ABSTRACT

JONES, ELIZABETH R. The Effectiveness of Wildlife Crossing Structures for Black Bears in Madison County, North Carolina. (Under the direction of Professors R.A. Lancia and P.D. Doerr).

Roads have become an integral part of our society, but recently society has begun to realize the ecological impact that roads have on their surroundings. One major effect that roads have on large mammals is creating a barrier to movement of individuals both between and within populations. In an effort to alleviate this problem on a new interstate project, the North Carolina Department of Transportation constructed 2 8 x 8 feet (2.4 x 2.4 m) concrete box culverts on I-26 in Madison County, North Carolina, intended for use by North American black bears (*Ursus americanus*). Black bears have been observed using a variety of crossing structures, and it is not known what type of design best suits their needs. To determine the effectiveness of these crossing structures, each culvert's wildlife activity was recorded by Cuddeback digital still cameras. In addition, digital video data were captured at one of the culverts and sampled to detect wildlife use of the culvert. From these data, detection probabilities and an overall estimate of wildlife use were calculated. Wildlife crossings at other structures along the roadway were also recorded, specifically at culverts built to carry streams under the interstate. Also, still cameras were installed at a few likely crossing locations along the roadway in an attempt to capture black bear presence adjacent to the roadway. Lastly, local residents were solicited for their crossing observations.

Data were collected for at least a year, with some cameras running over a year. During that time 1,715 pictures were taken by the still cameras, and 152 clips of animal activity were collected from the video data. Black bears were detected or reliably

reported along I-26 12 times, twice inside Culvert 2. A black bear was detected crossing the road at Culvert 2 4 times, with 1 instance resulting in a bear-fatal vehicle collision. A GIS model was created to locate areas of possible high black bear movement in Madison County. While the primary goal was to evaluate the location of the culverts and predict bear crossing locations along the I-26 roadway, a secondary goal was to create a tool that could be used to aid in the placement of black bear crossing structures on future roads in the southern Appalachian Mountains. The general concept of the model is that every landscape variable included influences black bear movement a certain degree, either in a positive or negative manner. To determine each variable's weight, a group of black bear researchers with experience in the southern Appalachian Mountains was surveyed. The weight of all variables was added together to determine total bear movement values for each cell of the map.

The map produced by combining the weights for all factors contained values ranging from –317 to 239, with negative values representing areas that impede black bear movement, and positive areas representing areas that promote it. Most of the cells contained positive values (385,973 cells); only 81,066 cells (17.35% of all cells) contained negative values.

Black bear movement locations were collected along I-26 in order to validate the model. Values for the known bear locations were significantly different from the entire set of movement values (Chi square = 25.78, $p = 0.002218$, df = 9), and significantly different from the movement values within 1640.42 feet (500 m) of I-26 (Chi square = 47.12, $p = 3.75\ e^{-7}$, df = 9). Visually comparing the 2 sets of values indicated that most of the area near the interstate deterred bear movement, and bears chose locations with more positive movement values to actually move through.

Bears have been detected in the area of the crossing structures, but have been rarely detected in them. This indicates that they are placed in fairly appropriate locations, which the GIS model confirms. However, wildlife use of crossing structures is thought to be influenced by a myriad of other factors, including human use, vehicle traffic levels, structure design, and wildlife fencing. Two factors can be addressed in an attempt to improve the crossing rates of black bears through the culverts on I-26: human use of the structures and the lack of wildlife fencing. Human use of the culverts could be discouraged by hanging signs and educating the public. Extending wildlife fencing from the culvert entrances would funnel bears to the culverts to cross under the interstate.

The Effectiveness of Wildlife Crossing Structures for Black Bears in Madison County, North Carolina

by
Elizabeth R. Jones

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APPROVED BY:

Dr. Richard Lancia
Co-Chair of Advisory Committee

Dr. Phil Doerr
Co-Chair of Advisory Committee

Dr. Ken Pollock

DEDICATION

This work is dedicated to my family. Without the support of my mom, dad, and brother, I would never have made it to where I am today. Thanks guys, I love you!

BIOGRAPHY

Elizabeth R. Jones was born October 14, 1983 in Richmond, Virginia. Her family moved to Durham, North Carolina just a few months later. There, she learned that the woods behind her yard and the creek following the power line cut were the best places to explore. This love of the outdoors was supplemented with My Little Ponies, New Kids on the Block, and playing dress up.

After moving to Raleigh in fourth grade, Elizabeth's love of the outdoors was further fostered through nature camps with the Museum of Natural Sciences. She was a member of the Girls Science Club at the Museum, and went on to become a Junior Curator at the Museum. The Junior Curator program opened Elizabeth's eyes to the unique wildlife of North Carolina, as well as career possibilities in the natural sciences. The knowledge and connections she gained from the program will be irreplaceable tools in her future career.

Elizabeth graduated from WG Enloe High School in 2001, and started at North Carolina State University in the fall of that year. She earned a Bachelor's degree in Zoology, as well as in Environmental Science, concentration in Ecology in May of 2005, and graduated as a University Valedictorian. More importantly, she participated in an assortment of extra-curricular activities during her 4 years at NCSU. She was a member of the Wolfpack Clogging Team, and then helped found the Second String Cloggers. She was a very active member in the Leopold Wildlife Club, re-invigorating the club's community outreach efforts. She also worked part time at Hemlock Bluffs Nature Preserve and the Museum of Natural Sciences during her entire undergraduate career.

Currently, Elizabeth works at the Museum of Natural Sciences as the Educational Events Specialist. Upon graduation, she hopes to find a position with an environmental consulting firm. Her lifetime career goal is to integrate wildlife habitat areas with human development in an ecologically sustainable way.

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Several NCSU undergraduate students helped with the project. Thanks to Nathan Beasley and Billy Paugh for reviewing the video data. Sara Watts, Miranda Wood, Hope Bryant, Jason Smith, Jonathan Garrow, Billy Paugh, and Mary O'Brien helped collect data in the field.

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Most importantly, thanks to my family! Especially my mom, who was my honorary field technician for the project. She traveled to the site with me several times, and held her own out in the field. Thanks mom!!

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LITERATURE REVIEW

Impacts of Roads on Wildlife

Roads have become an integral part of the American society, with most Americans coming in contact with a road every day. Roads act as connectors, allowing the exchange of goods, and the movement of people. There are close to 300 million people in the US (World Factbook 2005), and over 200 million registered vehicles (CarAccident.com 2005) traveling on 3.84 million miles (Forman and Alexander 1998) of roads that link practically every area of the county. America's roads cover 1% of its area, approximately the size of the state of South Carolina (Forman and Alexander 1998). North Carolina has over 77,000 miles of state-maintained roads and bridges, and the largest state Department of Transportation (DOT) in the country to manage them.

Ecologically, roads have several impacts on their surrounding environment, many of which are most likely unknown. One estimate suggests that 19% of the US is affected ecologically by roads, or 22% of the contiguous US (Forman 2000). With this much area affected, it is important for ecologists, urban planners, and roadway engineers to understand all the ways a road influences its environment.

Roads can have direct and indirect effects on the environment. Direct effects most often occur during construction and include the loss of habitat due to the footprint of the road, and the movement and compaction of soil due to machinery. While direct effects can severely affect local animal populations, often their impact is minimal compared to indirect effects. Indirect effects consist of the different ways that roads influence their surrounding environment; many of these impacts severely affect wildlife through vegetation changes, noise, animal-vehicle collisions, wildlife avoidance of areas near a road, and the creation of a barrier to movement.

Vegetation along roadsides is most often not natural. The construction of a road creates a break in the canopy, and introduces more edge habitat into the ecosystem. Wide shoulders are commonly landscaped with non-native plants, and maintained through mowing and herbicide. Many state DOTs have begun programs to plant native wildflowers and other native vegetation along roadsides; while this decreases the impact of road-related vegetation change, it does not eliminate it.

Noise created by traffic can impact wildlife nearby, especially songbirds through interference with communication (Forman and Alexander 1998). However, it is thought that mid- and large-sized mammals may acclimate to the noise.

Animal-vehicle collisions are the most easily observed impact of roads on wildlife, and the most detrimental to humans. There are over 1.5 million deer-vehicle crashes every year in the US, averaging to 4,000 a day, causing 150 occupant deaths (Insurance Institute of Highway Safety 2004). Large animal collisions cost insurance companies millions of dollars per year, deer crashes alone cost over $1 billion every year in vehicle damage, which is 38% of all comprehensive losses (Insurance Institute of Highway Safety 2004). There are an average of 12 deer claims per 1,000 insured vehicles, with the average cost per claim being $1960 (Insurance Institute of Highway Safety 2004). It is estimated that about 1 million vertebrates are killed on roads each day in the US, but surprisingly, most bird and mammals populations are generally unaffected by road kill rates (Forman and Alexander 1998). Exceptions to this include threatened or endangered species, such as the endangered Florida Panther whose leading cause of mortality at one time was vehicle collisions (Forman and Alexander 1998). Other animal populations that can be severely impacted are amphibians, whose small size and tendency for mass migration can lead to an entire population being killed on a road in one night. High-use roads have been shown to be correlated with reduced population density of frogs and toads in areas adjacent to the roads (Fahrig et al. 1995). For small mammals, it is likely that most of the individuals hit are young dispersing or adults searching for mates (Burnett 1992). It appears that large animals typically cross roads to access better quality habitat, or find mates.

Avoidance occurs when animals do not use quality habitat because of its proximity to a roadway. This may cause a species to lose a larger percentage of their habitat than that directly affected by construction (Brody and Pelton 1989, Brandenburg 1996). Grizzly bears were found to avoid habitat within 100 m of any type of road, with males using the area near roads less than females, and yearlings using the area more than any other age group (McLellan and Shackleton 1988). The amount of traffic on the road can influence the area of avoidance; grizzly bears were found further from high-volume roads than low-volume roads (Chruszcz et al. 2003).

Roads often become an impediment to normal wildlife movements; this is referred to as the barrier effect. If roads are a barrier for a species, the species population is broken into small, isolated populations with little genetic exchange between them. These small populations are more prone to genetic abnormalities and have a higher risk of extinction. Due to these severe impacts, the barrier effect is considered the largest ecological impact of roads (Forman and Alexander 1998). Roads are more likely to be an impermeable barrier for small-sized animals. Carabid beetles do not cross roadways, and mice will not even cross unused forest roads (Mader 1984). When mice were relocated to the opposite side of the road, only 2 of 14 returned to their original side (Mader 1984). Some small mammal populations, such as some species of rats (*Rattus fuscipes* and *Antechinus flavipes*), do cross roads up to 12 m wide (Burnett 1992). The creation of the barrier effect for these species may be due to a behavioral instinct of avoiding open spaces, or a sociological solution of aligning territories with the road, therefore eliminating the need to cross it (Burnett 1992). Roads can also be a barrier for large animals. Guardrails, walls, and steep embankments discourage deer and elk from crossing roads (Barnum 2003). However, the permeability of roads to large mammals depends on traffic volume (Barnum 2003).

Impacts of Roads on the North American Black Bear (*Ursus americanus*)

Black bears are the largest wild land animals found in North Carolina. In the state, there are two populations of black bears: one in the coastal plain, and the other in the mountains; both are hunted. Black bears have fairly large home ranges, with the average female's home range in the mountains being 15-20 square kilometers, and the average male's in the mountains being 20-40 square kilometers (Powell et al. 1997). With the ever-increasing human population in the state, it is difficult to find an area where a black bear's home range does not encompass at least one road. An individual black bear shifts its areas of activity throughout a normal year to correspond with the location of seasonally available food. Black bears feed on soft and hard mast, as well as grain, carrion, and the occasional captured prey. Usually these resources are in different locations, and their availability at each location differs year to year. So black bears must have the freedom to move between areas and habitats in order to obtain the resources they need. Fragmentation due to development, or a year of poor mast production, can restrict the amount of resources available to bears, and force them to travel further for forage. For this reason, roads need to be permeable to black bears. Also, black bears need to be able to move between fragmented populations for genetic flow. Because of their diverse use of habitat, black bears are often considered an umbrella species; by protecting habitat for the bears, numerous other species are protected as well.

One study found that black bears might primarily cross roads to access additional food sources (McCowen et al. 2004). Males may cross roads in search of mates. One bear in Florida traveled 507 km in 1 month, crossing 4 interstates, for an unknown reason (Stratman et al. 2001), so black bears infrequently may travel long distances. Roads influence the movements and lives of black bears through the creation of a barrier to movement, bear-vehicle collisions, and avoiding habitat near roads.

Roads can be a barrier to black bear movement, with the road type significantly affecting crossing rates (Brody and Pelton 1989). One study found an inverse relationship between traffic volume and permeability of a road to black bears (Serrouya 1999). Secondary roads may not inhibit movement in the coastal plain of North Carolina, but primary roads were found to (Brandenburg 1996). Black bears were found to cross the Trans-Canada Highway less than expected by chance (Serrouya 1999), and rarely crossed Interstate 40 in the North Carolina mountains (Brody and Pelton 1989). Another study recorded bears crossing I-40 12 times in 2 years, with most of the crossings occurring near a tunnel the road goes through; however black bears were also observed to approach the road and then turn around, indicating that those individuals considered the roadway a barrier (Berringer 1986).

Black bear-vehicle collisions do occur regularly in North Carolina. Most road kills occur during the fall, when black bears may be searching for sources of hard mast (Gilbert and Wooding 1996). In years of poor mast production, road mortality increases (McCowan et al. 2004). Black bears usually cross roads at night (Brandenburg 1996), this combined with their dark color leads to lower visibility of black bears to drivers, which could contribute to the cause of most road kills. Most populations of bears in North Carolina are not severely impacted by road mortality, however road mortality can have a very large impact on isolated populations (Brandenburg 1996). Vehicle collisions accounted for 71% of the total mortality of an isolated black bear population on Camp Lejune, North Carolina (Brandenburg 1996). This is the largest road-related mortality recorded for a black bear population.

Black bears have also been found to avoid habitat along roads; one study suggested that 209 acres of black bear habitat are lost for every mile of roadway due to avoidance of the road combined with the footprint of the road (Gilbert and Wooding 1996). In a population index study, black bears were more likely to visit bait stations on trails than those along roads (Powell et al. 1996). Black bears were found to avoid habitat within 100 m of any road, regardless of road size or season; they also avoided habitat 100-200 m from primary roads more than habitat the same distance from secondary roads (Brandenburg 1996). Brody and Pelton (1989) found that black bears do not avoid roads within their home range, but rather align or shift their home range to not include major roads. Home ranges of black bears in the mountains of North Carolina often are bordered by valleys and ridge tops, possibly to avoid humans and roads commonly built on valleys and ridges (Powell and Mitchell 1998). One reason for black bear road avoidance suggested by several researches is the use of roads by bear hunters (Beringer 1986, Powell et al. 1996). Bear hunters often use dogs to find bear trails by driving along roads, and bears that have crossed these roads are more likely to be found by the dogs. Black bears were also found to avoid roads in a bear sanctuary with a high poaching rate (Powell et al. 1996).

<u>Methods to Minimize Ecological Effects of Roads</u>

With the US's constantly growing population, more roads are going to be built and existing roads used more. For wildlife to persist, the ecological impacts of roads need to be minimized. The Federal Highway Administration (FHA) has recognized this and has begun to utilize an ecosystem approach to road planning (Garrett and Bank 1995). Part of the FHA's policy is the creation of Environmental Impact Statements prior to construction to aid in identifying possible environmental problems (Garrett and Bank 1995). The FHA also promotes the use of mitigation banking and the construction of wildlife crossings to increase usable wildlife habitat, and fund ecosystem-based research to aid in future planning (Garrett and Bank 1995). Forman (2000) suggests additional ways to reduce the ecological impacts of roads, including the use of construction techniques to reduce the area affected by roadway noise (such as earthen berms), concentrating traffic on primary roads in rural areas, reducing traffic noise by changing tire design, vehicle aerodynamics, roadway surface, proportion of truck traffic, and reducing overall daily driving distance. It has also been suggested to make roads narrower, leave the canopy intact, or install sub-roads (Burnett 1992).

Even though the barrier effect could be the most detrimental effect of roads on wildlife, there is the possibility that it can be easily solved through the construction of wildlife crossings. Wildlife crossings can either be underpasses or overpasses, and can be designed specifically for wildlife, or be a modified structure for another purpose. For instance, a culvert for a stream could be made wider, or a bridge could be used instead. Underpasses are either culverts or bridges. While they can expensive, a typical underpass costing from $200,000 to $500,000 (Long 2005), the costs can be reduced by including them in a road's initial design. Wildlife crossing structures will play a key role in the development of greenway corridor networks (Smith et al. 1996), which several state and local governments are creating. Crossing structures will need to be located at the intersection of greenways and roads.

In general, the effectiveness of a wildlife crossing depends upon its location. A perfectly designed crossing will not have any wildlife use it if they cannot find it (Barnum 2003). A crossing should have suitable habitat on both sides (Rodriguez et al. 1996, Barnum 2003, Ng et al. 2004, Donaldson 2005), and that habitat needs to be protected from future development (Rodriguez et al. 1996, Scheick and Jones 2000, Barnum 2003). Landscape features, such as drainages and ridges, help direct wildlife to crossings, so their location should be noted (Barnum 2003, Donaldson 2005). Vegetation and/or cover should be provided at both entrances to the crossing (Hunt et al. 1987, Yanes et al. 1995, Rodiguez et al. 1996) to ensure that wildlife feel protected when using the crossing. Crossings should also be placed in areas where cover extends as close to the roadway as possible (Barnum 2003). To help direct wildlife to the crossing, and prevent them from entering the roadway, fencing can be installed either along the entire roadway or just extending out from the crossing; fencing greatly improves a crossing's effectiveness (Yanes et al. 1995, Walker and Baber 2003). It is important to remember that existing structures already built into the roadway can also serve as crossings, and are probably already being used for that purpose (Hunt et al. 1987, Rodriguez et al. 1996, Ng et al. 2004, Donaldson 2005). Once a crossing is constructed, it may take time for local wildlife populations to adapt to its presence (Reed et al. 1975), and researchers should keep in mind that species typically display seasonal usage of crossing structures (Rodriguez et al. 1996, Walker and Baber 2003).

The design of a structure depends upon its target species or group of species. The structure should be sized appropriately for the target species, and generally a larger structure will serve a wider range of species. A common measurement of underpasses is their "openness value" which is a ratio of area of the opening to the length of the underpass (height times width all divided by length). The openness value reflects the power of the tunnel effect- some species will not enter an underpass if they cannot clearly see the other side. These species require underpasses with high openness values. Any barriers used in conjunction with the crossing should be appropriately designed for the target group as well. For example, chain-link fence will not be effective in funneling salamanders to an underpass. Amphibians, reptiles, and mammals have all been found to use appropriately designed wildlife crossing structures.

In areas with high road-kill rates of migrating amphibians, a small pipe can be installed under the road as a crossing. The first salamander crossing in the US is in Amherst, Massachusetts, and was built for spotted salamanders to travel to their breeding pools. Studies showed that 75.9% of the salamanders that reached the tunnel entrances successfully crossed through the tunnels (Jackson 1996). A similar, but larger system is being used by hundreds of turtles and a few other animals at Lake Jackson, Florida (Aresco 2005). A highway divides the lake and is a barrier to turtle migration between the two new lakes. Prior to installation of a drift fence leading to an existing culvert, mortality was close to 100% for turtles that attempted to cross the road, with an average of 11.9 turtles dead on the road per kilometer per day (Aresco 2005). After fence installation, roadway mortality was reduced to 0.09 turtles dead on the road/km/day (Aresco 2005).

