always shown unwavering faith in me and my dreams, and for that I thank them. I learned from them how to aim high in life. There are simply no words to explain the gratitude I have for all that they are and all that they have done for me.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Roads pose numerous threats to humans and wildlife throughout the World. Roads act as barriers to wildlife movements thereby fragmenting previously connected populations into smaller subpopulations, 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 one-fifth of the land (Forman 2000). Vehicle accidents caused by animals on roadways are costly not only because of the resultant property damages, but more importantly because of human injuries and lives lost. Thus, steps must be taken to mediate negative effects roads have on wildlife populations and dangers that arise when animals attempt to cross roadways.

Barrier Effects and Road Avoidance

Roads act as barriers and contribute to habitat, population, and genetic fragmentation by interrupting wildlife movements between areas of suitable habitat and reducing the size and quality of available habitats (Spellerburg 1998). Forman and Deblinger (2000) found that in addition to reducing the amount of suitable habitat, travel routes between quality habitats for white-tailed deer (*Odocoileus virginianus)*, fisher (*Martes pennanti*), and black bear (*Ursus americanus*) were interrupted by a highway in Massachusetts. Reed et al. (1996) found that roads fragmented forests in Wyoming, decreasing the amount of habitat available for forest specialists and increasing the number of forest patches, which resulted from roads bisecting previously larger patches of forest. Roads increased distances between forest patches, potentially reducing the ability of forest specialists to migrate between patches, which could result in isolation of subpopulations (Reed et al. 1996). Reed et al. (1996) also found the amount of edge created by roads to be 1.54 times higher than the edge created by clearcuts and concluded that roads have greater fragmentation effects than clearcuts. The edge created by roadside habitats can be beneficial to some rodents (Baker 1971), and the presence of prey near roads provides hunting opportunities for predators.

Roads interfered with movements of small forest-interior mammals in Canada (Oxley 1974). Oxley (1974) found road width to be the most significant factor hindering movement of small forest-interior mammals across roads. Roads introduced human disturbance through increased access to habitats, thus contributing to habitat fragmentation (Trombulak and Frissell 2000). Gerlach and Musolf (2000) found that a highway near Engen, Germany, created a barrier to movement between populations of bank voles (*Clethrionomys glareolus*) separated by the highway, resulting in reduced gene flow between the two populations which caused genetic subdivision in the population.

The extent to which roads act as barriers depends on species mobility, behavior, and habitat preferences (Goosem et al. 2001, Mech and Hallett 2001). The barrier effects of roads may be especially detrimental for habitat specialists and endangered species that have limited mobility or small populations (Gerlach and Musolf 2000). Mech and Hallett (2001) found greater genetic distances in isolated populations of red-backed voles (*Clethrionomys gapperi*), which prefer forests with closed canopies, than populations of voles connected by corridors, thus providing evidence for the importance of landscape connectivity. Therefore, wildlife corridors that are bisected by roads may provide little benefit for species unless mitigation techniques are implemented.

In addition to the physical barriers that roads and traffic create for wildlife, behavioral alterations such as road avoidance may exacerbate the barrier effects of roads (Forman and Deblinger 2000, Trombulak and Frissell 2000). Clevenger et al. (2001) reported that noise and other traffic-related disturbances may cause animals to decrease activity or altogether avoid areas near roads. Trombulak and Frissell (2000) reported that road avoidance, and the resulting changes in behaviors and movements of animals attempting to avoid roads, contributed to population fragmentation. Rost and Bailey (1979) suggested that mule deer (*Odocoileus hemionus)* and elk (*Cervus elaphus)* avoided roads, but the authors cautioned that the observed distribution of deer and elk in relation to roads may have been confounded by unmeasured variables.

Animal-vehicle Collisions

Animal-vehicle collisions (AVCs) are dangerous to humans as well as wildlife. Conover et al. (1995) estimated that over 1 million deer-vehicle collisions (DVCs) occur annually in the U.S. Human injuries often result from AVCs, and while fatalities do occur, they are rare (Allen and McCullough 1976). Approximately 200 deaths are reported annually in the U.S. as resulting from collisions involving animals (Centers for Disease Control and Prevention (CDCP) 2004). In 2001-2002, 26,647 injuries resulted in the U.S. from accidents involving animals, 85% of which involved large mammals (CDCP 2004). These estimates of injuries and fatalities are similar to those of Conover et al. (1995), who estimated that 29,000 injuries and 211 fatalities annually result from DVCs in the U.S. Groot Bruinderink and Hazebroek (1996) estimated that there are over 507,000 vehicle collisions annually involving ungulates in Europe (excluding Russia), resulting in 300 fatalities, 30,000 injuries, and $1 billion U.S. dollars in damages each year. Slightly more than half of AVCs in the U.S. involved a direct collision with an animal, while the remainder were secondary collisions that occurred when drivers attempted to avoid animals on roads (CDCP 2004). It is important to note that many injuries and fatalities resulting from AVCs are caused by secondary accidents that result from drivers attempting to avoid animals on roads or losing control of vehicles (Allen and McCullough 1976).

In addition to the dangers that exist for humans, AVCs can negatively affect not only individual animals, but also animal populations. Allen and McCullough (1976) found that over 91% of deer involved in DVCs in southern Michigan were killed in the accidents. Porter et al. (2004) found that of 25 deer deaths near an urban area in New York, 44% of deaths resulted from vehicle collisions. Road mortality is especially damaging to threatened or endangered species. Increased road mortality resulting from a road upgrade in a Tasmanian national park led to local extinction of eastern quolls (*Dasyurus viverrinus*) and a 50% reduction of a Tasmanian devil (*Sarcophilus laniarius*) population 22 months after the upgrade (Jones 2000). There appears to be a sharp increase in road mortality of deer for one to two years immediately following construction of new highways (Reilly and Green 1974). After this period, road mortality of deer apparently decreases for several years before either leveling off or varying between years due to factors such as population fluctuations or weather (Reilly and Green 1974). Because roadside habitats may be attractive to some rodents (Baker 1971), and therefore predators, animals that are active and hunt near roads are vulnerable to vehicle collisions (Bennett 1991). Carrion along roadsides also attracts animals to roadways, exposing carrion feeders to the threat of vehicle collisions (Bennet 1991).

In addition to the dangers associated with AVCs, these collisions result in significant economic and aesthetic losses. Conover et al. (1995) estimated the average cost of repairs per vehicle involved in DVCs to be approximately $1,500, resulting in $1 billion in reported vehicle damages each year. Because deer provide valuable hunting and recreational opportunities, deer losses resulting from DVCs result in monetary losses (Conover 1997). Conover (1997) estimated that deer have a net value of $12 billion annually, not taking into account human injuries and fatalities associated with DVCs. Updating estimates of the value of a deer from Romin (1994), Sullivan and Messmer (2003) estimated the value of a deer to be approximately $1,600.

Deer-vehicle collisions do not occur randomly with respect to time and space (Bashore et al. 1985) and appear to be influenced by a number of variables including deer density, temporal and seasonal distribution of deer in relation to roadways, traffic volume and speed, road characteristics, and characteristics of the surrounding landscape. Allen and McCullough (1976) found that for almost 87% of DVCs, only one deer was seen; two deer were seen in over half of the remaining 13% of DVCs. However, Waring et al. (1991) found that 72% of deer crossed an Illinois highway in groups, 55% of which were does with fawns.

Temporal and Seasonal Distribution of Animal-vehicle Collisions

Frequencies of animal-vehicle collisions show temporal and seasonal variations. Allen and McCullough (1976) found that DVCs were positively correlated with traffic volume between 1800 and 0700 hrs and tended to be higher on weekends due to increased traffic volumes during times of peak deer activity at dusk and throughout the nighttime hours. Fritzen et al. (1995) found that road crossings by deer in Florida occurred most frequently at night from two hours after sunset to two hours before sunrise. Allen and McCullough (1976) found that DVCs occurred most frequently between 1600 and 0200 hrs, with peaks occurring at sunrise and one to two hours after sunset.

Seasonal variations in AVCs have been recorded. Oxley et al. (1974) found that road mortality of small mammals in Canada was highest in July due to summer traffic volume increases and increased activity of young mammals. Seasonally, two peaks in DVCs occur. The highest peak, occurring in autumn and early winter, is influenced by deer behavior and increased activity during the rut (Puglisi et al. 1974, Allen and McCullough 1976) as well as increased human disturbance with the onset of deer hunting season (Puglisi et al. 1974, Carbaugh et al. 1975). A secondary peak occurred in the spring (Rongstad and Tester 1969, Puglisi et al. 1974, Allen and McCullough 1976), and may be influenced by greater foraging movements associated with the appearance of green vegetation or dispersal of deer from wintering grounds (Rongstad and Tester 1969, Puglisi et al. 1974, Reilly and Green 1974). Fall and spring peaks in road mortality of deer and other animals have been documented in other studies (Jahn 1959, Bellis and Graves 1971, Reilly and Green 1974, Case 1978, Hubbard et al. 2000). Groot Bruinderink and Hazebroek (1996) found that road mortality was highest for male ungulates during the rut, while female mortality was highest during the period after young were born. Feldhamer et al. (1986) reported that more groups of deer were seen on an interstate right-of-way (ROW) during fall than any other season. Human injuries resulting from DVCs were most frequent during fall (CDCP 2004). In addition, seasonal migratory routes may intersect roads, as occurs with mule deer in the western U.S. (Goosem et al. 2001, Gordon et al. 2004).

Traffic Volume and Speed

Traffic volume and speed appear to influence AVCs. Hubbard et al. (2000) found number of traffic lanes to be positively associated with high DVC sites, but the relationship between traffic volume and DVCs was not significant. Bashore et al. (1985) found that vehicle speed was negatively correlated with DVCs, indicating that either deer were less likely to cross roads where vehicles travel quickly or that posted speed limits did not accurately reflect actual vehicle speeds. However, Reed and Woodard (1981) found that 70% of successful crossings of a four-lane highway by deer in Colorado occurred when traffic was within 100 m of the crossing location. Jones (2000) reported that increased traffic speed following road upgrade may be the most important factor influencing increased road mortality of eastern quolls and Tasmanian devils. Vehicle speed at time of impact seemed to have little effect on whether deer survived vehicle collisions, suggesting that the nature of the impact was a bigger factor (Allen and McCullough 1976). Vehicle speed, however, did influence the amount of damage that was inflicted upon the vehicle involved (Allen and McCullough 1976).

Road Characteristics

Jones (2000) suggested that changes in road surface, and consequently road surface color, may have contributed to increased mortality of eastern quolls and Tasmanian devils following road upgrade by decreasing the contrast of animals on the road, thus making animals less apparent to drivers.

The presence of guardrails along roadways may affect the manner in which deer approach roads. When guardrails were present along roads, deer moving from the highway toward the ROW were observed jumping over the guardrail, while deer moving in the opposite direction were more likely to move around the edge of the guardrail than to jump over it (Carbaugh et al. 1975). Carbaugh et al. (1975) suggested that the differences in behavior when circumventing guardrails may be due to guardrails functioning as visual barriers when located at the top of an incline.

Characteristics of Landscapes Surrounding Roadways

Deer-vehicle collisions tend to be influenced by characteristics of the surrounding landscape. Hubbard et al. (2000) found that over 25% of 32,296 DVCs in Iowa occurred near 3.4% of 1,284 sample sites, suggesting that DVCs tended to be clustered. Deer-vehicle collisions tend to be aggregated near protected or public areas, where concentrations of deer are likely to be high (Allen and McCullough 1976, Forman and Deblinger 2000, Nielsen et al. 2003). Density of buildings appears to be negatively associated with DVCs (Bashore et al. 1985, Nielsen et al. 2003). Hubbard et al. (2000) found number of bridges, which may be related to wildlife movement corridors, to be positively correlated with areas characterized by high numbers of DVCs. Stocker and Gilbert (1977) found edges between forest and open habitats to be the most beneficial non-wintering habitat for white-tailed deer in southern Ontario. Thus, edges between wooded and open habitats tend to be areas prone to DVCs because deer often venture from wooded to open areas to feed (Bashore et al. 1985).

Food availability also appears to influence prevalence of DVCs. Vegetation along ROWs that is attractive deer forage increased the likelihood of DVCs by providing incentives for deer to approach and cross roadways, especially in forested areas (Bellis and Graves 1971). In heavily wooded areas where forest openings providing quality forage were not available, planted ROWs provided prime feeding opportunities for deer (Bellis and Graves 1971). This idea was supported by Montgomery (1963) who concluded that deer ventured out of wooded areas and into open areas to feed due to lack of forage in the wooded areas. Feldhamer et al. (1986) observed deer using an interstate ROW as feeding grounds where the adjacent habitat was over 93% wooded. In areas where food was abundant for deer, such as agricultural areas, deer were able to find quality foraging opportunities away from roads (Bellis and Graves 1971, Carbaugh et al. 1975). Carbaugh et al. (1975) recorded fewer deer feeding along roadsides and fewer vehicle-killed deer in agricultural areas than forested areas. Waring et al. (1991) observed more deer crossing a highway with agricultural fields on one side of the highway, but observed fewer deer feeding on the ROW than sections of the same highway with forests on both sides of the road. Carbaugh et al. (1975) found that the highest percentage of deer in winter was observed along sections of roads containing vetch. Roadway sections containing grass had the highest percentage of deer in spring, and sections containing clover had highest percentage of deer in summer and fall (Carbaugh et al. 1975).

Highway Mitigation Techniques

The objectives of mitigation techniques are to decrease the negative effects that roads have on deer and reduce dangers that exist for humans when animals attempt to cross roads. Efforts to mitigate AVCs should target humans as well as animals (CDCP 2004). Mitigation efforts have focused on: preventing deer from entering roadways; alerting drivers about potential wildlife crossing areas or the presence of animals on roads; providing drivers with more time to react to animals on roads; managing habitats to reduce incentives for deer to approach roadways; reducing deer density; and educating the public about factors that influence AVCs and how to react properly when encountering animals on roads (Jones 2000). Techniques that incorporate all of these factors may prove to be most effective (CDCP 2004).

Mitigation techniques should be cost effective in the sense that the costs of mitigation should be equal to or less than the average cost of AVCs prevented annually for as long as the technique is used (Hansen 1983). Costs associated with loss of wildlife should be taken into consideration as well. Hubbard et al. (2000) suggested that efforts to mitigate DVCs were likely to be cost-effective since DVC sites tended to be clustered. Reed et al. (1982) suggested that fencing was most effective at sites characterized by high DVCs, and the higher the rate of DVCs at a site before fencing is installed, the more cost-effective fencing would be. Reed et al. (1982) recommended a cost-benefit ratio of 1.36 for mitigation strategies. This ratio corresponded to the following number of pre-fencing deer deaths resulting from DVCs per 1.6 km (1 mi) per year: eight for fencing on one side of a road, 16 for fencing on both sides of a road, and 24 for fencing on both sides of a road with an underpass.

Forman and Deblinger (2000) suggested that a “landscape ecology approach” for mitigation strategies be applied to minimize large-scale effects of roads on animal populations and habitats. In addition, mitigation projects should be collaborative efforts between ecological and transportation research communities and transportation engineers (Goosem et al. 2001). Involving more parties in planning mitigation projects increases the number of stakeholders, allowing the exchange of ideas and information and providing impetus to maximize effectiveness of mitigation techniques. Once implemented, the effectiveness of mitigation techniques should be evaluated. Through surveys of state natural resource agency personnel, Romin and Bissonette (1996) found that over 95% of states had not conducted studies evaluating the efficacy of implemented mitigation techniques; for many respondents, effectiveness of mitigation techniques was based on opinion rather than science. Through surveys of state wildlife agencies (SWAs) and state Departments of Transportation (DOTs), Sullivan and Messmer (2003) found that DVC mitigation costs ranged from $0 to $1 million, with most agencies spending $10,000 or less. In the same survey, most respondents indicated that the Federal Highway Administration should be responsible for evaluating the effectiveness of mitigation strategies (Sullivan and Messmer 2003). State wildlife personnel indicated that DOTs, developers, and insurance agencies should be more financially responsible for research evaluating effectiveness of mitigation techniques, while DOT personnel reported that state wildlife agencies need to take more financial responsibility for such research (Sullivan and Messmer 2003). State wildlife agency and DOT personnel reported that the Federal Highway Administration and state DOTs should fund mitigation techniques (Sullivan and Messmer 2003). However, DOT personnel indicated that SWAs should help fund mitigation costs, while SWAs indicated that funding for mitigation projects should be shared with developers and motorists (Sullivan and Messmer 2003). Only 10% of respondents indicated that their agency had personnel whose responsibilities included DVC prevention (Sullivan and Messmer 2003). Deer-vehicle collisions affect DOTs, motorists, developers, and wildlife resource agencies alike. Thus, mitigation efforts should be collaborations between these groups. Sullivan and Messmer (2003) recommended standardizing the collection of DVC data and creating a database of research evaluating the efficacy of mitigation techniques.

Fencing

Much research has been conducted investigating the effectiveness of fencing in preventing DVCs. Fencing is one of the most common mitigation techniques used to prevent AVCs (Falk et al.

1978). In a survey by Sullivan and Messmer (2003) of SWAs and DOTs, 42% of respondents used fencing to reduce DVCs, and 43% of respondents believed highway fencing had the greatest long-term potential to reduce deer vehicle collisions. Bashore et al. (1985) found that properly maintained highway fencing was negatively correlated with DVCs. Thus, they suggested that fencing may be the most successful and efficient method of preventing DVCs along short sections of highways (Bashore et al. 1985). Bellis and Graves (1971) and Feldhamer et al. (1986) also recommended that fencing may be the most successful method of preventing DVCs. Fencing may be most appropriate in areas where other mitigation techniques such as underpasses or overpasses would not be cost-effective (Nielsen et al. 2003).

As previously mentioned, Reed et al. (1982) recommended a cost-benefit ratio of 1.36 for mitigation strategies. Feldhamer et al. (1986) observed fewer deer on an interstate ROW in areas where 2.7-m high fencing was installed than on sections of road with 2.2-m high fencing. Reed et al. (1982) studied the effectiveness of 2.4-m high fencing at six sites characterized by frequent DVCs along Interstate 70 in Colorado. At five of the six sites, fencing was installed on only one side of the interstate; fencing was installed on both sides of the interstate at the sixth site. After installation of fencing, DVCs declined by an average of 78.5% for the six study areas. Feldhamer et al. (1986) recommended using 2.7-m high fencing and reducing the attractiveness of ROWs to deer. Fencing placed close to highways would allow deer to access vegetation along ROWs, perhaps reducing the incentive for deer to cross roadways (Bellis and Graves 1971). This idea was supported by Puglisi et al. (1974) who found that road mortality of deer was lower in areas where fencing was located close to roadways, thus providing deer access to vegetation on ROWs, than in areas where deer had to breach fencing to access vegetation on ROWs.

Fences are most effective at keeping deer from entering roadways when they are properly maintained. Falk et al. (1978) found that maintenance of a 2.26-m high deer fence reduced the number of deer that entered sections of Interstate 80 in Pennsylvania. The authors found that gaps under the fence greater than 23 cm allowed deer to cross under the fence onto the highway; such gaps were common where fencing crossed streams and ravines (Falk et al. 1978) or when caused by erosion (Feldhamer et al. 1986). Most deer entering an interstate ROW observed by Feldhamer et al. (1986) did so by crossing under 2.7-m high fencing. Deer also jumped over low spots in the fence caused by fallen trees (Falk et al. 1978). Mesh sizes of fencing should be small to prevent deer from crossing through the fence (Feldhamer et al. 1986).

Installation of fencing to prevent DVCs requires time and financial commitment to ensure that fences are regularly repaired to prevent deer from entering ROWs (Foster and Humphrey 1995). Reed et al. (1982) arbitrarily estimated annual maintenance costs of fencing to be 1% of initial fence costs, and reported the average cost of erecting 2.4-m high fencing at six study sites to be approximately $16,600 per kilometer, including costs of one-way gates (Reed et al. 1974). Adjusting this estimate for inflation using the Consumer Price Index, equivalent fencing in 2005 would cost approximately $34,200 per kilometer. Falk et al. (1978) warned that even properly maintained 2.26-m high fencing will not be completely effective at preventing deer from entering highways.

Decreased numbers of DVCs would likely result if deer that enter fenced ROWs could easily leave the ROW (Feldhamer et al. 1986). In areas where fencing was present on one or both sides of a road (Bellis and Graves 1971, Reed et al. 1974), one-way gates can be installed to allow deer that enter a ROW to exit (Reed et al. 1974). Fencing does not mitigate barrier effects that roads have on wildlife movement, and may actually increase fragmentation, so fencing should be used in combination with crossing structures such as underpasses, culverts, or overpasses to provide the greatest benefit for wildlife (Foster and Humphrey 1995). In a study of wildlife use of culverts in Spain, Yanes et al. (1995) noted that, in some locations, roadside fencing blocked wildlife access to culverts. Therefore, placement of fencing should not interfere with any possible wildlife crossing structures and instead should be designed to direct wildlife movements toward crossing structures (Yanes et al. 1995).

Reflectors

Swareflex Wildlife Highway Warning Reflectors are designed to prevent deer from crossing roadways, thus reducing DVCs, by reflecting light from approaching vehicle headlights at a 90º angle from the road, creating a visual "barrier" for deer (Schafer and Penland 1985, Waring et al. 1991). In response to the visual barrier created by an oncoming vehicle, deer are supposed to cease movement until the visual barrier disappears once the vehicle has passed (Schafer and Penland 1985). In a study investigating the effectiveness of Swareflex reflectors, Schafer and Penland (1985) found that road mortality of deer was significantly less when the reflectors were in operation than when the reflectors were not functional. However, the reflectors are not effective during the day, and the authors cautioned that deer may become habituated to the visual barrier created by the reflectors, potentially decreasing the effectiveness of the reflectors (Schafer and Penland 1985). Swareflex reflectors were also tested by Waring et al. (1991) who found no difference in deer behavior before and after installation of reflectors and no significant decrease in deer mortality during nighttime hours when the reflectors were in operation. The authors noted that deer positioned at the edge of the pavement were out of range of the reflectors (Waring et al. 1991). In the two months immediately following installation of reflectors, no deer mortality occurred. After two months, however, the number of deer killed by vehicles returned to the pre-reflector mortality rate even though the deer population decreased, possibly reflecting habituation to the reflectors (Waring et al. 1991).

Warning Techniques

Warning techniques, such as temporary and permanent deer signs, deer whistles attached to vehicles, and systems alerting drivers to the presence of wildlife on roadways are used in attempt to decrease DVCs. In a survey of SWAs and state DOTs, Sullivan and Messmer (2003) found that 89% of respondents used permanent deer signs to mitigate DVCs, although most respondents considered temporary and permanent deer signs to be ineffective at reducing DVCs. Romin and Bissonette (1996) suggested that drivers become habituated to deer warning signs when the signs are observed without the presence of deer, potentially decreasing the effectiveness of the signs. The effectiveness of deer whistles was tested by Romin and Dalton (1992), who found no differences in responses of mule deer to a vehicle with and without deer whistles, and therefore concluded that the whistles are ineffective at preventing DVCs. Gordon et al. (2004) tested the effectiveness of the Flashing Animal Sensing Host (FLASH™, Victoria Gooch, Meridian, Idaho) system at reducing motorist speeds on a section of highway in Wyoming located along a mule deer migration route. The FLASH system, which alerts drivers to the presence of deer on the road with flashing warning signs when a deer activates an infrared sensor on the roadside, was installed at a wildlife crossing gap in exclusion fencing lining the highway (Gordon et al. 2004). The 2.4-m high exclusion fencing extended for 5.5 km on either side of the crossing gap, and there was a high prevalence of DVCs on this section of highway (Gordon et al. 2004). While drivers reduced vehicle speeds when the FLASH system warning signs were activated, the decrease was not enough to effectively reduce DVCs, leading the authors to conclude that the FLASH system was ineffective at reducing incidence of DVCs in the study area (Gordon et al. 2004).

Highway Lighting

Highway lighting has been thought to reduce AVCs by increasing the response time of drivers to animals on roadways by improving driver visibility (Reed and Woodard 1981). On a four-lane highway in Colorado, Reed and Woodard (1981) found no difference in the number of deer crossings per accident with and without highway lighting, and vehicle speeds were not significantly different between lights on and off. These results indicate that highway lighting, and thus increased visibility of drivers, did not significantly decrease the number of DVCs per deer crossing (Reed and Woodard 1981). Deer crossing locations did not differ between trials with lights on and lights off (Reed and Woodard 1981).

Habitat Management

In heavily wooded areas, timber harvests near roads may reduce the attractiveness of ROWs to deer by creating quality foraging opportunities away from roads (Feldhamer et al. 1986). In areas where salt is used to melt snow on roads, salt may be another incentive for deer to enter ROWs. Providing salt licks in the habitats adjacent to roads may reduce the attractiveness of ROWs to deer (Feldhamer et al. 1986). Nielsen et al. (2003) recommended manipulating habitats by decreasing availability of forest and shrub cover on public lands adjacent to roads, particularly in urban areas, to increase driver visibility. Romin and Bissonette (1996) recommended intercept feeding to reduce incentive for deer to approach roadways.

Deer Harvest

Reduction of deer herd size through harvesting may effectively reduce DVCs (Allen and McCullough 1976). In areas of high deer densities, Feldhamer et al. (1986) recommended harvesting deer to within the sociological carrying capacity of the surrounding environment. In a survey distributed to state natural resource agencies, Illinois and Michigan were using deer harvests to decrease DVCs, with Michigan reporting success using this mitigation strategy (Romin and Bissonette 1996). Thirty-seven percent of survey respondents from SWAs and DOTs reported using deer harvests to mitigate DVCs, and most respondents considered reducing herd size to be the most cost-effective mitigation technique (Sullivan and Messmer 2003).

Public Education

Implementing public education programs informing drivers of the factors influencing DVCs may reduce the prevalence of such accidents (Allen and McCullough 1976). Informing drivers about how to properly react when deer and other wildlife enter ROWs may decrease the injuries and fatalities that are associated with secondary accidents (Allen and McCullough1976). In a survey of SWAs and state DOTs, Sullivan and Messmer (2003) found that 39% of respondents used public education through newspapers to reduce DVCs.

Overpasses

Overpasses designed to allow wildlife to cross over roadways may help reduce AVCs and mitigate barriers that roads create to wildlife movement (Forman 2000). Overpasses can be constructed in areas where underpasses sometimes cannot (Putnam 1997). Wildlife overpasses may play an important role in large-scale habitat connectivity in that light conditions and precipitation are the same as the surrounding habitats (Ruediger 2001). In addition, vegetation similar to that of adjacent habitats can be planted on overpasses (Ruediger 2001). Wider overpasses are thought to be preferred by animals over narrow overpasses (Putnam 1997). Two wildlife overpasses in the Netherlands are approximately 30-m wide, with wider openings at the overpass "entrances" (Putnam 1997). Two wildlife overpasses constructed along the Trans Canada Highway in 1997 are approximately 50-m wide and heavily used by deer (Clevenger and Waltho 2005). The floor of overpasses should be vegetated rather than concrete (Putnam 1997). In addition, fencing can be used to funnel animals toward overpasses (Groot Bruinderink and Hazebroek 1996).

Culverts and Underpasses

Culverts and underpasses that allow passage of animals under roads may be the most effective method of decreasing AVCs and reducing the barrier effects of roads (Forman 2000). Foster and Humphrey (1995) found that underpasses in Florida reduced the number of animals killed by vehicles and provided connectivity between habitats on opposite sides of a highway; species observed using underpasses included Florida panthers (*Felis concolor coryi*), bobcats (*Lynx rufus*), white-tailed deer, raccoons (*Procyon lotor*), alligators (*Alligator mississipiensis*), and black bears (*Ursus americanus*) (Foster and Humphrey 1995). Many factors are thought to influence species use of these structures and should be taken into consideration in the design of new passages. It is important to consider the species of interest when designing and distributing culverts or underpasses throughout landscapes. Animals with small home ranges will require closer placement of crossing structures, while passages can be located much farther apart for highly mobile animals with large ranges. After construction, the effectiveness of culverts and underpasses should be monitored to evaluate the effects on both target and non-target species (Clevenger and Waltho 2000), because mitigation efforts aimed at a target species may fail to lessen barrier effects on non-target species (Clevenger and Waltho 2005). Note that animals may require time to adapt to new crossing structures. The rate of adaptation depends on species' behavior, mobility, and habitat preferences, as well as the structural and landscape design near the underpass.