Small mammals have been commonly found to use existing culverts to travel under roads (van Manen et al. 1995, Yanes et al. 1995, Clevenger et al. 2001), but they are most likely using them to access disturbed habitat on both sides of the road, not to migrate long distances (Yanes et al. 1995). Mammals observed using culverts include raccoons and rats (van Manen et al. 1995), mice, weasels, shrews, voles, martens, showshoe hare, and red squirrels (Clevenger et al. 2001), and mice, shrews, and rabbits (Yanes et al. 1995). Several factors influence the use of culverts by small mammals. The presence of cover at the culvert entrances increases use, while roadway noise levels negatively affect the crossing frequency of a few species (Clevenger et al. 2001).

The small size of typical existing culverts often prevents use by large mammals, so crossings must be specifically designed for them. Large mammals are usually the targeted group for specially designed crossing structures due to vehicle collisions leading to property damage and human injury. In locations where high quality below-grade crossings are available, large mammals may prefer to use them instead of crossing at grade when given the choice (Barnum 2003). When designing or studying large mammal crossings, it is important to distinguish between carnivores and ungulates because their behavior and movements are often very different. However, crossings can be designed to meet both groups' needs.

Carnivores are less particular than ungulates about the design of the structure; they will use culverts, bridges, or overpasses. However, they prefer large culverts (greater than 1m wide, and over 0.9 m tall) or small bridges (short in height) (Smith 2003). Carnivores also prefer structures shorter in length (Smith 2003), with the total width of the road affecting crossing rates (Yanes et al. 1995). Landscape factors greatly influence the success of locations for carnivore crossing structures. Bridges surrounded by wetlands, shrubland, or hardwood forests were preferred in one study (Smith 2003), another study more specifically identified distance to nearest drainage a key factor in the use of underpasses by carnivores (Clevenger and Waltho 2000). Brown bears in Europe used riverbeds to cross under roads (Molinari and Molinari-Jobin 2001), and grizzly bears preferred areas with dense vegetation (Chruszcz et al. 2003). Cover should extend as close to the roadway and crossing structure as possible to maximize carnivore use (Smith 2003). Crossing structures should be located as far from human influence as possible since human and domestic predator use of underpasses restricts carnivore use (Clevenger and Waltho 2000, Smith 2003).

Ungulates require underpasses with higher openness values than carnivores. Often deer and elk will only use underpasses that are bridges (Ng et al. 2004), but white-tailed deer will use culverts with a minimum height of 12 ft. (Donaldson 2005) and a large openness value (Clevenger and Waltho 2005). Deer used one relatively small culvert 10 feet wide and 12 feet tall, but there was a high frequency of hesitancy behavior, more than at other sites (Donaldson 2005). Landscape factors influence the use of crossings by ungulates. Ungulates appear to avoid steep areas (Barnum 2003), so ridges create a linear guideway for ungulates. If landscape features intersect with a road, crossing structures in the vicinity are more likely to be used (Donaldson 2005).

Crossing Structure Use by North American Black Bears

North American Black Bears have been found to use a variety of crossing structures, in numerous locations across North America. When given the option, they do not appear to have a preference between overpasses and underpasses (Clevenger et al. 2002). Bears have been observed using both culvert and bridge underpasses, including existing structures and those designed for wildlife. It is thought that black bears have used an existing vehicle tunnel to cross over I-40 (Beringer 1986). At a pre-existing culvert, black bears approached but never entered the culvert, possibly because of its small size (3.05 m wide by 3.66 m tall) (Donaldson 2005), but other unknown factors could have affected the bears'decisions. Other studies have found black bears to use culverts with a minimum height of 1.5 m and openness value of 0.23 (Smith 2003), and a culvert 7.3 m wide by 2.4 m tall was used by at least 5 bears 73 times over 2 years (Walker and Baber 2003). Clevenger and Waltho (2005) found that black bears appeared to prefer structures with small openness ratios and long in length, and attributed this to a need for cover. Black bears have also been observed using dry bridges built for panther and bear use in Florida. At one 13.1-m wide bridge, 2 photos of black bears using it were taken (Foster and Humphrey 1995), it is unknown whether it was 2 different black bears, or the same bear using it twice.

With black bears willing to use so many types and sizes of structures, it appears that the location of a crossing structure may have more of an impact on the frequency of its use. Large-sized mammals, including bears, do not cross highways randomly in mountainous areas (Barnum 2003). As was already discussed briefly, landscape features, particularly linear ones, play a role in determining wildlife movements, and linear features such as streams and ridges can either encourage or discourage roadway crossings depending on its orientation to the roadway (Barnum 2003). Black bears have been found to prefer traveling along drainages (van Manen et al. 2001, McCowan et al. 2004) and to prefer to cross roads at drainages (Brandenburg 1996, Gilbert and Wooding 1996). In accordance with these findings, black bears have been found to prefer wildlife crossings located near drainages (Clevenger et al. 2002, Clevenger and Waltho 2005). Black bears also cross roads in areas with their preferred habitat on both sides of the road. In eastern North Carolina, these areas included pocosins and pure hardwood stands (Brandenburg 1996), and in Florida, wooded wetlands and floodplains (Gilbert and Wooding 1996). However, the use of these habitat areas as crossing points did not appear to be different from overall habitat use (Brandenburg 1996). Preferred travel corridors can be determined prior to road construction, and the intersection of corridors with the proposed road are the ideal location for an underpass (Scheick and Jones 2000).

If there are not any prominent features in the landscape to influence black bear road crossings, the bears may not cross in any particular area of the roadway, so several crossings, and fencing, may be needed (McCowan et al. 2004). In this situation, curved sections of the road may create mortality hotspots due to the limited sight-line of drivers, and bears may feel less exposed crossing at curves due to their own limited sight-line (McCowan et al. 2004). In cases like this, crossing structures should be placed at regular intervals, one study found that a maximum distance of 200 m-250 m was necessary to sustain 90% passage for most species (Donaldson 2005). It may also be helpful to manipulate the habitat surrounding the crossing and create linear features to lead bears to the structure. At a large culvert in Florida, trails were bulldozed in the woods on one side of the underpass to direct wildlife to the structure; 14 of 73 bear crossings recorded were aligned directly north/south, possibly due to the influence of the trails (Walker and Baber 2003).

There are several limitations to underpass use by black bears. The most important is human presence. Black bears prefer to use crossing structures with low human use (Clevenger and Waltho 2000) given the reported negative relationship between human use and black bear use (Clevenger et al. 2002). If black bear crossings cannot be located in remote areas, it is important to regulate human use of crossing structures through postings or fencing. Concrete pillars can also be installed 0.9 m apart to prevent all terrain vehicles from traveling through crossings (van Manen et al. 2001). If fencing is installed to direct bears to the crossing, wooden posts should not be used, as black bears can easily climb them and enter the roadway (Clevenger et al. 2002).

After the completion of construction, it may take time for bears to adapt to the crossing's presence; one study found that use of crossings steadily increased in the four-year period following completion (Clevenger et al. 2002), while another study found that older bears were better at using the crossings, indicating a learned behavior (Serrouya 1999). When studying the effectiveness of a crossing for black bears, it is important to consider that crossing use is a learned behavior, and allow enough time after completion for black bears to adapt to the crossings presence. Collecting observations year-round permits assessment of seasonal use of crossings (Walker and Baber 2003), and should continue for several years to account for variation in mast availability during the fall (van Manen et al. 1995). If a study is conducted in too short of a period, it may falsely lead to the observation of no black bear crossings (van Manen et al. 1995).

BLACK BEAR USE OF WILDLIFE CROSSING STRUCTURES ON I-26 IN MADISON COUNTY, NORTH CAROLINA

Introduction

Wildlife crossing structures are being installed more frequently across the country, in a variety of sizes for multiple species (Foster and Humphrey 1995, Roof and Wooding 1996, Scheick and Jones 2000, Clevenger et al. 2002a, Donaldson 2005). As this is a relatively new technology, little is known about what structure types are best suited for individual species. To fully understand species interactions with structural designs, it is vital that structures are studied to determine how species use different structure types. With data from a variety of structures, more can be understood about each species structural needs, and landscape characteristics that aid in wildlife movement. This information will lead to more efficient planning of wildlife crossing structures in the future.

Crossing structures can be evaluated using a variety of methods, including track detection areas, video cameras, and still cameras. Track detection areas are the least complex method, and are commonly used in studies (Hunt et al. 1987, Rodriguez et al. 1996, Clevenger and Waltho 2000, Clevenger et al. 2001). Multiple media have been used to detect tracks, including sand (Hunt et al. 1987, Rodriguez et al. 1996, Clevenger and Waltho 2000), sooted track plates (Hunt et al. 1987, Clevenger et al. 2001), gypsum powder (Ng et al. 2004), and the existing soil (Roof and Wooding 1996, Walker and Baber 2003). All studies utilizing track detection used at least 1 strip of tracking material across the entire width of the structure, some used 1 strip at each end (Clevenger and Waltho 2000), and a few used a strip at each end along with 1 in the middle (Ng et al. 2004). Multiple strips of tracking material enable the researcher to estimate the number of complete and incomplete crossings. Tracking strips have been checked on a variety of schedules, ranging from 4 (Ng et al. 2004) to 15 days per month (Rodriguez et al. 1996).

Very few studies used video cameras to detect wildlife activity in crossing structures. Reed et al. (1975) used a modified security system to record mule deer (*Odocoileus hemionus*) activity at a culvert for 12 hours each night; the video was then reviewed each day by watching it on fast-forward. Kleist (2005) used a similar system, but sampled the data to detect white-tailed deer (*Odocoileus virginianus*) behavior at a bridge. Continuously recording video systems produce large amounts of data that require labor intensive review, but do not have the complication of a trigger mechanism.

Still cameras are frequently used to record wildlife use of crossing structures. Still cameras can be triggered by motion or an individual "breaking" a laser beam. Some studies rely solely on still cameras (Foster and Humphrey 1995, van Manen et al. 1995), while others use them in combination with another method, such as track detections (Roof and Wooding 1996, Clevenger et al. 2002a, Walker and Baber 2003, Ng et al. 2004, Donaldson 2005).

I used both still and video cameras to record wildlife use of 2 concrete box culverts in Madison County, North Carolina. The culverts were included on a recently constructed section of I-26 in northwestern North Carolina, with the purpose of making the interstate permeable to black bears. Data collected on species use of these culverts will aid in future planning of crossing structures not only for black bears, but also other mammal species in the Appalachian Mountains.

Methods

Description of Site and Structures

Two culverts included in this study were on a recently constructed, 8.8-mile (14.16-km) section of I-26 in Madison County, North Carolina (Figure 2). The section began at the Tennessee/North Carolina border at Sam's Gap, and ran south almost to Mars Hill, NC. The 8.8 miles (14.16 km) were constructed under 2 NCDOT projects, A-10C and A-10D. The roadway opened to traffic in August of 2003. The more northern culvert (Culvert 2) was about 0.75 miles (1.2 km) from the state line, and the more southern one (Culvert 1) was 6.7 miles (10.78 km) from the state line (Figure 2, 3). Area around the road was very sparsely populated. A large portion of the County, and the land on either side of the interstate, was part of Pisgah National Forest. Land use/land cover surrounding the sites consisted mostly of deciduous and mixed forest (Figure 4), along with small crop fields, pastures, and low-density residential areas. Due to the high elevation of the area (culvert 1 is circa 3,000 feet (914 meters), culvert 2 is circa 3,500 feet (1067 meters)), weather was often much cooler, and received more precipitation than surrounding areas.

The 8 x 8 feet (2.44 x 2.44 m) concrete box culverts (Figure 5) were installed at the time of road construction. Culvert 1 was 155-feet (47.24-m) long and Culvert 2 was 140-feet (42.67-m) long (Table 1); both had earthen floors. Culvert 1 stayed wet, with part of the culvert usually containing standing water. Cattails (*Typha* spp.) grew at 1 of the entrances. Culvert 2 was usually dry, although there were signs that water ran through the culvert occasionally. They both had high openness values: Culvert 1 0.41 and Culvert 2 0.46 (Table 1). Openness is an index describing the "tunnel effect" and is defined as (width x height)/length. In theory, the closer this value is to 1, the more appealing the crossing structure is to wildlife.

Right-of-way fencing led up to the entrances of the culverts in an effort to direct wildlife to them. Fencing was made of woven-wire topped with a single strand of barbed-wire, strung between wooden fence-posts (Figure 6). All together, the fence was about 4.5 feet (1.4 m) high. While the fence was not "bear-proof," Barnum (2003) found that small perceived "barriers" could influence where wildlife cross roads (Barnum 2003). For example, deer and elk would not enter a roadway in a section with guardrail; instead they would follow the guardrail to the end and then go around it (Barnum 2003).

Vegetation inside the fencing was not mowed (Figure 7) and contained tall herbaceous vegetation (including grasses and *Lespedeza* spp.) with a few small trees (*Pinus* spp., *Robinia pseudoacacia*) interspersed. Most of the vegetation outside of the fencing was not mowed either and could provide suitable cover for black bears and smaller mammals.

There were no barriers to human use of the culverts. All-terrain-vehicle tracks, as well as human footprints, were detected in the culverts.

History of Site

In March 1991, the NC Wildlife Resources Commission (NCWRC) initially addressed the impacts of habitat fragmentation on black bears anticipated by the proposed corridor for I-26. NCWRC urged that the road be designed to minimize the fragmentation effect for black bears, and suggested the use of bridges wide enough to include dry banks to replace planned stream culverts. The Draft Environmental Impact Statement for the project was released in June 1992, and mentioned the need for "adequate wildlife crossings" to aid in black bear movements, but no details were given. Soon after, both the US Department of the Interior and NCWRC brought to the attention of NCDOT that the proposed roadway corridor would separate 2 existing black bear sanctuaries: Flat Top Bear Sanctuary 8 miles (12.9 km) east and Rich Mountain Bear Sanctuary 12 miles (19.3 km) to the west. Combined with secondary development due to the interstate, the proposed road could create a total barrier between these sanctuaries. At a meeting held on September 22, 1992, the representative from NCWRC stated that black bear crossings were needed in Section C of the project, and that they wanted to walk the location with NCDOT representatives to determine the best locations for crossings.

NCWRC supplied NCDOT with data on black bear locations in Madison County. Based on nuisance complaints, road kills, and hunter data (a majority of the county's hunter-killed bears being located within 6 miles (9.66 km) of the corridor), black bears were documented east, west, and south of the proposed corridor. With this information, NCWRC felt confident in stating that black bears were present in the area of the roadway, and traveled across the proposed roadway corridor. In November 1992, NCWRC made design suggestions for bear crossings. They recommended enlarged box culverts with openings having 1 square unit of area for each unit of length in order to reduce the "tunnel effect." The recommended culverts included retaining walls on each end to funnel wildlife into the crossing. They also suggested that right-of-way fencing be used to direct wildlife to the culvert and away from at-grade crossing locations. Lastly, NCWRC emphasized the need for NCDOT to acquire land adjacent to the crossings to protect it from development, and recommended a key section of forest at the Tennessee border that would aid in habitat connectivity. From the walk-through, 6 potential locations were chosen for crossings, 2 sites with 3 specific locations each. At a joint meeting, it was determined that 1 location would not be suitable for a culvert. Final decisions concerning locations and design for the culverts would be made during final design of the road. The Final Environmental Impact Statement released in March 1994 summarized all of these considerations and requirements for black bear crossings, and stated that a study would be done to determine their effectiveness.

Documenting Wildlife Use of Culvert 1

To document wildlife use of Culvert 1, 2 still digital cameras were installed on November 4, 2005, 1 at each end of the culvert. Still cameras were Cuddeback 3.0 Digital Scouting Cameras (Figure 8), which utilized passive infrared technology to detect motion and heat to activate the camera. The camera at the eastern entrance was mounted to the outer crossbeam and positioned to look out from the opening, while the camera at the western entrance was mounted on the ceiling looking down at the floor of the culvert.

The cameras were set to have a 1-minute delay between pictures. During the week of January 23, 2006, the camera looking out from the opening was repositioned, as it had not collected any photos of wildlife. The camera was mounted on a post, about 18 inches (45.72 cm) off the ground and 10 feet (3.05 m) from the culvert entrance, and aimed to look into the culvert opening. Paul Weisner and Roger Bryan, NCDOT District 13 engineers, installed and relocated the cameras. The Compact Flash memory cards for the cameras were exchanged regularly, and the batteries changed every other month.

Documenting Wildlife Use of Culvert 2

Cameras

Culvert 2 was observed using both digital still and digital video systems. Two still cameras (Cuddeback 3.0 Digital Scouting Cameras) were installed at the culvert in the week of January 23, 2006 in the same configuration as the final one described for Culvert 1. However, due to vandalism, data collection could not begin until May 2006. The camera on the post outside the culvert was moved inside the culvert on the side wall, 10 feet (3.05 m) inside the entrance, about 20 inches (50.8 cm) above the ground.

Culvert 2 was also observed with a digital video system (Figure 9). The video system (Sentinel 5 system from Sandpiper Technologies, Inc.) used 4 digital ultra low-light cameras mounted on 35-foot (10.67-m) tall wooden telephone poles. Two of the cameras were used to observe the culvert entrances; the use of the other 2 cameras is described in a following section. One telephone pole was installed on each side of the road, about 20 feet (6.1 m) from the culvert entrance. One camera was on each pole, looking down at the culvert. Invisible infrared Light Emitting Diode (LED) spotlights were mounted directly above the entrance to each culvert to provide nighttime illumination. The system was powered by 4, 123-watt Panasonic solar panels and 4, 98-amp batteries.

Video Data Analysis

Only the first frame of each minute was reviewed. Each frame was inspected for evidence of wildlife crossings through the culvert, if anything was detected, the video was viewed in real time to determine the nature of the event. For each observed crossing event, duration, species, and direction were recorded. Each observed event was recorded and saved; these video segments are referred to as "clips."

Because only a portion of the available video frames were sampled (1 frame per minute), a detection probability for crossing events was estimated (Kleist 2005). For each event less than 1 minute, the duration was divided by 60 seconds to determine the probability of detecting this event. Each event 1 minute or longer has a detection probability of 1.0, since 1 frame per minute was observed, thus:

$p_i = d_i /60$ if d_i is less than or equal to 59 seconds

$p_i = 1$ if d_i is greater than 59 seconds,

where p_i = probability of detection for each event, and d_i = the duration of the event in seconds. An estimated number of animals that actually crossed was calculated as the sum of the animals per event divided by each event-specific detection probability, or $N = \sum$ (number of animals per event / p_i), where N = the estimated number of animals. Lastly, overall detection probability for wildlife activity was calculated by dividing the actual number of observed animals by the estimated number of animals, $P_{detection} = n / N$, where n = actual number of animals observed in the sample of the video data. Detection probabilities were calculated, both overall and by species.

For a limited time period, data were reviewed in full from the eastern entrance's camera. From the complete viewing of this portion of the video data, the percentage of the crossings that were at least a minute long was calculated, which can be compared to the sampling results. The video clips collected through the complete viewing were not included in any of the statistical analysis as they were not a part of a sample.

Other Below-Grade Crossing Possibilities

In addition to the ones studied, there were 3 more concrete box culverts along the roadway that carried streams (Bear Branch, Higgins Branch, Jarvis Branch) under I-26 (Figure 3). Because black bears have been documented traveling along stream corridors (Brandenburg 1996, Clevenger et al. 2002a, McCowan 2004, Clevenger and Waltho 2005), they could cross I-26 at any one of these culverts. To see whether this occurred, 1 Cuddeback 3.0 Digital Scouting Camera was installed at 1 end of each stream culvert (Table 1).