Many variables potentially influence species' use of underpasses and culverts, and these factors can be broken down into the following categories: structural, human-related, and landscape-related (Clevenger and Waltho 2000), as well as road-related (Clevenger et al. 2001) and biologically-related (Clevenger et al. 2001, Goosem et al. 2001, Clevenger and Waltho 2005). Structural factors include underpass width, height, and length (from an animal's perspective), "openness," and noise (Clevenger and Waltho 2000), as well as substrate of underpass floor and underpass lighting (Reed et al. 1975). An important factor in the design of culverts and underpasses is the concept of "openness," which is calculated from (height x width)/length, where height, width, and length are viewed as from an animal's perspective. Putnam (1997) stated that the original source of the openness ratio came from Olbrich's (1984) study of red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), and fallow deer (*Dama dama*) use of over 800 overpasses and underpasses in West Germany. 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." Human-related variables include human use of underpasses, including foot, bicycle, and equestrian traffic (Clevenger and Waltho 2000). Landscape variables include distance to forest cover, towns, and major drainages (Clevenger and Waltho 2000), as well as vegetation at entrances and characteristics of adjacent habitats (Goosem et al. 2001). Road-related factors include traffic volume and noise (Clevenger et al. 2001). Biologically-related factors include predator-prey relationships near underpasses (Clevenger et al. 2001, Goosem et al. 2001, Clevenger and Waltho 2005).

In a study of underpasses in Banff National Park in Alberta, Canada, Clevenger and Waltho (2000) found that structural variables most significantly influenced ungulate use of underpasses, followed by landscape-related and human-related variables. The most significant structural variables influencing use by ungulates included openness (negative correlation), noise (positive correlation), and underpass width (negative correlation) (Clevenger and Waltho 2000). While ungulate use of underpasses was negatively related to openness and underpass width, the authors were doubtful that ungulates would prefer smaller underpasses to larger, more open structures (Clevenger and Waltho 2000). Upon further analysis, they found that openness was significantly related to underpass length, noise, and distance to town (Clevenger and Waltho 2000). Clevenger and Waltho (2005) conducted a study similar to Clevenger and Waltho (2000) of crossing structures located further from towns in Banff National Park, and found that structural attributes were most closely correlated with crossing structure use by large mammals, including carnivores and ungulates. They suggested that confounding human-related variables in Clevenger and Waltho (2000) may have masked the importance of structural attributes to wildlife use of crossing structures in that wildlife may avoid structures with high levels of human activity, regardless of the structural characteristics of the underpasses (Clevenger and Waltho 2005). The authors also found that deer selected undivided over divided structures (Clevenger and Waltho 2005). Foster and Humphrey (1995) suggested that visibility, or a clear view of habitat on the opposite side of an underpass, may be more important than underpass width and height. For deer, they found that a height of 2.1 m was adequate for use by white-tailed deer (Foster and Humphrey 1995). Reed (1981) recommended large “open-bridge” underpasses approximately 4-m high x 18-m wide x 14-m long to decrease DVCs. Other structural factors include substrate of underpass floor and underpass lighting. Reed et al. (1975) found that in a concrete box culvert with soil partially covering the underpass floor and skylights in the ceiling, most deer crossed where soil covered the underpass floor. In addition, the authors concluded that skylights were detrimental to deer use because they allowed traffic noise and precipitation to enter the underpass (Reed et al. 1975). Reed et al. (1975) also tested the effect of lighting on deer behavior and use of the underpass, and concluded that lighting had no effect on number or behavior of deer using the underpass and thus was unnecessary. Therefore, underpasses should be designed with earth floors and without skylights or artificial illumination (Reed et al. 1975).

In Banff National Park, human-related variables, including distance to town and human presence within an underpass, were negatively associated with underpass use for all species studied. Distance to nearest town was the most significant factor influencing use by carnivores (Clevenger and Waltho 2000). Underpasses located closer to towns had increased human presence within the underpasses (Clevenger and Waltho 2000). Therefore, human use of underpasses should be controlled to optimize use of these crossing structures for wildlife (Clevenger and Waltho 2000). Groot Bruinderink and Hazebroek (1996) recommended managing underpass entrances as refuges to ensure that primary use is by wildlife.

Landscape-related variables also influence wildlife use of underpasses and culverts. Hunt et al. (1987) found that vegetation near underpass entrances directly influenced wildlife use. Goosem et al. (2001) found that native vegetation near underpass entrances positively influenced underpass use by native species. Species habitat preferences should be taken into consideration during the design process, as landscape-related or structural variables may affect the willingness of individuals to use underpasses. For example, forest specialists that tend to avoid open areas may be less likely to approach open areas adjacent to roads. Native vegetation should be planted at underpass entrances to entice individuals to use the underpasses and to provide cover for species that generally do not enter open areas (Goosem et al. 2001). Clevenger and Waltho (2000: 48) suggested that "…species select underpasses that best correlate with their ecological needs and behavior." The relationship between habitat and underpass attributes is exemplified by martens (*Martes americana*) and weasels (*Mustela* spp.), as documented by Clevenger et al. (2001). Martens, which are found in areas with thick canopies, preferred culverts with low height and high openness, while weasels, which tend to travel and hunt in tight spaces such as rodent tunnels, preferred culverts with high ceilings, low openness, and low visibility (Clevenger et al. 2001).

Culverts are a relatively inexpensive AVC mitigation technique, especially when such structures must be incorporated into road design for purposes other than wildlife crossings, and play a vital role in connecting habitats separated by roads (Clevenger et al. 2001). Improving existing culverts to encourage use by wildlife can be much less costly than installing new crossing structures (Yanes et al. 1995). In a study of wildlife use of culverts in Banff National Park, Clevenger et al. (2001) found the most significant factors affecting wildlife use of culverts to be traffic volume, which was positively correlated with use by small- and medium-sized animals, followed by noise, culvert length and road width, and elevation, all of which were negatively correlated with use of culverts. Thus, road-related factors appeared to be the most important variables affecting use of culverts by small and medium-sized mammals (Clevenger et al. 2001). Yanes et al. (1995) found that culvert use by small mammals was negatively correlated with road width and culvert length, and positively correlated with culvert height, width, and openness. Clevenger et al. (2001) suggested that species that generally avoid open areas may learn to use culverts from surviving individuals, and recommended that culverts be placed at 150-300-m intervals to allow use by maximum numbers of animals. A variety of culvert sizes should be used to ensure use by animals of all sizes, and attractive food and cover plants should be present at culvert entrances (Clevenger et al. 2001).

Biological factors such as predator-prey relationships may influence wildlife use of underpasses and culverts. Prey species may avoid using underpasses and culverts due to presence of predators. Clevenger et al. (2001) frequently observed fecal scent marking of culvert entrances by weasels and martens, which may have deterred use by small prey. Structural characteristics of underpasses and culverts may decrease the ability of prey species to detect and escape predators

(Little et al. 2002, Clevenger and Waltho 2005). In addition, cover near underpass entrances may decrease the ability of prey to detect predators (Little et al. 2002, Clevenger and Waltho 2005). In their study of wildlife underpasses in Florida, Foster and Humphrey (1995) observed possible predation by a bobcat (*Lynx rufus*) and barred owls (*Strix varia*) near underpasses. Little et al. (2002) reviewed literature for evidence of wildlife passages acting as prey traps, and found little evidence of predation patterns centering on passages or predation at passages negatively affecting prey populations. Experimental studies on predation at wildlife crossing structures, however, have yet to be conducted (Little et al. 2002). To facilitate use by prey species, Goosem et al. (2001) incorporated objects, such as rocks and logs that provided cover and ropes and chains that hung from the ceiling, within underpasses to provide prey with opportunities to escape from predators within the underpasses.

Underpasses and culverts should be placed along wildlife travel corridors (Foster and Humphrey 1995), migratory routes (Reed et al. 1975), or near areas with high concentrations of animals such as wintering grounds for deer (Reilly and Green 1974). Wildlife underpasses and culverts could be incorporated along streams, along which wildlife frequently travel, or anywhere else bridges are necessary (Hubbard et al. 2000). Philcox et al. (1999) found otter road mortality in Britain to be correlated with high river flows and deduced that otters are more likely to cross onto roads while culverts and underpasses are flooded. Thus, culverts and underpasses designed to allow water and wildlife to pass under roadways should be constructed to allow use by wildlife during periods of high water. Where wildlife underpasses and culverts span rivers, Philcox et al. (1999) recommended underpasses with high riverbanks or large culverts with ledges above flood level to allow use by wildlife during high water periods. Foresman (2001) found that incorporating shelving into culvert design allowed use by small and medium-sized mammals when the floor of the culvert was covered with water; interestingly, shelves used in the study had 2.54-cm, diamond-shaped grate openings, which animals seemed reluctant to use. Many small mammals crossed through the culverts on the solid edge of the shelving frame rather than on the grate surface.

Specific behaviors of deer as they approach and exit underpasses and culverts reflect their "willingness" to use underpasses and culverts (Reed et al. 1975). Reed et al. (1975) examined deer behavior when approaching a 3.05-m tall x 3.05-m wide x 30.48-m long (from an animal's perspective) concrete box culvert under a four-lane section of Interstate 70 in Colorado where 2.44-m high exclusion fencing and eight one-way gates (Reed et al. 1974) had been installed along the highway. The authors observed that out of 4,450 deer approaching the underpass, 1,739 deer entered the underpass, yielding an approach per crossing ratio of 2.56, which did not change significantly from 1970 to 1972 (Reed et al. 1975). Those deer that did not use the underpass: 1) breached the fence and entered the highway ROW; 2) crossed the highway near the ends of the exclusion fencing; or 3) did not move across the highway in any way (Reed et al. 1975). Deer reluctance in entering the underpass was reflected by the following behaviors: 1) the look-up behavior (which researchers interpreted as an attempt by deer to investigate the overhead structure), occurred when a deer raised its muzzle above an imaginary horizontal line through the middle of the rostrum to the bottom of the ear; 2) the muzzle-to-ground behavior (which researchers interpreted as an olfactory investigation of the ground) occurred when a deer lowered its muzzle to the ground near the underpass entrance; and 3) the tail-up behavior (a behavior reflecting excitement in ungulates) occurred when a deer raised its tail parallel to the ground or higher (Reed et al. 1975). The look-up, or "head bobbing" behavior, which has been interpreted to reflect curiosity, was described for caribou (*Rangifer tarandus*) by Pruit (1960). Reed et al. (1975) observed that 24% of deer exhibited the look-up behavior, 28% exhibited the muzzle-to-ground behavior, and few exhibited the tail-up behavior. From these behaviors, the authors suggested that mule deer showed reluctance in using an underpass of this size and design. They recommended that underpasses should be larger and more open for use by deer (Reed et al. 1975). Reed (1981) recommended underpasses approximately 4-m high x 18-m wide x 14-m long.

From 1974 through 1979, Reed (1981) examined exit behaviors as deer moved toward the exit of the aforementioned concrete box culvert studied by Reed et al. (1975), and noted a change in behavior as deer approached the exit. He used the following exit behaviors to evaluate whether mule deer exhibited hesitation or reluctance in using the culvert: walking, trotting, bounding, and hesitating near the underpass exit. The author interpreted trotting, bounding, and hesitating near the underpass exit to be indicative of deer reluctance and cautiousness when leaving the underpass, while walking indicated that deer were "comfortable" with using the underpass (Reed 1981). Trotting, bounding, or hesitating near the underpass exit was observed in 75% of deer, suggesting that most deer observed were cautious or hesitant (Reed 1981). Based on mule deer entrance (Reed et al. 1975) and exit behaviors observed at this underpass, Reed (1981) concluded that mule deer reluctance and hesitation at the underpass did not change over the 10 years separating the study of entrance behaviors from the study of exit behaviors, indicating that deer had not habituated to the underpass. Reed (1981) suggested that deer would be more willing to use and thus show less wariness of larger, more open underpasses.

Underpasses, overpasses, and culverts provide connectivity between habitats separated by roads, permitting gene flow between populations and maintaining the integrity of wildlife corridors. While the issue of corridors remains controversial, research indicates that corridors may be essential in maintaining connectivity between habitat patches, particularly in fragmented areas (Gonzalez et al. 1998). In addition, researchers have shown that underpasses, overpasses, and culverts are readily used by animals and effectively reduce AVCs by creating a safe passage through which animals can circumvent roads, thereby decreasing road mortality of animals and reducing the dangers that AVCs pose to humans. Crossing structures alone may not be entirely effective in preventing AVCs, and a combination of crossing structures and exclusion fencing may be the best approach (Foster and Humphrey 1995).

Wildlife crossing structures are costly and careful considerations should be made when selecting the most appropriate type of crossing structure for a site. Costs of wildlife crossing structures can be incorporated into road construction costs, rather than taking funds from conservation projects such as land purchases (Simberloff et al. 1992). Wildlife underpasses and culverts may not be realistically incorporated into the landscape in some areas (Gordon et al. 2004). Typically, incorporating crossing structures into future road designs can be less costly than "retrofitting" existing roads with crossing structures (Groot Bruinderink and Hazebroek 1996, Putnam 1997, Hubbard et al. 2000, Nielsen et al. 2003). Overpasses can be built to facilitate wildlife movement over existing roadways. Because culverts and underpasses are necessary components of road design for such land features as rivers, creeks, and drainages, designing and installing structures that double as wildlife crossings would be less expensive than constructing wildlife overpasses (Reed 1981).

SIGNIFICANCE OF CURRENT RESEARCH

According to Spellerburg (1998), plentiful research has been conducted on design of culverts, underpasses, and overpasses that incorporate wildlife concerns, but little research has been conducted to evaluate the efficacy of such structures in terms of intensity of wildlife use and reduction of AVCs. Therefore, the North Carolina Department of Transportation (NCDOT) requested a study to monitor white-tailed deer and other wildlife use of the space under the New Hope Creek (NHC) bridge on U.S. Highway 15/501, which runs northeast and southwest, between Durham and Chapel Hill, North Carolina (Figures 1 and 2). The NHC underpass is important as a wildlife passage, especially for white-tailed deer, because forests associated with NHC create a corridor between two natural areas: the Korstian and Durham Divisions of Duke 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 provides wildlife habitat and recreational opportunities for humans in an area that is becoming increasingly urbanized. Highway 15/501 creates a barrier to movement as animals move along the NHC corridor. To access habitat and resources on the opposite side of the highway, animals must either cross onto the highway or cross under the highway through the NHC underpass. The current structure, a dual bridge with two lanes of traffic on each bridge and an open median, is currently 41.1-m (135 ft) long and crosses over New Hope Creek, which is approximately 15.2-m (50 ft) wide (Figure 3). The width of each of the dual bridges is 6.5 m (21.4 ft), and the width of the open median is 6.1 m (20 ft) (NCDOT 2001). There is approximately 6.4 m (21 ft) and 5.5 m (18 ft) of horizontal clearance on the east and west sides of the creek, respectively, through which wildlife may cross. The floor of the underpass is soil with sparse vegetation, and can be underwater approximately 16 days per year after periods of heavy rainfall (Garrett 2001). The underpass has a vertical clearance of 2.4 to 3.0 m (8 to 10 ft). The southbound bridge was built in 1951, and the northbound bridge was added in 1955. The section of Highway 15/501 that includes the NHC bridge was built on extensive fill, which created a steep slope approximately 3- to 4.6-m (10 to 15 ft) high leading up to the road. The "openness ratio" of the current bridge is approximately 11.3 feet (English units) [(8-ft [2.4-m] high x 89-ft [27.1-m] wide between slope walls) / 63-ft [19.2-m] long including the median].

In 2007, a longer bridge designed to facilitate deer use of the underpass and to provide a greenway trail will be constructed as part of a project to upgrade from four to six lanes the section of Highway 15/501 containing the NHC underpass. In 2001, the traffic volume for the section of Highway 15/501 containing the NHC bridge was about 46,300 vehicles per day (NCDOT 2001). The collision rate for this segment of highway in 2001 was 374 collisions per 100 million vehicle miles (c/100mvm), which was well over the state average of 193 c/100mvm for similar roads, and traffic volumes exceeded capacity for this section of Highway 15/501 (NCDOT 2001). The proposed upgrade is intended to improve safety and traffic flow on Highway 15/501 (NCDOT 2001). The section of Highway 15/501 containing the NHC underpass is bordered by Mt. Moriah Road, which is 1.3 km (0.8 mi) south of the NHC underpass, and Garrett Road, which is 0.48 km (0.3 mi) north of the NHC underpass. The proposed bridge, which will be a dual bridge design with three lanes of traffic on each bridge and an open median between the two bridges, will have a length of approximately 91 m (300 ft), which would create horizontal passages of approximately 40 m (130 ft) on the west side of the creek and approximately 23 m (75 ft) on the east side of the creek (NCDOT 2003) (Figure 4). The width of each of the dual bridges will be 17 m (56 ft), and the proposed bridge will have minimum vertical clearance of 3.0 m (10 ft) (NCDOT 2003). Approximately 3.7 m (12 ft) on each side of the creek will be dedicated to the future construction of paved greenway trails by the City of Durham (NCDOT 2003). The greenway trails will be separated from the wildlife crossing areas by a physical barrier, such as a wood pile or post-rail fence to minimize interactions between wildlife and humans (Garrett 2001). Upon completion of the new bridge, my study will be replicated to determine whether intensity of wildlife use of the longer bridge increases in comparison to use of the current bridge. Current and future studies of the NHC underpass will evaluate the efficacy of a bridge built to facilitate wildlife movement and to reduce AVCs.

The objectives of my study are as follows: 1) document level of wildlife use of the existing underpass, which will provide a baseline estimate of intensity of underpass use that will be compared to that of the future underpass; 2) examine deer responses to the underpass for signs of reluctant or hesitative behaviors; 3) estimate effectiveness of the current NHC underpass by estimating road mortality through roadkill surveys and records of deer-related vehicle collisions on the 15/501 between Mt. Moriah and Garrett Roads; and 4) determine whether vegetation near the underpass entrances and within the open median potentially influenced wildlife use of the underpass by comparing level of wildlife use and deer behaviors near the underpass before and after mowing of vegetation at the underpass.

The area surrounding the NHC corridor is becoming increasingly urbanized. A shopping center is located 0.48 km (0.3 mi) south of the NHC underpass, and another shopping center is located 1.29 km (0.8 mi) north of the NHC underpass. During the study period, a parcel of land adjacent to the NHC corridor along Highway 15/501 was available for purchase for future development. Thus, the importance of the NHC corridor as wildlife habitat and landscape linkage is likely to increase as development continues.

METHODS

Wildlife and Human Use of the NHC Underpass

Wildlife and human use of the underpass was documented using two digital ultra low-light cameras (Sentinel 5 System, Sandpiper Technologies, Inc., Manteca, CA) installed on the north side of the southbound bridge (Figure 5). Recording began in December of 2003 and continued through May of 2005. Cameras continuously filmed two underpass entrances on the north side of the southbound bridge (Figures 6-7). Invisible infrared Light Emitting Diode (LED) spotlights were installed at the two underpass entrances for collection of night data. Video data were recorded onto a 40-GB disk cartridge using a digital video recorder (DVR) housed in a waterproof box and located on top of the cement cap of the bridge support pillars (Figure 8). From December 2003 until February 2005, the camera system was powered using two to three 12-volt deep cycle marine batteries, which allowed 4-7 days of continuous recording. From February 2005 through May 2005, the cameras were powered by two 123-watt solar panels which permitted continuous recording with minimal interruptions (Figure 9).

Camera 1 filmed the northeast corner of the underpass. The field of view for Camera 1 extended approximately 15.8 m east of NHC and approximately 7.3 m north of the underpass entrance (Figure 10). Camera 2 filmed the northwest corner of the underpass. The field of view for Camera 2 extended approximately 33.5 m west of NHC and approximately 13.1 m north of the underpass entrance (Figure 11).

Data were reviewed using iMovie software on a PowerMac G5 computer. Because the components of the camera system were modified from a security system, video data could not be directly edited. Instead, the video had to be played into a digital editing program before the video could be manipulated; iMovie was used to capture and edit the video data. The footage could be played into an editing program at the following speeds: real time, double time, beginning of one minute to the beginning of the next minute, beginning of a five-minute period to the beginning of the following five-minute period, beginning of a ten-minute period to the beginning of the following ten-minute period, beginning of a twenty-minute period to the beginning of the following twenty-minute period, and so on. Due to time and computer memory limitations, the minute-to-minute playback option was used to sample video data. The minute-to-minute option allowed the first second of each minute to be observed. Any inconsistency from one minute to the next was investigated by viewing the data in real- or double-time. Footage with animal activity was extracted from the original recording and analyzed using a standardized form documenting the details of each animal crossing (Appendix 1). In addition, a detailed account of each animal's behavior, including duration of each behavior, was recorded.

Underpass use was categorized using the following terms: 1) "crossings," which included underpass entrances, that occurred when individuals disappeared into the underpass, and exits, that occurred when individuals emerged and moved away from the underpass; and 2) "activity," which included all underpass entrances, exits, and deer approaches, that occurred when deer moved toward and then retreated from the underpass, and all other activity within view of the cameras.

Seasonal and temporal differences in underpass use were examined for all species, as were differences in use between the northeast and northwest corners of the underpass. The four seasons were defined as winter (December 1 through February 29), spring (March 1-May 31), summer (June 1-August 31), and fall (September 1-November 30).

Because a sample of video data was taken, it was necessary to evaluate the probability that events involving wildlife use of the NHC underpass would be detected using the minute-to-minute sampling technique. Based on the duration of each incident, detection probabilities were used to provide an estimate of the total number of wildlife crossings and activities occurring near the NHC underpass (Pollock, personal communication). To determine the probability that each event would be detected using the sampling technique, the duration of each event occurring for less than one minute was divided by 59 seconds. An event occurring for less than one minute was detected only if an animal was within view of the cameras during the first second of each minute. The detection probability for events occurring for one or more minutes was 1, since the beginning of each minute was observed in the sample. The formulas used to determine detection probabilities for each event were as follows:

$$p_i = d_i / 59 \quad \text{if } d_i \text{ was less than or equal to 59 seconds}$$

$$p_i = 1 \quad \text{if } d_i \text{ was greater than 59 seconds}$$

where

p_i = probability of detection for each event

d_i = duration of event in seconds

From the above formulas, the estimated number of animals was calculated as the sum of the number of animals per event divided by each event-specific detection probability, or:

$$\hat{N} = \sum(\text{number of animals per event} / p_i)$$

where

$\hat{N}$ = estimated number of animals

The overall detection probability for crossings and activities was calculated by dividing the actual number of observed animals 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

Overall detection probabilities were calculated for: 1) wildlife crossings, including all entrances and exits; 2) wildlife activity, including all entrances, exits, and other activities occurring within view of the cameras; 3) deer crossings, including all entrances and exits; and 4) deer activity, including all entrances, exits, approaches, and other activities occurring within view of the cameras. Wilcoxon rank sum tests were used in SAS V.8 to identify pairwise differences in detection probabilities between wildlife entrances and exits, and deer entrances and exits. Kruskal-Wallis tests (Chi-Square approximation) were used in SAS V.8 to identify significant differences in detection probabilities between wildlife entrances, exits, and other activities, and deer entrances, exits, approaches, and other activities.

Estimated numbers of animals were calculated for wildlife crossings, including entrances and exits, wildlife activity, including entrances, exits, and other activities, deer crossings, including deer entrances and exits, and deer activity, including deer entrances, exits, approaches, and other activities. Inflating the number of animals observed in the sample by the detection probabilities, as described above, accounted for those animals that were not detected by the sampling technique.

Deer Behavior at the NHC Underpass

Using the video data, I closely examined deer as they approached, entered, or exited the underpass. I documented reluctant behaviors of deer when 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 may have been confounded by deer feeding near the underpass during all seasons, this behavior was not interpreted in my study to be indicative of hesitation or reluctance. I also documented reluctant or hesitative behaviors of deer as they exited the underpass. As described by Reed (1981), these behaviors include trotting, bounding, and hesitating near the underpass exit. As an indicator of how willing deer were to use the underpass, the number of deer that approached but did not enter the underpass was compared with the number of deer that entered and exited the underpass.

Road Mortality and Animal-related Vehicle Collisions near the NHC Underpass

As an index of road mortality on the section of Highway 15/501 containing the NHC underpass, surveys of vehicle-killed animals were conducted at least once a week while driving north and south along the 1.8 km (1.1 mi) section of Highway 15/501 between Mt. Moriah and Garrett Roads. The species and location of all vehicle-killed animals were recorded, as well as the date of discovery. In addition, the date, time, location, and habitat of all vehicle-killed deer observed along a driving route established for a deer abundance index (see below) were documented.

Records of AVCs on Highway 15/501 between Mt. Moriah and Garrett Roads were obtained from NCDOT. Details of each accident, including date, time, vehicle speed, total damages, and injuries were documented as well. This information, along with the information gathered by roadkill surveys, provided an index to the number of AVCs that occurred on Highway 15/501 between Mt. Moriah and Garrett Roads. In addition, these records were examined for seasonal and temporal trends in factors associated with deer-related vehicle collisions on Highway 15/501 between Mt. Moriah and Garrett Roads.

Deer Abundance Index

Because several years will separate my study from the future study of the expanded NHC underpass, a deer abundance index was developed to account for any obvious growth or reduction in the deer population. If, during the future study, more deer use the new underpass as compared with the current underpass, this index will allow researchers to evaluate whether increased deer use of the underpass can be accounted for by an increase in the deer population. The number of deer observed during my study will be compared to the number of deer observed along the same route during the future study, with the assumption that probability of detection will be uniform between the two studies.

The deer abundance index was developed using a count of deer observed during a driving route along roads west and north of the NHC underpass. The route included roads from the NHC underpass, through Duke Forest, and back to the NHC underpass. Specifically, the route was from the bridge site on Highway 15/501 west to Mt. Moriah Road, Mt. Moriah to Erwin Road, then Erwin to Mt. Sinai, Mt. Sinai to Friends School Road, Friends School Road to Murphy School Road, Murphy School Road to Cornwallis, Cornwallis back to Erwin, Erwin to the gravel portion of Pickett Road, then the paved portion of Pickett Road to Garrett Road, and finally Garrett Road back to Highway 15/501 (Figure 12). Habitat types along the route included residential, forest, early successional fields, and urban. All roads along the route except Highway 15/501 were two lane roads. An average of 24 km was covered weekly, with 23.5 km of paved road and 0.5 km of gravel road.

Effects of Vegetation Alteration on Wildlife Use of the Underpass

Vegetation at the NHC underpass reflected a disturbed early successional community (NCDOT 2002). Species that characterized sections of the highway shoulder that were not maintained regularly included saplings of red maple (*Acer rubrum*), red cedar (*Juniperus virginia*), and sweetgum (*Liquidambar styraciflua*), blackberry (*Rubus argutus)*, Japanese honeysuckle (*Lonicera japonica*), beadgrass (*Lespedeza* spp.), goldenrod (*Solidago* spp.), foxtail grass (*Setaria* spp.), and broom sedge (*Andropogon* spp.) (NCDOT 2002). Species present in the regularly maintained highway shoulder included panic grass (*Panicum* spp.), wild garlic (*Allium vineale*), English plaintain (*Plantago lanceolata*), Carolina geranium (*Geranium carolinianum*), and fescue (*Festuca* spp.) (NCDOT 2002).

Species at the northern and southern entrances of the underpass and the open median between the northbound and southbound bridges included Japanese grass (*Microstegium vimineum*), poison ivy (*Toxicodendron radicans)*, Japanese honeysuckle, river oats (*Chasmanthium latifolium*), grape vines (*Vitis* spp.), false nettle (*Boehmeria cylindrica*), wingstem (*Verbesina alternifolia*), blackberry, multiple species in the greenbrier genus (*Smilax* spp.), beadgrass, and saplings of painted or dwarf buckeye (*Aesculus sylvatica*), green ash (*Fraxinus pennsylvanica*), American elm (*Ulmus americana)*, tulip poplar (*Liriodendron tulipifera*), northern red oak (*Quercus rubra)*, and basket oak (*Q. michauxii*). During spring and summer seasons, overall height of the vegetation at the underpass entrances was approximately 1.5 to 2.4 m in height. Vegetation in the open median was denser than at the entrances, primarily due to vine clusters, and the overall height of vegetation in the open median was approximately 1.8 to 2.7 m. The ground directly underneath the bridge was primarily bare earth with poison ivy and false nettle scattered throughout. Hall and Sutter (1999) classified the forest to the north of the NHC bridge, which floods frequently, as Piedmont Alluvial Forest, based on categorizations of Schafale and Weakley (1990). Forests south of the study site have been classified by Hall and Sutter (1999) as Dry-Mesic Oak-Hickory Forest, based on categorizations of Schafale and Weakley (1990).