Bear Branch

Bear Branch intersected with I-26 adjacent to the Bear Branch Road interchange, and was the most northern creek culvert on the project. The stream crossed under I-26 through a double-box culvert. A camera was installed on the western end of the culvert on its right wing-wall, approximately 3 feet (0.91 m) above the ground. The culvert was 675 feet (205.74 m) long, and each half was 6 x 7 feet (1.83 x 2.13 m), leading to an openness value of 0.06 for each half (Table 1). At this end, the culvert opened to a small floodplain field, well below the grade of the interstate, the interchange, or the road leading to the interchange. Because the camera was on the wing-wall, it viewed out from the culvert entrance, and also slightly across the entrance. The tip of the opposite wing-wall was visible in the photos.

Jarvis Branch

Jarvis Branch intersected with I-26 just north of Higgins Branch. The eastern culvert entrance was adjacent to the intersection of Jarvis Road and US 23, both of which were just a few feet beyond the entrance. A private residence was directly across Jarvis Road from the culvert entrance. The culvert was 1,375 feet (419.1 m) long, with an opening of 8 x 7 feet (2.44 x 2.13 m), leading to a low openness value of 0.04 (Table 1). On the western end, the culvert opened to private property. On that end, Jarvis Branch Road passed over the culvert near its entrance.

A camera at this culvert was installed on the eastern end of the culvert. Due to a high level of human activity adjacent to both ends of this culvert, the camera was positioned inside the culvert, on the ceiling, to conceal it and prevent vandalism or theft.

Higgins Branch

Higgins Branch intersected with I-26 near the beginning of the section being studied, and was the most southern of the creek culverts. The culvert was 6 x 7 feet (1.83 x 2.13 m), and 420 feet (128.02 m) long, leading to an openness value of 0.10 (Table 1). On the eastern end, the entrance to the culvert was very close to the intersection of NC Highway 23 and Higgins Branch Road. On the western end, the culvert entrance opened to private farmland. NC 1609 crossed over the culvert a few feet from the entrance.

A camera at this culvert was installed on the western end on the crossbeam, which has an angled surface so that the camera view was both down and out from the top of the culvert.

At-Grade Crossings Adjacent to Culvert 2

Video cameras placed at Culvert 2 attempted to capture black bears crossing the interstate. Two video cameras were positioned to view the roadway from the top of the telephone poles. One was aimed to view the roadway north of Culvert 2, whereas the other was aimed south of Culvert 2. The field of view was approximately 0.6 to 1 miles (0.97 to 1.61 km) of the roadway, depending on visibility due to ambient weather conditions.

Video data collected by these 2 cameras were analyzed using similar methods to those described above. Video was sampled by viewing the first frame of every minute. Clips were collected of any animal or human detected by sampling, and their activity was recorded. Detection probabilities were calculated for each clip, and summarized overall and by species.

Because of the difference in the available field of view, raw data from the 2 cameras on the culvert could not be compared to the 2 roadway cameras. The roadway cameras encompassed a larger area, so the detection probability of each event would differ from events at the culvert entrances.

Activity Adjacent to Roadway

Still cameras were placed in a few likely locations along the roadway in an attempt to detect black bear presence and possible crossings. Locations were chosen based on accessibility, distance to the roadway, and likelihood of bear presence. Descriptions of these locations follow:

Little Creek

Little Creek was 0.5 miles (0.8 km) from the Tennessee state line, and several hundred feet below grade. On the western side of the road, the drainage had been left in a natural condition, and the stream emerged from a National Forest just a few hundred feet away from the road. A camera was mounted on a small tulip poplar (*Liriodendron tulipifera*), looking upstream, away from the road, about 100 feet (30.48 m) from where the creek entered a 60-inch (1.52-m) steel pipe culvert.

Northern Fill

This fill was 0.9 miles (1.45 km) from the state line on the western side of the road, and just south of Culvert 2. The fill was below grade, and contained natural grassy vegetation (*Poaceae* spp.), and several small black locust trees (*Robinia pseudoacacia*). A camera was mounted in the rear of the fill, on a small black locust tree, overlooking a small stream.

Southern Fill

This fill was also on the western side of the road, and stretched from 1.7 to 2.0 miles (2.74 to 3.22 km) from the state line. There was a section of fencing at the edge of the fill, along the roadway. This fencing was the same design as the right-of-way fencing, but was a separate section intended to keep people from driving onto the fill. As the fencing could be a perceived barrier to wildlife, a camera was mounted to each end-post of the fence, about 20 inches (51 cm) above the ground. This section of fence was 0.3-miles (0.48 km) long, with most of it on grade. The northern end of the fence was about 25 feet (7.62 m) below grade, while the southern end was about 100 feet (30.48 m) above grade. Each camera was installed directly on 1 of the end fence-posts, about 20 inches (51 cm) above the ground, and viewed away from, but in line with, the fence.

Other methods of collecting at-grade crossings:

Three run-away truck ramps along the section of roadway were checked regularly for bear tracks, which would have indicated black bear presence directly adjacent to the roadway. The entire right-of-way fence, on both sides of the road, was checked for signs of bear crossings. Locals were solicited for sightings of bears along the stretch of road through flyers hung in public places, and placed in individual's newspaper boxes in the summer of 2006. There was also a radio broadcast highlighting the project, and requesting information on bear locations. Lastly, accident reports for black bear collisions were obtained from the State Highway Patrol, and the Madison County DOT Maintenance Crew.

Results

Data were collected for at least a year, with some cameras running over a year. During that time 1,715 pictures were taken by the still cameras, and 152 clips of animal activity were collected from the video data. Black bears were detected or reliably reported 12 times, twice inside Culvert 2 (Table 2). A black bear was detected crossing the road at Culvert 2 4 times, with 1 instance resulting in a bear-fatal vehicle collision (Table 2). Scientific names for species detected are listed in Table 3.

Culvert 1

The 2 still cameras at Culvert 1 ran continuously from November 4, 2005 to June 1, 2007. Over that time, they collected 454 pictures, 138 of which contained animals. White-tailed deer was the most commonly recorded species, followed by northern raccoon, and Virginia opossum (Tables 4 and 5).

Culvert 2

The 2 still cameras at Culvert 2 ran continuously from May 5, 2006 to June 1, 2007. Over that time, they collected 337 pictures, 204 of which contained animals. Northern raccoon was the most commonly recorded species, followed by Virginia opossum, and bobcat (Tables 4 and 5).

Two bear pictures were taken by the camera on the wall of the culvert. The first picture was taken October 27, 2006; the second was taken May 24, 2007 (Table 2). Both showed the bear heading towards the other end of the culvert. Both were taken in the evening, after sunset. It is unknown if it is the same or different individuals in the pictures.

Video cameras ran continuously from April 15, 2006 to May 23, 2007. Unfortunately, the infrared LED spotlights placed at the culvert entrances were ineffective at illuminating the entrances sufficiently enough for animals to be detected at night. For most of the year, only video from sunrise to sunset could be reviewed for animal activity. One hundred nineteen video clips were taken of activity near the culvert entrances by the 2 video cameras, with 220 individual animals and humans detected. Of these, 37 animals in 14 clips were seen entering the culvert, whereas 39 animals in 14 clips were seen exiting the culvert (Table 6). Five species were detected entering and/or exiting the culvert: domestic dog, domestic cat, human, groundhog, and northern raccoon (Table 6).

As previously described, video data were sampled for a majority of the study time. Time periods sampled for both cameras were April 15, 2006 to April 20, 2006 (6 days), May 25, 2006 to June 8, 2006 (15 days), and July 21, 2006 until May 23, 2007 (306 days). Seventy-eight clips were taken from the sampled video data. Video data were completely viewed from April 27, 2006 to May 23, 2006 (26 days), and June 8, 2006 to June 22, 2006 (15 days). Only the data from the eastern end's camera were completely viewed. Forty-one clips were taken from the completely reviewed video data. A majority of the clips were under 60 seconds. Only 11 of the clips were at least 60 seconds, or 27% of the clips.

From the group of sampled clips, 60 of the 111, or 54%, were at least 60 seconds; whereas 27% of the completely reviewed clips were at least 60 seconds. Thus, sampled data yielded a larger percentage of clips at least 60 seconds, suggesting that activities with short durations may have been frequently missed during the sampling process, assuming that the section of video completely reviewed was representative of all the video data collected.

One hundred fifty-four animals were detected by sampling the data. Based on the detection probability of each instance, an estimated 240 animals were near an entrance to the culvert. This leads to an overall detection probability of 0.64 for the sampled clips (Table 7).

Only 1 clip from the culvert cameras contained a black bear. This clip was from the western end's camera on June 7, 2006, and showed a bear approaching the culvert, enter for a few seconds, and then run back out (Table 2). The bear can be seen for a total of 56 seconds, giving it a detection probability of 0.93, which leads to 1 estimated bear near the culvert entrances (Table 7).

Other Below-Grade Crossing Possibilities

Bear Branch

The still camera at Bear Branch ran from April 27, 2006 until June 2, 2007, and took 109 pictures over that time. Seven pictures contained animals. Humans were the most commonly detected species, and white-tailed deer were the only other species detected (Tables 4 and 5).

Higgins Branch

The still camera at Higgins Branch ran from May 5, 2006 until it failed. Exactly when the camera failed could not be determined, but the last picture was taken August 16, 2006. The camera appeared responsive until the spring of 2007, but it may have failed before then. During the short time it was functioning, the camera took 53 pictures, 14 of which contained animals. Northern raccoon were the most commonly detected species, and other species detected were groundhogs, Great Crested Flycatcher, Northern Cardinal, and a rat species (Tables 4 and 5).

Jarvis Branch

The Jarvis Branch still camera ran continuously from May 5, 2006 until June 2, 2007. During this time, it took 65 pictures, of which 22 contained animals. Northern raccoons were the most commonly detected species, followed by humans (Tables 4 and 5).

At-Grade at Culvert 2

Data from the video camera looking south were reviewed for April 15, 2006 to April 20, 2006 (6 days), May 25, 2006 to June 8, 2006 (14 days), and from July 21, 2006 until data collection stopped on May 23, 2007 (306 days). The camera aimed north came unplugged just after installation, so data review for this camera began with May 25, 2006, and then followed the same dates as the other camera.

Thirty-three video clips were collected of activity near the road, adjacent to Culvert 2. Several species were detected (Table 6); animals in 3 clips could not be identified, and were labeled unknown. A variety of activities were detected adjacent to the roadway. Seven instances of an animal crossing or attempting to cross the road were detected, and animals were seen walking along the road in 8 instances (Table 6). All of the clips ranged in duration from 20 seconds to 453 seconds, with 1 clip of humans lasting 44 minutes.

Sixty animals were detected from the video camera data. Based on the duration of the clips, the estimated number of animals that actually went near the road was 69, making the overall detection probability 0.87 (Table 8).

Bears were detected twice, first on October 19, 2006. The bear completely crossed the road, and was in the video frame for 138 seconds. The second instance was on October 27, 2006 (Table 2). The bear went halfway across the road before turning around, and was in the video frame for 33 seconds. Based on the detection probabilities of the 2 events, an estimated 3 bears were near the road, leading to an overall detection probability of 0.71 for black bears on or near the road.

Activity Adjacent to Roadway

Little Creek

The Little Creek still camera ran from May 5, 2006 to June 2, 2007. During this time it took 87 pictures, 14 of which contained animals. White-tailed deer were the most commonly seen species; coyotes and humans were the only other species detected by the camera (Tables 4 and 5).

Northern Fill

This camera was installed on July 21, 2006, but when checked a month and a half later it had been turned upside down. It is unknown whether the camera was turned by a human or an animal, but the positioning of the camera allowed water to enter the body, ruining the camera. Unfortunately, the camera was only able to collect data for about a month. During this time it took a total of 7 pictures, none of which contained an animal (Table 5).

Southern Fill (both cameras)

These cameras were installed on different dates. The still camera on the northern end of the fence was installed on April 27, 2006, while the one at the southern end of the fence was installed July 21, 2006. Both ran continuously until they were taken down

June 1, 2007. The northern camera collected 276 pictures, of which 35 contained animals. White-tailed deer were the most commonly detected species, followed by coyotes (Tables 4 and 5). The southern camera collected 327 pictures, of which 9 contained animals. White-tailed deer were again the most commonly detected species (Tables 4 and 5). Both of these cameras appeared to have an overly sensitive triggering mechanism in the summer, and they would take dozens of pictures a day of moving grass. These 2 cameras were the only ones installed in places that received direct sunlight, and it appeared the heat made the infrared sensor less sensitive, making the movement sensor the primary trigger.

Other Bear Activity and At-Grade Crossings

Sixty-four locations were found where bears crossed right-of-way fencing along both sides of the road. Most detections of crossings were found on the bottom of the woven-wire or barbed-wire, where the fence did not completely touch the ground. Locations appear to be evenly distributed across the study area (Figure 10). Of the 64 locations where bears crossed the right-of-way fence, 18 were where the fence was within 328 feet (100 meters) of the road, and 17 were on sections within 656 feet (200 meters).

Bear tracks were found once on Truck Ramp 2 (Table 2), but were not found on any other ramps, or other visits to the same ramp. Only a few local citizens responded to the flyers soliciting information, with only 1 providing information on bears along the interstate. However, in the process of hanging the flyers, a few locals provided some useful information (Table 2). The state highway patrol did not have any recorded incidents of black bears being hit in the study area, and the Madison County DOT crew did not report finding any killed bears along the interstate. We recorded 1 road-killed bear at the site of culvert 2; it was not reported by either agency.

Discussion

Twenty-three species were detected in or near the entrances of the 2 crossing structures, suggesting that the design appeals to a broad range of species. The smallest species detected were songbirds (Song Sparrows and Eastern Phoebes), the smallest mammals detected were mice, and the largest were black bears. Many of the smaller mammal species might rely on these structures to traverse the road; the large Jersey barrier in the center of the road probably prevents all but the largest and/or most agile species from crossing the interstate. Many of the smaller species might use the structures to regularly access sections of their territory divided by the road. During the summer, 2006, a family group of bobcats, consisting of an adult and 2 juveniles, repeatedly crossed through Culvert 2. A northern raccoon family group was also repeatedly detected during the same time period. The 2 family groups were thought to be using the culvert to travel between foraging areas because of their repeated detections. Small mammals probably use crossing structures to access disturbed habitat on both sides roads (Yanes et al. 1995). Because the majority of small mammals killed on roadways are young dispersing or adults searching for mates (Burnett 1992), crossing structures may also aid in maintaining the genetic viability of these species populations by allowing sub-adults to disperse. Culverts probably provide safe passage across I-26 for small mammals.

Black bears were recorded in Culvert 2 on 2 separate occasions. Whether they crossed through the culvert is unknown because only 1 of the 2 still cameras inside the culvert recorded them. However, their presence in the culvert indicates that the structural design is acceptable to black bears. Because bears readily crossed the right-of-way fencing and were detected on 4 occasions attempting to cross I-26 at Culvert 2, the presence of bears in the culvert could indicate a "choice" for crossing through the culvert. If bear-proof fencing were installed to eliminate the option of crossing the roadway, then bears could probably use the crossing structures rather than not crossing the road at all. Non-structural factors may have deterred some bears from using the culverts. These factors could include noise from traffic and human use of the culverts.

Humans were detected in the crossing structures 16 times. A majority of the humans observed appeared to be hunters, and all were on foot. Black bears in this area are heavily hunted; there were 27 reported harvests in the county in 2005, and 16 in 2006 (NC Wildlife Resources Commission). Black bears have been found to avoid areas frequented by hunters, including roads used during hunting season (Beringer 1986, Powell et al. 1996). Black bears also prefer to use crossing structures with low human use (Clevenger and Waltho 2000), with an observed negative relationship between human use and black bear use (Clevenger et al. 2002a). Because of this, occasional human presence could limit black bear use of the culverts, especially during hunting season. While there is no way to prevent people from using the culverts without also preventing bear passage, human use could be discouraged through signs and education of the public.

Wildlife and Bear Use of Other Structures

While several species of wildlife were detected at the entrances to the stream culverts, there was little evidence that many used the culverts to cross the road. The 3 stream culverts were all wet, long, dark, and curvy with 1 entrance not visible from the other. Only muskrats used the stream culverts as crossing structures. The other species detected were most likely foraging or traveling along the stream, and they may have turned around upon reaching the culvert entrance. Animals detected would possibly use the culverts for safe passage if a dry walkway was included in the design, or if the culverts were shorter.

Black bears have been found to prefer traveling along drainages (van Manen et al. 2001, McCowan 2004) and to prefer to cross roads at drainages (Brandenburg 1996, Gilbert and Wooding 1996). In accordance with these findings, black bears have been found to prefer wildlife crossings located near drainages (Clevenger et al. 2002a, Clevenger and Waltho 2005). Black bears were not detected at any of the creek culverts entrances in my study. This may be because all the creek culverts were relatively close to human development and secondary roads.

Bears Near the Road

Black bears were present in the area surrounding I-26. The number of locations found where bears crossed the right-of-way fencing indicated that bears were common in this area, and they were not intimidated by simple structures. Previous studies have suggested that black bears avoid habitat adjacent to roads, particularly habitat within 328 feet (100 meters) of any road, regardless of road size or season (Brandenburg 1996). In the same study, bears also avoided habitat from 328 to 656 feet (100-200 meters) from primary roads more than habitat the same distance from secondary roads (Brandenburg 1996). During my study, black bears did not appear to avoid the area adjacent to I-26, which is a primary road.

Bears were only recorded and reported on the road a few times during my study; however, it was impossible to record all bear activity along the entire 8.8 miles (14.16 km) constantly. Based on the level of activity found along the fence, bears probably crossed the interstate more times than were recorded. Because bears likely do cross the interstate, there is a need to manage these interactions. However, the high level of bear activity in Madison County also indicated that 2 structures may not be sufficient as crossing alternatives for 8.8 miles (14.16 km) of road. Donaldson (2005) found that crossing structures should be placed at regular intervals, and that a maximum distance of 650 to 820 feet (200-250 meters) between structures was necessary to sustain 90% passage for most species. Based on this estimate, the 8.8-mile (14.16-km) section of road in this study should contain 56-71 crossing structures.

Conclusions

If the circumstances surrounding the 2 culverts constructed for wildlife use were modified, black bears might use them more frequently. Bears were present in the area, and were willing to cross the interstate, with such activity recorded in both the summer and fall. There is no way to know which factor is the most limiting to bear use of the culverts, so it may be best to address all the issues possible. Enhanced management might include improving the fencing, discouraging human use of the structures, and possibly working to decrease or muffle the noise from the traffic.

It is also possible that repeating this study in a few years may yield different results. This study began 2 years after the road was opened to traffic; more time might be needed for black bear populations to acclimate to a crossing structure's presence. Clevenger et al. (2002a) found that use of crossings steadily increased in the 4-year period following completion, while Serrouya (1999) found that older bears were better at using the crossings, indicating a learned behavior. When studying the effectiveness of a crossing for black bears, it is important to take this into account and allow enough time after completion for black bears to adapt to the crossings presence. It is also important to collect observations year-round to account for seasonal use of crossings (Walker and Baber 2003), and for several years to account for variation in mast availability during the fall (van Manen et al. 1995). My study lasted for 14 months and only encompassed 1 fall, it is likely that black bear interactions with the structures could vary year-to-year, and it is impossible to know how the conditions of this study compare to other years.