Regularly maintained powerline and sewer easements were located adjacent to 15/501. On the north side of the highway, a powerline corridor paralleled the highway on the east side of the creek, crossed over the creek, and ran perpendicular to the highway on the west side of the creek (Figure 13). A sewer easement also ran parallel to the north (Figure 13) and south (Figure 14) sides of the highway. Species observed along the powerline and sewer easements included blackberry, black willow (*Salix nigra*) saplings, box elder (*Acer negundo*) saplings, goldenrod, greenbrier (*Smilax bona-nox*), Japanese grass, privet (*Ligustrum sinense*), sedge (*Carex* spp.), strawberry bush (*Euonymus americanus*), and sweetgum saplings (NCDOT 2002).

The vegetation immediately adjacent to and under the 15/501 bridge is cut every one to two years by NCDOT's bridge maintenance crew. When the study period began in December 2003, the vegetation near the underpass entrances and in the open median had been growing for approximately two years (Figures 15, 17). During the winter of 2004, the vegetation was mowed at ground level (Figures 16, 18). By late spring of 2005, the vegetation rebounded to the pre-cut state. To investigate whether mowing of vegetation influenced the level of use or willingness of deer and other wildlife to use the underpass, wildlife use and deer behavior at the underpass before and after mowing was evaluated by comparing the number of crossings and deer hesitation behaviors during the pre-mowing periods of winter 2003/2004 and spring 2004 to those during the post-mowing periods of winter 2004/2005 and spring 2005. Vegetation that provided cover and foraging opportunities near wildlife underpass entrances is thought to entice animals to such crossing structures. Hunt et al. (1987) found that vegetation at underpass entrances influenced wildlife use. Thus, the mowing of vegetation near the entrances of the NHC underpass could potentially decrease wildlife, and especially deer, use of the underpass.

RESULTS

Wildlife and Human Use of the NHC Underpass

Wildlife Crossings

From December 11, 2003, through May 31, 2005, the underpass was filmed for 458 days (24-hour periods), which was 85% of total days during the study period (Table 1). Number of days recorded by season was significantly different (χ^2=22.53, d.f.=5, $p<0.05$), with the highest proportion of days recorded occurring during the spring of 2005 after the installation of solar panels, and the lowest proportion of days recorded occurring during the winters of 2003/2004 and 2004/2005. Throughout the entire study period, 126 crossings were observed in the sample of video data, including 81 entrances and 45 exits, by at least 10 species during 102 events, which represented a minimum number of crossings (Tables 2-3). Events were instances in which one or more animals were observed in the video footage. Because individual animals could not be identified in the video footage, the number of crossings could have consisted of multiple crossings by the same individuals. The median duration of crossing events for all species observed was 1.31 minutes. Based on the sample of video data, 42.2% of all wildlife crossings, including 47.1% of entrances and 35.5% of exits, were detected (Table 4). Detection probabilities for wildlife entrances and exits were not significantly different ($z = -1.31$, $p>0.05$). Thus, an estimated 299 wildlife crossings occurred, including 172 entrances and 127 exits.

The number of animals observed entering and exiting the underpass in the sample was significantly different between seasons (χ^2=14.69, d.f.=5, $p<0.05$). In the sample of video data, level of wildlife use of the underpass was highest during the summer of 2004 and lowest during the fall of 2004 (Figure 19). Wildlife crossing rates in the sample increased by 11% between winter of

2003/2004 and spring of 2004 and by 17% between the spring of 2004 and summer of 2004. Underpass crossing rates decreased by 56% from the summer of 2004 to fall of 2004. Crossing rates increased by 1.5% between fall of 2004 and winter of 2004/2005, and then increased by 30% between the winter of 2004/2005 and spring of 2005.

Two hourly peaks in crossings were observed in the sample of video data (Figure 20). The primary peak in wildlife crossings occurred about sunrise, while a secondary peak occurred about sunset. The number of animals observed entering and exiting the underpass in the sample was not significantly different between the east and west sides of the creek (χ^2=1.03, d.f.=1, p>0.05). In the sample, 68 crossings, including 41 entrances and 27 exits, occurred on the west side of the creek and 58 crossings, including 40 entrances and 18 exits, occurred on the east side (Figure 21).

Wildlife Activity near the Underpass

During the entire study period, the sample revealed 330 animals of at least 12 species as active near the underpass, including 81 entrances, 45 exits, and 204 other activities occurring within view of the cameras, during 277 events, which represented a minimum number of crossings (Table 5). Based on the sampling technique of video data, 59.3% of all wildlife activities, including 47.1% of entrances, 35.5% of exits, and 79.1% of other activities within view of the cameras, were detected (Table 4). Detection probabilities for all wildlife activities, including entrances, exits, and all other activity occurring within view of the cameras, were significantly different (χ^2=16.37, d.f.=2, p<0.05). An estimated 557 wildlife activities occurred, including 172 entrances, 127 exits, and 258 other activities. Species observed as active near the underpass during site visits included deer, river otter (*Lutra canadensis*), great blue heron (*Ardea herodias*), and five-lined skink (*Eumeces fascianatus*). The river otter was observed swimming in the creek, the great blue heron on the west creek bank, and the skink on the bridge pillars.

Seasonal wildlife activity at the underpass was examined, as was wildlife activity by corner of the underpass. Since detection probabilities were significantly different for overall wildlife activities including entrances, exits, and other activities, the estimated number of activities, rather than the number of activities observed in the sample, was used to analyze seasonal differences in wildlife activity as well as differences in wildlife activity by corner of underpass. The estimated number of entrances, exits, and other activities was significantly different between seasons (χ^2=63.18, d.f.=10, $p<0.05$). Species observed as active within view of the cameras, including entrances, exits, and all other activity, differed from those observed crossing through the underpass in that one beaver and one opossum were observed within camera view near the NHC underpass but did not cross through the underpass. Most frequent activities observed in the sample were by deer, followed by woodchuck and unidentifiable medium-sized mammals.

Wildlife activity rates observed in the sample of video data near the NHC underpass showed similar seasonal trends as wildlife crossing rates, with summer of 2004 having the highest activity rate and fall of 2004 having the lowest activity rate (Figure 22). From winter of 2003/2004 to spring of 2004, wildlife activity rates observed in the sample increased by 26% (Figure 22). Activity rates then increased by 138% between spring of 2004 and summer of 2004. Between summer of 2004 and fall of 2004, activity rates decreased by 196%. Observed activity rates increased by 19% between fall of 2004 and winter of 2004/2005, and then increased by 21% between winter of 2004/2005 and spring of 2005.

Hourly wildlife activities observed in the sample of video data had two distinct peaks (Figure 23). The primary peak occurred in the evening, while a secondary peak occurred near dawn. Wildlife activity in the sample was greater on the west side of NHC than the east side, with 209 observed activities occurring on the west side of the creek, including 41 entrances, 27 exits, and 141 other activities, and 121 activities occurring on the east side, including 40 entrances, 18 exits, and 63 other activities (Figure 24). The estimated number of entrances, exits, and other activities was significantly different between the east and west sides of the creek (χ^2=63.41, d.f. =2, $p<0.05$). An estimated 350 activities, including 67 entrances, 100 exits, and 183 activities occurred on the west side of NHC, while an estimated 207 activities, including 105 entrances, 27 exits, and 75 activities occurred on the east side.

Human Activity near the Underpass

From the sample of video data, 146 human activities were observed near the NHC underpass, of which 77 were work-related and 69 were recreational (Table 6). Work-related activities included work by NCDOT personnel or contractors, but did not include 81 site visits by researchers to maintain the camera system. Recreational activities included walking/hiking, fishing, and off-road vehicle (ORV) use. Sixty people in the sample were observed walking or hiking near the underpass, seven were fishing, and two were riding ORVs. Based on the sample, 80.8% of all human activity was detected, including 91.7% of work-related and 71.4% of recreational activities. An estimated 181 human activities occurred, including 84 work-related and 97 recreational activities. Detection probabilities were significantly different for work-related and recreational activities ($z = -2.71$, $p < 0.05$). Significant differences in detection probabilities between recreational and work-related activities required that the estimated number of people, rather than the number of people observed in the sample, be used to evaluate seasonal differences in work-related and recreational activities as well as differences in human activities between the northeast and northwest corners of the underpass.

Estimated numbers of people involved in recreational and work-related activities were significantly different between seasons ($\chi^2 = 61.35$, d.f.=5, $p < 0.05$). Estimated recreational activities were highest during winter of 2003/2004 and lowest during the winter of 2004/2005, while estimated work-related activities were highest during the spring of 2004 and lowest during the winter of 2003/2004. Levels of work-related and recreational activities observed in the sample showed similar trends as estimated levels of seasonal work-related and recreational activities (Figure 25). All human activity observed in the sample occurred between 0600 and 1800 hrs (Figure 26). Estimated numbers of people involved in recreational and work-related activities were significantly different between corners of the underpass ($\chi^2 = 4.92$, d.f.=1, $p < 0.05$), with 107 estimated activities occurring on the west side of the creek, including 57 work-related and 50 recreational, and 74 estimated activities occurring on the east side, including 27 work-related and 47 recreational. In the sample of video data, 86 people were active on the west side of the creek, including 52 work-related and 34 recreational activities, while 60 people were active on the east side of the creek, including 25 work-related and 35 recreational activities (Figure 27).

Deer Use and Behavior at the NHC Underpass

Deer Crossings

From December 11, 2003 through May 31, 2005, the sample revealed 75 deer crossing through the underpass during 53 events, which represented a minimum number of crossings. Fifty-four deer were observed entering the underpass and 21 deer were observed exiting the underpass in the sample. Individual deer could not be identified in the video footage, so the number of crossings could have consisted of multiple crossings by the same individuals. Based on the sampling technique of video data, 40.5% of all deer crossing events, including 42.4% involving entrances and 36.5% involving exits, were detected (Table 7). Detection probabilities for deer entrances and exits were not significantly different ($z = -0.56$, $p > 0.05$). An estimated 185 deer crossings occurred, including 127 entrances and 58 exits.

Numbers of deer observed entering and exiting the underpass in the sample were significantly different between seasons ($\chi^2 = 15.38$, d.f.=5, $p < 0.05$). In the sample, crossing rates by deer were lowest during the fall of 2004 and highest during the spring of 2005 (Figure 28). The highest number of entrances occurred during the spring of 2005, with 22 entrances observed, and the lowest number of entrances occurred during the fall of 2004 and winter of 2004/2005, with one entrance occurring during both seasons (Figure 29). The highest number of exits occurred during the spring of 2004, with 10 deer observed exiting, while no exits occurred during the fall of 2004 and winter of 2004/2005.

Two hourly peaks in deer crossings occurred in the sample of video data (Figure 30). The primary peak occurred near dawn and a secondary peak occurred near sunset. Eighty-six percent of deer crossings and approaches in the sample occurred within two hours of sunrise and sunset. Numbers of individuals observed entering and exiting the underpass in the sample were not significantly different between the northeast and northwest corners of the underpass (χ^2= 0.77, d.f.=1, $p>0.05$) (Figure 31). Twenty-four entrances and seven exits occurred on the east side of the creek in the sample, while 30 entrances and 14 exits occurred on the west side. Solitary individuals accounted for 71.7% of crossings in the sample, while 18.9% of crossings involved two deer, 5.6% of crossings involved three deer, and 3.8% of crossings involved four deer.

Deer Activity

In addition to 75 deer observed entering and exiting the underpass in the sample, 17 deer were observed in the sample approaching and retreating from the underpass during 15 events and 103 were observed as active within view of the camera without approaching the underpass, during 80 events. Based on the sampling technique of video data, 62.9% of all deer activities were detected, including 42.4% of entrances, 36.5% of exits, 92.1% of approaches, and 96.6% of other deer activities occurring within view of the cameras (Table 7). Detection probabilities for all deer activity, including entrances, exits, approaches, and all other activity within view of the cameras, were significantly different (χ^2= 24.27, d.f.=3, $p<0.05$). An estimated 310 deer activities occurred, including 127 entrances, 58 exits, 18 approaches, and 107 other activities.

In the sample of video data, overall deer activity, including all entrances, exits, approaches, and other activity within view of the cameras, was highest during summer of 2004 and lowest during fall of 2004 (Figures 32-33). Significant differences in detection probabilities between deer entrances, exits, approaches, and other activities required that the estimated number of activities, rather than the number of activities observed in the sample, be used to analyze seasonal differences in overall deer activity as well as differences in deer activity by corner of underpass. The estimated number of entrances, exits, approaches, and other activities were significantly different between seasons (χ^2=73.01, d.f.=15, p<0.05). The estimated number of entrances was highest during spring of 2005 and lowest during fall 2004, while the number of estimated exits was highest during summer of 2004 and lowest during the fall of 2004 and winter of 2004/2005. The estimated number of approaches was highest during summer of 2004 and lowest during winter 2003/2004 and winter 2004/2005, while the estimated number of other deer activities was highest during summer of 2004 and lowest during fall of 2004.

Two hourly peaks in overall deer activity, including crossings and approaches, were observed in the sample of video data (Figure 34). The primary peak occurred in the evening, and the secondary peak occurred near dawn. Eighty-one percent of deer activity in the sample occurred within two hours of sunrise and sunset. In the sample of video data, 72 activities, including 24 entrances, 7 exits, 10 approaches, and 31 other activities were observed on the east side of the creek, while 123 activities, including 30 entrances, 14 exits, 7 approaches, and 72 other activities were observed on the west side (Figure 35). The estimated number of entrances, exits, approaches, and other activities was significantly different between the east and west sides of the creek (χ^2=48.94, d.f. =3, p<0.05), with 168 estimated activities occurring on the west side of the creek and 142 estimated activities occurring on the east side. Solitary individuals accounted for 77.7% of all deer activity, while 15.5% of activities involved two deer, 4.1% of activities involved three deer, and 2.7% of activities involved four deer.

Deer Behavior

Twenty-five hesitation behaviors were observed in the sample of video data during the study period, nine of which were associated with exits and 16 were associated with entrances and approaches. There were two episodes in which the heads of deer were not visible to observe the look-up behavior, and 13 episodes in which the tails of deer were not visible to observe the tail-up behavior. As previously mentioned, the muzzle-to-ground behavior described by Reed (1981) was not included as indicative of hesitation or reluctance, as this behavior could have been confused with foraging behavior during all seasons. Hesitation behaviors were observed during 27.2% of all crossings and approaches. The look-up behavior occurred during 14.1% of all crossings and approaches, while hesitation while exiting occurred during 4.3%, bounding and tail-up each occurred during 3.3%, and trotting occurred during 2.2% of all crossings and approaches (Figure 36).

Road Mortality and Animal-related Vehicle Collisions near the NHC Underpass

Road Mortality

From December of 2003 through June of 2005, five road killed animals, including raccoon, Virginia opossum, woodchuck, wild turkey (*Meleagris gallapavo)*, and an unidentifiable medium-sized mammal, were observed on Highway 15/501 between Mt. Moriah and Garrett Roads. The raccoon was observed during the fall of 2004, the opossum, turkey, and unidentifiable mammal during the spring of 2005, and the woodchuck during the summer of 2005.

From December of 2003 through May of 2005, eight road approaches, including five by deer and three by small mammals, were observed in the sample of video footage (Table 8). Seven (87.5%) road approaches occurred during the winter of 2003/2004, while one (12.5%) occurred during the spring of 2005. Seven (87.5%) road approaches occurred at the northwest corner of the underpass, while one (12.5%) occurred at the northeast corner. In three out of the five road approaches by deer, the individuals approached the road and were visible later retreating from the road. All three road approaches by small mammals could potentially have been road crossings, as the animals approached the road and were not later observed in the video footage. The number of road approaches represented a minimum number due to the sampling technique.

Deer-related Vehicle Collisions

No evidence of DVCs was apparent during the driving survey for vehicle-killed animals on Highway 15/501 between Mt. Moriah and Garrett Roads. The NCDOT recorded 16 deer-related vehicle collisions between January 1, 1990 and October 30, 2004 (Table 9). No injuries were reported as resulting from the accidents. Nine DVCs occurred during the fall, four occurred during the winter, two occurred during the spring, and one occurred during the summer. Number of DVCs peaked at midnight (Figure 37). The average vehicular speed during these DVCs was 46.25 mph (74.4 kph), ranging from 30 to 55 mph (48 to 88 kph). The average damage estimate for these DVCs was $2,184, ranging from $650 to $4,000. Allen and McCullough (1976) found that vehicle speed influenced the amount of damage inflicted upon vehicles involved in DVCs. However, a significant correlation between vehicle speed and damages was not observed in my study ($r=0.02$, $p>0.05$).

During driving counts of deer between March 23, 2004 and May 31, 2005, 10 dead deer, the deaths of which likely resulted from vehicle collisions, were observed (Table 10). This number does not include those deer that were fatally wounded by vehicles but ventured off of roadways. Most vehicle-killed deer were observed during the winter of 2004/2005, followed by spring 2005, fall 2004, and summer of 2004. In three instances, the deer were found in forested habitat, in one instance the habitat was early-successional field, and in five instances deer were found on roadsides.

Deer Abundance Index

From March 23, 2004 through May 31, 2005, 205 deer were seen during 53 driving routes. Researchers spent 45 minutes to an hour each week traveling this route, which took place between 0900 and 1900 hrs. The number of deer observed was not significantly different between seasons ($\chi^2=0.66$, d.f.=4, $p>0.05$). Seasonal deer observation rates were highest during summer of 2004 and lowest during fall of 2004 (Figure 38). Over 50% of deer were observed in residential yards (Figure 39). The number of deer observed in each habitat type was significantly different per season ($\chi^2=106.09$, d.f.=20, $p<0.05$) (Figure 40). Number of deer observed peaked at 1900 hrs, with a secondary peak occurring at 1600 hrs (Figure 41). There was a significant positive correlation between number of deer observed and number of routes driven per hour ($r = 0.77$, $p<0.05$).

Effects of Vegetation Alteration on Wildlife Use of the Underpass

Comparing the number of wildlife crossings that occurred pre-mowing during the winter of 2003/2004 and spring 2004 to those that occurred post-mowing during the winter of 2004/2005 and spring 2005 revealed that wildlife crossing rates in the sample decreased by 35% following mowing (Figure 19). Wildlife activity rates in the sample, including all crossings and other activities within view of the cameras, decreased following mowing by 32% (Figure 22).

Overall, fewer deer crossings were observed in the sample of video data post-mowing than during the pre-mowing period, with 32 and 24 crossings occurring pre- and post-mowing, respectively (Figure 29). However, more entrances occurred during the post-mowing period in the sample, while more exits occurred during the pre-mowing period (Figure 29). In the sample, more deer approaches and peripheral deer activity occurred during the post-mowing period (Figure 33). Fewer estimated deer activities occurred during the post-mowing period than the pre-mowing period. Sixty-five estimated activities, including 26 entrances, 3 exits, 5 approaches, and 31 other activities, occurred during the post-mowing period, while 75 estimated activities, including 30 entrances, 21 exits, 4 approaches, and 20 other activities, occurred during the pre-mowing period. Numbers of deer hesitation behaviors observed in the sample were higher during the pre-mowing period than the post-mowing period, with 12 hesitation behaviors occurring pre-mowing and 8 occurring post-mowing. These results should be interpreted with caution, however, due to small sample sizes of deer hesitation behaviors during the pre- and post-mowing periods.

DISCUSSION

Wildlife and Human Use of the NHC Underpass

Wildlife species observed crossing through the underpass most frequently were deer, followed by humans, woodchuck, and unidentifiable medium-sized mammals. Most species represented in the footage were those commonly found in urban areas. Notably, one fox was observed but could not be identified by species. I observed one other canid, but could not determine whether it was a coyote (*Canis latrans)* or domestic dog. The species observed in the sample of video data were primarily diurnal because the spotlights used during the study were inadequate in lighting the entire width of the underpass entrances. Thus, if an animal walked through the portions of the underpass entrances that were illuminated, the animal would be observable. However, if the animal walked outside of the area illuminated by the spotlights, it would most likely not be detected. Therefore, the sample observed in the video footage represented a minimum of all wildlife activity at the NHC underpass.

Patterns of hourly wildlife crossings observed in the sample revealed that animals used the NHC underpass during periods of low human activity. More specifically, wildlife crossings began pre-dawn and decreased before humans became active at the site (Figure 42). Use then increased in the evening after human activity decreased. There was a weak negative correlation between hourly human activity and wildlife crossings, but the correlation was not significant ($r = -0.18$, $p>0.05$). Trends in hourly wildlife activity resembled those of hourly crossings, with activity beginning earlier in the morning than human activity, then tapering during periods of high human activity (Figure 43). Activity again increased in the evening when human activity dwindled, but there was some overlap in wildlife and human activity from 1500 to 1800 hrs. Whether the observed activity patterns of wildlife resulted from high levels of human activity at the bridge site remains unknown. The peak times of underpass use by wildlife may be partly explained by crepuscular activity patterns of species such as white-tailed deer and raccoons. As previously mentioned, 86% of deer crossings and approaches occurred within two hours of sunrise and sunset.

While the number of underpass entrances and exits by wildlife was not significantly different between the east and west sides of New Hope creek in the sample, more than twice as many activities within view of the camera, excluding entrances and exits, were observed on the west side of the creek than on the east side. More estimated wildlife activities occurred on the west side of NHC than the east side, with 350 estimated activities occurring on the west side and 207 estimated activities occurring on the east side. One possible explanation of the higher occurrence of wildlife activity on the west side of the creek is the presence of the powerline corridor that runs parallel to NHC on the west side of the creek. This powerline easement may be a travel route for deer and other animals between habitats located north and south of Highway 15/501. Deer were observed in the video footage frequently foraging as they traveled along the powerline corridor on the west side of the creek. While a powerline parallels the highway on the east side of New Hope Creek, the corridor stretches from New Hope Creek and ends next to a shopping center. Thus, proximity of the underpass to the shopping center located east of the NHC bridge may have deterred wildlife from being as active on the east side of the creek as the west.

Interestingly, estimated levels of human use were higher on the west side of NHC than the east side. Human activity was expected to be higher on the east side of the creek, due to close proximity to commercial and residential developments. Estimated levels of recreational activity were similar between the east and west sides of NHC, so greater human activity on the west side of the creek was accounted for by a higher occurrence of work-related activities.

Deer Use and Behavior at the NHC Underpass

From December 2003 to May 2005, an estimated 185 deer crossed through the underpass, and 18 deer were estimated to have approached the underpass before retreating. Thus, for every deer estimated to have approached and retreated from the underpass, approximately 10 deer crossed through the underpass. In the sample of video data, 75 deer were observed crossing through the underpass and 17 were observed approaching and retreating. Thus, the crossing-per-approach ratio in the sample revealed that for every deer that approached the underpass, approximately 4 deer crossed through the underpass. In a study of mule deer use of a 3.05-m tall x 3.05-m wide x 30.48-m long concrete box culvert, Reed et al. (1975) observed an approach-per-crossing ratio of 2.56, indicating that fewer deer entered the underpass than approached and retreated. Because more deer entered the NHC underpass than approached, deer apparently had adapted to using the underpass to circumvent

Highway 15/501 and were willing to use an underpass of such size and design. The estimated number of deer using the underpass in Reed et al. (1975) was much higher than the current study, however.

I expected deer use of the underpass to increase during the fall and early winter as a result of increases in movement during the rut. During the fall of 2004, only 9 deer were estimated to be active near the underpass. During the winter 2004/2005, 20 deer were estimated to be active near the underpass. Thus, overall deer activity near the NHC underpass was lowest during periods that are typically characterized by greater activity and movements (Puglisi et al. 1974, Allen and McCullough 1976). One explanation may be that rather than moving along the NHC corridor during the rut in late fall and early winter, deer generally used the NHC underpass more for the foraging opportunities available at the underpass than its location along a corridor. The median duration of deer activities during the fall of 2004 and winter of 2004/2005 was 5.4 minutes, suggesting that other factors may have affected underpass use during these seasons.

Decreases in underpass use by deer during the fall of 2004 and winter of 2004/2005 may have been influenced by the coincidence of deer hunting season, as hunting is prohibited in Duke Forest but permitted in the southern portions of the corridor in New Hope Game Lands located north of B. Everett Jordan Lake. The northern tip of New Hope Game Lands is approximately 0.3 km (0.5 mi) downstream from the NHC underpass. Therefore, decreases in deer movement along the section of the NHC corridor containing the NHC bridge during the fall of 2004 and early winter of 2005 could have been associated with concurrence of deer archery, muzzleloader, and gun seasons from approximately mid-September through December. While 16 deer crossings and approaches were observed in the sample of video data during the winter of 2003/2004, deer became active near the NHC bridge only after the conclusion of deer hunting season. Thus, deer use of the NHC underpass appeared to have decreased during hunting season. Decreases in deer observability during and following deer hunting season were reported by Sage et al. (1983). Human activity near the NHC underpass is not likely responsible for the observed decrease in deer activity during the fall of 2004 because human activity was lower during the fall of 2004 than all other seasons.

The number of deer moving north and south along the NHC corridor, as reflected by the number of underpass exits and entrances, respectively, was expected to be similar. In the sample of video data, over twice as many deer entered the underpass as exited. Over twice as many estimated entrances occurred than estimated exits. The difference in the number of underpass entrances and exits by deer was likely not due to undetected exits at night, as 46% of entrances and 48% of exits in the sample occurred between sunset and sunrise. One possible explanation for the difference between underpass entrances and exits by deer 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 would act as a source of deer, while the New Hope Game Lands and habitats associated with B. Everett Jordan Lake would act as a sink. The difference in the number of entrances and exits was likely not due to deer exiting the underpass and traveling out of view of the cameras more quickly than deer entering the underpass, as the median duration of events involving exits in the sample was 1.9 minutes, while the median duration of event involving entrances in the sample was 1.4 minutes.

Hourly deer crossings in the sample were highest during crepuscular periods. Similar peaks in activity were observed by Montgomery (1963). Michael (1970) found that feeding activity of deer was greatest during crepuscular periods, with small peaks occurring at noon and midnight. Deer activity generally began several hours before dawn and decreased before humans became active (Figure 44). Deer activity began increasing prior to sunset as human activity began to decrease, but there was overlap in deer and human activity near the NHC underpass from 1600 to 1800 hrs.

Twenty-seven percent of all deer observed crossing through or approaching the NHC underpass in the sample exhibited hesitation behaviors. In the sample, 18% of deer that approached or entered the underpass exhibited the look-up behavior, while 4% exhibited the tail-up behavior. Reed et al. (1975) observed that 24% of mule deer approaching or entering a 3.05-m tall x 3.05-m wide x 30.48-m long concrete box culvert exhibited the look-up behavior and few exhibited the tail-up behavior. In the sample, 43% of deer exiting the underpass exhibited reluctant behaviors. Reed (1981) found that trotting, bounding, or hesitating near the underpass exit was observed in 75% of exiting mule deer, suggesting that most deer observed were cautious or hesitant. The proportion of deer exhibiting hesitation behaviors at the NHC underpass was lower 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 the current study, however.

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. The willingness of deer to use the underpass and small proportion of hesitation behaviors observed may be due to the age of the bridge. Built in the 1950s, the bridge structure has offered at least five to 10 generations of deer an alternate route for reaching the opposite side of the highway. Young deer may begin using the underpass by following older individuals through the underpass. In one event during the summer of 2004, two fawns were observed entering the underpass with two adult-sized deer. Several events, judging by size of the individuals, appeared to involve adult and yearling deer. Thus, older deer experienced in crossing through the NHC underpass may lead younger deer through the underpass. Younger deer entering the underpass as they follow older deer may be less reluctant to enter the underpass compared to solitary, inexperienced deer encountering the underpass on their own.