ASSESSMENT OF POTENTIAL BLACK BEAR MOVEMENT IN MADISON COUNTY, NORTH CAROLINA

Introduction

Background

Proper planning is vital to the success of any wildlife crossing structure. While identifying a suitable structural plan is important (Smith 2003, Ng et al. 2004), the placement of the structure in the landscape may ultimately determine its effectiveness (Clevenger and Waltho 2000, Barnum 2003). Habitat type adjacent to structures can influence crossing rates (Rodriguez et al. 1996), with nearby human development having a negative influence on crossing rates of most species of wildlife (Clevenger et al. 2002a, Clevenger and Waltho 2005). Linear landscape features, such as streams and ridges, can be used to predict crossing sites for wildlife (Barnum 2001). As the importance of location has become more apparent, more effort has been put into selecting sites for crossing structures (Burch et al. 2007, Watkins and Garvey-Darda 2007). Most road projects do not have the time or funding for an extensive field study, as was done by Scheick and Jones (2000), and reliable alternatives are needed. Using a geographic information system (GIS) to evaluate landscape data is becoming a more popular choice (Klein 1999, Kobler and Adamic 1999, Clevenger et al. 2002b).

A GIS is a computer system and program used to store and analyze spatial data. This technology can be used to create maps and query data, as well as to conduct more sophisticated analyses such as predicting human population growth patterns, modeling the spread of disease or invasive species, and evaluating land use change over time. GIS has become a commonly used tool in wildlife management, used to evaluate habitat-species relationships for multiple purposes including locating rare species (Carter et al. 2006, Greaves et al. 2006, Rachlow and Svancara 2006), identifying areas for conservation (Singleton et al. 2004, Wikramanayake et al. 2004, Peralvo et al. 2005), and identifying hotspots for road kill (Gilbert et al. 2001).

GIS modeling can be more efficient and accurate than field studies. Carter et al. (2006) used GIS to locate possible Florida Scrub Jay habitat, limiting the area that needed to be surveyed in the field. Greaves et al. (2006) used GIS to predict habitat areas for a rare species, the New Zealand long-tailed bat. Of the sampled areas identified by the model as suitable habitat, 45% contained the bat; previous surveys in areas identified as suitable habitat based solely on vegetation type had a success rate of only 12% (Greaves et al. 2006). GIS was also used by Newton-Cross et al. (2007) to predict badger habitat in Great Britain. Newton-Cross et al. (2007) found the model predictions were more accurate than habitat evaluations made in the field.

Habitat models can either be data-driven (inductive) or knowledge-based (deductive); both methods are commonly used. Data-driven models begin with field-collected locations of individual animals, and extrapolate relationships between the locations and habitat variables. Knowledge-based models are built from known relationships between the species and habitat variables, and do not require any location data on the species. Data-driven models have the ability to incorporate variables with unknown relationships to the species, but there is also the danger of identifying relationships that do not actually exist.

Data-driven models can be built on field survey data, locations collected with GIS collars, or mortality data (such as road kills) depending on the species, objective, and data available. Many studies have used this technique to evaluate habitat preferences of rare species, and to predict their distribution (Peralvo et al. 2005, Greaves et al. 2006, Rachlow and Svancara 2006, Newton-Cross et al. 2007).

If species location data are not available, a knowledge-based model can be constructed using information available in the literature, and/or advice from experts. Both Klein (1999) and Brown et al. (2000) created models using information from the literature. Craighead (2005) developed a grizzly bear habitat model based on expert opinion that was comparable to data-driven models created in the region. Clevenger et al. (2002b) created 3 models for the same region: 1 based on locations of black bears, 1 from a literature review, and 1 from expert opinion. The models based on the literature review and expert opinion performed as well as the data-driven model (Clevenger et al. 2002b). Knowledge-based models can be very accurate, but are limited by the accuracy of the information used to create the model.

My study used a knowledge-based model to identify areas conducive to movement of black bears in the Appalachian Mountains. The model could be used to determine locations for black bear crossing structures on future road projects in the region.

Problem and Objectives

In 1992, the North Carolina Department of Transportation (NCWRC) decided to include 2 crossing structures for black bears on a new section of I-26 in Madison County, North Carolina. Locations for the structures were suggested by the North Carolina Wildlife Resources Commission (NCWRC) based on local habitat characteristics, without a landscape-level analysis. The final locations for the structures were chosen by the project engineer, with the objectives of placing the structures as far from human development as possible, and in locations that minimized the structural limitations of the culvert design.

In conjunction with a study on wildlife use of the 2 culverts, a GIS model was created to locate areas of possible high black bear movement in the Appalachian Mountains. While the primary goal was to evaluate the location of the culverts and predict bear crossing locations along the I-26 roadway, a secondary goal was to create a tool that could be used to aid in the placement of black bear crossing structures on future roads in the Appalachian Mountains. To achieve both goals, several criteria were used as guidelines for creating the model:

1. Based on pre-existing, available data
2. Simple to use
3. Accurate
4. Applicable in other areas of the southern Appalachian Mountains

The first 2 criteria are to promote the use of the model by government agencies as a planning tool. It will be more likely to be used if all the data required are already available for multiple regions, and if someone unfamiliar with GIS is able to use and understand the model; the last 2 criteria are vital to the continued use of the model as a planning tool. If it is inaccurate or overly site-specific, it could lead to poor placement of crossing structures in the future.

Methods

Study Area

The model was built to reflect the general movements patterns of black bears throughout the southern Appalachian Mountains. The sample data used to test the model were from Madison County, North Carolina, which is on the western edge of the state.

Spatial Data

The data used were from several sources, including NCDOT, the North Carolina Center for Geographic Information and Analysis, and NCWRC. Details about all data used are contained in Table 9. All of the data were converted to raster format with 50-meter resolution for use in the model.

Analysis Methods

Landscape variables to include in the model were chosen based on an extensive literature review of studies on black bear habitat use and movement. Several factors were consistent across the studies. Black bears prefer to travel along drainages (Brandenburg 1996, Gilbert and Wooding 1996, Clevenger et al. 2002a, McCowan 2004, Clevenger and Waltho 2005), as well as ridges and valleys (defined as areas with shallow slopes) (Barnum 2003). For habitat, black bears prefer forested areas, and often hardwoods (Brandenburg 1996, Gilbert and Wooding 1996). They also tend to avoid human development and large roads (Clevenger and Waltho 2000). One study found that black bears preferred to cross large roads in areas with low human use (Clevenger and Waltho 2000).

The general concept of the model is that every landscape variable included influences black bear movement a certain degree, either in a positive or negative manner. Similar analyses have been done for other species of bears (Kobler and Adamic 1999, Singleton et al. 2004), and black bears in other regions (Larkin et al. 2004, Clevenger et al. 2002b). In this model, each landscape variable is assigned a weight based on how much it promotes or impedes black bear movement. Because I did not have bear locations, I was limited to a knowledge-based modeling scheme. To determine weights for each variable, a group of black bear researchers with experience in the southern Appalachian Mountains ("the experts") was surveyed (Appendix A). Experts were asked to rate each variable on a scale of –100 to +100 for its effect on bear movement, with negative values representing characteristics that impede bear movement, and positive values being characteristics that promote it. Responses were arithmetically averaged to determine the final weight for that variable.

Each land cover category (from the National Land Cover Dataset classification scheme of the Multi-Resolution Land Characteristics Consortium) was weighted based on its contents, as well as the area of the individual habitat patch. Since area could influence black bear movement differently for every land cover type, each combination of land cover and area was assessed individually by the experts. Patch area was broken into 4 categories: 0-6.18 acres (0-25,000 m^2), 6.18-24.71 acres (25,001-100,000 m^2), 24.71-247.11 acres (100,001 m^2-1 km^2), and anything larger than 247.11 acres (1 km^2). The experts were asked to assign each combination of land cover and area 1 of 5 values: 0.01, 0.5, 1.0, 1.5, and 2.0. Responses were averaged to assign each area class/land cover combination an adjustment value. The overall movement value for each patch of land cover was determined by multiplying the value assigned to the land cover type by the adjustment value for the patch's area.

A tool was created in ArcMap to reclassify the land cover data. The user must input the land cover data, and the tool reclassified each land cover patch based on its area and cover type. A second custom ArcMap tool reclassified every other landscape variable to its expert determined weight, and combined them all with the reclassified land cover. The reclassified variables were combined by adding the values from each layer for each cell. The output was a map predicting the likelihood of bear movement through each cell.

Model Assessment

Black bear movement locations were collected along I-26 in order to validate the model. The movement locations were found by checking the right-of-way fence for signs of bear crossings. I assumed that if a bear was willing to cross the fence, it was moving through the area, as opposed to purely selecting the area for habitat use. The top and bottom of the fence were checked for hair caught on the edges. The fence on both sides of the road was checked in the spring of 2007. GPS coordinates were collected with Trimble GeoXT, GeoExplorer 3, or GeoExplorer 2 units wherever black bear hair was found on the fence.

These locations, along with road kills and locations of crossings from cameras, were used to test the model. The locations were overlaid with the movement values to determine the movement value for each known movement location. Movement values for known locations were compared to the entire set of movement values, and the movement values within 0.31 miles (500 meters) of I-26 using the Chi-squared goodness of fit test.

Results

Analysis Methods

Nine landscape variables were identified from the literature as possibly influencing black bear movement: slope, city boundaries, state game lands, rivers, streams, roads, bear sanctuaries, human population density, and land cover. Roads were broken into 4 categories: interstates, primary roads, secondary roads, and other roads.

Thirteen land cover/land use classifications were used in the model: water, low intensity residential, high intensity residential, commercial, bare rock, deciduous forest, evergreen forest, mixed forest, shrub lands, grasslands, pasture land, row crops, and wetlands.

Seven black bear researchers responded to the survey ranking the landscape variables. The experts represented several southeastern states including South Carolina, North Carolina, Tennessee, Virginia, and West Virginia. Values given by the experts for each factor were compared, and a few outliers were eliminated (13 out of 194 responses were eliminated). In this case, outliers were values that were drastically different from the rest of the set, probably due to 1 expert interpreting the factor differently from the rest of the panel. Remaining values for each landscape variable were arithmetically averaged (Table 10).

Four experts responded to the patch size survey. None of the responses appeared to contain outliers due to mis-interpretation, so no values were eliminated from analysis. Responses for each category were arithmetically averaged (Table11).

The map produced by combining the weights for all factors contained values ranging from –317 to 239, with negative values representing areas that likely impede black bear movement, and positive areas representing areas that likely promote it (Figure 11). Most of the cells contained positive values (385,973 cells); only 81,066 cells (17.35% of all cells) contained negative values; 5 times more area of the county had positive values than negative values. Cells did not appear to be evenly distributed amongst the positive values (Figure 12). Of the positive cells, 14.15% had values between 0 and 100, leaving 85.85% of the values greater than 100. The largest spike in the distribution occurred at the movement value of 141; 146,552 cells contained this value. This single value represented 37.97% of the positive cells, and 31.36% of all the cells.

The area within 1640.42 feet (500 m) appeared to have much lower movement values than the distribution of the entire county (Figure 13). Over half the cells were negative (50.79%), 18.42% were between 0 and 100, and 30.78% were greater than 100.

Model Assessment

Sixty-four locations were found where bears had crossed the right-of-way fence. In addition, there were 4 locations where live bears were detected by cameras and 1 location where a bear was fatally hit by a vehicle. When overlaid with the movement values, these 69 locations corresponded to movement values ranging from –201 to 166. The values were more heavily distributed towards the higher end of the scale (Figure 14), however, less so than the entire set of values for the county. Fourteen of the locations (20.09%) had negative values, 17 (24.64%) had values between 0 and 100, and 38 (55.07%) had values over 100. Values for the known bear locations were significantly different from the entire set of movement values (Chi square = 25.78, $p = 0.002218$, df = 9), and significantly different from the movement values within 1640.42 feet (500 m) of I-26 (Chi square = 47.12, $p = 3.75\ e^{-7}$, df = 9).

Discussion

All of the criteria for model performance were addressed during its creation. The first 2 were successfully addressed. First, data required as input for the model were easily acquired from government agencies and most did not require much preparation prior to being used in the analysis. Second, the custom tools created for the analysis were relatively easy to use, and with the proper data, could be implemented by an untrained user (Appendix B).

The map produced showed patterns related to several landscape variables. Influence of a few landscape variables was obvious upon visual inspection of the model output at a small scale. Areas designated as black bear sanctuaries had the highest movement values and were found mostly in the northern and western areas of the County. This was also the portion of the County with the most forest cover. The southern section of the County had the lowest movement values, which corresponded with the most development and highest human population density.

Inspection of the output at a larger scale reflected the influence of other variables. Streams could easily be seen as linear streaks of higher movement values. Interstates, primary, and secondary roads corresponded to low movement values, but small roads, that were aligned with streams, often had higher movement values than surrounding areas. The movement value assigned to streams (16) outweighed the negative value assigned to other roads (-3), leading to an overall positive value assigned to those cells.

To evaluate the third criterion of model accuracy, actual bear movement locations were used to test the model. The locations used had a significantly different distribution of movement values than the entire distribution for Madison County, and the distribution of the area closest to I-26. If the model created accurate information, I expected that predicted movement values for actual bear movement locations would be significantly different from, and obviously more positive than, the entire set. The apparent lower distribution could indicate that the model performed poorly by producing inaccurate information. Another possibility is that the methods used to collect the actual bear locations were biased. Locations were collected through a study that focused on the I-26 corridor in Madison County, and a majority came from surveying the right-of-way fence for the interstate. The proximity of the points to the interstate could have influenced the movement values assigned to each point. If the points were within 164 feet (50 m) of the interstate, they would have received the value assigned to the roadway because each pixel in the model represented 164 x 164 feet (50 x 50 meters). Areas near the interstate were also more likely to have cleared areas and development, both of which received negative values in the expert assessment of landscape variables.

In an attempt to eliminate the bias from the proximity of the points to I-26, I compared the movement values for the actual bear locations to movement values within 1640.42 feet (500 m) of the interstate. Visually comparing the 2 sets of values indicated that most of the area near the interstate deterred bear movement, and bears chose locations with more positive movement values to actually move through. The distributions were significantly different; the Chi squared test produced an extremely small p-value. Unlike comparing the bear locations to entire sets of movement values, the movement values for the actual bear locations do appear to be obviously more positive than the distribution of values adjacent to the interstate. This appears to validate the model.

Another way to evaluate the model could be to use an unbiased set of movement locations to test the model. An unbiased set of locations should represent a large portion of the County, and would probably have to come from a study involving bears fitted with GPS collars. These data are currently unavailable for Madison County.

The low movement values could also be anecdotal due to the small sample size of the set used to test the model. Only 69 bear movement locations were found and used, which corresponded to 0.0148% of the 467,265 cells in the entire county's output. As mentioned above, data from GPS collars could provide a much larger set of movement locations to test the model. Clevenger et al. (2002b) used data from radio-collars to test their black bear model.

To ensure that the model met the fourth criterion of being applicable in other parts of the southern Appalachian Mountains, experts from throughout the region were asked to contribute to the landscape variable evaluation. Arithmetically averaging their responses should create a general response that represented the entire region. However, it would be advantageous to evaluate the model with black bear movement data from other areas of the southern Appalachian Mountains.

The model was created to predict black bear movement in order to more accurately place crossing structures in the future. The model may be the most useful at a large scale. In the absence of any black bear movement data, crossing locations provided by my model should be more informative than randomly placing black bear crossing structures. Making educated placement decisions is thought to be vital to the success of crossing structures (Clevenger and Waltho 2000, Barnum 2003).

ASSESSMENT OF I-26'S WILDLIFE CROSSING STRUCTURES AND RECOMMENDATIONS FOR IMPROVEMENT

Factors influencing use

Wildlife use of crossing structures is thought to be influenced by a myriad of factors, including some as yet unrecognized by researchers. While it may take decades to fully understand wildlife's interactions with roads and crossing structures, our current state of knowledge indicates that several factors play a large role in crossing rates. These factors include human use, vehicle traffic levels, structure design, crossing structure location, and wildlife fencing all of which have been found to influence crossing rates in other studies.

Human Use of the Culverts

Human use of wildlife crossing structures has been found to negatively affect wildlife use the structures receive (Clevenger et al. 2002a, Smith 2003). Some structures are designed to include human use (such as for greenway or hiking trails), others are not. The culverts on I-26 were not designed to include human use; however, humans have been observed using the culverts.

It appears that the culverts are used by locals to access hunting areas in the adjacent national forest. Prior to the start of my study, all terrain vehicle tracks and human footprints were seen in the dirt floor of the northern culvert. The still cameras installed at this culvert were vandalized in the beginning of April 2006, which corresponded to the opening of turkey season and could indicate that hunters were utilizing the culvert at this time. Over the course of my study, 5 pictures of people were taken in the wildlife culverts, 2 at the northern and 3 at the southern (Table 5). Fourteen video clips were taken of people near Culvert 2 (Table 6). In all of the pictures, people were wearing camouflage and/or blaze orange, indicating that they were hunting. While this is a low level of human use, it could influence bear use of the culverts. In other studies of black bear populations that are hunted, bears were found to avoid areas frequented by hunters (Beringer 1986, Powell et al. 1996, Powell and Mitchell 1998).

Humans were detected in many other places along the I-26 corridor. Pictures of people were taken by cameras at Jarvis Branch, Bear Branch, and Saddle Branch. People were conducting different activities at each location. At Jarvis Branch, men appeared to be workers wearing orange safety vests. An older man was detected repeatedly by the Bear Branch camera while he was fishing in the stream. The only human detected at Saddle Branch was a man running away from the camera; the purpose of his presence was unknown. Humans are probably more active in the areas adjacent to the road than this information indicates.

Frequent human use of the crossing structures could limit bear use; however, it is impossible to prevent people from using culverts without preventing bears from using them as well. Poles can be installed in the ground to prevent all terrain vehicles from traversing the culverts. Barbed wire could be strung over the opening to deter human use, but it would not be impenetrable and could create liability issues. To discourage foot traffic, public education is needed. Signs at the site describing the culverts' purpose, and the negative impacts of human presence, could impact regular human users. Large-scale public education that utilizes media outlets is needed to gain community support and to encourage community ownership of the project, which would aid in preventing future human use of the crossing structures.

Vehicle Traffic Levels

Vehicle traffic levels influence road permeability for some species of wildlife, and wildlife use of crossing structures. Clevenger et al. (2001) found higher traffic levels to negatively affect culvert crossings for a variety of species. Smith (2003) had similar results in Florida, finding that carnivore crossing rates were significantly lower in areas with higher traffic volume. Black bears have been found to cross heavily trafficked roads less often than those with lower volumes (Brody and Pelton 1989, Serrouya 1999).

Because traffic could have an influential role on black bear interactions with I-26, counts were done to assess traffic volume. Traffic was counted for 8 days throughout the year, 2 days in each of the 4 seasons, with 1 weekday and 1 Saturday tallied in each season. The number of vehicles traveling west on I-26 were tallied per hour for 24 hours using the video data collected to record wildlife crossing the interstate. Vehicles were classified, if possible, into passenger vehicles, tractor trailers, and motorcycles, but it was impossible to differentiate the types at night based solely on headlights, so only total vehicles were reported. Data were summarized for the entire year, by season, and comparing weekdays to weekends. All of the traffic data reflect only 1 direction of traffic; it was assumed that traffic was equivalent in the other direction. Raw data are reported in Table 12.

All days surveyed showed a similar trend in hourly traffic volumes (Figure 15), with traffic being the lowest in early morning, increasing sharply around 6:00 AM, peaking in mid-afternoon, and then dropping again around 6:00 PM. The average daily traffic in the westbound direction during the was 3,651 vehicles (Table 12), which is equivalent to 152.12 vehicles an hour. Traffic levels reported by NCDOT reflect traffic in both directions, so the daily average was doubled to 7,302 for comparison purposes. Saturdays had higher traffic levels than weekdays (Figure 16, Figure 17). Of the 4 months surveyed (March, June, September, December), June had both the highest weekday and Saturday (Figure 17). Madison County is a year-round tourist destination; tourism is probably the cause of higher weekend and summer traffic on this section of I-26.