Road Mortality and Animal-related Vehicle Collisions near the NHC Underpass

Road Mortality

Five vehicle-killed animals were observed on Highway 15/501 between Mt. Moriah and Garrett Roads between December of 2003 and June of 2005. Three mortalities occurred during the spring of 2005. Road mortality during spring of 2005 may be attributed to increases in movement during the spring associated with increased availability of new plant growth (Rongstad and Tester 1969, Puglisi et al. 1974, Reilly and Green 1974).

Five potential road crossings were observed during the study period, including two by deer and three by small mammals. All potential road crossings occurred on the west side of the creek, which coincided with a higher level of wildlife activity occurring on the west side of the creek. In addition, more road length was visible in the frame of the camera filming the west side of the creek than the east side, so potential road crossings occurring on the east side of the creek may have occurred outside of the view of the camera. All potential road crossings represented animals approaching or attempting to cross Highway 15/501 at the bridge site. While the camera view was limited to the length of the NHC bridge, and more road approaches likely occurred outside of the view of the camera, the number of road approaches and potential road crossings was low, considering the level of wildlife activity at the bridge site. Only 2.4% of the animals observed in the sample near the NHC underpass approached Highway 15/501, indicating that the underpass likely plays a role in diverting animals from the road.

Deer-related Vehicle Collisions

The NCDOT recorded 16 deer-related vehicle collisions between January 1, 1990 and October 30, 2004 on Highway 15/501 between Mt. Moriah and Garrett Roads. While Allen and McCullough (1976) found that vehicle speeds influenced the amount of damage inflicted on vehicles involved in DVCs, no such relationship was observed from the records of DVCs near the NHC underpass. Eighty-one percent of DVCs near the NHC underpass occurred during fall and winter. A higher occurrence of DVCs during fall and winter was observed by Allen and McCullough (1976) and Puglisi et al. (1974) and were attributed to increases in activity during the rut.

In the sample, 81% of DVCs occurring on Highway 15/501 between Mt. Moriah and Garrett Roads took place between 1800 and 0600 (Figure 37). Fritzen et al. (1995) found that road crossings by deer in Florida occurred most frequently between two hours after sunset to two hours before sunrise. Allen and McCullough (1976) found that DVCs occurred most frequently between 1600 and 0200, with peaks occurring at sunrise and one to two hours after sunset. While numbers of DVCs on the section of Highway 15/501 containing the NHC underpass increased after sunset, only two DVCs occurred from 0600 to 0800 hrs. Thus, an increase in DVCs around sunrise was not observed in my study.

Winter was the season with the second highest number of DVCs occurring on Highway 15/501 between Mt. Moriah and Garrett Roads, and had the highest proportion of deer road approaches. The increases in road approaches and DVCs during the winter may be related to decreased food availability. Deer may approach roads during this time to forage along ROWs. The duration of episodes involving deer road approaches during the winter of 2003/2004 ranged from 14.9 to 30.6 minutes, during which time deer were mainly observed foraging. The duration of the road approach that occurred during the spring of 2005 was 1.8 minutes. Thus, deer observed approaching the road during winter were foraging, while the road approach occurring during spring did not involve feeding activity. These results need to be interpreted with caution, however, since few road approaches were observed in the sample.

During the driving counts of deer in areas north and west of Highway 15/501, 10 vehicle-killed deer were observed from March 23, 2004 through May 31, 2005 (Table 10). Ninety percent of vehicle-killed deer were observed during the fall of 2004, winter of 2004/2005, and spring of 2005, but this needs to be interpreted with caution, as only 10 dead deer were observed. As previously mentioned, the occurrence of DVCs during the fall likely corresponded to increases in deer activity during the rut, while the DVCs occurring in winter may have been influenced by deer approaching roadways to forage. The number of vehicle-killed deer observed along the driving count during spring was likely influenced by increases in deer activity associated with dispersal and increases in plant growth during this time (Rongstad and Tester 1969; Puglisi et al. 1974; Reilly and Green 1974).

In an area with a large population of deer, as occurs in the broader areas surrounding the NHC bridge, 16 deer-related accidents over 14.8 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 pre-fencing mortality rate of 8.9 to 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 between Mt. Moriah and Garrett Roads per year. However, Romin (1994) estimated that only about 50 percent of DVCs are reported or documented, so the number of actual DVCs may be higher than the number reported. In the sample of video data, only 2.6% of deer observed near the underpass approached the highway. While many factors may 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 powerline and sewer corridors may 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, while the early successional habitat in utility corridors provides deer with foraging opportunities away from the road. Thus, there may 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 may help to funnel deer toward the underpass. While the steep slopes are in no way barriers to deer movement, decreased visibility past the top of the slopes may deter deer from crossing the road. The presence of guardrails at the top of the slopes may further decrease the ability of deer to see past the top of the slopes. Carbaugh et al. (1975) suggested that guardrails may act as visual barriers to deer when located on top of inclines.

Deer Abundance Index

During the 53 driving counts of deer conducted between March 23, 2004 and May 31, 2005, 34% of deer were observed during the fall of 2004 and winter of 2004/2005 (Figure 38). The number of deer observed during the fall of 2004 and winter of 2004/2005 is of interest because overall deer activity occurring near the underpass in the sample decreased during the fall of 2004 and winter of

2004/2005, while the number of deer observed during the driving count did not decrease greatly during this time. Thus, decreased activity near the underpass was not likely due to lower numbers of deer in the vicinity, but rather changes in movement patterns along the NHC corridor.

Over 87 percent of deer along the driving route were observed in residential yards, fields, powerline corridors, edges between woods and fields or yards, and roadside (Figure 39). The low proportion of deer observed in wooded habitats may be due to lower visibility of deer in woods from spring through fall. Carbaugh et al. (1975) observed more deer in fields than wooded areas, and suggested that the differences in observed deer may be accounted for by increased visibility of deer in open areas.

Effects of Vegetation Alteration on Wildlife Use of the Underpass

Wildlife use of the underpass decreased following mowing at the NHC underpass, as did overall wildlife activity near the bridge site. Estimated deer crossing rates decreased between the pre- and post-mowing periods by 41%. While fewer deer crossings occurred during the post-mowing period than the pre-mowing period, the number of deer observed along the driving count during these seasons did not decrease greatly. On the surface, decreases in deer crossings and overall wildlife activity may suggest that crossings by deer and other wildlife decreased after mowing at the underpass. These results, however, may be misleading because use of the underpass by deer and other wildlife, and wildlife activity observed in the sample near the underpass, was low during the fall of 2004 before the vegetation near the underpass entrances was cut. For deer and other wildlife in the sample, there was less overall activity near the underpass during the fall of 2004 before mowing than during the winter of 2004/2005 after mowing. These data indicate that some other factors not measured by this study influenced deer use of the underpass during these times.

White-tailed deer are extremely adaptable creatures. They continue to exist in high numbers along the New Hope Creek corridor, despite increasing urbanization. Because the vegetation at the bridge site rebounded to approximately pre-mowing height during late spring following mowing, the effects of mowing were likely of short duration. Thus, deer and other wildlife may not have been adversely affected by mowing at the underpass. In general, vegetation may increase attractiveness of underpasses to wildlife, decreasing the incentive for animals to approach roadways to feed. However, number of deer road approaches did not increase following mowing. Eighty percent of observed road approaches by deer occurred during the winter of 2003/2004 before any alterations of the vegetation were made, while 20 percent occurred during the spring of 2005 following mowing. Additional road approaches may not have occurred within view of the cameras or were not detected in the video footage. The road approaches occurring during the winter of 2003/2004 ranged from 14.9 to 30.6 minutes in length, during which time deer mainly foraged. Thus, deer foraged along the roadside during the winter of 2003/2004 despite the presence of vegetation near the underpass entrances. These results suggest that mowing vegetation at the NHC underpass did not adversely affect deer use of the underpass. However, few underpass crossings by deer occurred during the fall of 2004 and winter of 2004/2005. In addition, mowing during other seasons may influence deer use of the underpass differently than mowing during winter.

Vegetation may play an important role in the attractiveness of underpasses to wildlife. Vegetation is thought to enhance the appearance of underpasses by making such structures appear more natural to animals (Ruediger 2001). In addition, vegetation near underpasses provides foraging opportunities and cover. Foraging opportunities created by vegetation near underpass entrances may decrease incentives for animals such as deer to approach roads to feed. Cover may be important in facilitating wildlife use of underpasses by providing protection for approaching animals (Little et al. 2002, Clevenger and Waltho 2005), which may be particularly important for sensitive species such as forest interior specialists that may be reluctant to enter open areas (Goosem et al. 2001).

CONCLUSION

Hubbard et al. (2000) suggested that creating bridges that function as wildlife underpasses where bridges must be incorporated into road design may 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. Although the current bridge has been considered to be inadequate for terrestrial wildlife movement (Hall and Sutter 1999), the bridge is frequently used by terrestrial mammals to move under the highway. Few animals were observed approaching the highway in the sample of video footage, and surveys of vehicle-killed animals on Highway 15/501 between Mt. Moriah and Garrett Roads revealed that wildlife road mortality is low through this section of highway. Deer appeared willing to use the underpass, as only 27 percent of deer observed entering, exiting, or approaching the underpass in the sample exhibited behaviors associated with hesitation or reluctance.

Sixteen DVCs were reported along this section of Highway 15/501 between January 1, 1990 and October 30, 2004. During the study period from December 2003 through May 2005, 195 deer were observed near the NHC bridge in the sample and 310 were estimated to be active near the underpass. Compared to the observed and estimated numbers of deer near the NHC underpass during the study period, the number of DVCs occurring on this section of Highway 15/501 was relatively low, averaging 1.1 DVCs per year. While many factors may have contributed to the low rate of DVCs on the section of Highway 15/501 containing the NHC bridge, the underpass provided deer with an alternate route for accessing habitat on the opposite side of the highway without crossing onto the highway. Deer underpass crossings observed at the NHC underpass constituted a sample of 75 and an estimate of 185 instances during which deer reached habitat on the far side of the highway without crossing onto the road. Thus, the NHC underpass likely plays a role in the low number of DVCs occurring along the section of Highway 15/501 containing the underpass.

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. Wildlife underpasses can lessen the negative impacts of roads on wildlife by maintaining landscape connectivity and reducing the numbers 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. Although not designed to facilitate movement of animals under the road, the Highway 15/501 bridge over New Hope Creek functions as a wildlife underpass, providing landscape connectivity and likely increasing motorist safety by decreasing the necessity of deer to cross the highway.

RECOMMENDATIONS

Future New Hope Creek Underpass Study

Animals will require time to habituate to the new bridge. The current bridges were built in 1951 and 1955, so animals have had many generations to habituate to the underpass structure. It is imperative that sufficient time passes between the conclusion of construction of the new bridge and the future NHC underpass study so that the results are not confounded by unfamiliarity of wildlife to the new bridge. At least one growing season should pass between conclusion of construction and the beginning of the future NHC underpass study in order for vegetation to colonize the former construction areas at the underpass. In addition, construction-related human activities at the site may impact wildlife use of the underpass, so the future NHC study should commence after construction-related human activities at the site have concluded.

Fencing

While Garrett (2001) recommended that fencing be installed along the four quadrants of the NHC underpass to prevent deer from crossing onto the highway and funnel wildlife toward the underpass, the willingness of deer to use the NHC underpass and relatively low rate of DVCs for this section of Highway 15/501 suggests that fencing may not be cost effective. As previously mentioned, fencing is costly and requires regular maintenance to be effective in preventing deer from entering roadways. Deer easily jump over low sections of fencing, such as those that occur when trees fall on fences (Falk et al. 1978), and readily cross under gaps where fencing meets the ground (Falk et al. 1978, Feldhamer et al. 1986). Therefore, fencing will not be effective unless it is regularly maintained, which increases the overall costs. Reed et al. (1982) recommended a cost-benefit ratio of 1.36 for mitigation techniques. This ratio corresponds to the following number of pre-fencing deer deaths resulting from DVCs per 1.6 km (1 mi) per year: eight for fencing on only one side of the road, 16 for fencing on both sides of the road, and 24 for fencing on both sides of a road with an underpass. In the records of DVCs occurring in the 1.8 km (1.1 mi) between Mt. Moriah and Garrett Roads, only 16 DVCs were reported between January 1, 1990 and October 30, 2004. Using the estimates provided by Reed et al. (1982), fencing along Highway 15/501 near the NHC underpass will likely not be cost effective on a purely economic basis. Installing fencing after construction of the future NHC bridge will increase the costs of mitigating DVCs, while providing few, if any, benefits in addition to those created by the future NHC underpass. However, human safety issues will ultimately determine whether fencing should be installed at the NHC underpass. If fencing is not installed, the fill slopes leading up to the highway should be steep after construction, such as the slopes that are currently in place, to deter deer from crossing the road. Steep inclines may funnel deer toward the underpass and decrease the ability of deer to see past the top of slopes. Guardrails may further limit the ability of deer to see past the top of the fill slopes (Carbaugh et al. 1975). Carbaugh et al. (1975) cited decreased visibility caused by the presence of guardrails at the top of inclines as affecting the locations and manner in which deer crossed highways.

In addition to the expenses associated with fencing, fencing may confound the results of the future study of wildlife use of the NHC underpass if fencing is installed before the study commences.

Vegetation

The future NHC underpass study should begin after vegetation has colonized the underpass entrances, which may provide deer and other wildlife with foraging opportunities and cover. If vegetation will be planted at the underpass entrances, native species should be used to prevent infiltration of exotic or invasive species into the forests upstream and downstream of the NHC bridge.

Human Use of the Underpass

Careful considerations need to be made for both wildlife and human needs if greenway trails will be constructed through the underpass on the east and west sides of the creek. Unkempt, naturally growing vegetation may not be as aesthetically pleasing for humans as manicured vegetation, but likely is preferred by wildlife. Human safety is also an issue. Tall, dense vegetation will decrease visibility near the underpass for humans, but such vegetation may entice wildlife toward the underpass.

As per recommendations of Reed et al. (1975) and Garrett (2001), lights should not be installed in the underpass to deter human use during periods when animals readily use the NHC underpass. As previously mentioned, wildlife use of the NHC underpass occurred earlier in the morning and later in the evening than human activity. Whether these trends in wildlife activity resulted from human activity or were independent of human presence at the underpass remains unknown.

Barriers such as wood piles or solid fencing should be installed between greenway trails and wildlife crossing areas to decrease visual disturbances and physical interactions between wildlife and humans (Garrett 2001). Phillips et al. (2001) found visual barriers to be effective in reducing human disturbance of wildlife near underpasses.

Off-road vehicle (ORV) use of the area may increase with trails that are 12 feet (3.65 m) wide, especially if these trails are paved. Two occurrences of ORV use were observed in the video footage near the NHC underpass, with both instances occurring on the west side of NHC. Barriers should be placed at trail entry points to permit access by pedestrians and bicyclists but prohibit access to trails by ORVs.

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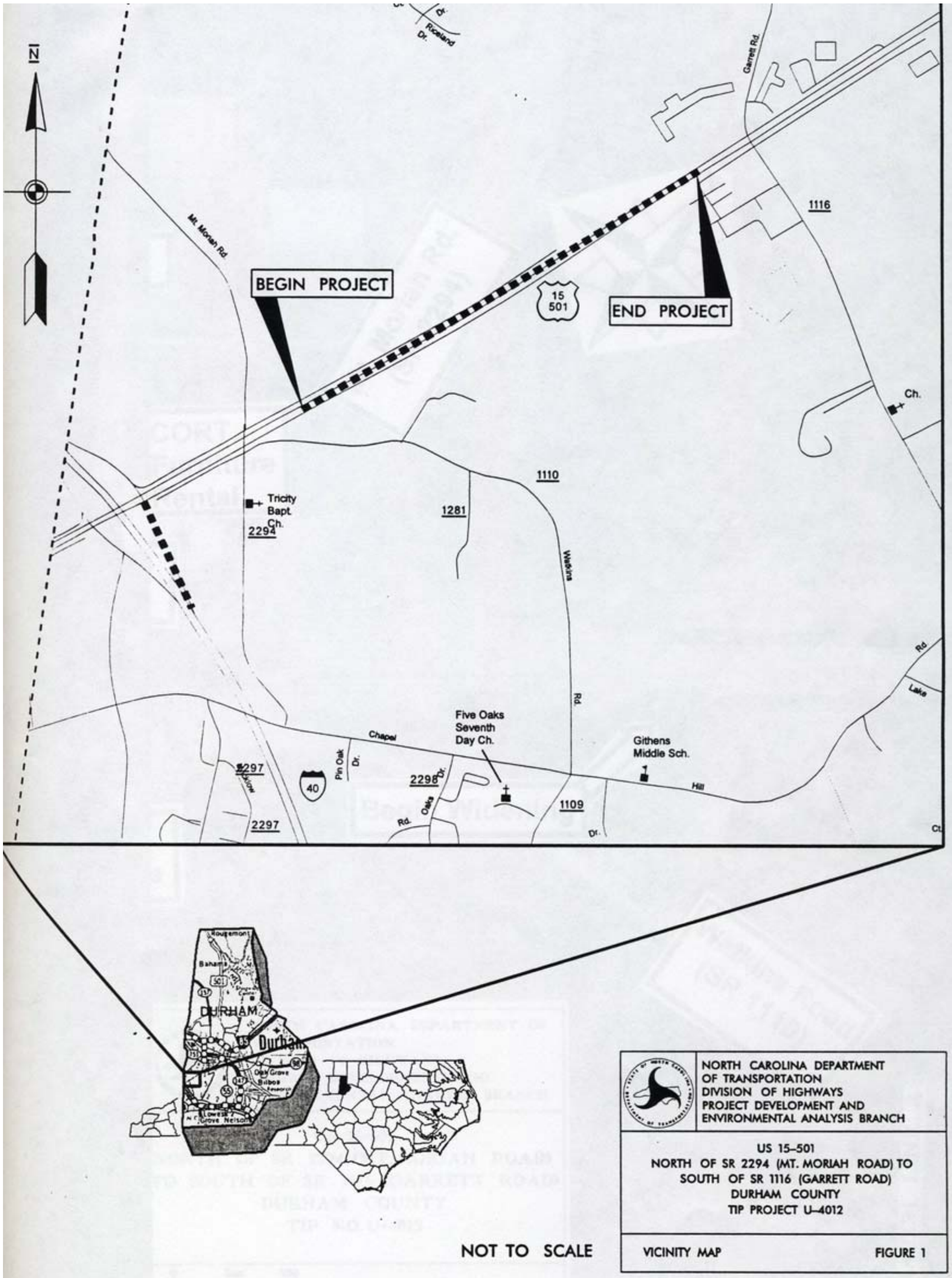

Figure 1. Map of the section of Highway 15/501 slated to be upgraded from four to six lanes (NCDOT 2003).

Figure 2. Photograph of the section of Highway 15/501 containing the NHC underpass (image from Google Earth).

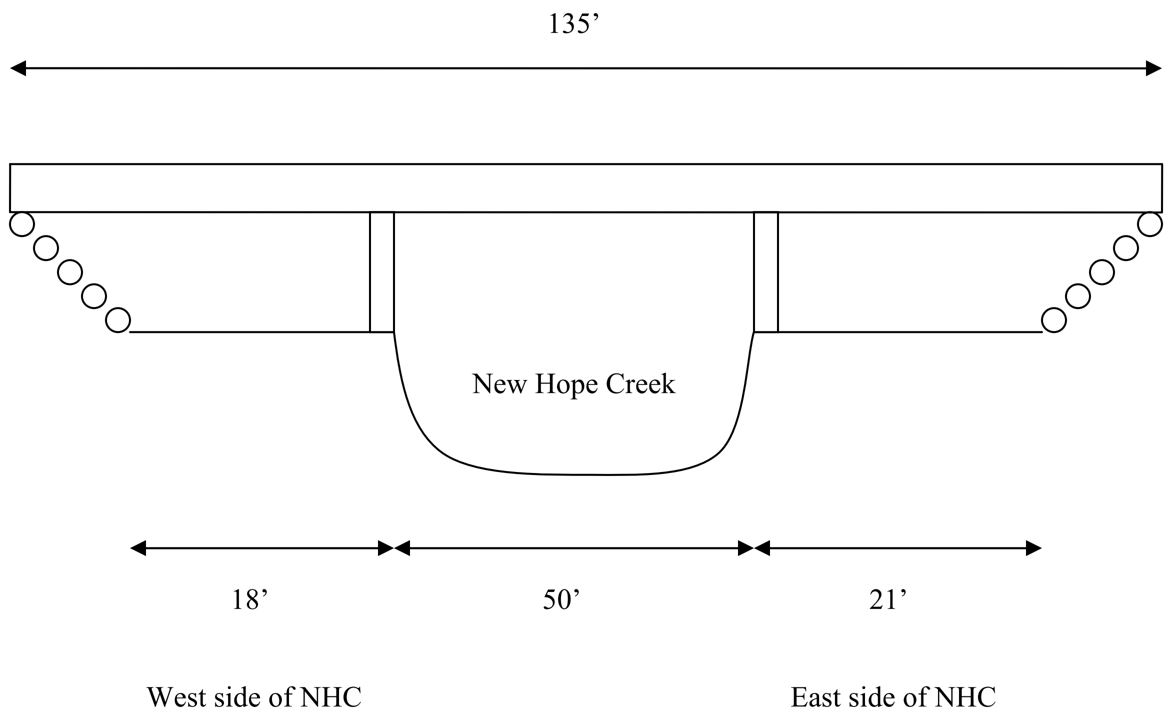

Figure 3. Diagram of the current NHC bridge (NCDOT 2001).

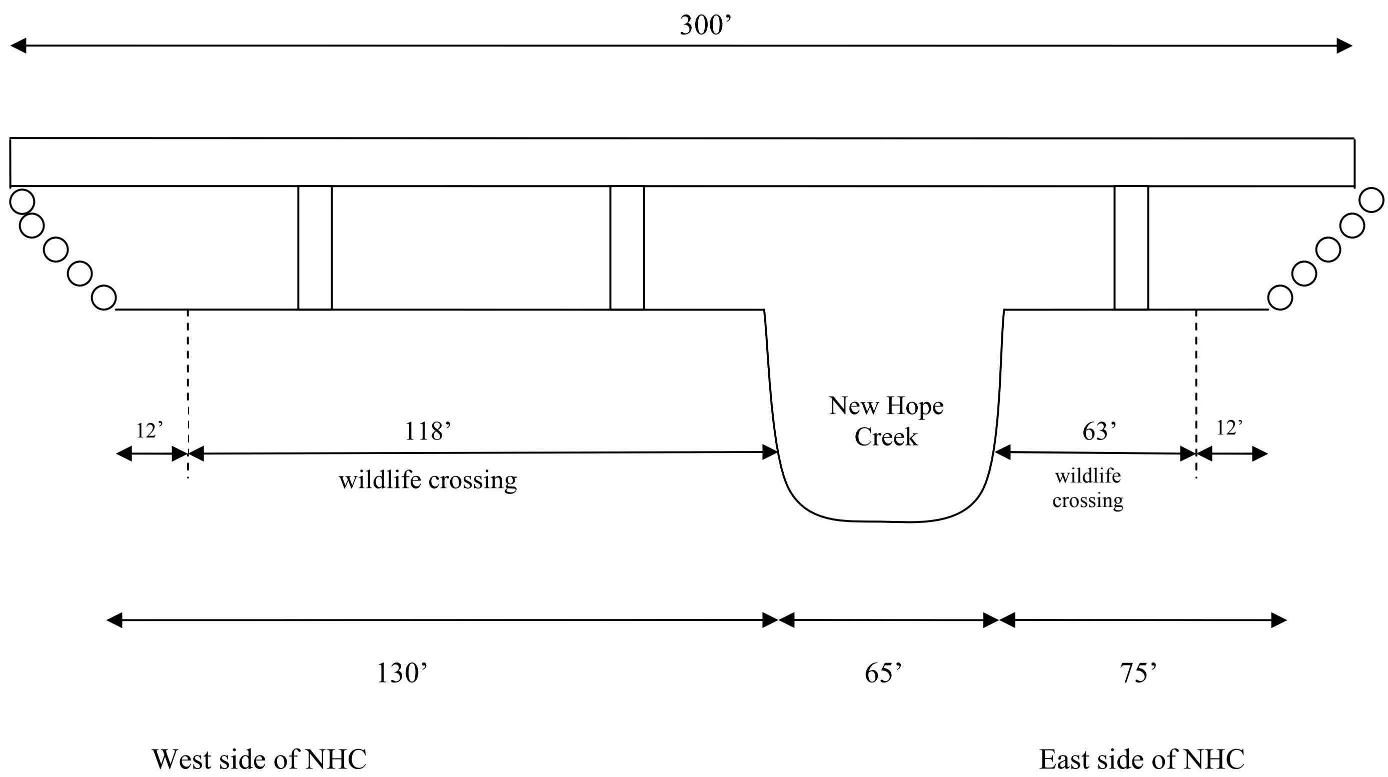

Figure 4. Diagram of the future NHC bridge. Twelve feet on both sides of the creek will be dedicated to greenway trails (NCDOT 2003).

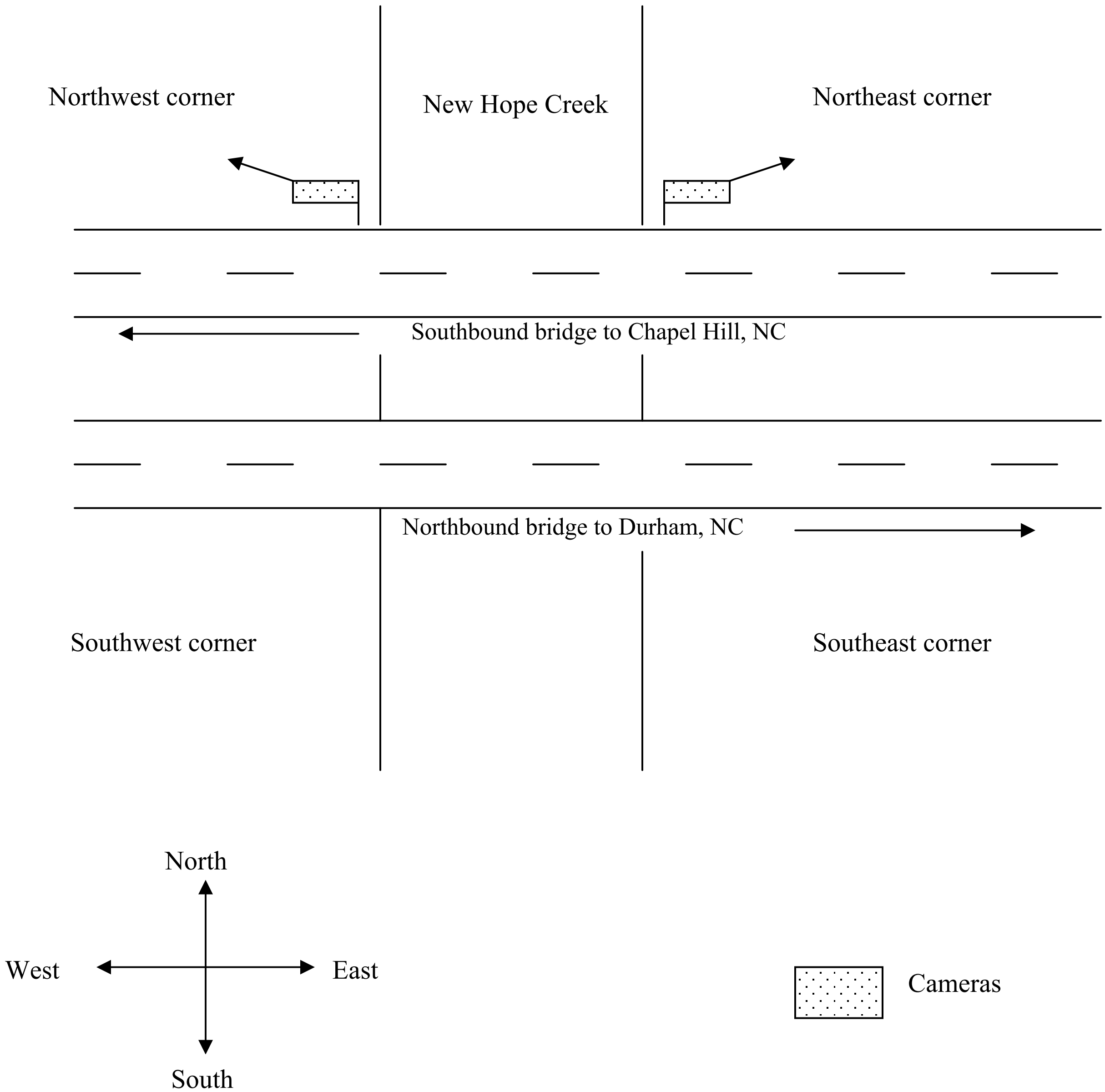

Figure 5. The northeast and northwest corners of the underpass were filmed.