A section of I-40 in Haywood County (approximately 30 miles (50 km) from this section of I-26) passes through relatively undisturbed habitat in Pisgah National Forest. Great Smoky Mountains National Park is just to the south, and Harmon Den Bear Sanctuary is to the north. In a black bear study conducted in Harmon Den, bears were found to approach I-40 (Beringer 1986). Black bears were recorded approaching but rarely crossing, instead they traveled along the interstate or turned around (Beringer 1986). Twelve crossings of I-40 were recorded over 2 years; most likely associated with an interstate tunnel, which created an overpass of natural habitat for black bears and other species (Beringer 1986). The average daily traffic level on this section of interstate during the time my study took place was 11,000 vehicles per day (NCDOT Planning and Traffic Branch, 1983), which is about one and half times as large as the current traffic level of 7,301.76 vehicles per day on I-26. Bears turning away from the road, but apparently using the overpass, indicated that moderate traffic levels may not prevent black bears from utilizing crossing structures, but may prevent road crossings.

Traffic on the 8.8-mile (14.16-km) section of I-26 in my study is expected to increase over the next 10 years. NCDOT expects traffic to reach 14,000 vehicles per day at the south end of the section, and 12,800 vehicles per day at the north end by 2018 (J. Lansford, NCDOT engineer, personal communication). These levels would exceed 11,000 vehicles per day that I-40 experienced during Beringer's (1986) study, indicating that I-26 may become less permeable to crossings of black bears in the near future.

Unfortunately, nothing can be done to prevent the increase in traffic levels on I-26, or the resulting decrease in permeability of the road to black bears. The influence of traffic levels should be noted and accounted for when examining other factors influencing future bear crossing rates.

Structure Design

The type of structure is best suited to black bears in the Appalachian mountains is unknown. Black bears have been observed using overpasses in Canada (Clevenger and Waltho 2005), dry bridges in both Florida (Foster and Humphrey 1995) and Canada (Clevenger and Waltho 2005), and culverts in both Florida (Smith 2003) and Canada (Clevenger and Waltho 2005). The smallest culvert used by black bears was 6.56 x 5.91

feet (2 x 1.8 meters) with an openness value of 0.02 (Clevenger and Waltho 2005), and the largest structure used by black bears was a 42.98 feet (13 meters) wide bridge (Foster and Humphrey 1995). The general consensus in the scientific community is that larger structures are more effective for most species; however, Clevenger and Waltho (2005) suggested that black bears might prefer relatively smaller structures based on their comparative study on the Trans Canada Highway.

The culverts in my study were smaller than many of the structures studied previously, being only 8 x 8 feet (2.44 x 2.44 meters), but they had relatively large openness values of 0.41 and 0.46. While bears have been observed in the culverts on 2 occasions (Tables 2, 5), conclusions cannot be drawn on bear preference for these culverts over other structure types because there were no other structures in the area. An experimental comparison would be required to make such conclusions. If compared to other structures, the design of these culverts may not necessarily be preferred, but they may be accepted by black bears as alternative option to crossing the roadway. I do not believe that the design of these culverts is the most limiting factor in current black bear use.

Location of Crossing Structures

Several studies have suggested that placement of a crossing structure in the landscape may ultimately determine its effectiveness (Clevenger and Waltho 2000, Barnum 2003). Several landscape factors influence wildlife crossing rates. One of most influential is habitat adjacent to structures (Rodriguez et al. 1996). Barnum (2003) found it was necessary to have suitable habitat on both sides of the road for a crossing structure to be successful. Brandenburg (1996) found that bears preferred to cross roads in areas with their preferred habitat on each side. Nearby human development has a negative influence on crossing rates of most species of wildlife (Clevenger et al. 2002a, Clevenger and Waltho 2005). Linear landscape features, such as streams and ridges, can predict crossing sites for wildlife (Barnum 2003).

Locations for the 2 crossing structures in my study were chosen by the North Carolina Wildlife Resources Commission (NCWRC) and NCDOT's engineer for the I-26 project. NCWRC chose several sites as possible locations for crossing structures based on knowledge of black bear habitat and movement. Final placement of the crossing structures was chosen by the NCDOT engineer to minimize construction limitations and to maximize distance of the structures from human development.

Both culverts are surrounded by deciduous forest and are away from human development. The landscape surrounding the interstate and the culverts is composed mostly of deciduous forest, with sparse bits of human development. Culvert 2 (the more northern one) is in line with a small stream and is situated on an area with medium slope values. Culvert 1 is in less ideal conditions; the area around it has higher slope values, and there is a stream nearby, but not in line with the culvert.

As a part of my study, a GIS model was created to locate areas of possible high black bear movement in the Appalachian Mountains. The purpose of the model was to serve as a tool that could be used to aid in placement of black bear crossing structures on future roads in the Appalachian Mountains. The model ranked different landscape variables based on their influence on black bear movement, and outputs a map with movement values for the entire county. Areas that discouraged black bear movement received negative values, and areas that promoted movement had positive values, with larger values indicating better movement potential. The model was tested using data for Madison County, and the map produced was used to further evaluate the placement of the crossing structures.

In the model output, both culverts were engulfed in the negative scores associated with the interstate; however areas directly adjacent to the culverts received positive scores. Both culverts were surrounded by fairly high positive scores. The area adjacent to Culvert 1 contained mostly values of 121; Culvert 2 was surrounded by scores of 141. These values reflect areas of likely bear movement.

Based on habitat and landscape evaluations, both culverts appear to be located reasonably well. Our evaluations indicate that Culvert 2 could be placed more advantageously than Culvert 1. Black bears were detected at the location of culvert 2 8 times, whereas bears were not detected at culvert 1 during the year-long study.

Big Laurel Creek and Little Creeks were the only locations on I-26 that had higher movement values than both culverts. The values along the Big Laurel Creek leading the road ranged from 157 to 185. This creek has a very large bridge spanning it, which would allow black bears to easily cross under I-26. However, there is also a road with houses along it that travels under the bridge. The large size of the bridge combined with human presence/personal property issues made it impossible to detect bears crossing under the bridge. This bridge should be considered a wildlife crossing structure on I-26.

Little Creek had values adjacent to it and I-26 ranging from 141 to 207. The still camera at this location did not detect any bears, but bear hair was found on the right-of-way fence where it crossed the creek. There is no structure at the creek for bears to cross the I-26, however the location may be ideal for an additional structure if one were to be added to the section of interstate.

Fencing

Proper fencing has been found to be vital to the success of wildlife crossing structures (Dodd et al. 2007). In my study, wildlife fencing was not installed. Instead, right-of-way fencing was connected to the culvert entrances in an effort to funnel wildlife to them. The fencing was made of woven-wire, with a strand of barbed wire on top, and is about 4.5 feet (1.3 meters) tall. Both wooden and metal posts were used along the fence. In places where the ground was uneven, barbed wire was also run along the bottom edge of the fence. Along this section of road, the fence ran through a variety of habitats, with a large portion in forested areas.

Sixty-four locations were found where bears crossed the fence along both sides of the road. Most of the samples were found on the bottom of the fence, where it did not completely touch the ground. Hair was also often found on top of the fence where a tree was within a foot of it. Locations were also found where bears had simply pushed down the woven-wire and crawled between the top strand of barbed wire. Black bears probably also crossed without leaving hair, including at several places where trees had fallen on the fence, holes were cut by people, and gaps were left during construction. Thus, the fence certainly did not halt bear movement, and it was likely ineffective at guiding bears to the crossings.

A properly designed fence would need to be at least 10 feet (3 m) tall, partially buried, and have metal posts. The ideal design would include fencing along the entire section of highway, however this is not feasibly financially. A reasonable alternative would be to extend the fence out from each side of the culvert a short distance. Unfortunately experimental studies have not been done to determine the minimum length fencing needed to have a positive effect. One study closely inspected black bear interactions with wildlife fencing. Roof and Wooding (1996) studied bear interactions with a fence adjacent to a Florida culvert. The fence ran 0.37 miles (0.6 km) to the west of the culvert and 0.68 miles (1.1 km) to the east. Roof and Wooding (1996) looked for tracks along the fence, and found that bears approached the fence 50 times during the year-long study. Of the 50 encounters, twice the bear went to the end of the fence and went around it (Roof and Wooding 1996). Most of the bears (64%) followed the fence for less than 82 feet (25 km), and only 25% followed the fence for more than 328 feet (100 meters) (Roof and Wooding 1996). Replacing the fence adjacent to the culverts with "bear-proof" fencing may be the most influential change that can be made to the crossing structures.

Summary of Recommendations

Two factors can be addressed in an attempt to improve the crossing rates of black bears through the culverts on I-26:

1. Discourage human use of the culverts. Specifically, signs can be hung at the culverts, the public can be educated through the press and mailings, and all-terrain vehicles can be prohibited through installing posts in front of the culvert entrances.
2. Install wildlife fencing adjacent to the culverts. Specifically, the fence needs to be chain-link, 10 feet (3 m) tall, partially buried, have metal posts, and extend a minimum of 300 feet (~90 m) away from the entrances to the culverts. A fence of this length would cost a minimum of $ per culvert for the materials; a fence of 500 feet (~150 m) would cost a minimum of $ per culvert.

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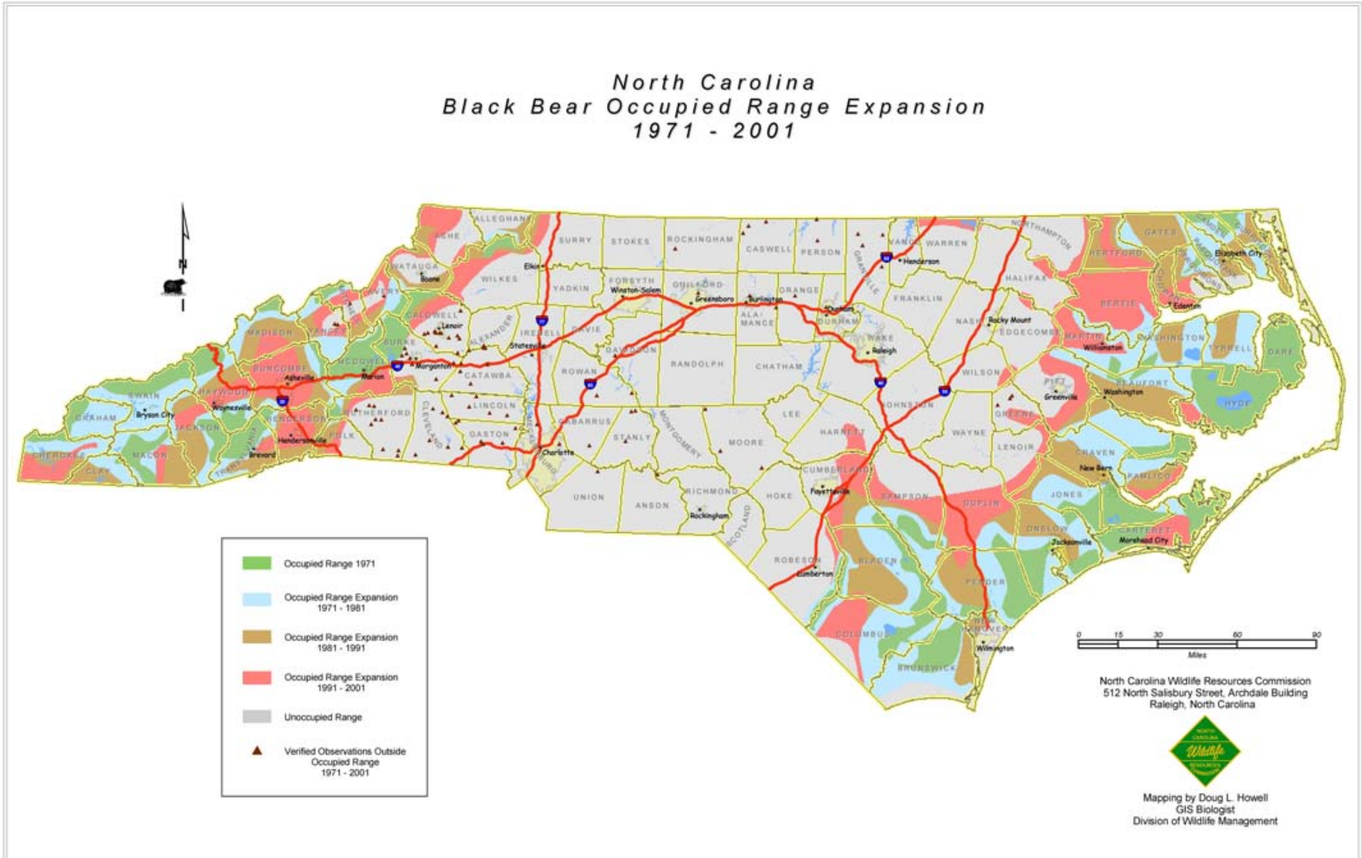

Figure 1. Black bear range in NC, produced by the NC Wildlife Resources Commission, and available on their website, www.ncwildlife.org

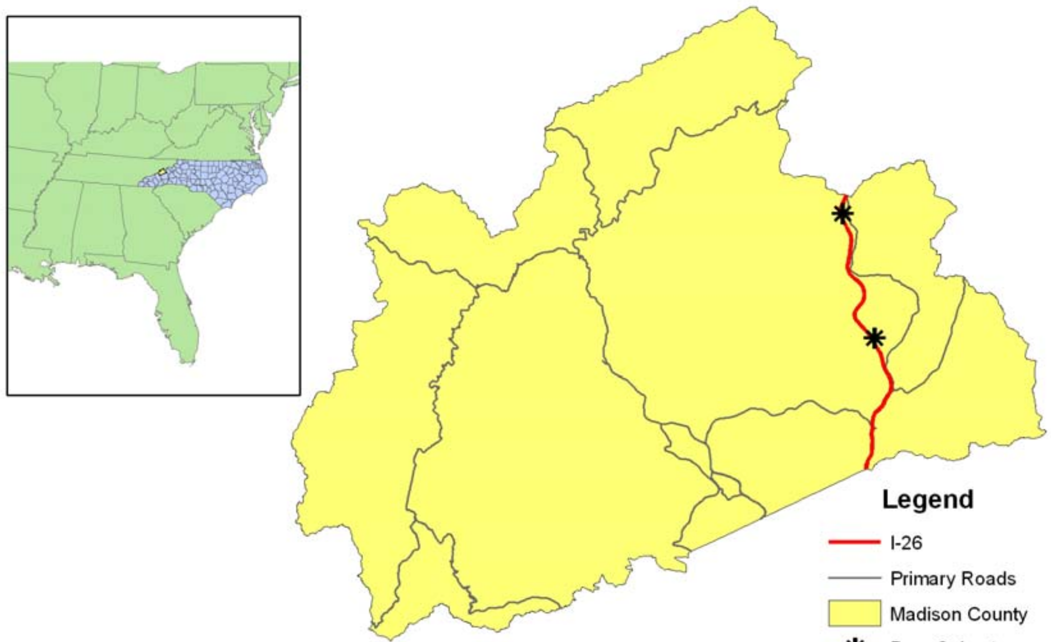

Figure 2. Map of Madison County (created by author) and the newly constructed section of I-26 (the part being studied) begins just north of Mars Hill, where Highways 19 and 23 split off to the east, and continues to the Tennessee state line. The approximate locations of the wildlife crossings are marked by black stars.

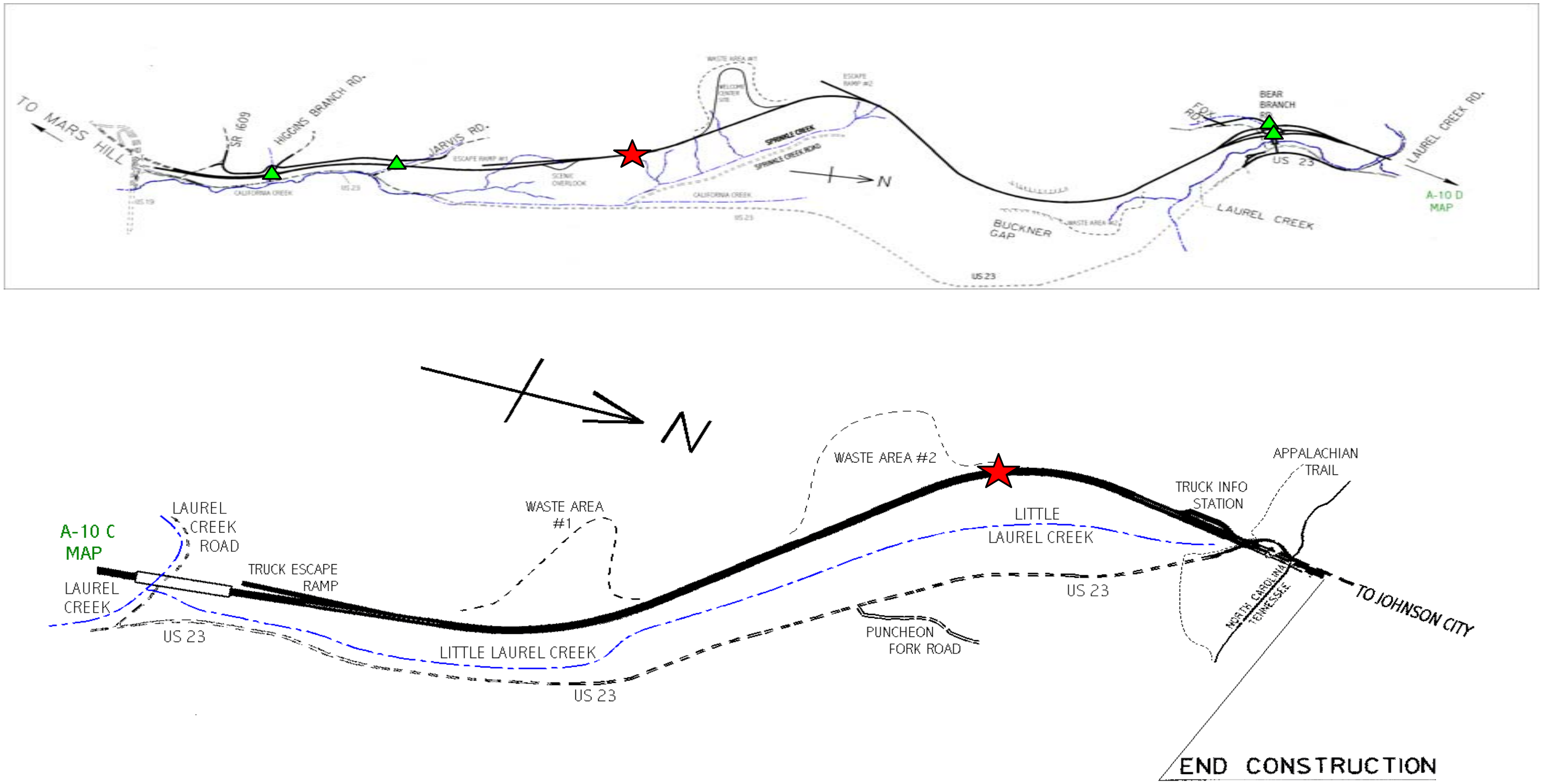

Figure 3. Maps of I-26. The right end of the top map connects to the left end of the bottom map, but the two maps are at different scales. The location of the crossing structures is marked with red stars. Stream culverts are marked with green triangles. Created by NCDOT, modified by author.

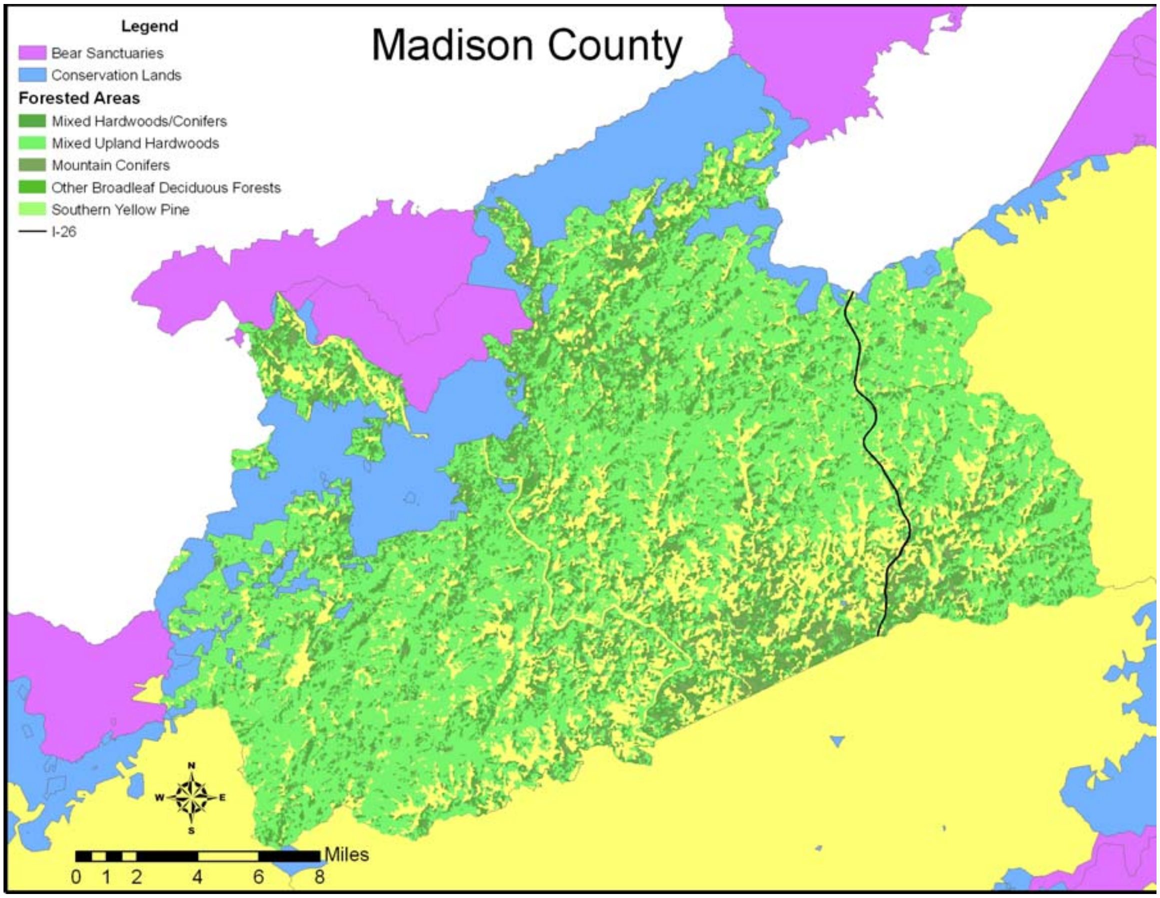

Figure 4. Map of Madison County showing the distribution of natural land cover in the county. The various shades of green represent different forest types. The blue and purple areas are conservation areas where habitat and/or bears are protected. Created by author.

Figure 5. One of the crossing structures just after completion. The right of way fencing leads up to the culvert to help direct wildlife to it, however the fencing is by no means "bear proof".

Figure 6. A more detailed view of the right-of-way fencing. It is constructed of welded wire, barbed wire, and wooded posts.

Figure 7. The entrance to Culvert 1 in May of 2005. The vegetation inside of the fencing is large, possibly providing cover. This picture was at the beginning of the growing season; the vegetation was much larger by the end.

Figure 8. The digital still cameras used both in the crossing culverts, the stream culverts, and along the roadway. Picture from Cabelas.com, our source for the cameras.

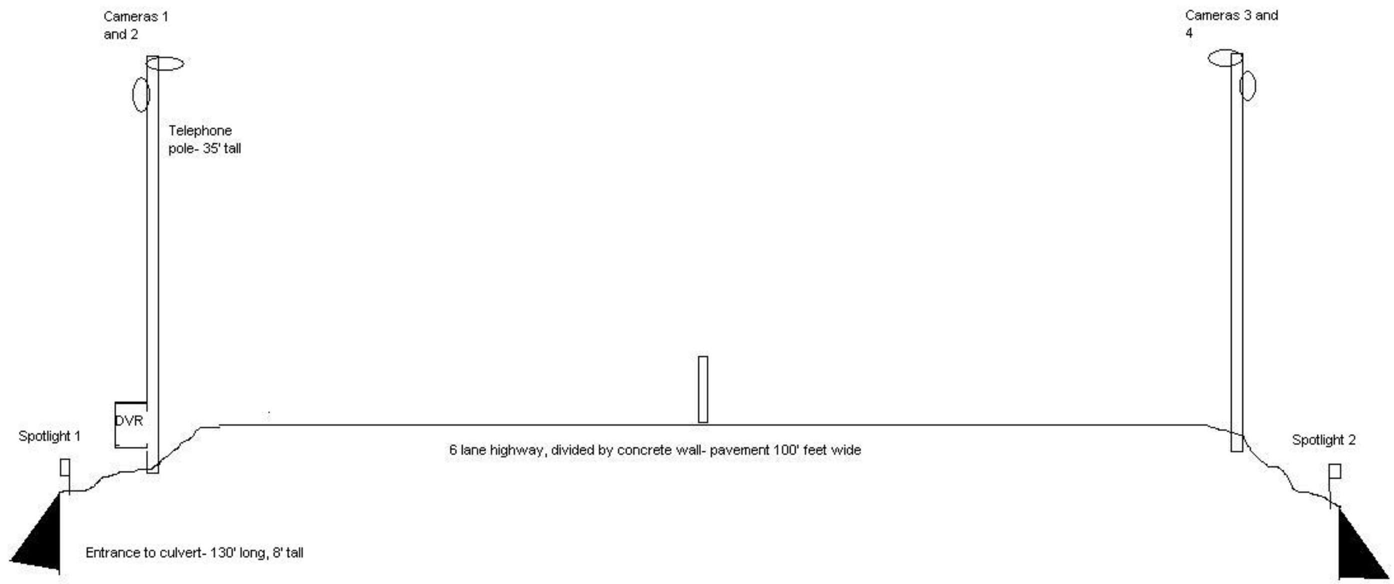

Figure 9. The video camera configuration at Culvert 2.

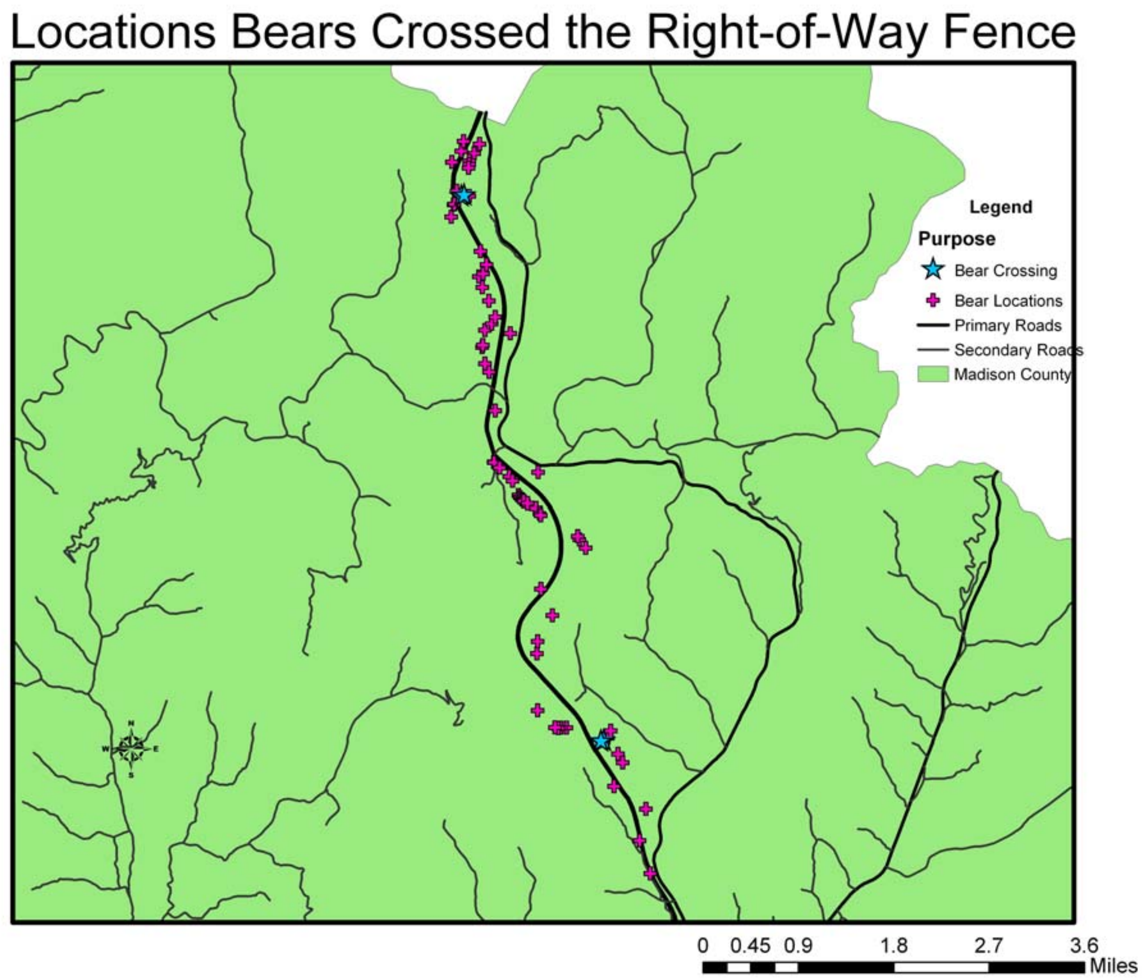

Figure 10. Map of locations found where bears had crossed the right-of-way fencing. These locations were usually hair samples caught on the fence, but also included tracks and scat.

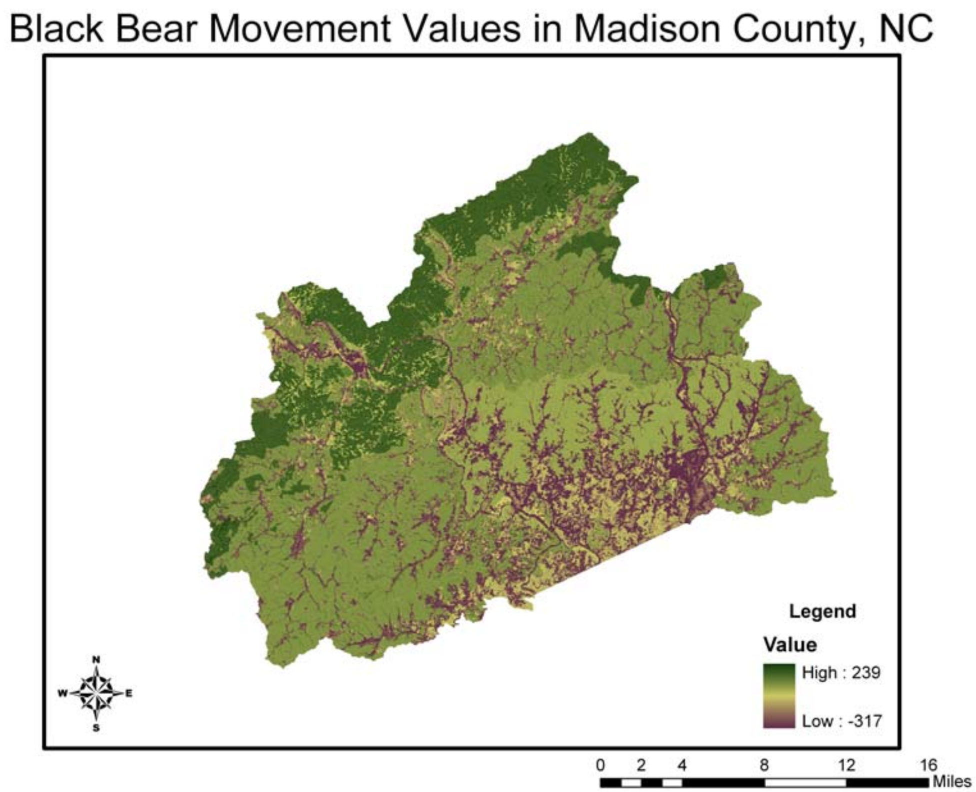

Figure 11. The final output from the black bear movement model. The highest values indicate areas that black bears are likely to travel, the low values are areas that discourage black bear movement.

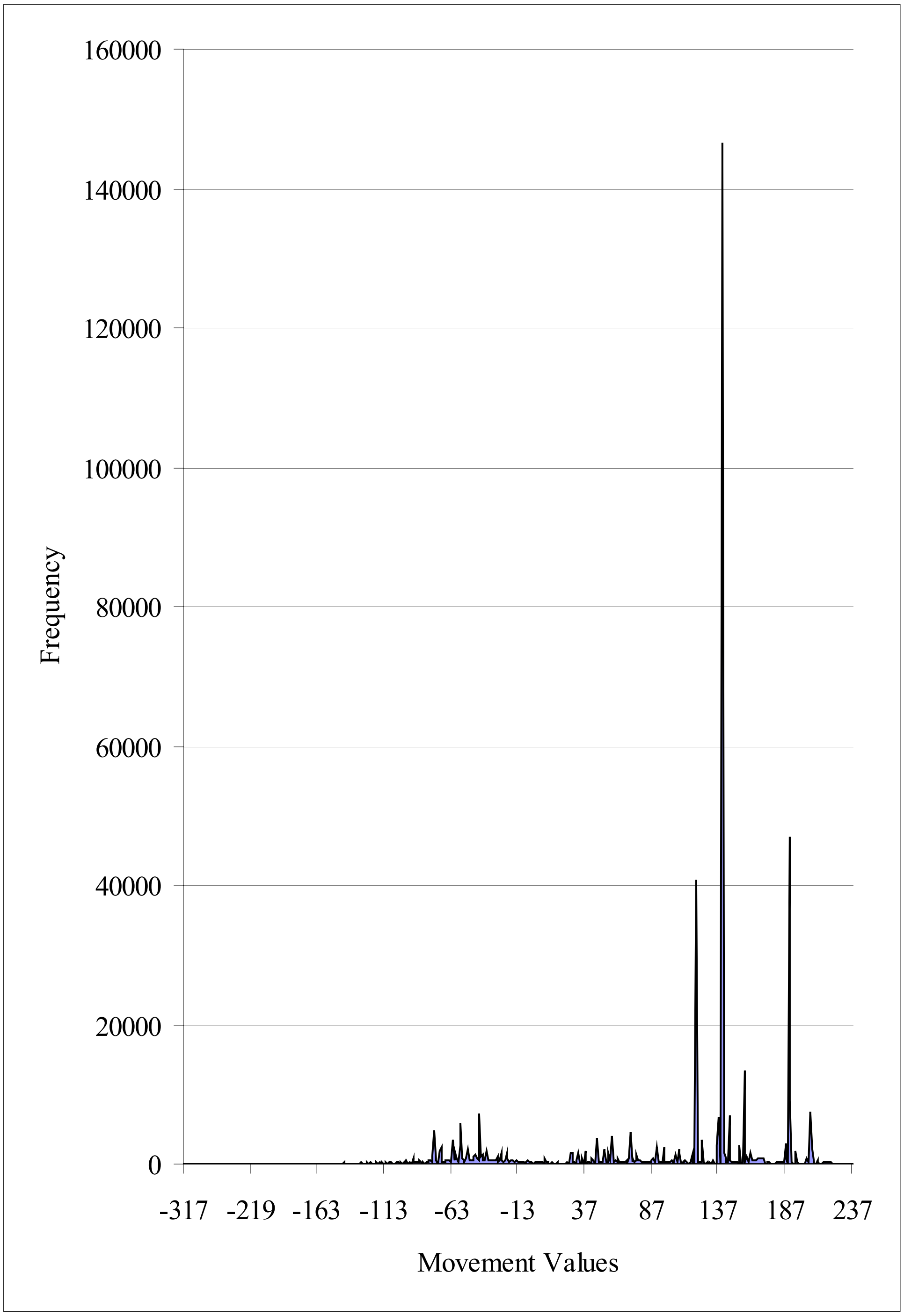

Figure 12. The frequency distribution of movement values in the final output of the bear movement model.

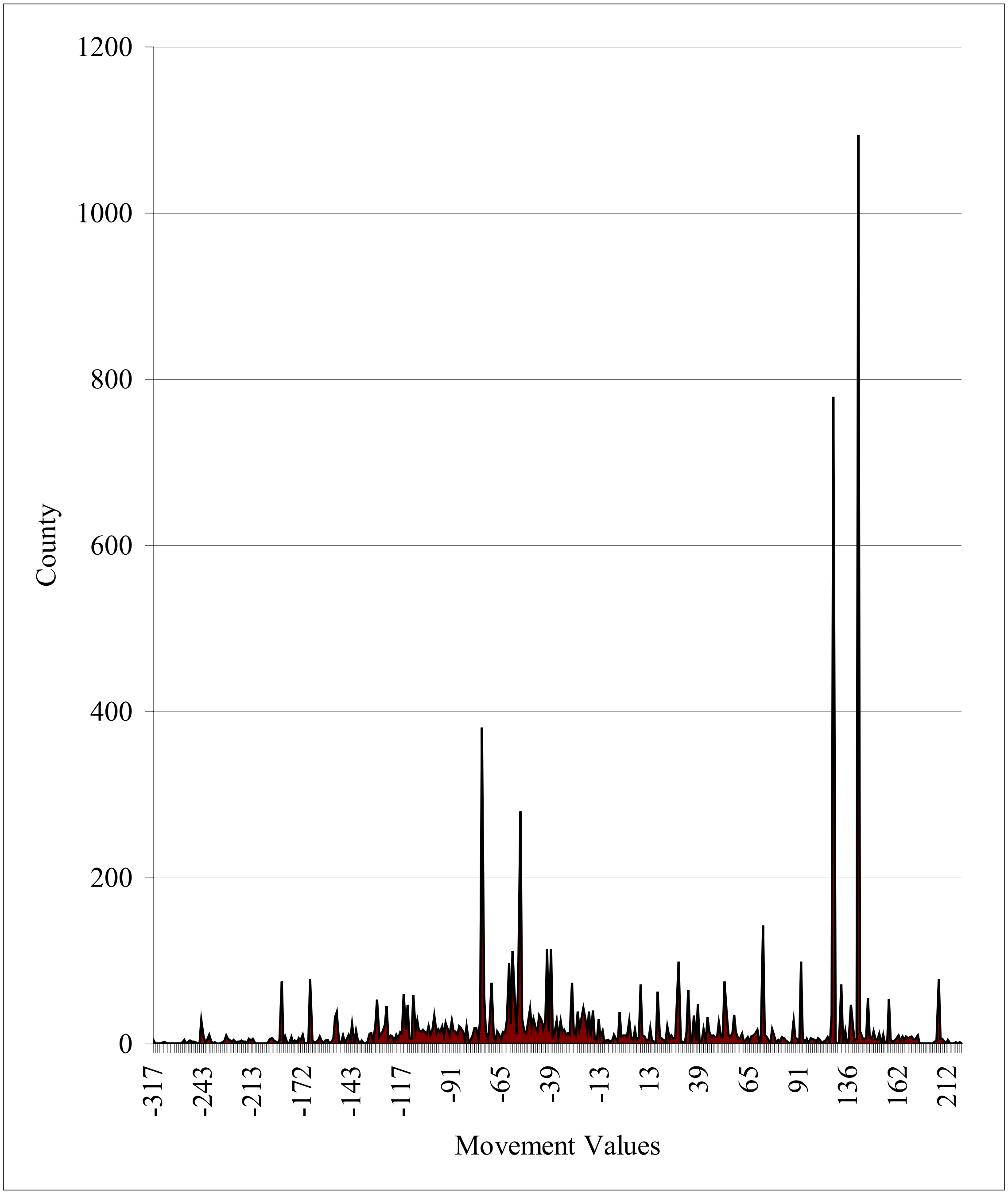

Figure 13. The frequency distribution of movement values within 1640.42 feet (500 m) of I-26.