Figure 6. Cameras mounted on the north side of the southbound bridge.

Photo courtesy of Derry Schmidt

Figure 7. Close-up picture of camera monitoring the northeast corner of the underpass.

Photo courtesy of Derry Schmidt

Figure 8. Digital video recorder and batteries located on top of the pillars of the NHC bridge.

Figure 9. Solar panels installed in the open median of the NHC bridge.

Figure 10. Field of view for Camera 1 on the northeast corner of the NHC underpass.

Figure 11. Field of view for Camera 2 on the northwest corner of the NHC underpass.

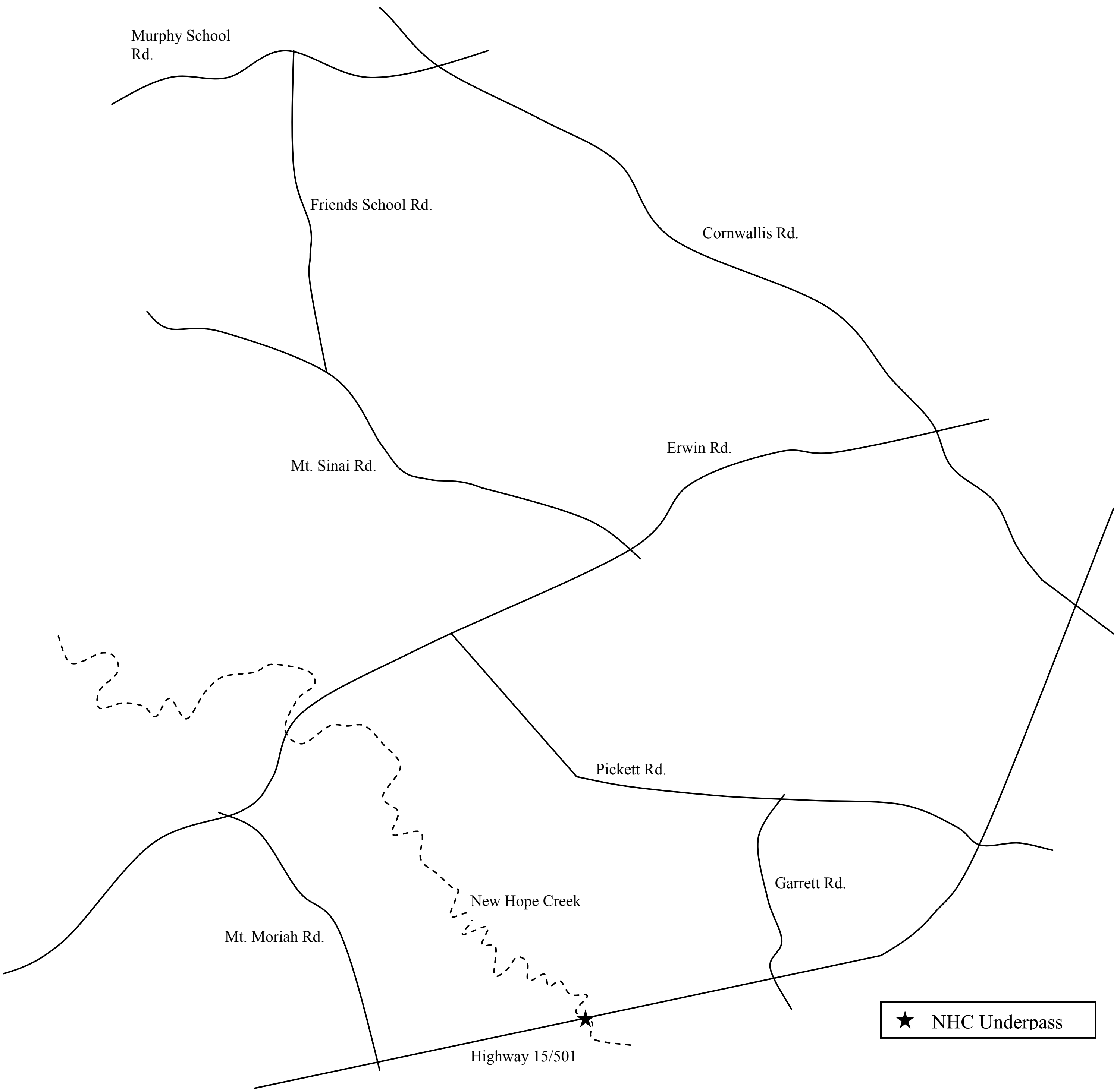

Figure 12. Map of the 24 km driving route along which deer counts were conducted. (Map not drawn to scale.)

Figure 13. Eastern aspect of powerline and sewer corridors north of the NHC underpass.

Figure 14. Eastern aspect of the sewer corridor south of the NHC underpass.

Figure 15. Camera view of the northeast corner of the underpass prior to mowing.

Figure 16. Camera view of the northeast corner of the underpass following mowing.

Figure 17. Camera view of the northwest corner of the underpass prior to mowing.

Figure 18. Camera view of the northwest corner of the underpass following mowing.

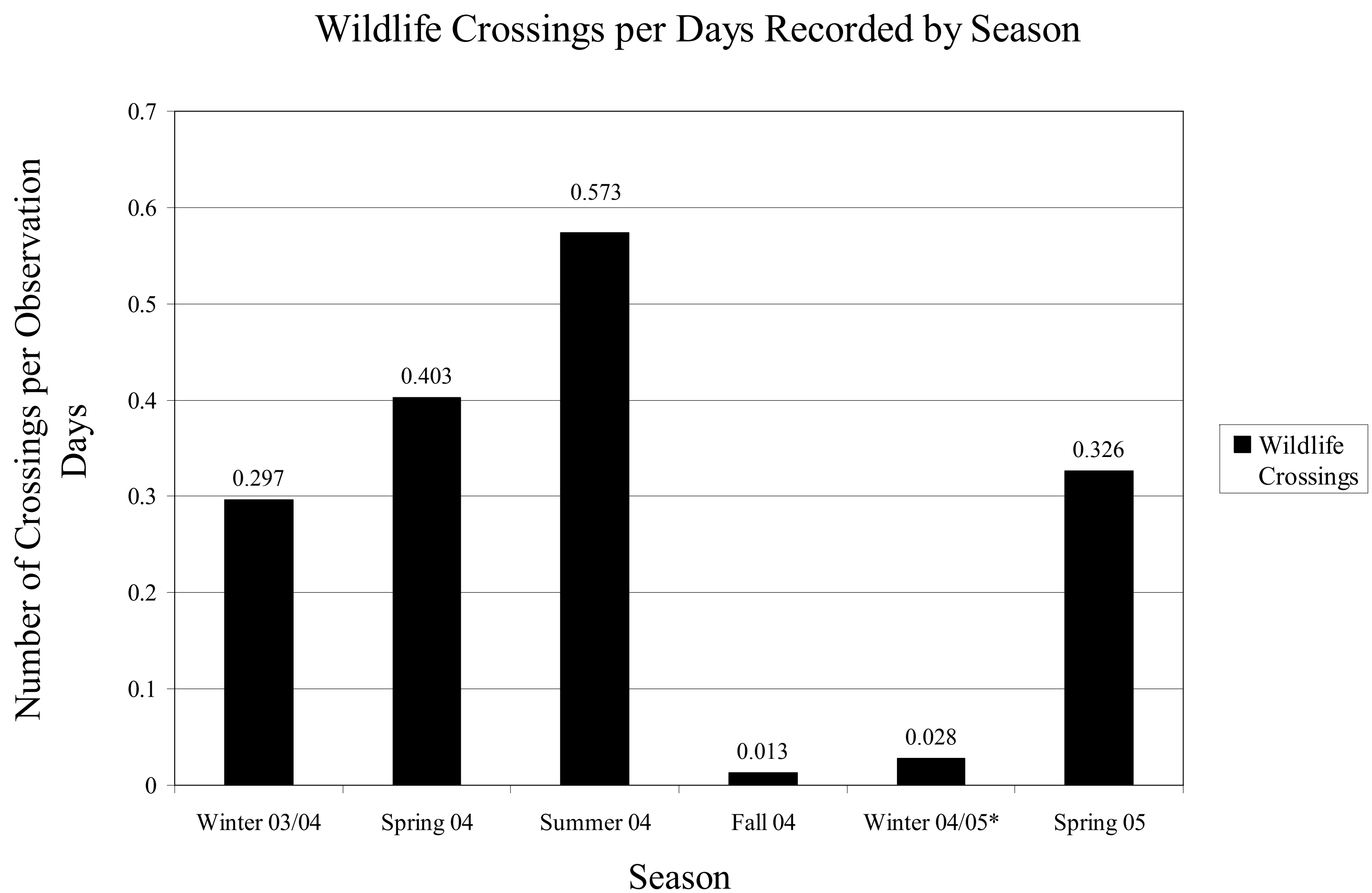

Figure 19. Number of wildlife crossings observed in sample of video data per days recorded by season.
* Vegetation was cut at the underpass during the winter of 2004/2005.

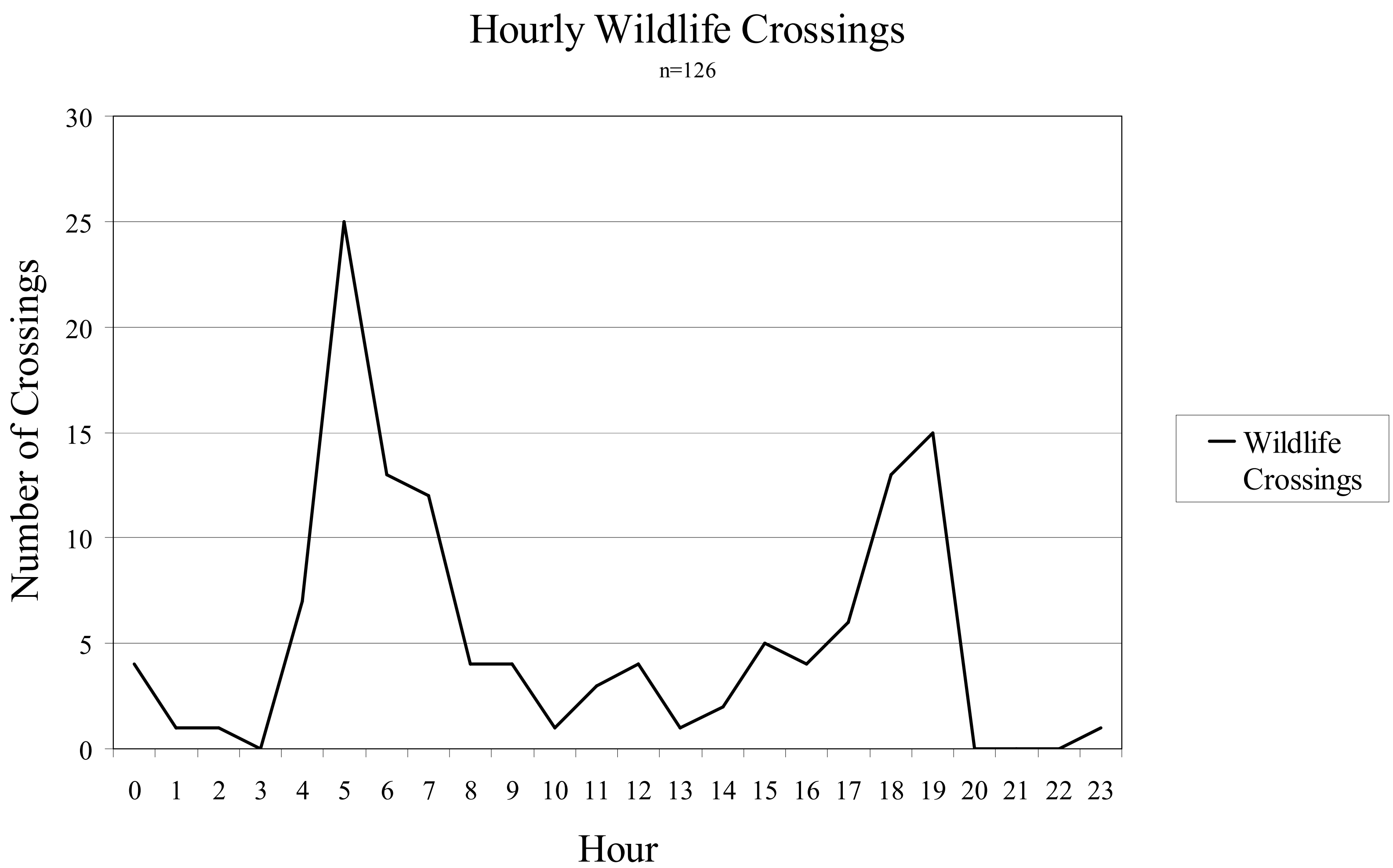

Figure 20. Hourly wildlife crossings observed in the sample of video data at the NHC underpass.

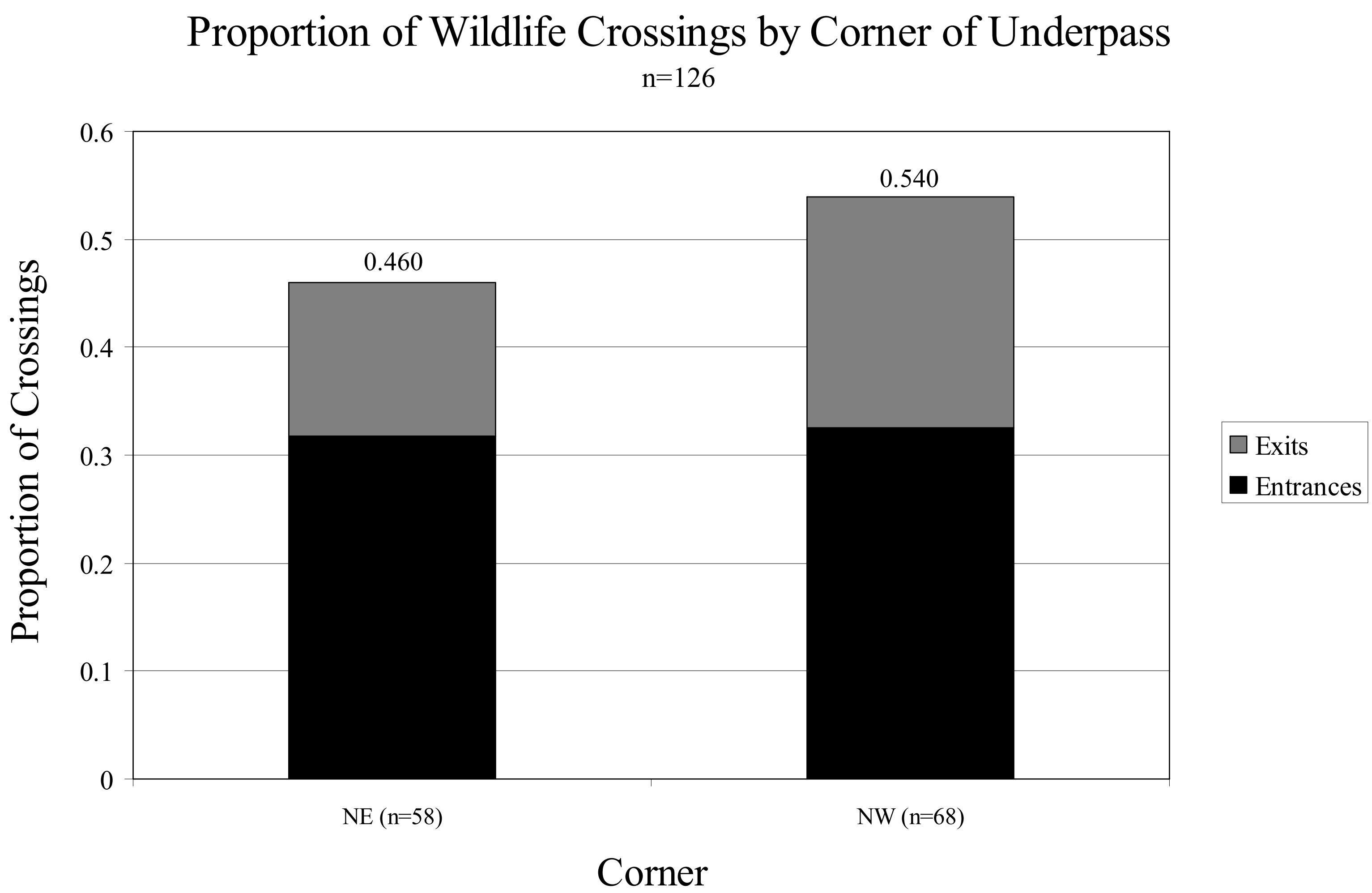

Figure 21. Proportions of wildlife crossings observed in the sample of video data at the NHC underpass by corner.

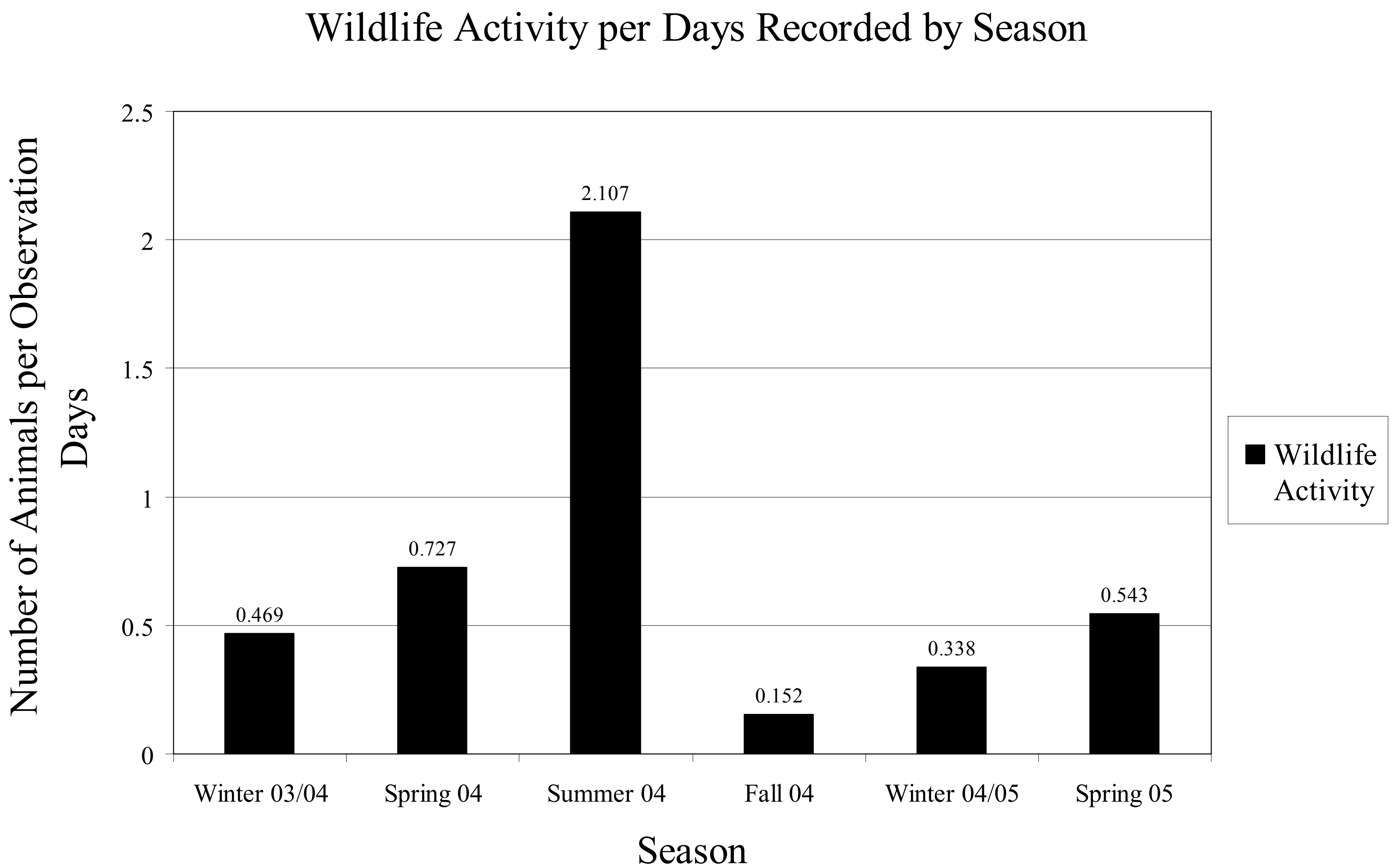

Figure 22. Wildlife activity observed in the sample of video data per days recorded by season.

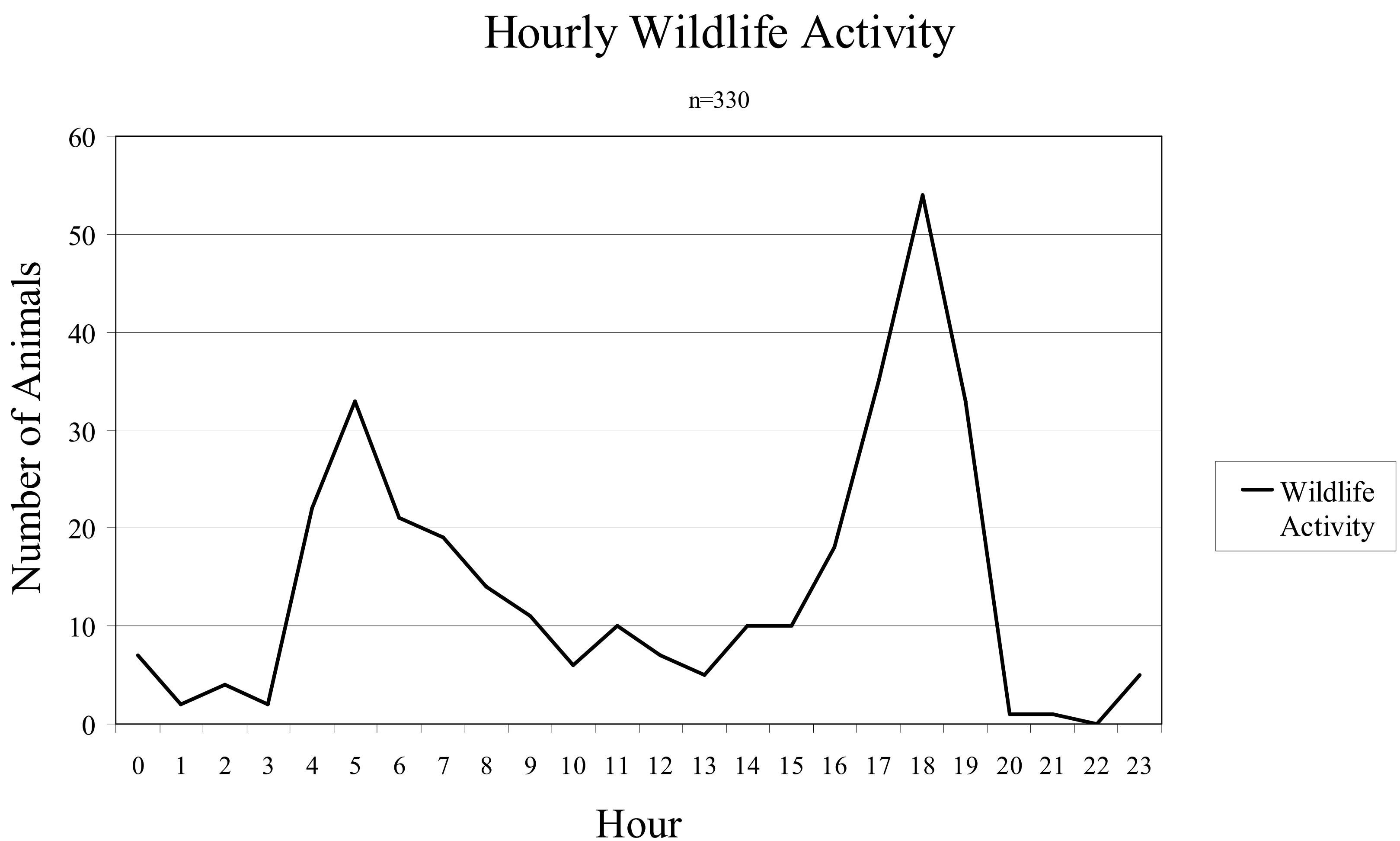

Figure 23. Hourly wildlife activity observed in the sample of video data at the NHC underpass.

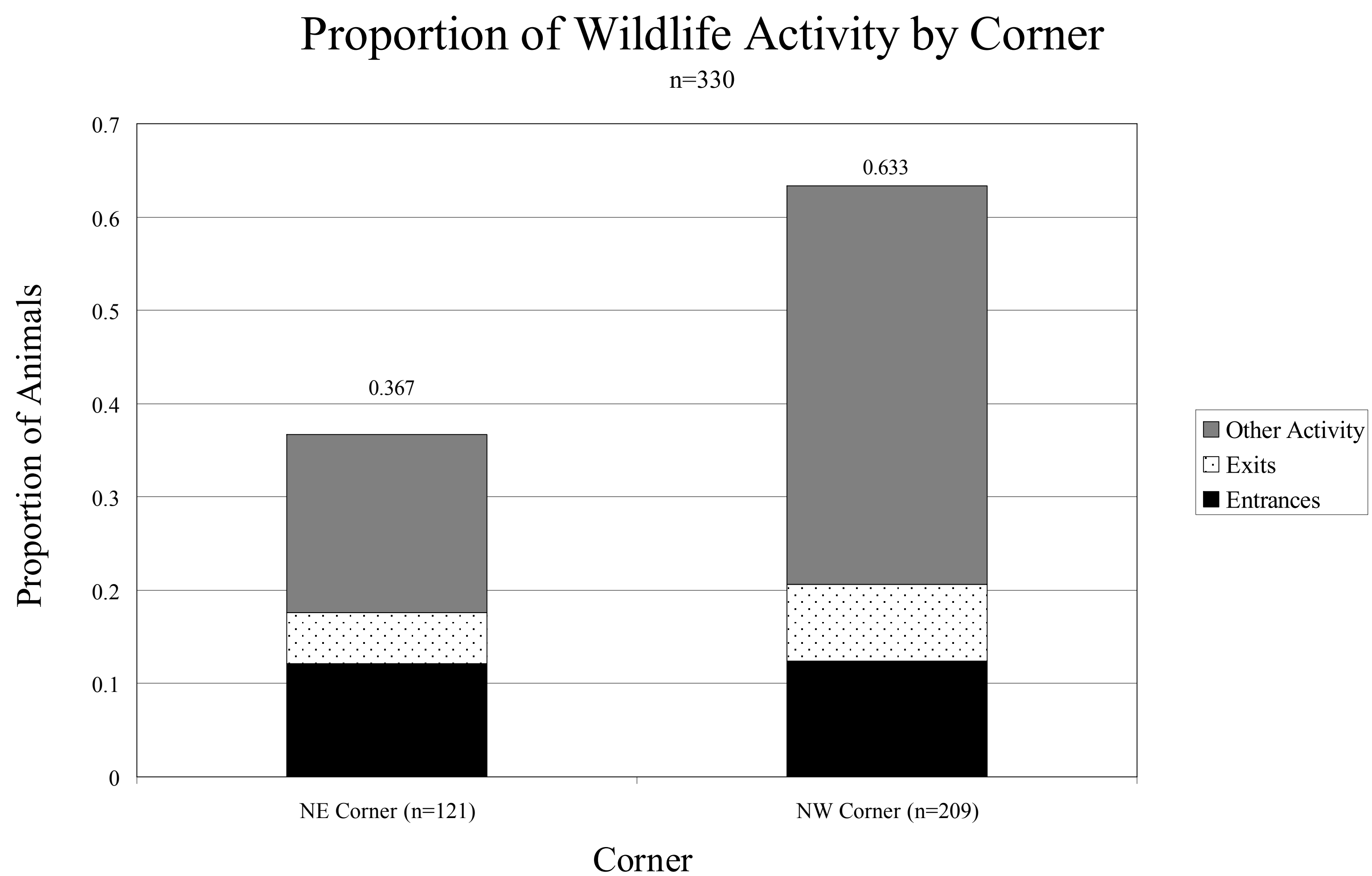

Figure 24. Proportions of wildlife activity observed in the sample of video data at the NHC underpass by corner.