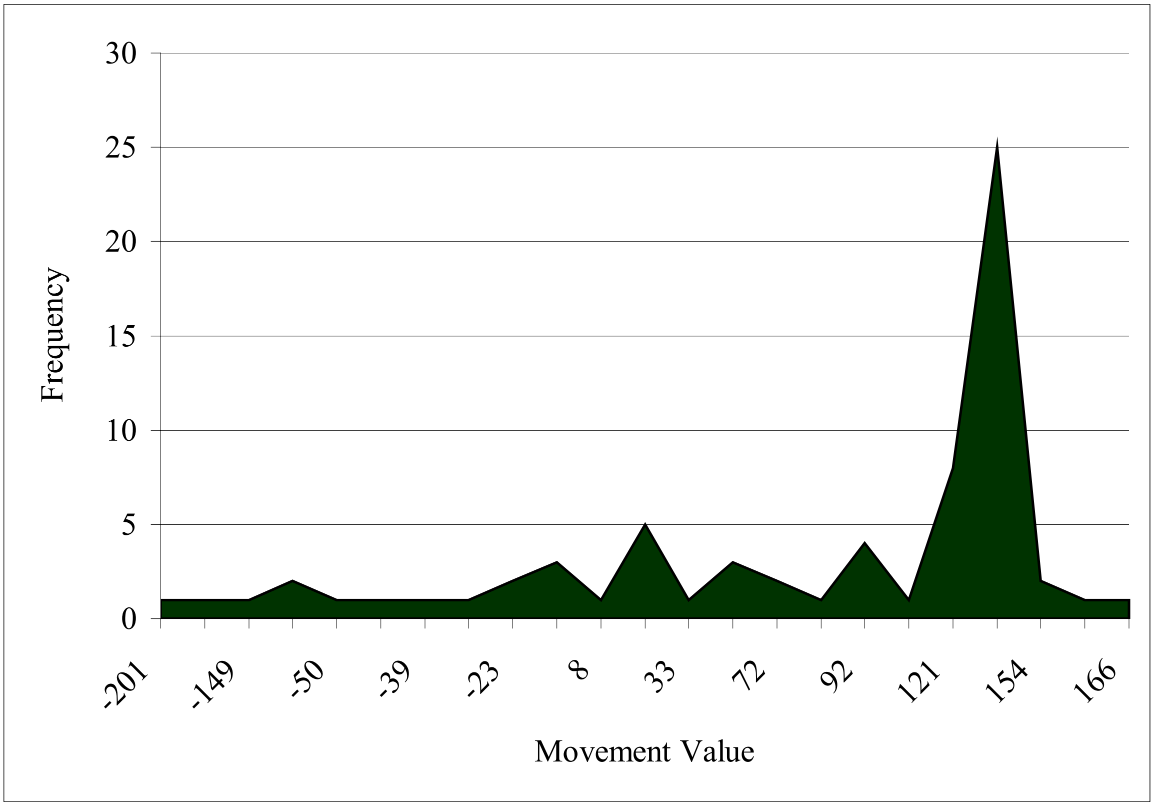

Figure 14. Frequency distribution of movement values at actual bear movement locations.

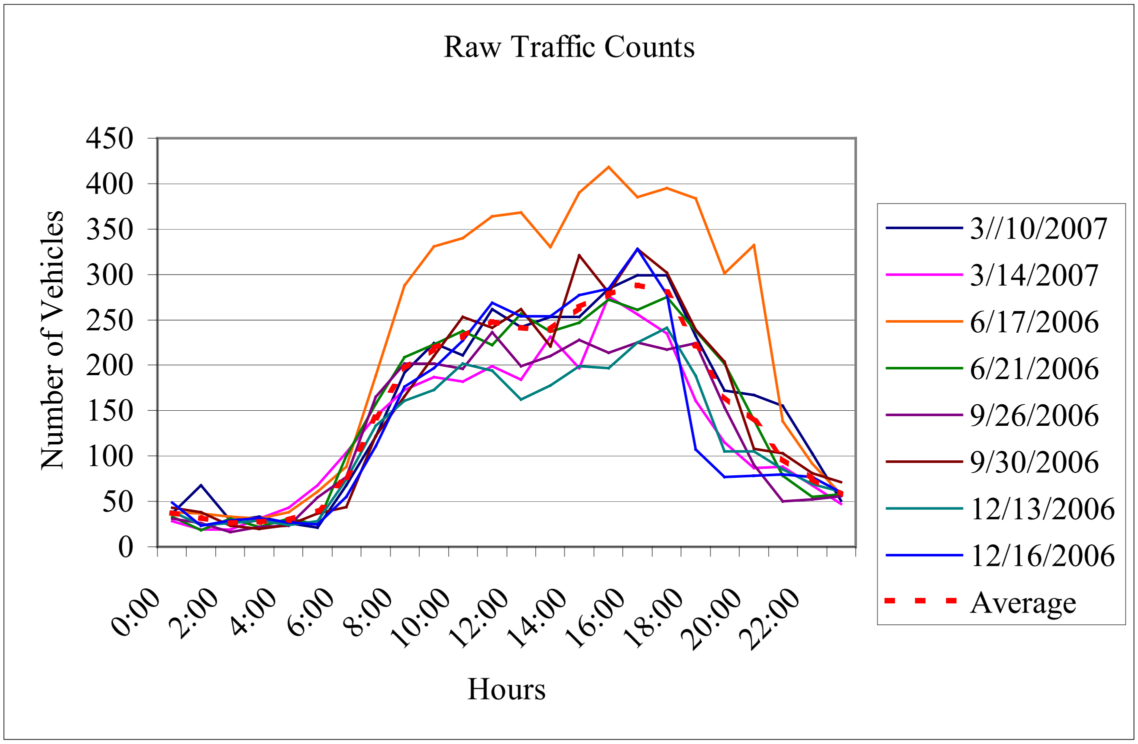

Figure 15. Raw traffic counts for each day. Each day's counts show similar trends in hourly volume. The average volume based on all 8 days is shown with the red dotted line.

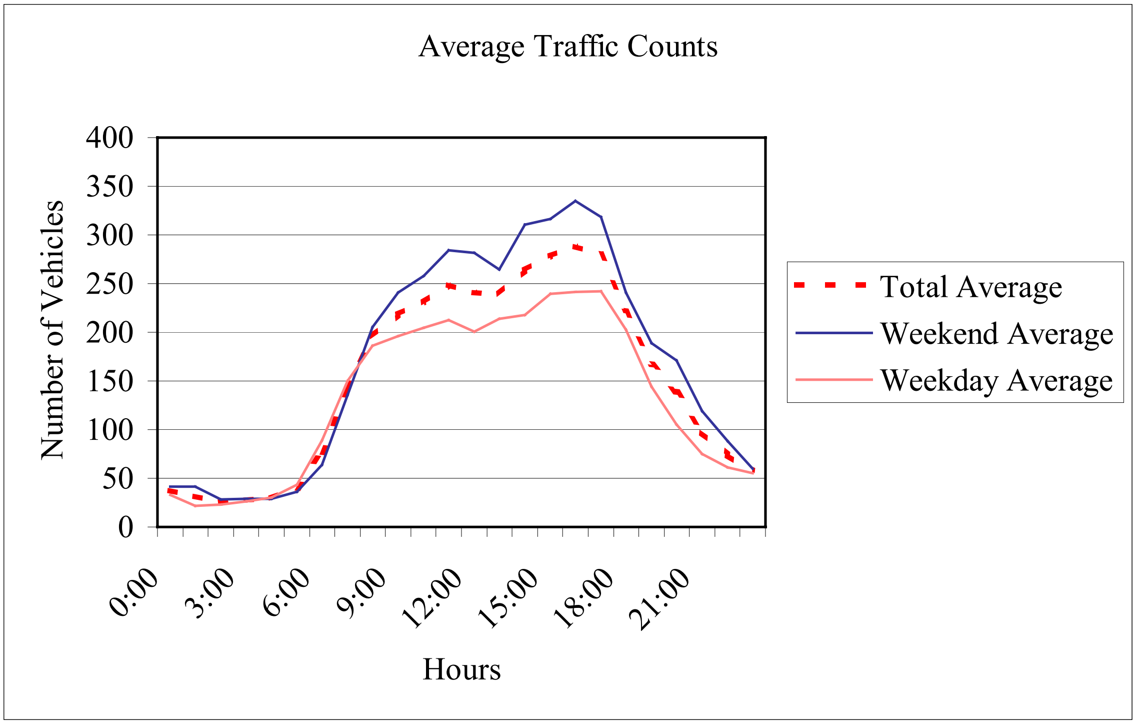

Figure 16. Weekend and weekday average hourly traffic volumes. Weekend traffic volumes were higher than weekday for most of the 24-hour period. The overall average is shown with the red dotted line.

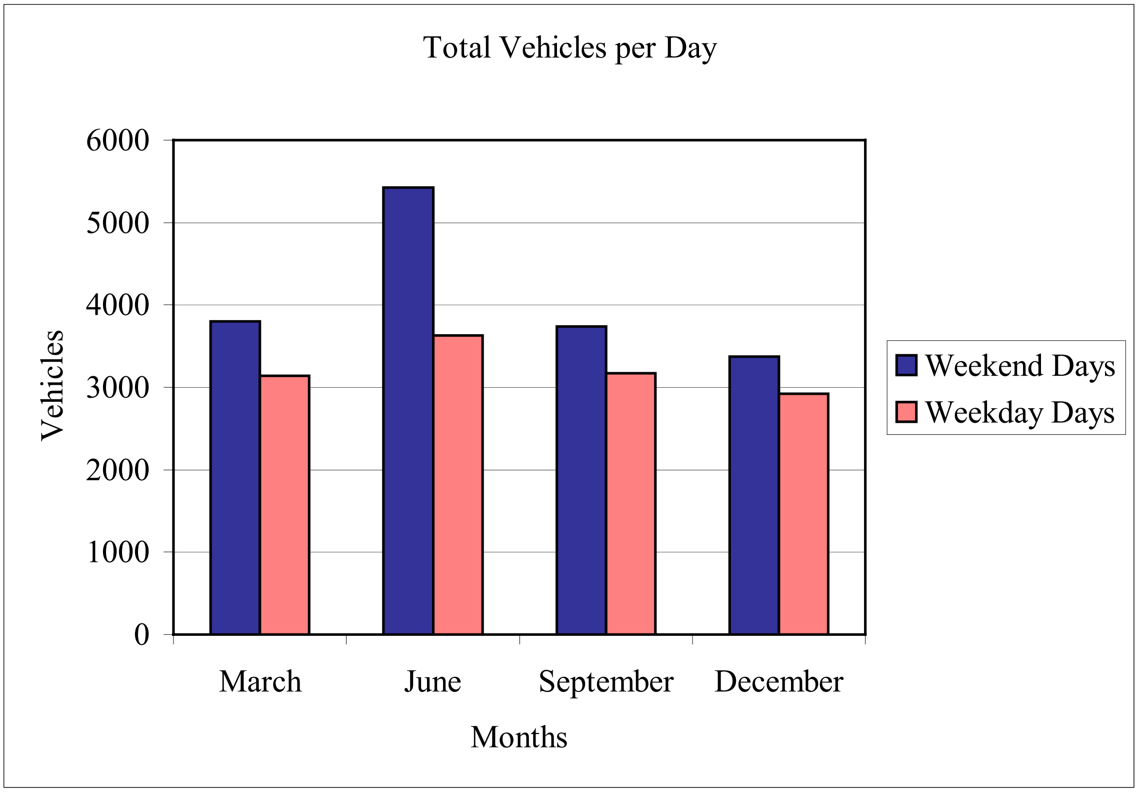

Figure 17. Total vehicles per day for each day surveyed.

Table 1. Physical characteristics of the box culverts that pass under I-26. All measurements (width, height, and length) are expressed in feet. Openness is an index describing the "tunnel effect" and is defined as (width x height)/length. In theory, the closer this value is to 1, the more appealing the crossing structure is to wildlife.

Name	***Width***	***Height***	***Length***	***Openness***	***Purpose***
Higgins Branch	6	7	420	0.10	Stream Crossing
Jarvis Branch	8	7	1375	0.04	Stream Crossing
Culvert 1	8	8	155	0.41	Wildlife Use
Bear Branch	6	7	675	0.06	Stream Crossing
Culvert 2	8	8	140	0.46	Wildlife Use

Table 2. Black bear detections or reliable reports along I-26. Most were detected through study methods; three came from reliable sources.

Date	*Time of Day*	*Source*	*Activity of Individual*
Some time in 2005	Unknown	Bear hunter, hardware store employees	Hit by a vehicle at the Wolf Laurel interchange
December 2005	Unknown	Hardware store employee	Foraging/wandering on a section of ground between I-26 and HW 23 at the Wolf Laurel exit
6/7/06	2:08 PM	Video camera watching eastbound entrance to Culvert 2, detected through sampling	Approached culvert, entered, then turned around and exited rapidly
6/17/06	10:18 AM	Video camera aimed south on road, detected through censusing for traffic counts	Attempted to cross road from east side, went halfway, then turned back
Found 8/8/06	Unknown	Tracks in truck ramp	Running away from road in a direct line
10/19/06	7:01 PM	Video camera aimed south on road, detected through sampling	Completely crossed road from east to west
10/26/06	11:50 PM	Southern Fill, northern camera	Traveling away from road
10/27/06	6:41 PM	Northern camera	Attempted to cross road from east side, ran back when traffic arrived
10/27/06	8:33 PM	Culvert 2, Camera 1	Entering culvert from eastern side
Found 11/12/06	Unknown	Roadkilled carcass	Hit by a tractor-trailer in westbound lanes on top of Culvert 2
5/24/07	10:50 PM	Crossing 2, Camera 1	Entering culvert from eastern side
6/29/07	Evening	Family member of NCDOT employee	Came out of woods, down hill towards Culvert 2, then turned and went back

Table 3. Common and scientific names of species identified during the study.

Common Name	***Scientific Name***
Black Bear	*Ursus americanus*
Bobcat	*Lynx rufus*
Broken-striped Newt	*Notothalmus viridescens*
Cliff Swallow	*Petrochelidon pyrrhonota*
Common Muskrat	*Ondatra zibethicus*
Coyote	*Canis latrans*
Domestic Cat	*Felis domesticus*
Domestic Dog	*Canis familiaris*
Eastern Bluebird	*Sialia sialis*
Eastern Chipmunk	*Tamias striatus*
Eastern Cottontail	*Sylvilagus floridanus*
Eastern Phoebe	*Sayornis phoebe*
Gray Fox	*Urocyon cinereoargenteus*
Great Blue Heron	*Ardea herodias*
Great Crested Flycatcher	*Myiarchus crinitus*
Groundhog	*Marmota monax*
Humans	*Homo sapien*
Least Weasel	*Mustela nivalis*
Long-tailed Weasel	*Mustela frenata*
Northern Cardinal	*Cardinalis cardinalis*
Northern Raccoon	*Procyon lotor*
Red Fox	*Vulpes vulpes*
Song Sparrow	*Melospiza melodia*
Virginia Opossum	*Didelphis virginiana*
White-tailed Deer	*Odocoileus virginianus*

Table 4. The number of individuals of each species detected by each still camera.

Species	*Bear Branch*	*Crossing 1, Camera 1*	*Crossing 1, Camera 2*	*Crossing 2, Camera 1*	*Crossing 2, Camera 2*	*Fill Fence Post 1*	*Fill Fence Post 2*	*Higgins Branch*	*Jarvis Branch*	*North Fill*	*Little Creek*	*Total*
Unknown Bird sp.	-	-	-	1	-	-	-	-	-	-	-	1
Black Bear	-	-	-	2	-	1	-	-	-	-	-	3
Bobcat	-	-	-	-	36	-	-	-	-	-	-	36
Broken-striped	-	-	-	-	1	-	-	-	-	-	-	1
Cliff Swallow	-	-	-	-	-	-	-	-	1	-	-	1
Common Muskrat	-	-	-	-	-	-	-	-	2	-	-	2
Coyote	-	1	-	-	-	9	2	-	-	-	1	13
Domestic Cat	-	-	-	-	4	-	-	-	-	-	-	4
Domestic Dog	-	5	-	2	-	-	-	-	-	-	-	7
Eastern Bluebird	-	-	-	-	-	-	1	-	-	-	-	1
Eastern Chipmunk	-	-	-	-	1	-	-	-	-	-	-	1
Eastern Cottontail	-	-	-	-	7	-	-	-	2	-	-	9
Eastern Phoebe	-	-	9	-	-	-	-	-	-	-	-	9
Gray Fox	-	-	-	-	1	-	-	-	-	-	-	1
Great Blue Heron	-	-	-	-	-	-	-	-	1	-	-	1
Great Crested Flycatcher	-	-	-	-	-	-	-	1	-	-	-	1
Groundhog	-	-	1	-	12	-	-	4	-	-	-	17
Human	5	2	1	1	1	3	-	-	3	-	1	17
Least Weasel	-	-	1	-	-	-	-	-	-	-	-	1
Long-tailed	-	-	-	-	1	-	-	-	-	-	-	1
Mouse species	-	-	1	-	-	-	-	-	-	-	-	1
Northern Cardinal	-	-	-	-	-	-	-	1	-	-	-	1
Northern Raccoon	-	-	28	-	99	-	-	10	10	-	-	147
Rat species	-	-	3	-	-	-	-	1	-	-	-	4
Red Fox	-	1	-	-	-	1	1	-	-	-	-	3
Song Sparrow	-	-	-	-	2	-	-	-	2	-	-	4
Virginia Opossum	-	-	24	-	58	-	-	-	1	-	-	83
White-tailed Deer	3	59	-	-	2	22	9	-	-	-	16	111
Unknown	-	3	-	-	3	1	-	-	1	-	-	11
Total	8	71	68	6	228	37	13	17	23	0	18	471

Table 5. The number of pictures taken of each species by each still camera.