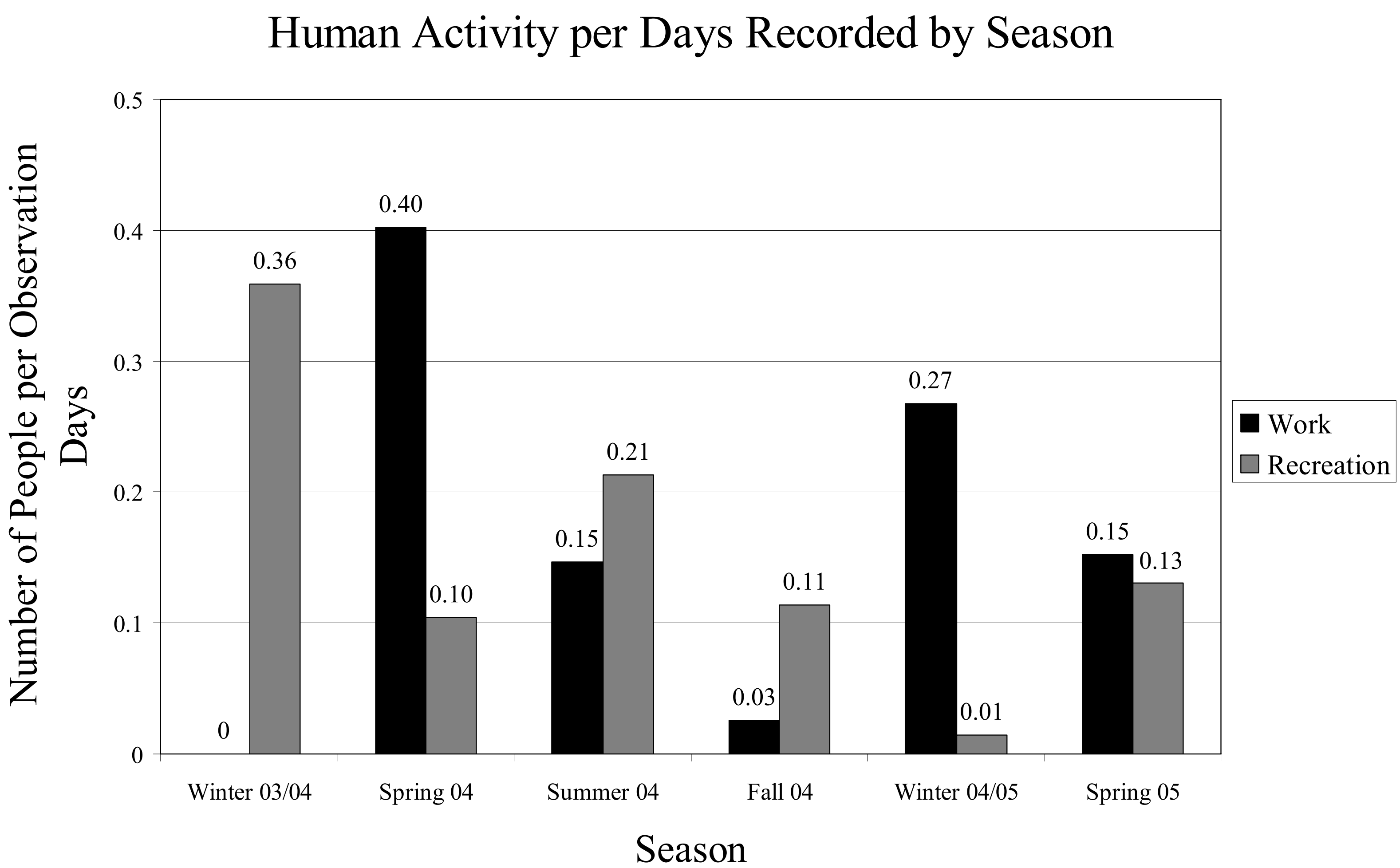

Figure 25. Human activity observed in the sample of video data per days recorded by season.

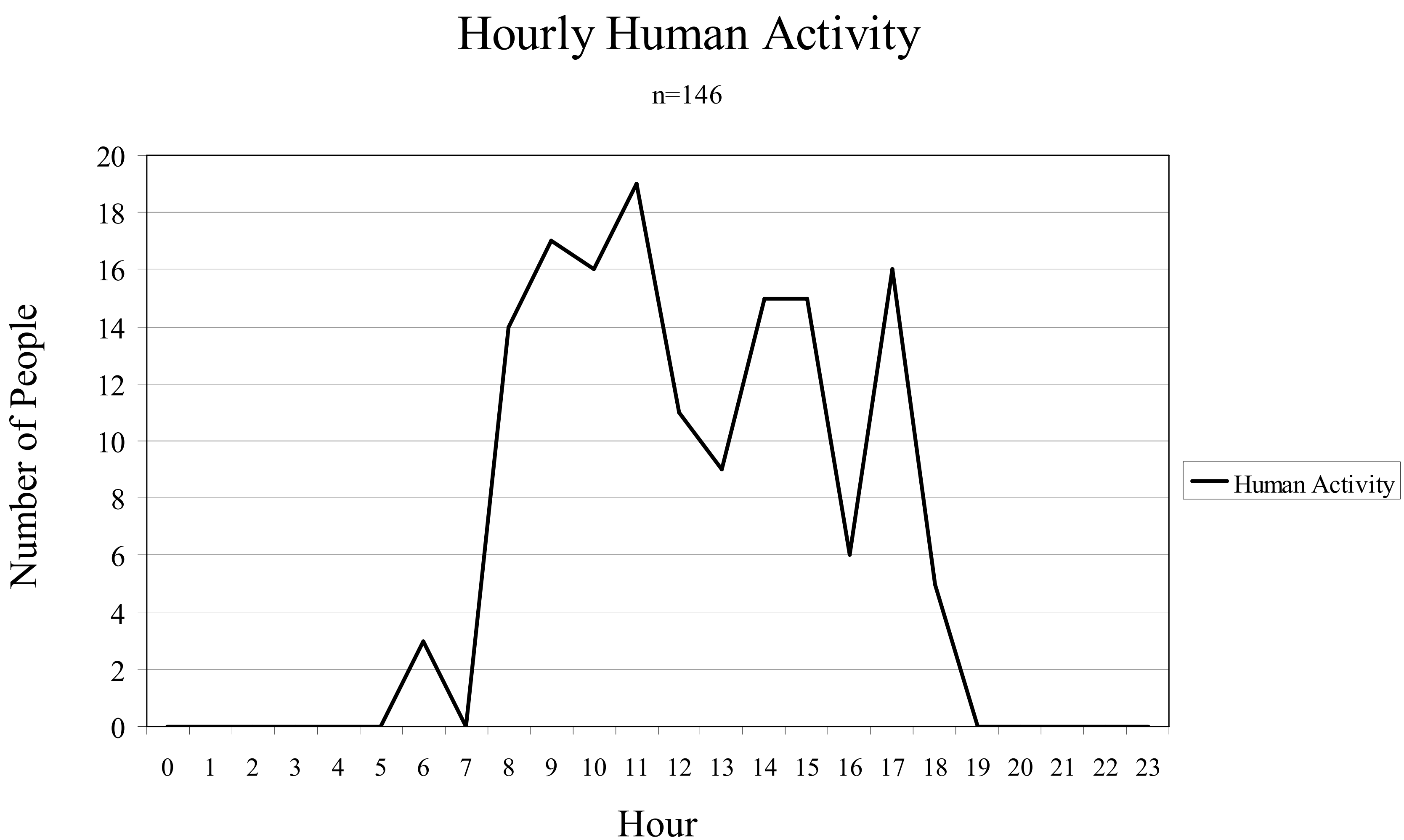

Figure 26. Hourly human activity observed in the sample of video data at the NHC underpass

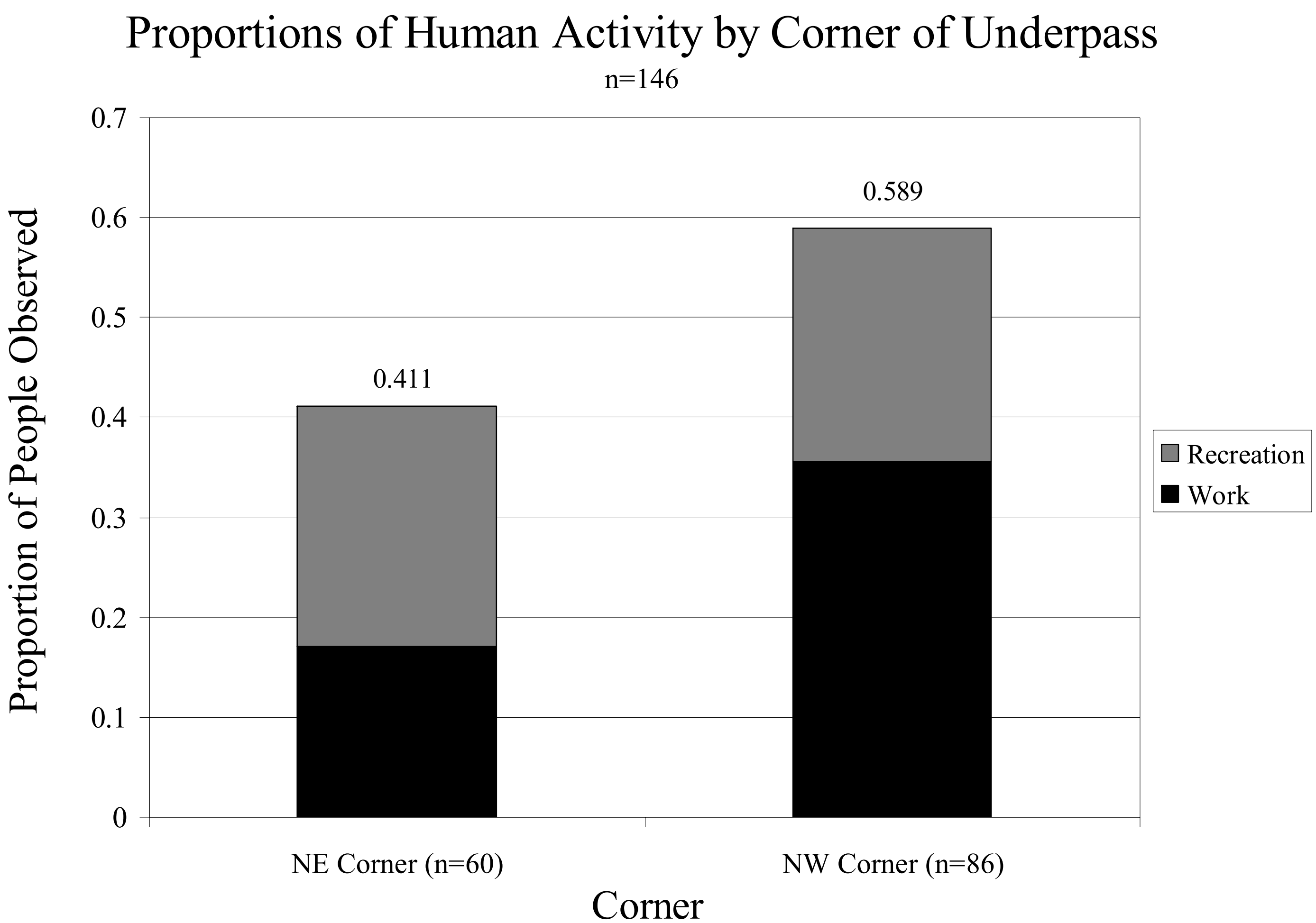

Figure 27. Proportions of human activity observed in the sample of video data at the NHC underpass by corner.

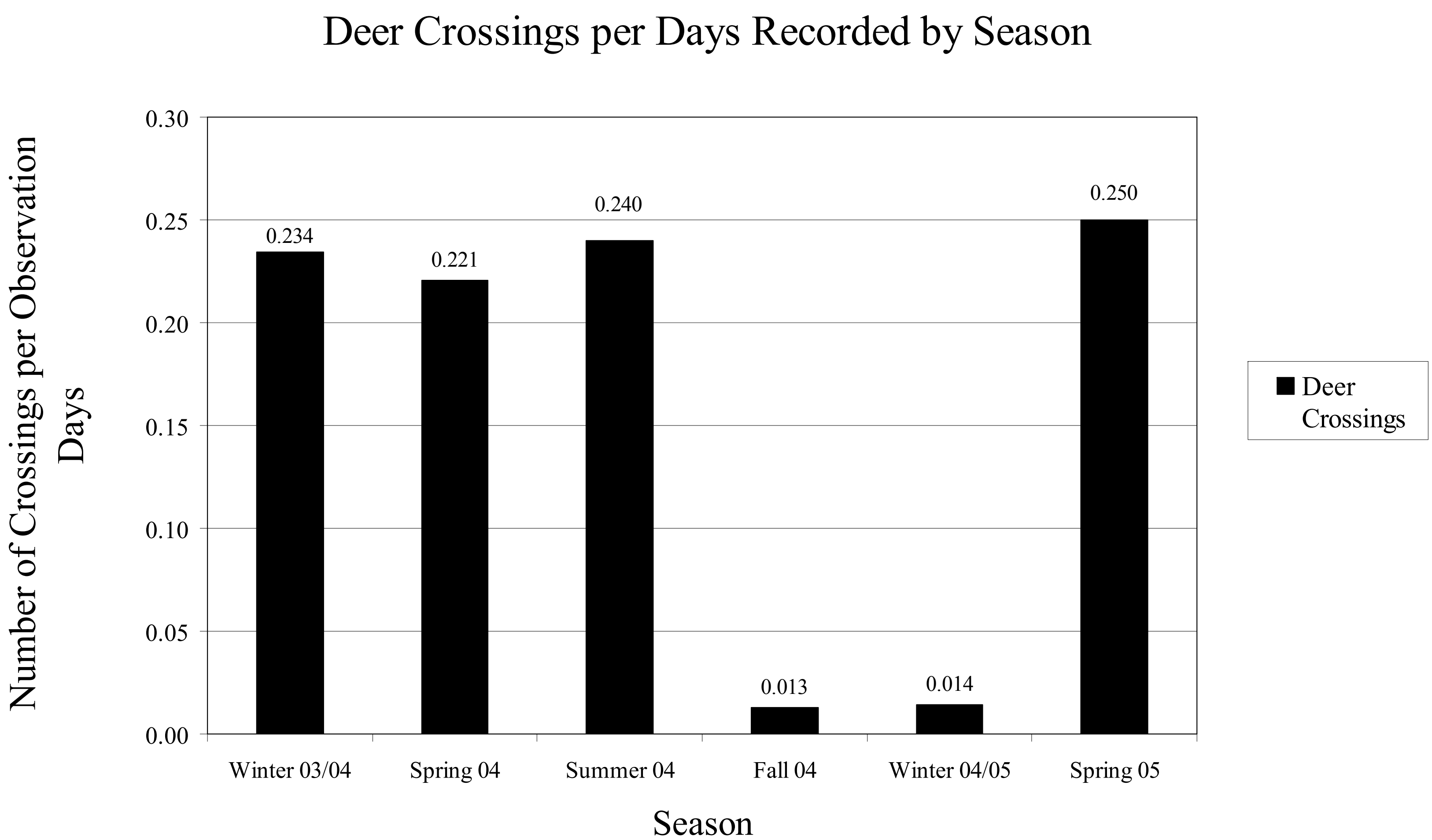

Figure 28. Deer crossings observed in the sample of video data per days recorded by season.

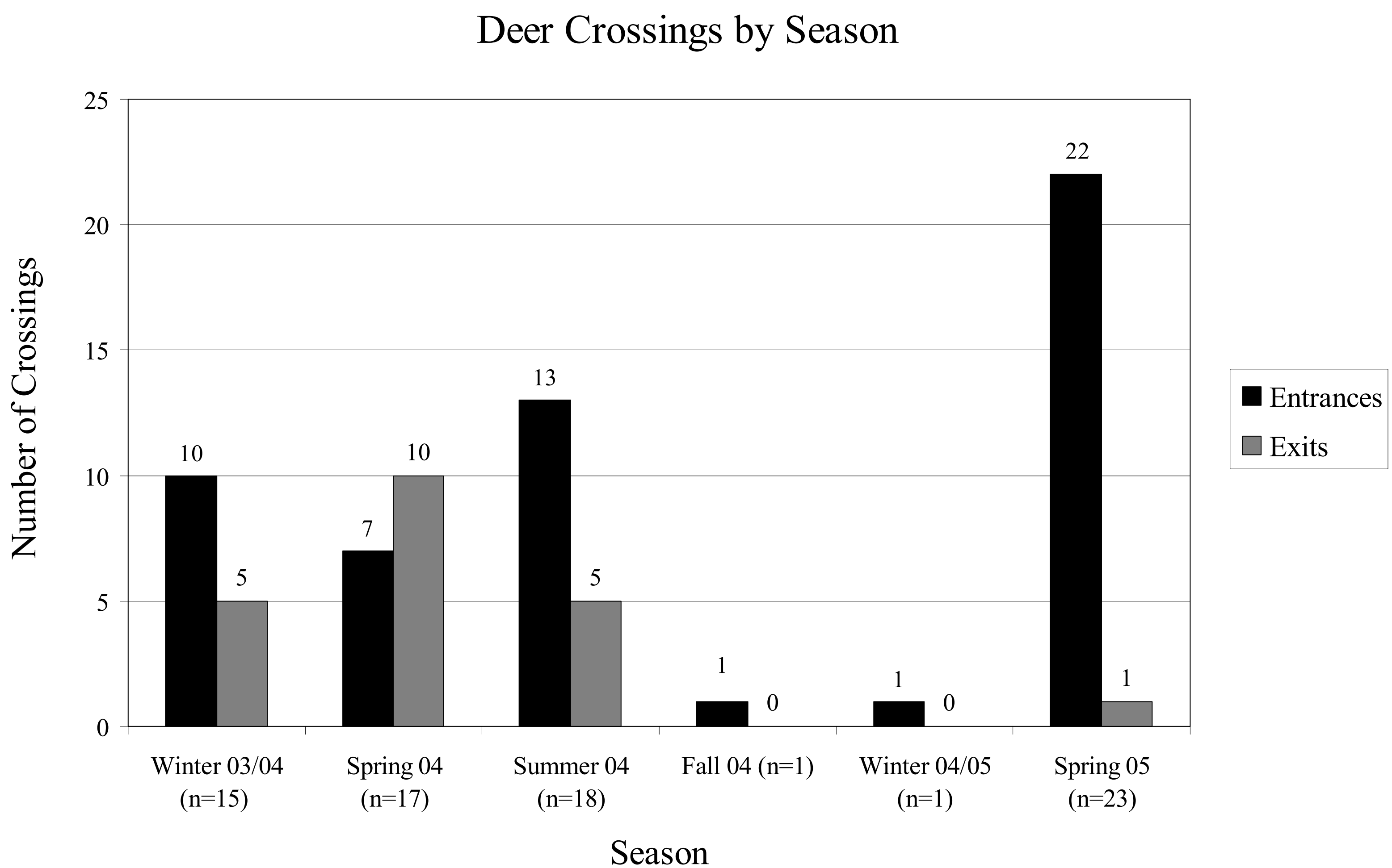

Figure 29. Deer crossings observed in the sample of video data at the NHC underpass by season.

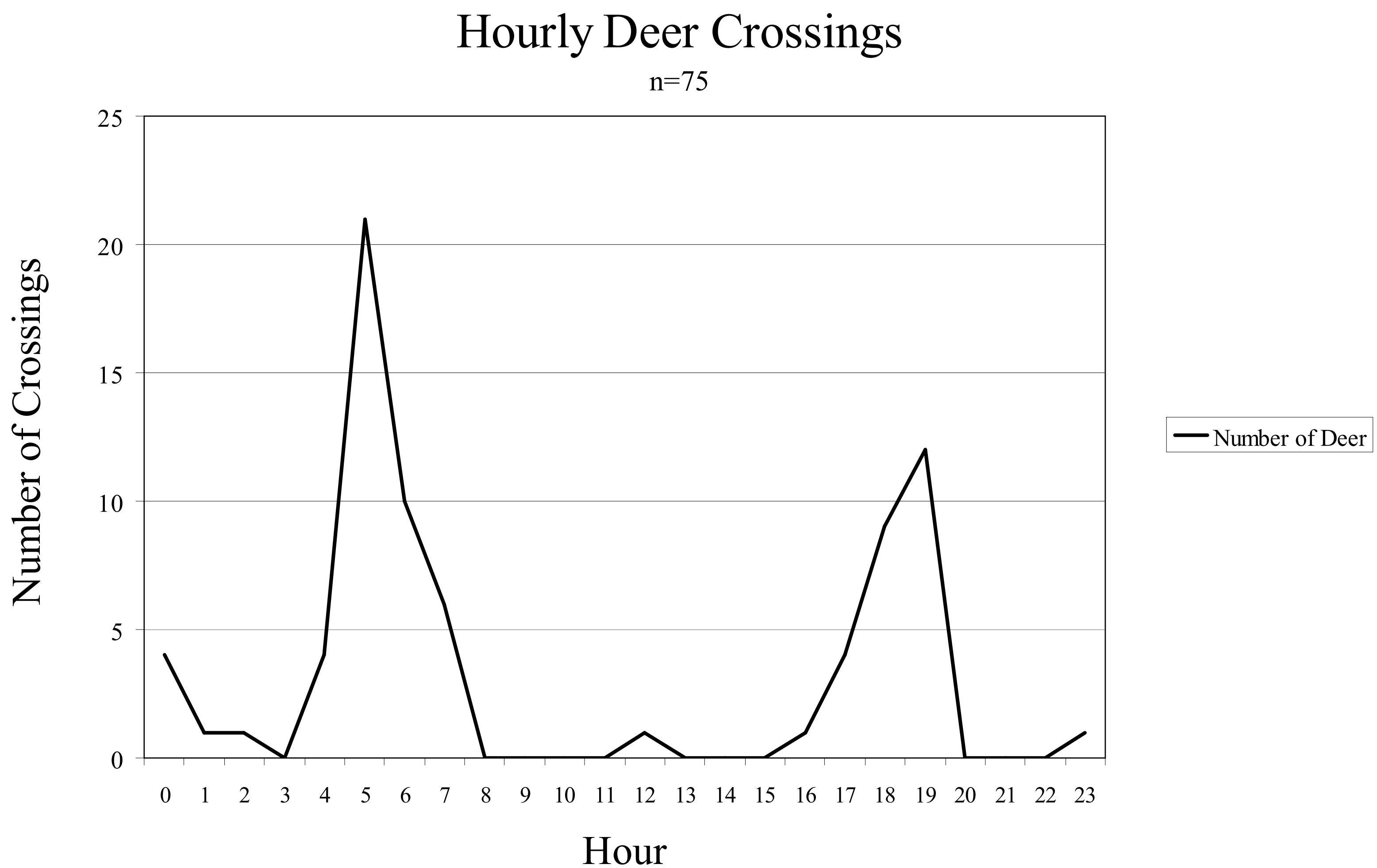

Figure 30. Hourly deer crossings observed in the sample of video data at the NHC underpass.

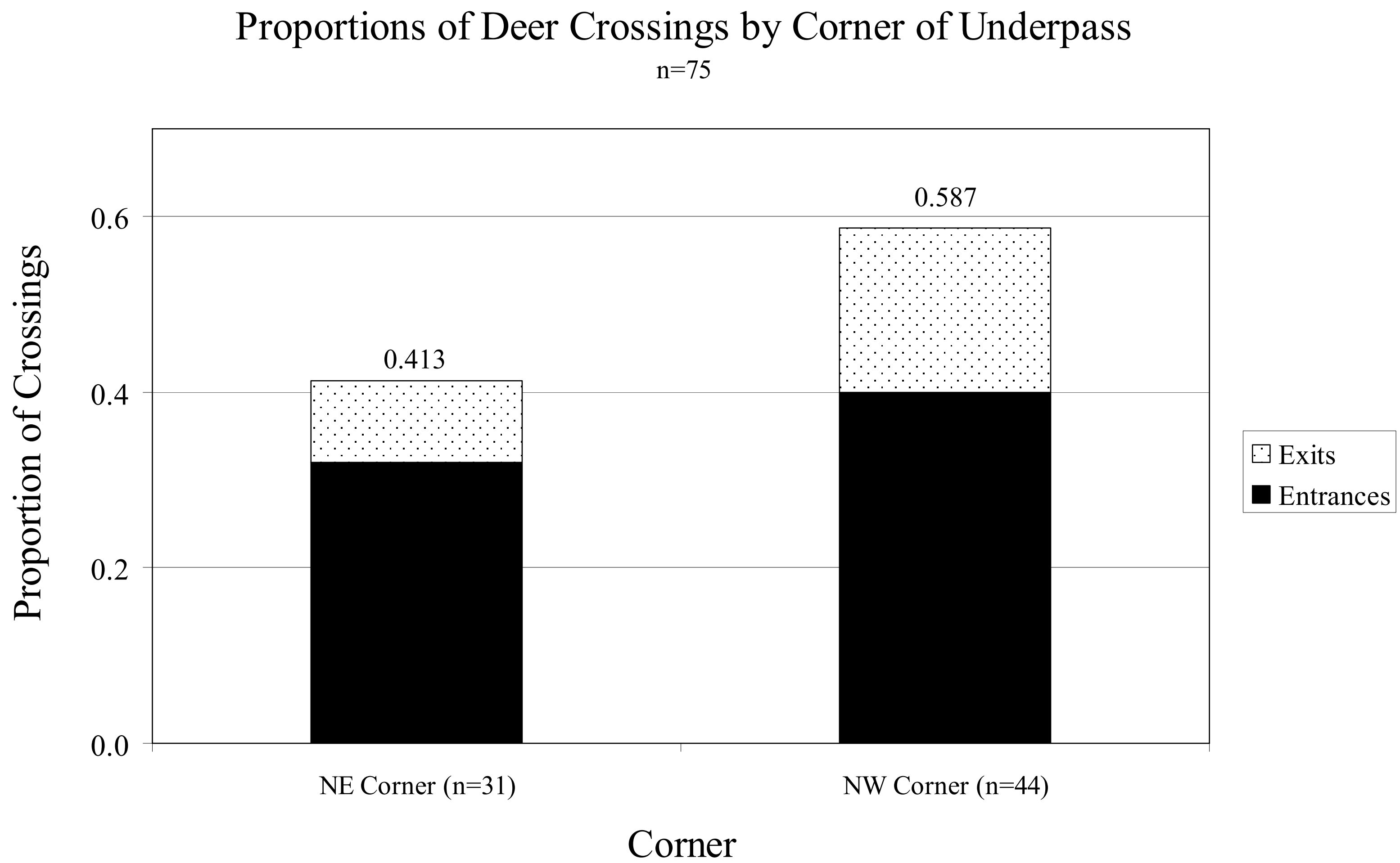

Figure 31. Proportions of deer crossings observed in the sample of video data at the NHC underpass by corner.