Species	*Bear Branch*	*Crossing 1, Camera 1*	*Crossing 1, Camera 2*	*Crossing 2, Camera 1*	*Crossing 2, Camera 2*	*Fill Fence Post 1*	*Fill Fence Post 2*	*Higgins Branch*	*Jarvis Branch*	*North Fill*	*Little Creek*	*Total*
Unknown Bird sp.	-	-	-	1	-	-	-	-	-	-	-	1
Black Bear	-	-	-	2	-	1	-	-	-	-	-	3
Bobcat	-	-	-	-	34	-	-	-	-	-	-	34
Broken-striped Newt	-	-	-	-	1	-	-	-	-	-	-	1
Cliff Swallow	-	-	-	-	-	-	-	-	1	-	-	1
Common Muskrat	-	-	-	-	-	-	-	-	2	-	-	2
Coyote	-	1	-	-	-	9	1	-	-	-	1	12
Domestic Cat	-	-	-	-	4	-	-	-	-	-	-	4
Domestic Dog	-	5	-	2	-	-	-	-	-	-	-	7
Eastern Bluebird	-	-	-	-	-	-	1	-	-	-	-	1
Eastern Chipmunk	-	-	-	-	1	-	-	-	-	-	-	1
Eastern Cottontail	-	-	-	-	7	-	-	-	2	-	-	9
Eastern Phoebe	-	-	9	-	-	-	-	-	-	-	-	9
Gray Fox	-	-	-	-	1	-	-	-	-	-	-	1
Great Blue Heron	-	-	-	-	-	-	-	-	1	-	-	1
Great Crested Flycatcher	-	-	-	-	-	-	-	1	-	-	-	1
Groundhog	-	-	1	-	12	-	-	4	-	-	-	17
Human	5	2	1	1	1	1	-	-	2	-	1	14
Least Weasel	-	-	1	-	-	-	-	-	-	-	-	1
Long-tailed Weasel	-	-	-	-	1	-	-	-	-	-	-	1
Mouse species	-	-	1	-	-	-	-	-	-	-	-	1
Northern Cardinal	-	-	-	-	-	-	-	1	-	-	-	1
Northern Raccoon	-	-	25	-	72	-	-	7	10	-	-	114
Rat species	-	-	3	-	-	-	-	1	-	-	-	4
Red Fox	-	1	-	-	-	1	1	-	-	-	-	3
Song Sparrow	-	-	-	-	1	-	-	-	2	-	-	3
Virginia Opossum	-	-	24	-	58	-	-	-	1	-	-	83
White-tailed Deer	2	58	-	-	2	22	8	-	-	-	12	104
Unknown	-	3	-	-	3	1	-	-	1	-	-	11
None	102	270	46	8	125	241	316	39	43	7	73	1270
Total	8	71	68	6	228	37	13	17	23	0	18	471

Table 6. The number of video clips containing each species, and the activity category best describing the individual(s) in the clip.

Activity Type	*Black bear*	*Bird*	*Coyote*	*Domestic Cat*	*Domestic Dog*	*Groundhog*	*Human*	*Northern Raccoon*	*Red Fox*	*Virginia Opossum*	*White-tailed Deer*	*Wild Turkey*	*Unknown*	*Total*
Across culvert entrance	-	-	-	-	-	-	-	-	1	-	-	-	-	**1**
Attempted road crossing	1	-	-	-	1	-	-	-	-	1	-	-	1	**4**
Away from road	-	-	-	-	-	-	-	-	-	-	4	-	-	**4**
Crossing road	1	-	-	-	-	-	2	-	-	-	-	-	-	**3**
Entering culvert	-	-	-	3	5	-	4	2	-	-	-	-	-	**14**
Exiting culvert	-	-	-	1	5	1	3	4	-	-	-	-	-	**14**
Foraging	-	9	-	-	-	-	-	-	-	-	64	-	-	**73**
Near culvert entrance	1	1	-	-	1	-	2	1	-	-	2	2	-	**10**
Other	-	1	4	1	2	-	5	-	-	-	-	-	-	**13**
Towards road	-	-	-	-	1	-	-	-	-	-	4	1	2	**8**
Walking along road	-	-	1	-	4	-	2	-	1	-	-	-	-	**8**
Total	**3**	**11**	**5**	**5**	**19**	**1**	**18**	**7**	**2**	**1**	**74**	**3**	**3**	**152**

Table 7. Detection probabilities and estimated number of animals for culvert clips by species.

Species	***Number of Clips***	***Overall Detection Probability***	***Number of Animals Detected***	***Estimated Number of Animals***
Black Bear	1	0.9333	1	1.071
Bird species	2	0.4541	2	4.405
Coyote	4	0.6898	4	5.799
Domestic Cat	3	0.2994	3	10.021
Domestic Dog	13	0.6168	43	69.719
Humans	11	0.6466	26	40.212
Northern Raccoon	7	0.5605	18	32.117
Red Fox	1	1.00	1	1
White-tailed Deer	35	0.7368	55	74.651
Wild Turkey	1	1.00	1	1
Totals:	***78***	***0.641***	***154***	***239.995***

Table 8. Detection probabilities and estimated number of animals for road clips by species.

Species	***Number of Clips***	***Overall Detection Probability***	***Number of Animals Detected***	***Estimated Number of Animals***
Bird species	9	1.00	20	20
Black bear	2	0.7097	2	2.818
Coyote	1	1.00	1	1
Domestic Dog	6	0.6454	6	9.297
Humans	7	0.9963	19	19.071
Red Fox	1	1.00	2	2
Virginia Opossum	1	0.8500	1	1.176
White-tailed Deer	3	0.5672	6	10.579
Total:	***30***	***0.870***	***60***	***68.942***

Table 9. Data types used in the model to determine areas of likely bear movement.

Name	***Description***	***Source***	***Format***
Land Cover	Land cover/land use delineations for NC	CGIA	Raster
Gamelands	Contains all the gamelands in NC	CGIA	Polygon
Bear Sanctuary	Contains all the bear sanctuaries in NC	NC WRC	Polygon
Madison County Boundary	Boundary of Madison County. Created from NC Counties layer	CGIA	Polygon
City Limits	Political boundaries for the three cities in Madison County	Madison County Mapping Dept.	Polygon
Roads	All the roads in Madison County (including interstates, primary and secondary roads)	NCDOT	Line
Streams	Streams in Madison County (all sizes)	NCDOT	Line
Rivers	Rivers in Madison County	Madison County Mapping Dept.	Line
Elevation	Elevation raster for the county	Madison County Mapping Dept.	Raster
Population Density	Human population data from a Tiger file	US Census Bureau	Polygon

Table 10. The final weighted movement values for the landscape variables included in the movement model. The values are based on rankings given by black bear researchers on a scale of –100 to 100, where factors that impede bear movement are given negative values, and factors that promote bear movement are given positive values.

Landscape Variable	*Weighted Value*
Conservation Designations:	
Bear Sanctuaries	52
State Gamelands	50
Human Factors:	
City Boundaries	-32
Roads:	
Interstates	-73
Primary Roads	-37
Secondary Roads	-12
Other Roads	-3
Human Population Density:	
0-25 people/sq km	-3
26-75 people/sq km	-23
76-125 people/sq km	-45
126+ people/sq km	-78
Habitat Factors:	
Rivers	-24
Streams	16
Slope:	
20-25 degrees	-7
25+ degrees	-12
Land Cover:	
Water	-28
Low Intensity Residential	-36
High Intensity Residential	-70
Commercial/Industrial	-74
Bare Rock	-24
Deciduous Forest	78
Evergreen Forest	71
Mixed Forest	84
Shrublands	58
Grasslands	-8
Pasture Land	-29
Row Crops	-4
Wetlands	28

Table 11. The final adjustment values for patch sizes for each land cover class.

Land Cover Classifications	*0-25,000 sq m*	*25,001-100,000 sq m*	*100,001 sq m-1 sq km*	*>1 sq km*
Positive Classes:				
Deciduous Forest	0.878	1.125	1.375	2
Evergreen Forest	0.878	1.003	1.5	1.875
Mixed Forest	0.878	1.125	1.5	2
Shrub lands	0.753	1	1.25	1.5
Wetlands	0.753	0.875	1.125	1.25
Negative Classes:				
Water	1.125	1.375	1.5	1.75
Low Intensity Residential	1.125	1.625	1.875	2
High Intensity Residential	1.625	2	2	2
Commercial	1.5	2	2	2
Bare Rock	1	1	1.5	1.75
Grasslands	0.75	0.875	1.375	1.375
Pasture Land	0.875	0.875	1.375	1.375
Row Crops	0.625	0.875	1	1.25

Table 12. Raw vehicle counts for I-26 north of Madison County. The counts represent only the westbound traffic.

Date:	***3/10/2007***	***3/14/2007***	***6/17/2006***	***6/21/2006***	***9/26/2006***	***9/30/2006***	***12/13/2006***	***12/16/2006***	***Hourly Average***
Day of Week:	*Saturday*	*Wednesday*	*Saturday*	*Wednesday*	*Tuesday*	*Saturday*	*Wednesday*	*Saturday*	
Hour of the Day:									
0:00	37	28	38	33	31	43	39	49	37.25
1:00	68	19	37	18	26	38	24	23	31.625
2:00	29	19	33	31	16	23	26	29	25.75
3:00	33	31	31	22	22	20	29	32	27.5
4:00	26	43	38	31	23	24	24	27	29.5
5:00	21	68	61	25	54	37	28	25	39.875
6:00	68	104	88	100	77	44	74	55	76.25
7:00	121	144	188	157	165	122	133	111	142.625
8:00	192	173	288	209	202	166	161	176	195.875
9:00	224	187	331	223	202	210	173	197	218.375
10:00	211	182	340	238	196	253	202	227	231.125
11:00	262	199	364	222	236	241	194	269	248.375
12:00	242	184	368	257	199	262	162	254	241
13:00	253	231	330	237	210	221	178	254	239.25
14:00	253	197	390	247	228	321	199	277	264
15:00	284	276	418	272	214	280	197	284	278.125
16:00	299	256	385	261	225	328	225	328	288.375
17:00	299	235	395	275	217	302	241	278	280.25
18:00	232	161	384	238	224	239	188	107	221.625
19:00	172	115	301	202	154	204	105	77	166.25
20:00	167	87	332	140	90	108	105	78	138.375
21:00	155	88	138	78	50	103	85	80	97.125
22:00	103	68	92	55	52	81	69	77	74.625
23:00	51	47	58	58	56	71	61	60	57.75
Totals:	***3802***	***3142***	***5428***	***3629***	***3169***	***3741***	***2922***	***3374***	***3650.875***

APPENDICES

Appendix A: Black Bear Movement Model Expert Survey

Two surveys were sent to a group of black bear field researchers in order to determine the parameters for our black bear movement model. The first survey's goal was to assign a value to each landscape factor based on its influence on bear movement. The second survey was to quantify the interaction between land cover categories and patch size. This appendix contains the survey as it was sent to the experts.

Contents:

1. Invitation letter to researchers
2. Instructions for Landscape Variable survey
3. Landscape Variable Survey
4. Instructions for Patch Size survey
5. Patch Size survey

Invitation letter to researchers:

Hello!

My name is Liz Jones, and I am a graduate student in NC State's Fisheries and Wildlife Program. My thesis project is to study the effectiveness of underpasses created for black bears on a new interstate in the mountains of North Carolina. Another part of my project is to create a model using GIS to predict where bears might cross a major road in the Appalachian Mountains. The purpose of my model is to show areas of likely black bear movement, while keeping the model as simple as possible. My goal is to create a model that can be easily and quickly applied by the DOT to any North Carolina mountain county, and only requires spatial data that can be easily acquired for multiple regions.

To create the model, I am trying to put together factors that influence bear movement in the Appalachian Mountains. Based on the literature, I have collected spatial data that appear to shape bear movements. My data are from the NCDOT, the Madison County Mapping Department, and the NC Wildlife Resources Commission. My next step is to weigh each factor in accordance to its relative influence on bear movement.

This is where I am requesting your assistance. My knowledge of black bears comes only from the literature; I do not have any field experience with them. The best knowledge of a species is obtained from the field, so I am hoping to utilize your experience and knowledge in the creation of my model.

If you are willing, I would like to send you a short survey that should only take 5-10 minutes to fill out. It does not require any data, just your opinions. Please let me know if you have time to fill out the survey, and I will email it to you, or mail you a hard copy if you would prefer.

Thanks in advance for your time and assistance!

Sincerely,

Liz Jones

Instructions for Landscape Variable Survey:

Thank you for agreeing to participate in my survey!

In the attached document, I have listed all of the factors I plan to incorporate into my model.

If you are willing, what I am asking you to do is to score each factor on how much it inhibits or promotes black bear movement, on a scale of –100 to 100. Factors that inhibit black bear movement should receive a negative score, while those that promote movement should receive a positive score. For example, if you think a factor would essentially stop bear movement, you would give it a score in the range of –90 to -100. A factor that has no influence on bear movement would receive a score of 0.

Please keep two things in mind as you fill out the survey:

1. Please rate the factors based on their effects on black bears in the Appalachian

Mountains, which may be different from bears in the Coastal Plain.

2. Think of each factor's influence on movement, which could be quite different from its habitat potential.

At the end of the list there is space for you to list any factors that you feel are important and not included. Please score any factors you list as well.

Feel free to pass copies of this survey on to other biologists with the appropriate experience. If you have any questions, comments, concerns, etc, please email me at erjones@ncsu.edu. Thank you in advance for your time and assistance!

Landscape Variable Survey:

Topographic Features:	**Score:**
Rivers	
Streams	
Within 10 ft. of streams	
Within 50 ft. of streams	
Slope:	
0-2 degrees	
2-5 degrees	
5-10 degrees	
10-15 degrees	
15-20 degrees	
20-25 degrees	
25+ degrees	
Land cover/Land use:	
Water	
Low Intensity Residential	
High Intensity Residential	
Commercial/Industrial	
Bare Rock	
Deciduous Forest	
Evergreen Forest	
Mixed Forest	
Shrublands	
Grasslands	
Pasture land	
Row Crops	
Wetlands	
Conservation Designations:	
Bear Sanctuaries	
State Gamelands	
Human Factors:	
City Boundaries	
Population Density (from Census Data)	
Interstates	
Primary Roads	
Secondary Roads	
Other Roads	
Human Population Density:	
0-25 people/sq km	
26-75	
76-125	
126+	

Instructions for Patch Size Survey:

The purpose of this survey is to assess how much area influences each land cover type's impact on bear movement. You will assign each land cover type a multiplier value for each of 4 categories of area. This multiplier will either increase or decrease the value of each land cover category for black bear movement.

The survey is in the attached excel spreadsheet. It is broken into two sections, one for land cover types with positive values, and the other for those with negative values. Under each section is a list of possible multiplier values and their meaning. The values for the two sections are the same, but their meanings are reversed since reducing the distance of a negative number from zero (by multiplying it by 0.5 or 0.01) means that it is better for bear movement. I know this can get confusing, so please reference the list of choices for the appropriate section as you fill out the form!

On the right-hand side of the form, I have listed the weighted values for each land cover type. These are an average of the earlier survey responses. If you feel that these values are incorrect, please let me know. These values will be multiplied by the average of your responses to this survey in the final model

.

Patch Size Survey:

Positive Types:

Land Cover Type	Patch Size: 0-25000 sq m (0-6.2 acres)	25,001-100,000 (6.2-24.7 acres)	100,000 sq m- 1 sq km (24.7-247 acres)	>1 sq km (>247 acres)	Weighted Score
Deciduous Forest					**78**
Evergreen Forest					**71**
Mixed Forest					**84**
Shrublands					**58**
Wetlands					**28**

Choices:	
0.01	Large decrease in bear movement
0.5	Some decrease in bear movement
1	No effect
1.5	Some increase in bear movement
2	Large increase in bear movement

Negative Types:

Land Cover Type	Patch Size: 0-25000 sq m (0-6.2 acres)	25,001-100,000 (6.2-24.7 acres)	100,000 sq m- 1 sq km (24.7-247 acres)	>1 sq km (>247 acres)	Weighted Score
Water					**-28**
Low Intensity Residential					**-36**
High Intensity Residential					**-70**
Commercial/Industrial					**-74**
Bare Rock					**-24**
Grasslands					**-8**
Pasture land					**-29**
Row Crops					**-4**

Choices:	
0.01	Large increase in bear movement
0.5	Some increase in bear movement
1	No effect
1.5	Some decrease in bear movement
2	Large decrease in bear movement

Appendix B: Instructions for Bear Movement Package Use

Required Software: ESRI's ArcMap, version 9 Or higher, with the Spatial Analyst Extension and 3D Analyst Extension activated. (To activate the extensions, go to the Tools menu, select Extensions, and make sure both are checked.)

Required Data:
All of the data required is commonly available from governmental organizations, including NCDOT and CGIA. The data can be raster or vector data, and can be statewide or for the county of interest. If one set of data is not available, use a null raster in its place.

1. **Landcover-** This data needs to be classified using the MRLC categories. The National Land Cover Dataset is one source. If this data is in vector format, it needs to be converted to a raster using the "Feature to Raster" tool (Conversion Tools: To Raster), with the field containing the numerical designation for the MRLC category selected.
2. **Elevation-** This data can be vector contour data, or a raster containing elevation values (such as a Digital Elevation Model). If using contour data, use the "Topo to Raster" tool (3D Analyst Tools: Raster Interpolation) to create an elevation raster layer.
3. **Roads-** Three types of road layers are needed for the analysis. One containing all the roads in the study area, one containing primary roads, and one containing secondary roads. If the only layer available contains all roads, use the "Select by Attributes" tool (under the Selection menu) to first select all primary roads (interstates, US highways, and major state highways) (Route Type 1, 2, 3). Then right-click on the layer, go to Selections, and click "Create layer from selected features". Clear the selection (under the Selection menu), and repeat the process selecting secondary roads (Route Type 4), and interstates.
4. **Streams and Rivers-** If these two data types are not available in separate layers, use the procedure described above for separating the roads to create a new layer containing only the rivers.
5. **Gamelands-** All areas where public hunting of black bears is allowed.
6. **Bear Sanctuaries-** This layer should include all areas that black bears are protected from hunting. This could include areas specifically designated as bear sanctuaries, and areas where bears are protected such as state and national parks.
7. **Human Population-** Use the most recent census data available. Census data is available online in a variety of formats, and it should be in a shapefile format. Either census blocks or groups will work. The data should have the total populations for each block, and the area of each in square meters. If the area is missing, use the Calculate Areas script (Spatial Statistics: Utilities) to calculate it (be sure the area is only as large as you need, this script can take a while if there

are many areas to calculate). Then use the "Human Density" model to calculate human density per square kilometer. (Convert to raster using Feature to Raster)

All of the data needs to have their projections defined. If it is missing, use the "Define Projection" tool (Data Management Tools: Projections and Transformations). If some of the data are in different projections use the "Project" tool to convert them to a uniform projection.

NC County Selection:
If you are conducting the analysis for a county in North Carolina, use the "NC County Selection" tool. In the first box, enter the county name in the same format as the title ('COUNTY' with single quotations), in the second, save the layer in a convenient place, and name with the county's name.

Set the Environments:
To do this, go to the Tools menu, Options, and then click on the Geoprocessing tab. Click the Environments button halfway down, then expand the General Settings section. Set a place to store all the intermediate data in the Scratch workspace line (the path-name cannot have any spaces in it). Use the county layer created in the above step to set the coordinate system and output extent (you can select the layer from the drop-down list). Under the Raster Analysis Settings, set the cell size to 50, and the mask to the same county layer.

Prepare the Vector Data:
For each vector layer to be used in the model, a field needs to be added to the attribute table. To do this, right-click on the layer and open the attribute table. Click on Options and add a field. Name this field "Convert" and leave the values as they are automatically set (they should be all zeros).

Next, use the "Vector Data Prep" tool. Select the county layer in CountyBoun box, select the vector data in the "Features to be clipped" box, select "Convert" in the field box, and then name the layer something descriptive, without any spaces. Run the tool. Repeat this process for each vector data set.

Land Cover Tool:
This tool assigns a value to each pixel based on the land cover present there, and the size of the patch of land cover the pixel is a part of. This tool can take an extremely long time to run; one of the functions took over an hour to run for one county. The input is the county boundary and the landcover for the area.

Movement Values Tool:
This tool combines the scores assigned to each layer of landcover data by adding them. For each variable type, select the proper layer created with the "Vector Data Prep" tool,

and the output from the "Land Cover" tool. The output of this tool shows the movement values for the county.