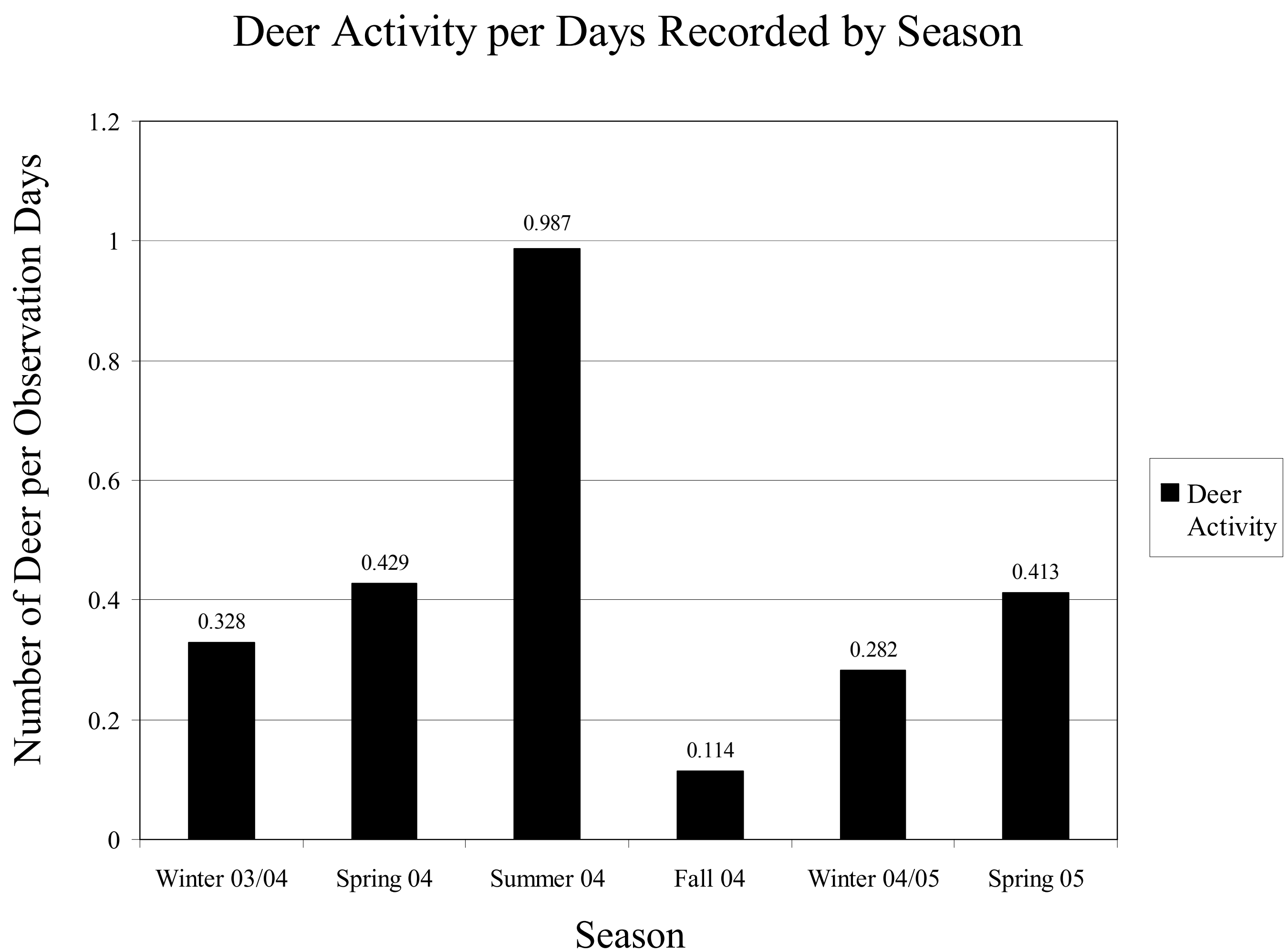

Figure 32. Deer activity observed in the sample of video data per days recorded by season.

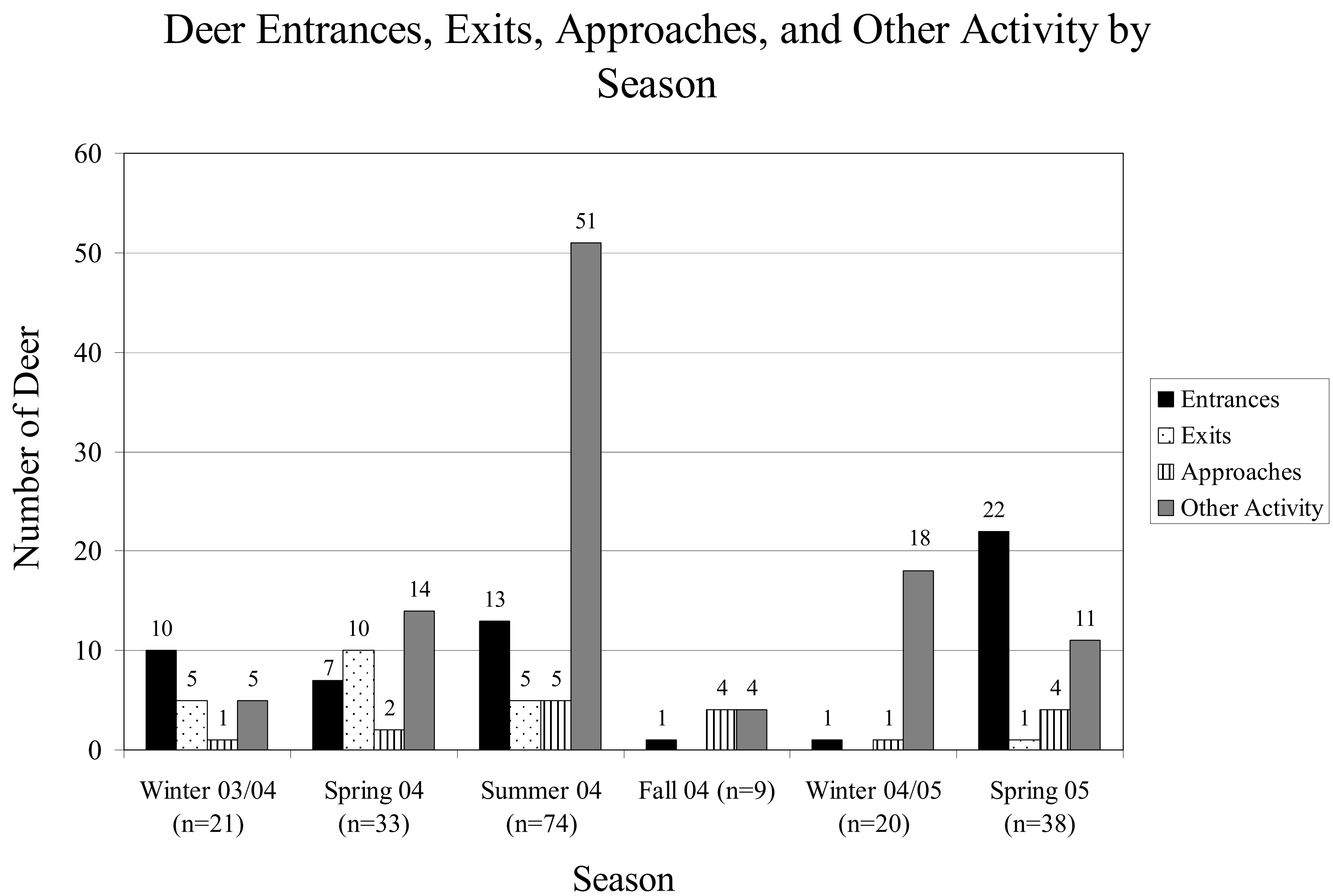

Figure 33. Deer activity observed in the sample of video data at the NHC underpass by season.

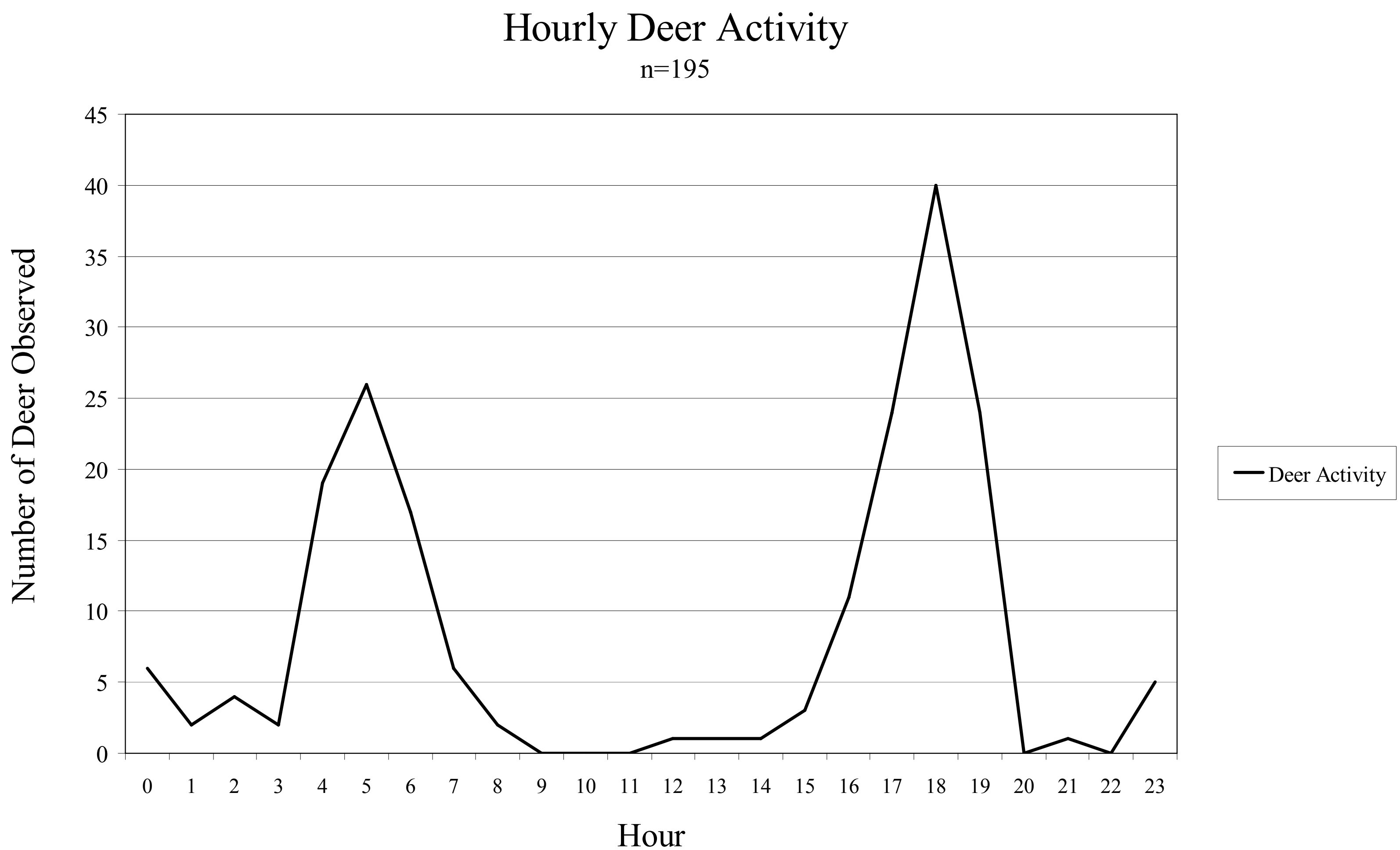

Figure 34. Hourly deer activity observed in the sample of video data at the NHC underpass.

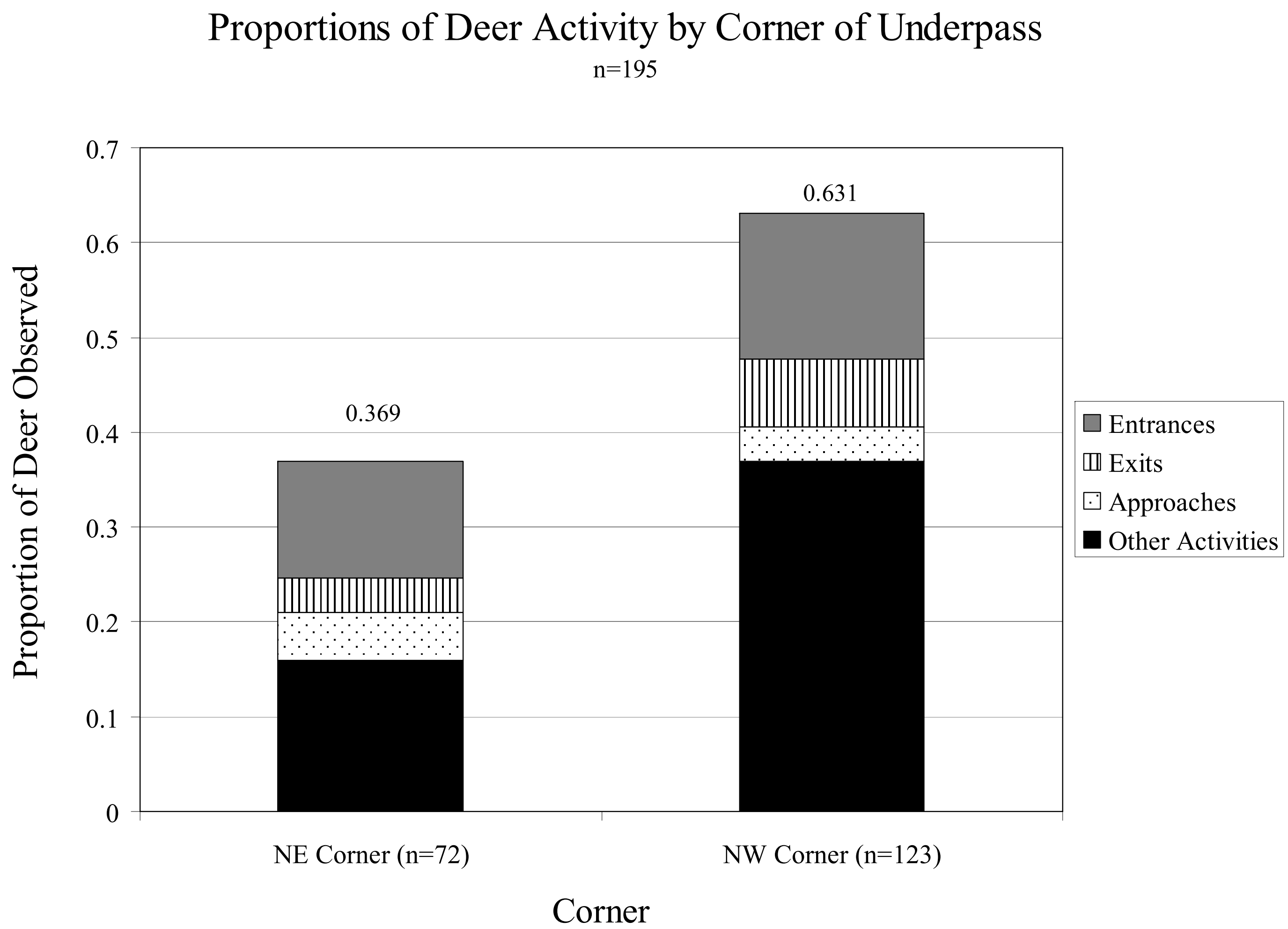

Figure 35. Proportions of deer activity observed in the sample of video data at the NHC underpass by corner.

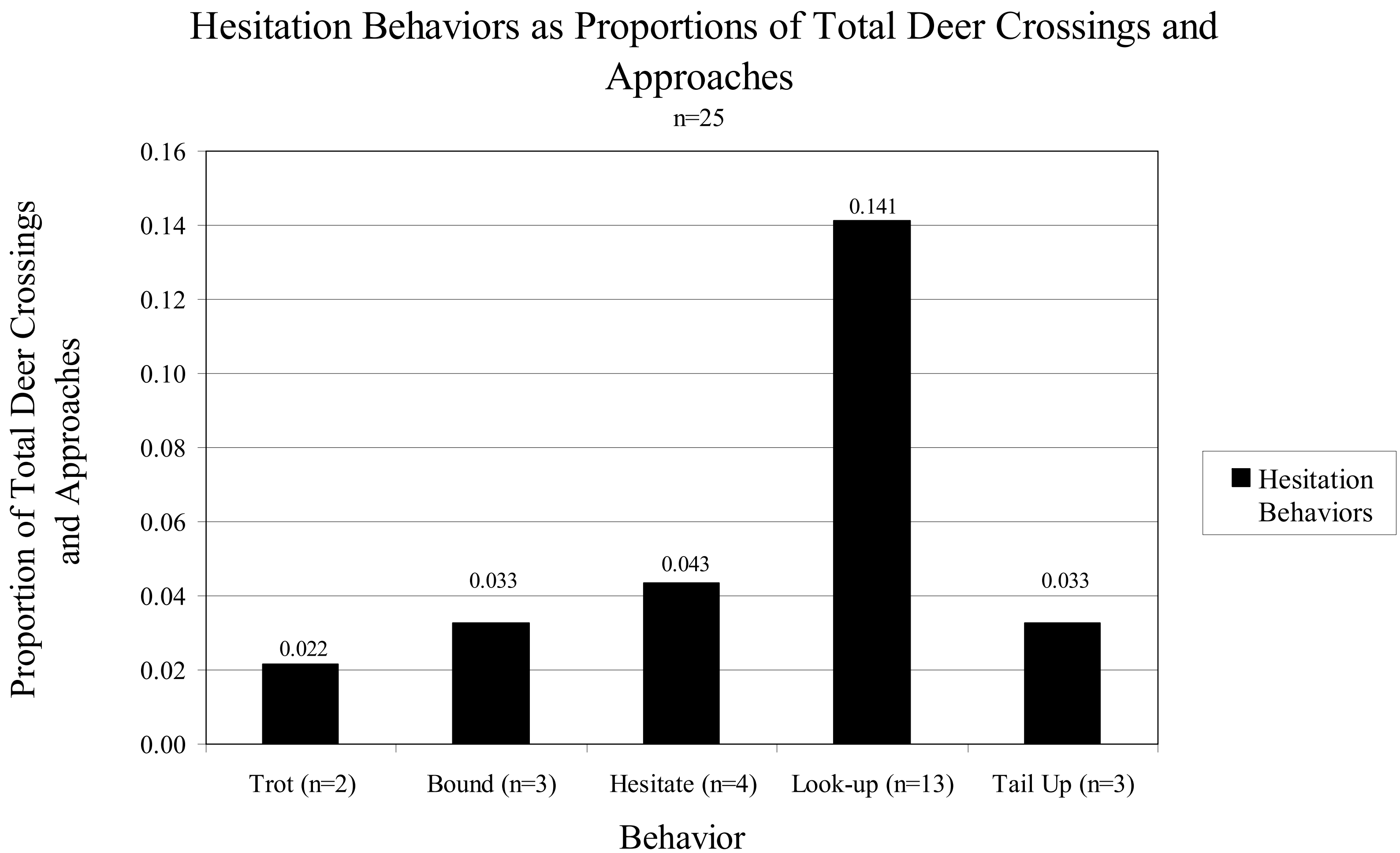

Figure 36. Deer hesitation behaviors observed in the sample of video data as proportion of total deer crossings and approaches.

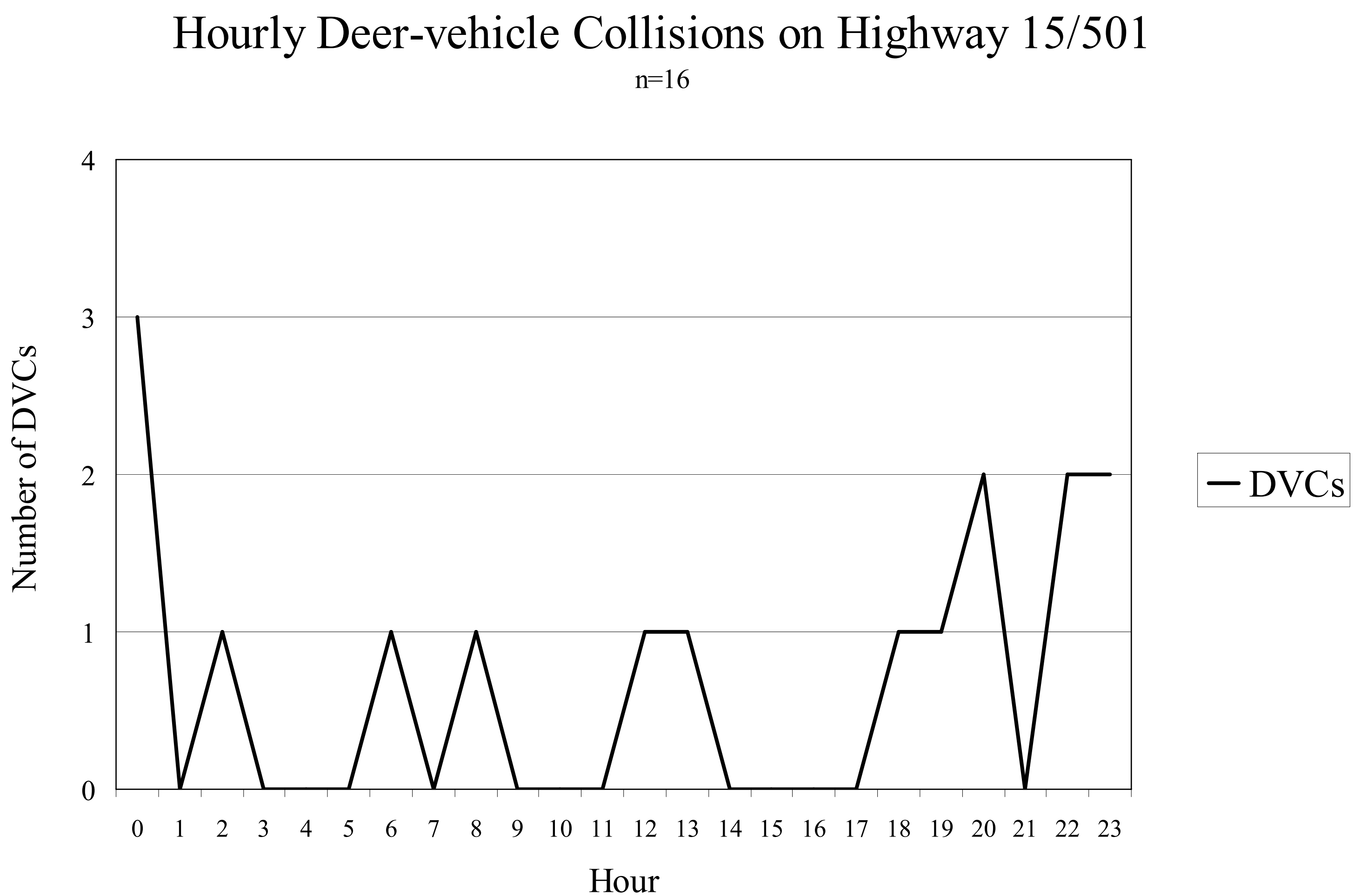

Figure 37. Hourly DVCs on Highway 15/501 between Mt. Moriah and Garrett Roads from January 1, 1990 through October 30, 2004.

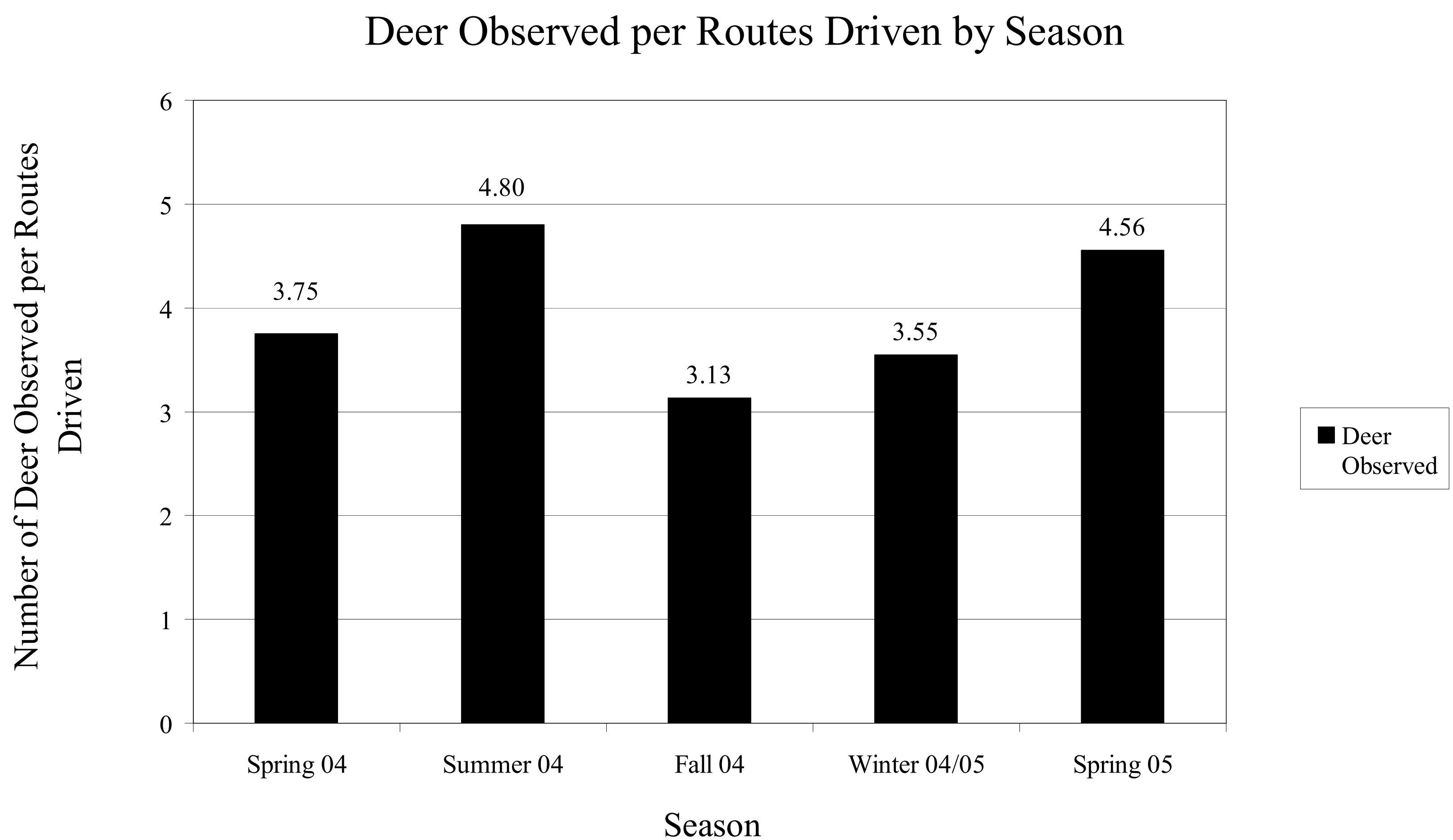

Figure 38. Number of deer observed during driving route per routes driven by season.

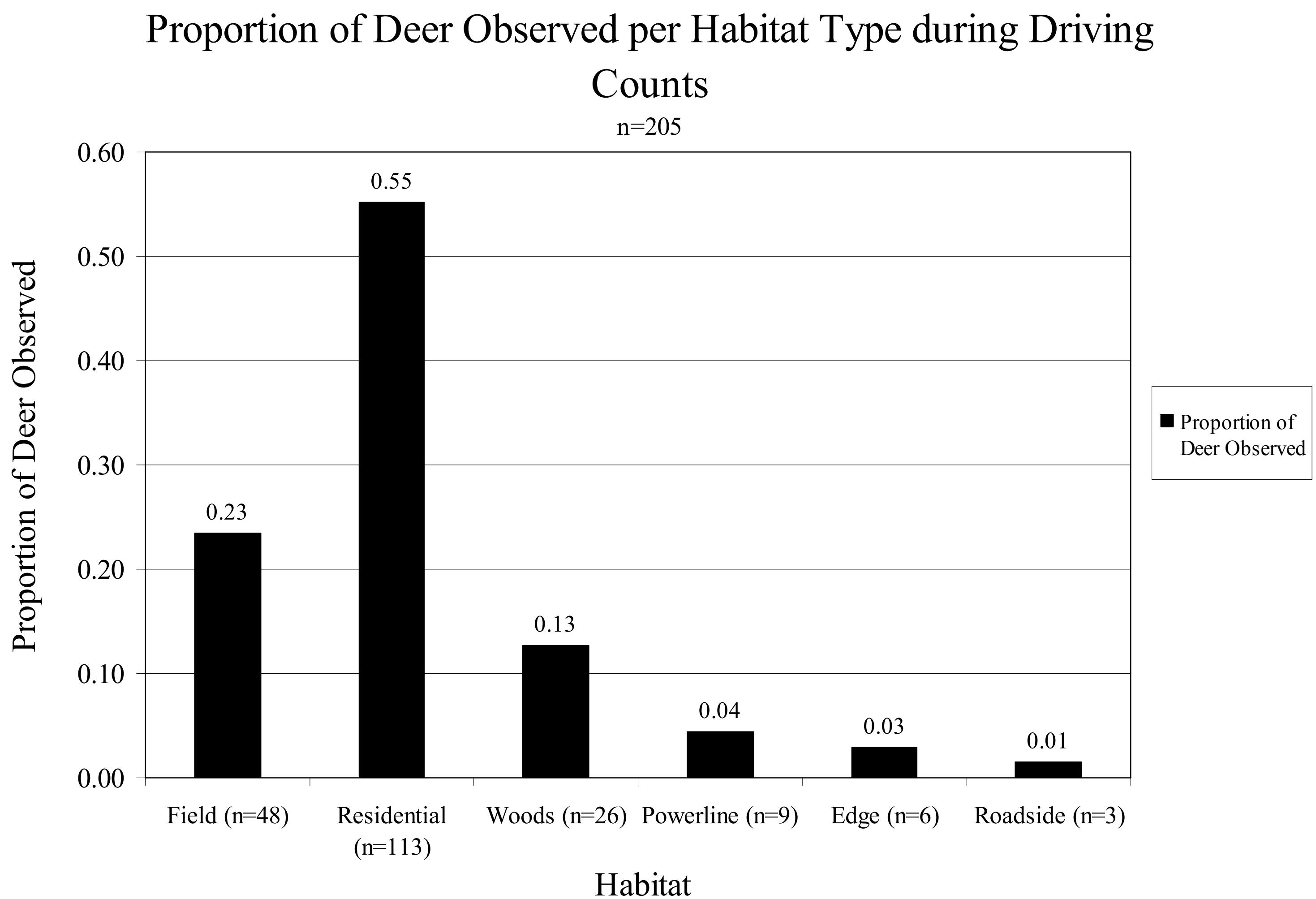

Figure 39. Proportion of deer observed by habitat types during driving counts of deer.

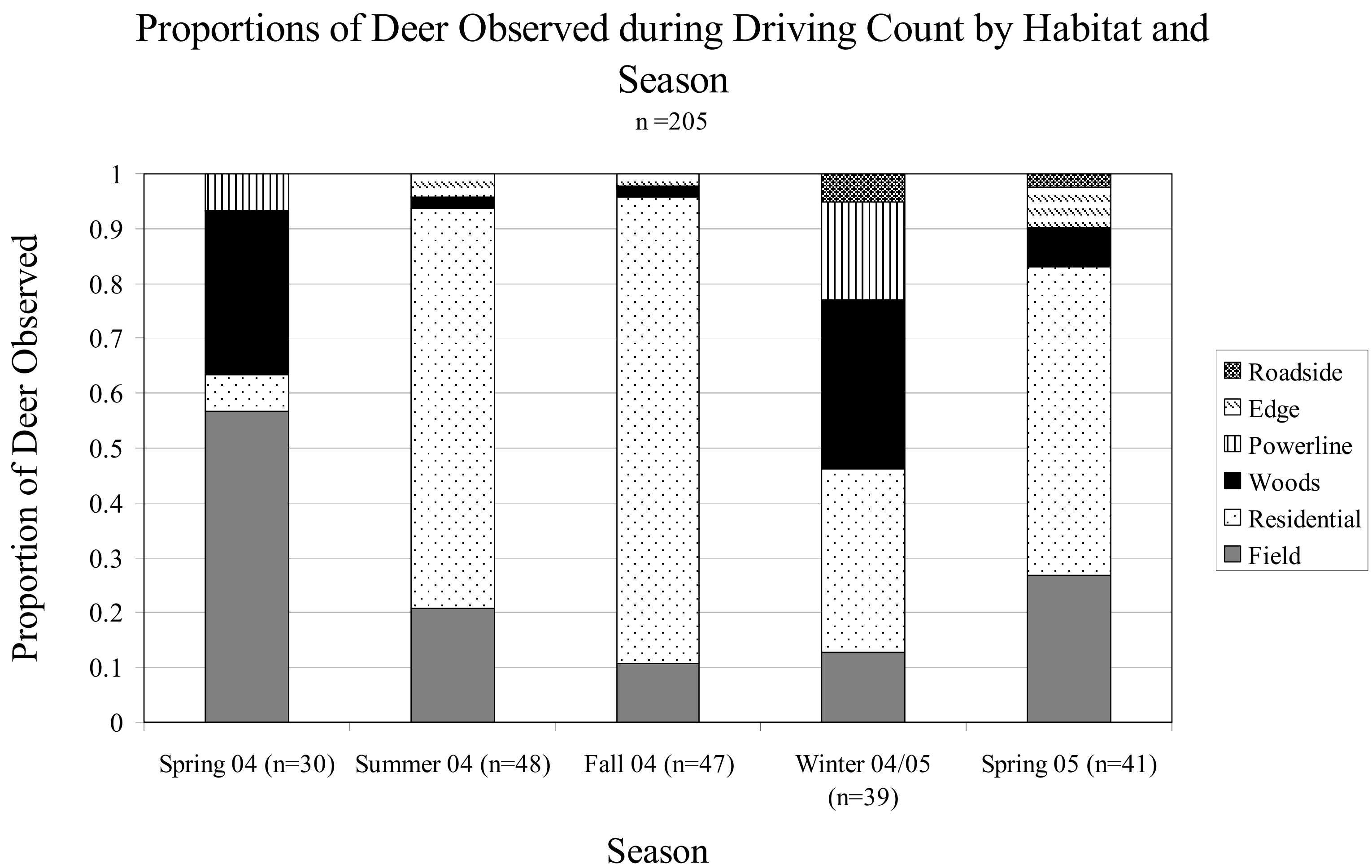

Figure 40. Proportions of deer observed during driving count of deer by habitat and season.

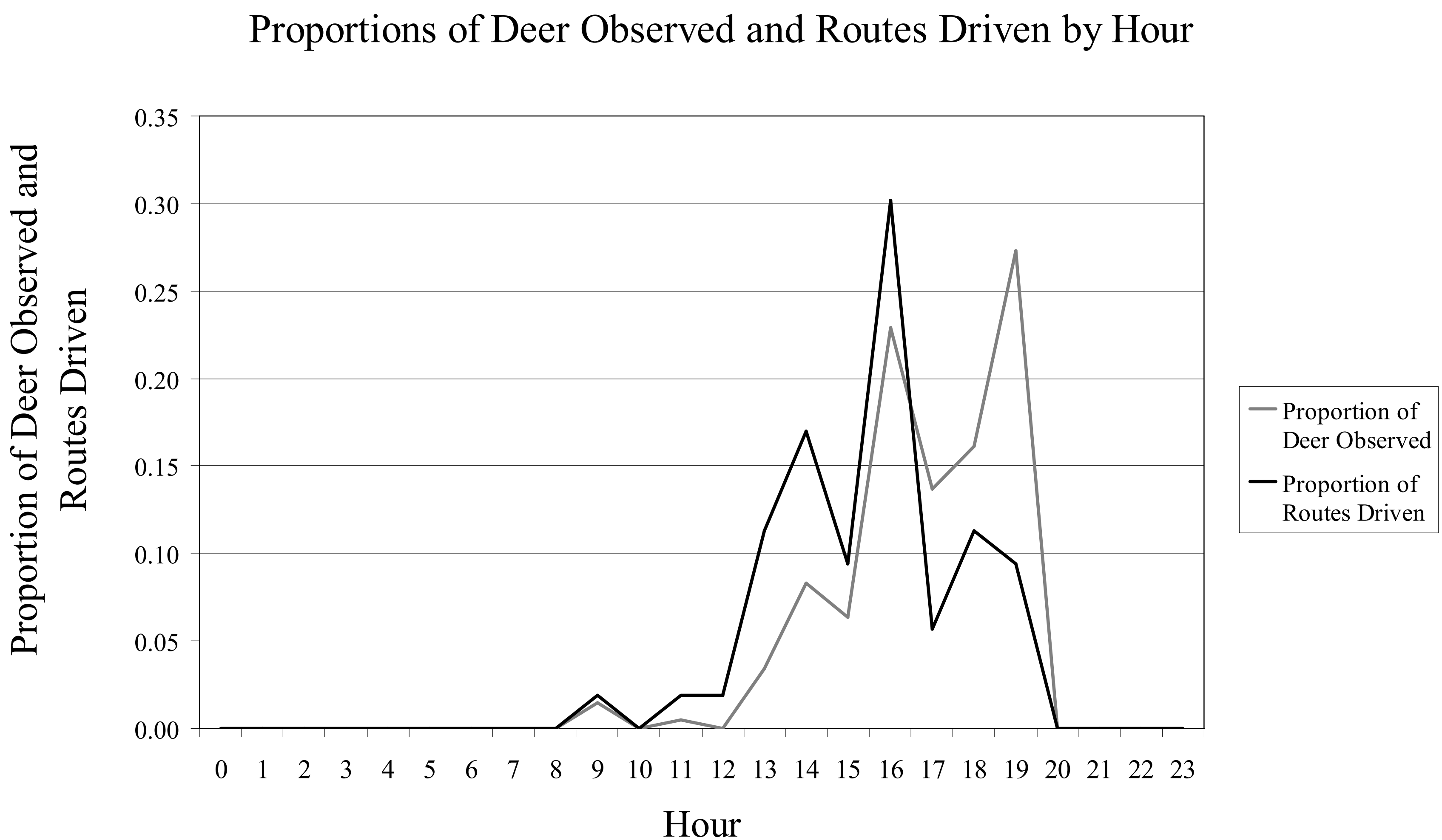

Figure 41. Proportions of deer observed during driving route and routes driven by hour (n=205 and n=53, respectively).

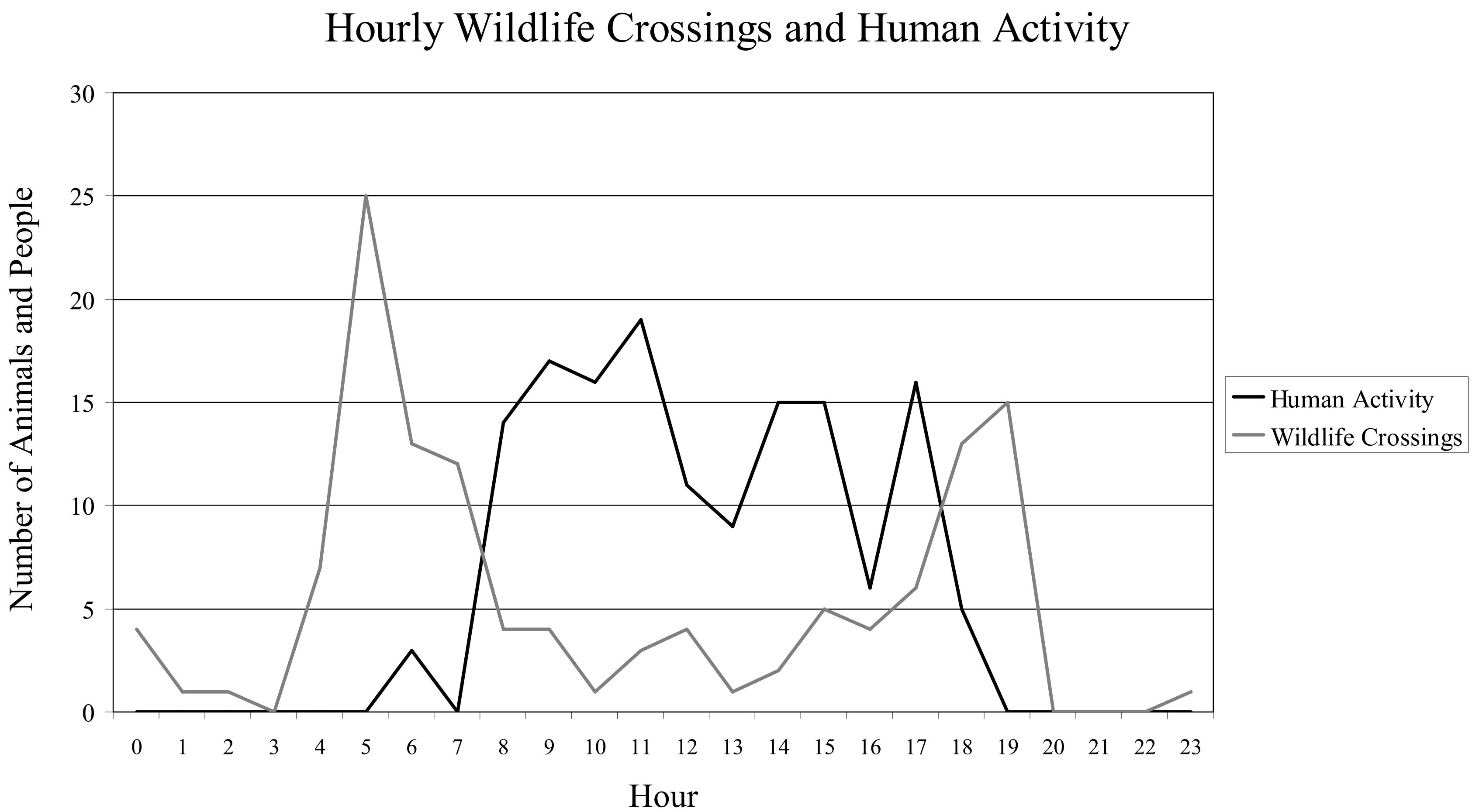

Figure 42. Hourly wildlife crossings and human activity observed in the sample of video data at the NHC underpass.

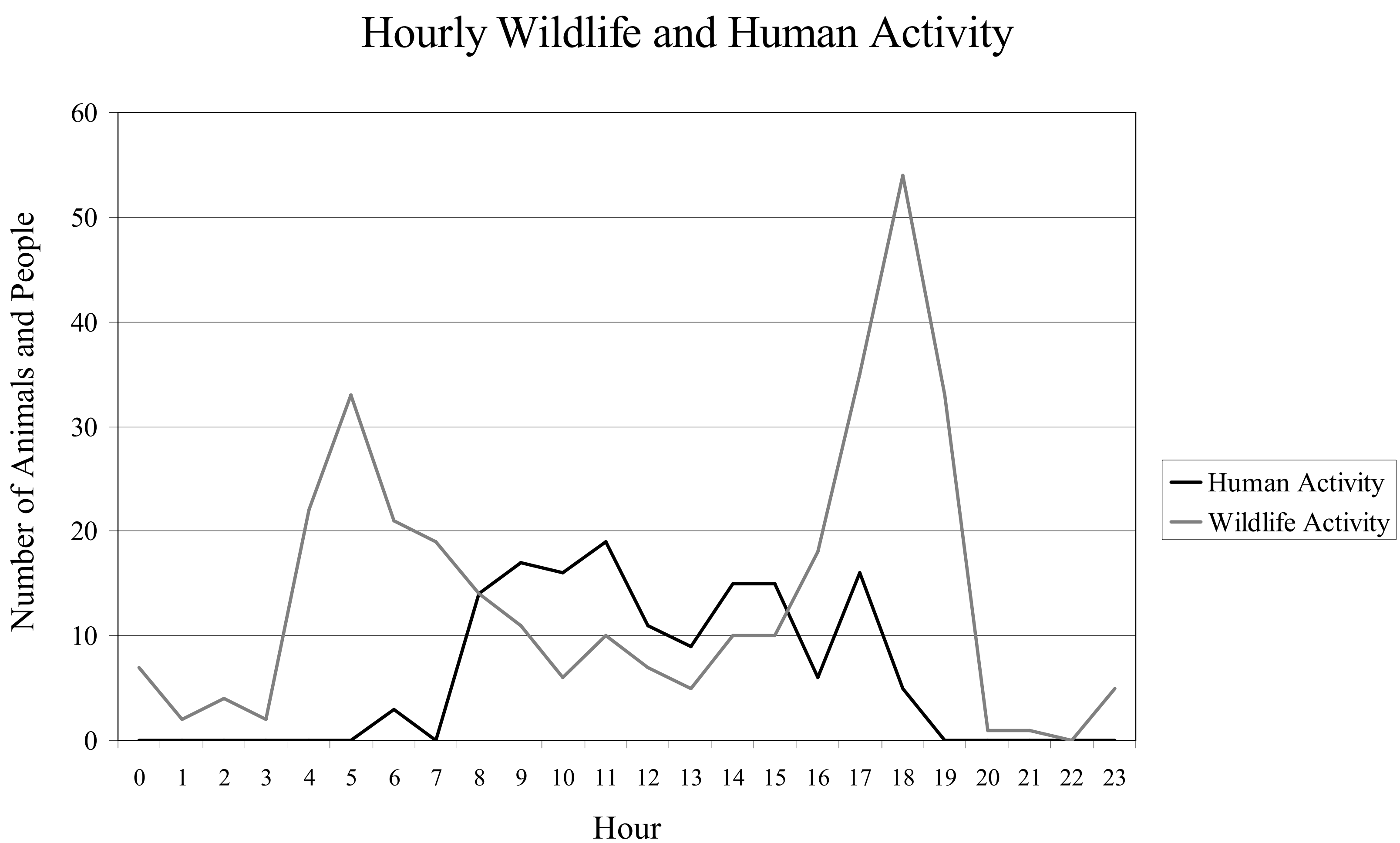

Figure 43. Hourly wildlife and human activity observed in the sample of video data at the NHC underpass.

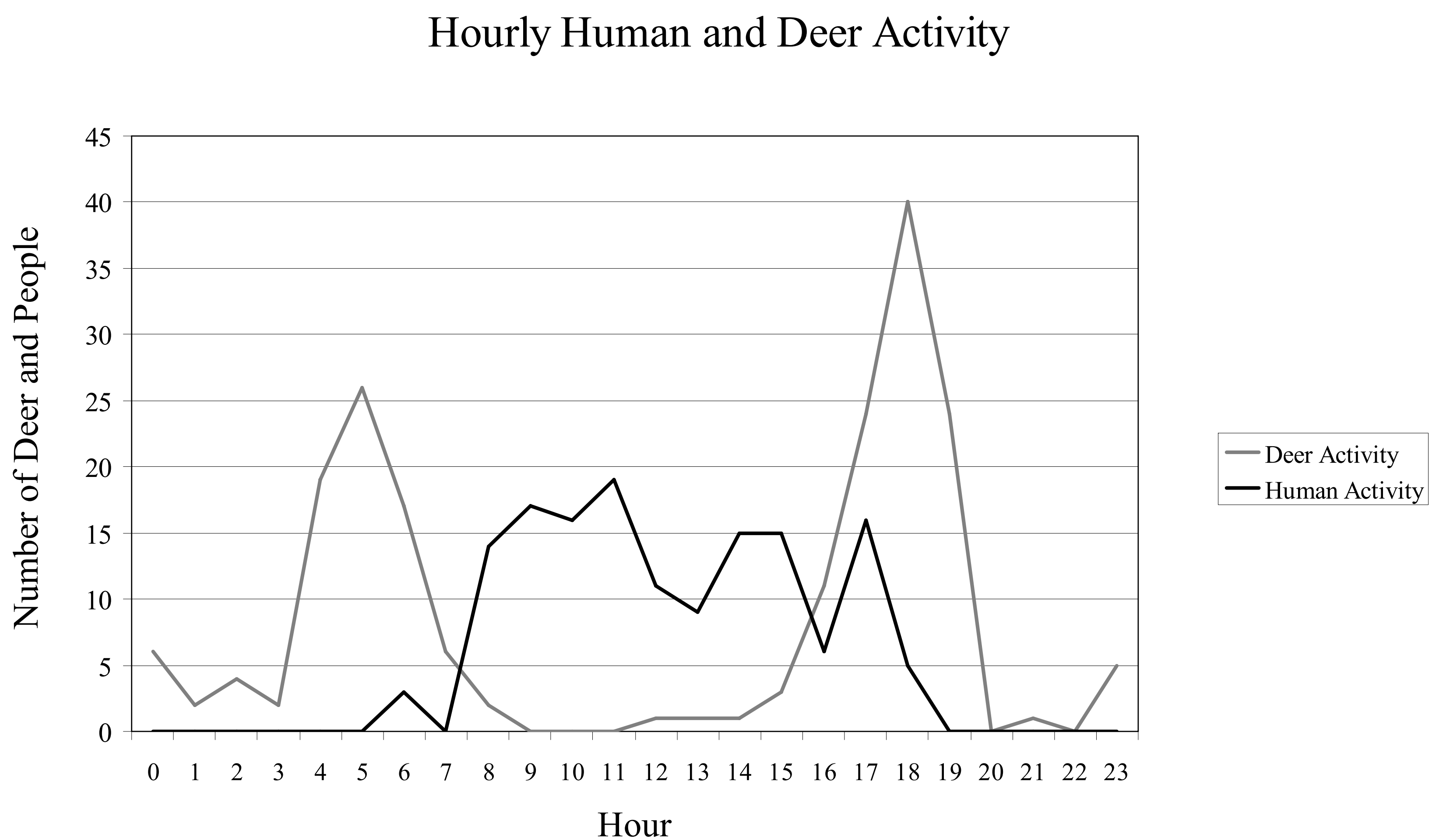

Figure 44. Hourly human and deer activity observed in the sample of video data at the NHC underpass.

Table 1. Number of days recorded by the camera system per season.

Season*	Number of Days Recorded	Number of Days	Proportion of Days Recorded
Winter 03/04	64	81	0.790
Spring 04	77	92	0.837
Summer 04	75	92	0.815
Fall 04	79	91	0.868
Winter 04/05**	71	90	0.789
Spring 05	92	92	1.000
Total	**458**	**538**	**0.851**

* Winter: December 1 through February 29
Spring: March 1 through May 31
Summer: June 1 through August 31
Fall: September 1 through November 30

** Solar panels were installed on February 10, 2005.

Table 2. Scientific and common names of species observed at the NHC underpass.

Scientific Name	Common Name
Canis spp.	domestic dog or coyote
Castor canadensis	beaver
Didelphus virginiana	Virginia oppossum
Felis catus	domestic cat
Homo sapiens	human
Marmota monax	woodchuck
Odocoileus virginianus	white-tailed deer
Ondatra zibethicus	muskrat
Procyon lotor	raccoon
Sciurus carolinensis	gray squirrel
Sigmodon hispidis	hispid cotton rat
Tamias striatus	chipmunk
Urocyon cinereoargenteus/Vulpes vulpes	fox

Table 3. Species observed crossing through the NHC underpass.

Species	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**

Table 4. Detection probabilities and estimated number of wildlife entrances, exits, and other activities.

Action	Number of Animals Observed in Sample	Estimated Number of Animals	Probability of Detection
Entrance	81	172	0.471
Exit	45	127	0.355
Subtotal	**126**	**299**	**0.422**
Activity	204	258	0.791
Total	**330**	**557**	**0.593**

Table 5. Species observed as active near the NHC underpass.

Species	Entrance	Exit	Other	Total	Proportion of Total
Domestic dog or coyote	1	0	0	1	0.003
Beaver	0	0	1	1	0.003
Virginia opossum	0	0	1	1	0.003
Domestic cat	0	1	0	1	0.003
Red or gray fox	0	2	0	2	0.006
Woodchuck	9	5	28	42	0.127
White-tailed deer	54	21	120	195	0.591
Muskrat	0	1	0	1	0.003
Raccoon	2	3	1	6	0.018
Gray squirrel	2	0	13	15	0.045
Hispid cotton rat	0	1	0	1	0.003
Chipmunk	2	4	5	11	0.033
Unidentifiable medium mammal	8	5	23	36	0.109
Unidentifiable small mammal	3	2	12	17	0.052
Total	**81**	**45**	**204**	**330**	**1**

Table 6. Work-related and recreational human activity observed in the sample of video data near the NHC bridge.

Action	Number Work-related*	Number Recreation**	Total
Entrance	0	4	4
Exit	0	29	29
Other Activity	77	36	113
Total	**77**	**69**	**146**

*Work-related activities included events involving DOT personnel or contractors but not 81 visits by researchers to the site for camera system maintenance.

**Recreational activities included walking/hiking, fishing, and off-road vehicle (ORV) use.

Table 7. Estimated number and detection probabilities of deer crossings, approaches, and other activities.

Action	Number of Deer Observed in Sample	Estimated Number of Deer	Probability of Detection
Entrance	54	127	0.424
Exit	21	58	0.365
Subtotal	**75**	**185**	**0.405**
Approach	17	18	0.921
Activity	103	107	0.966
Total	**195**	**310**	**0.629**

Table 8. Wildlife road approaches observed in the sample of video footage recorded at the NHC underpass.

Species	Date	Time (EST)	Number of Animals Approaching Road	Duration (Min)	Corner	Action
Unidentifiable small mammal	12/19/03	10:15:49	1	0.4	NW	Potential Road Cross
White-tailed deer	1/26/04	04:20:04	1	30.6	NE	Retreat
White-tailed deer	2/6/04	03:18:00	2	30.5	NW	Potential Road Cross
Gray squirrel	2/7/04	10:36:10	1	1	NW	Potential Road Cross
White-tailed deer	2/9/04	16:28:47	1	14.4	NW	Retreat
Unidentifiable small mammal	2/28/04	12:18:24	1	3.8	NW	Potential Road Cross
White-tailed deer	4/17/05	06:15:40	1	1.8	NW	Retreat
Total			**8**			

Table 9. Records of DVCs on Highway 15/501 between Mt. Moriah and Garrett Roads from January 1, 1990 through October 30, 2004.

Date	Time	Damage	Speed (mph)	Injury
3/9/91	23:32	$2,300	55	0
11/5/91	00:16	$2,000	55	0
5/19/92	22:25	$1,000	55	0
11/6/92	06:00	$650	50	0
12/26/93	23:30	$2,000	45	0
1/31/95	02:33	$1,000	35	0
10/17/97	08:44	$3,000	30	0
10/26/98	20:15	$3,500	45	0
9/4/99	13:10	$2,000	45	0
11/27/99	00:12	$2,000	45	0
12/2/00	22:01	$1,000	35	0
6/5/01	12:54	$4,000	50	0
1/4/03	19:28	$2,000	55	0
11/1/03	00:03	$3,000	55	0
11/9/03	18:47	$3,000	40	0
11/18/03	20:09	$2,500	45	0

Table 10. Vehicle-killed deer observed along the driving count of deer from 3/23/04 through 5/31/05. The route along which the count was conducted was driven 53 times.

Date	Time Observed (EST)	Location	Species	Number of Individuals	Habitat
6/20/2004	19:15	Mt. Moriah Rd.	deer (fawn)	1	roadside
11/2/2004	15:45	Mt. Moriah Rd.	deer	1	roadside
11/12/2004	15:50	Mt. Moriah Rd.	deer	1	woods
1/11/2005	16:30	Cornwallis Rd.	deer	1	n/a
1/20/2005	15:30	Erwin Rd.	deer	1	roadside
2/4/2005	16:38	Mt. Moriah Rd.	deer	1	roadside
2/4/2005	16:48	Mt. Sinai Rd.	deer	1	roadside
3/4/2005	16:10	Friends School Rd.	deer	1	field
3/30/2005	13:30	Pickett Rd.	deer	1	woods
4/27/2005	13:10	Pickett Rd.	deer	1	woods
Total				**10**	

APPENDIX

APPENDIX A

Wildlife Use of an Underpass of the Highway 15/501 Bridge Over New Hope Creek
Project: HWY-2004-07

Record the following information for each episode of activity recorded within view of the camera:

Enter/ Exit/ Neither	Approach /Non-Approach	Date	Time	Size	Genus/Species	Number of Individuals	Total Duration of Episode	Corner of Underpass

Coding Key:
Entrance, etc: 1=Animal entering underpass; 2=animal exiting underpass; 3=neither
If "Entrance, etc."=3, define Approach/Non-approach: 1=animal approaches underpass but doesn't disappear into underpass; 2= animal doesn't approach underpass; 3=N/A (i.e., us or DOT at site, critters moving away from underpass, etc.)
Date/Time: Date and start time of episode. Always record as Eastern Standard (Winter) Time.
Size:
1 = small mammal (squirrel size or smaller)
2 = medium mammal (fox size or smaller, but larger than squirrel)
3 = large mammal (larger than fox size)
4 = human
Species: Identify to most precise taxonomic level
Number of Individuals: Number of individuals in a given episode
Total Duration of Episode: Total length of episode

Give an account of the activities observed in the episode, including a detailed description of each behavior and the duration of each behavior (use back of sheet if necessary):