Title

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DETERMINING THE POTENTIAL MITIGATION EFFECTS OF WILDLIFE PASSAGEWAYS ON BLACK BEARS

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Abstract: North Carolina's U.S. Highway 64 is currently being expanded from a two-lane road to a four-lane divided highway from Raleigh to the Outer Banks. Concerns exist that collisions with vehicles may affect the demographics of wildlife populations and that potential disturbances and fragmentation associated with the highway may affect the ecological integrity of the landscape, particularly with regard to large carnivores. In response to these concerns, the North Carolina Department of Transportation (NCDOT) included three wildlife underpasses into the design of a 19.3-km section of the new U.S. Highway 64 in Washington County. The locations of the wildlife underpasses were determined based on a study by the North Carolina Wildlife Resources Commission during 1999. Areas that received frequent wildlife use were identified based on surveys of track counts, ditch crossings, and infrared cameras. The resulting data were used in combination with a geographic information system (GIS) to identify travel corridors for wildlife. Once the locations of the wildlife underpasses were established, the University of Tennessee initiated research in 2000 to determine whether wildlife passageways can mitigate impacts from highways. We chose a wide-ranging carnivore, the American black bear (*Ursus americanus*), as the focus species of our study because of its dependence on regional landscapes. We developed an experimental study design that will allow for collection of data before and after highway construction on a treatment and a control area. During the pre-construction phase of the study, we have collected over 6,000 locations on a total of 35 bears to document home-range sizes, activity patterns, movements, and habitat use. We are also analyzing 337 DNA samples from hair collected at 140 barbed-wire hair traps to estimate population density and to determine genetic relatedness within and among the two populations. Finally, we are using 243 photographs of wildlife from infrared cameras to measure use of the areas where the highway underpasses will be constructed. Field data collection during the pre-construction period was completed in June 2001; post-construction data will be gathered and compared after the anticipated completion of the highway in 2004.

Introduction

Highways can impact wildlife, particularly wide-ranging carnivores, in five basic ways: (1) habitat fragmentation, (2) associated human development, (3) direct mortality, (4) direct habitat loss, and (5) displacement and avoidance (Ruediger 1998). The first two factors may not become evident immediately because they represent potentially long-term impacts. The effects of the latter three factors on wildlife, however, may become apparent within a relatively short period after highway construction. Although the long-term impacts of highways should be an important consideration, few studies have been able to address these effects because of logistical, biological, and financial constraints.

Potential short-term impacts of highways have been studied on various carnivores. Many studies have documented displacement in response to highways by grizzly bears (*Ursus arctos*) (Gibeau and Herrero 1998), black bears (Brody and Pelton 1989, Beringer et al. 1990), wolves (*Canis lupus*) (Paquet and Callaghan 1996), wolverines (*Gulo gulo*) (Gibeau and Heuer 1996), and other carnivores (see Ruediger 1998). Direct mortality to carnivores has been fairly well documented and affects a wide variety of species (see Ruediger 1998).

Collisions between wildlife and vehicles raise highway safety concerns for motorists. Collisions have become commonplace in areas where high-speed roads traverse high-quality wildlife habitat. For example, Romin and Bissonette (1996) conservatively estimated the occurrence of >538,000 deer-vehicle collisions in the United States in 1991 alone. The frequency of wildlife-vehicle collisions will likely increase as the network of highways throughout the United States is upgraded and expanded to accommodate the growing number of motorists (Lehnert and Bissonette 1997).

Studies of various devices to reduce vehicle collisions have shown mixed results (e.g., ultrasonic warning whistles on vehicles [Romin and Dalton 1992], Swareflex® reflectors along roads [Schafer and Penland 1985, Reeve and Anderson 1993]). Other researchers have emphasized the use of highway underpasses (Foster and Humprey 1995), overpasses or 'ecoducts' (Bekker 1998), crosswalk systems (Lehnert and Bissonette 1997), and fencing (Clevenger et al. 2001) to improve human safety, reduce wildlife mortality, and maintain movement and migratory corridors of wildlife. Wildlife passageways and other mitigation measures, however, are expensive and quantitative studies are needed to evaluate their necessity and efficacy.

Rare and wide-ranging carnivores have received particular attention for such studies in part because of their dependence on regional landscapes (Ruediger 1998). For this reason, we chose the American black bear as the focus species of our study, particularly because this species can be studied relatively easily and baseline data already are available. For example, most states and Canadian provinces keep records on black bear mortality as a result of collisions with vehicles. Reported annual mortality of black bears in eastern North America ranges from <1 in Ohio to 150–200 in Pennsylvania; in the southeastern Coastal Plain region, the highest annual frequency of bear mortality caused by vehicle collisions occur in Florida (30–60) and North Carolina (>100) (Wooding and Maddrey 1994; M. D. Jones, North Carolina Wildlife Resources Commission, unpublished data). Vehicle-related mortalities tend to increase during seasons with increased bear movements (i.e., fall) and when availability of food sources is limited.

Few areas exist where passageways have been constructed specifically for black bears. Underpasses were constructed and evaluated for black bears on State Route 46 near Wekiva in Lake County, Florida. Three of 26 recorded road crossings by 16 bears occurred through underpasses (Roof and Wooding 1996). Although this frequency may seem low, it may still represent disproportionately high use. Clevenger (1998) studied a four-lane section of the Trans-Canada highway in Banff National Park, Alberta, Canada, and observed that elk (*Cervus elaphus*) and deer (*Odocoileus* spp.) used the underpasses more frequently than carnivores. However, of all carnivores studied, black bears were the most frequent users of underpasses. Carnivore use of underpasses was negatively correlated with human activity in the vicinity of the underpasses (Clevenger 1998). Clevenger (1998) suggested that, at least in the short term, possible barrier effects of the highway were reduced by the use of 11 underpasses on the 27-km stretch of highway. As is true for many other studies, this study was not able to determine wildlife use before highway construction to measure highway impacts or effectiveness of the underpasses (Clevenger 1998).

North Carolina's U.S. Highway 64 currently is being expanded from a two-lane road to a four-lane divided highway from Raleigh to the Outer Banks. Concerns exist that collisions with vehicles may affect the demographics of wildlife populations and that potential disturbances and fragmentation associated with the highway may affect the ecological integrity of the landscape, particularly with regard to large carnivores. In response to these concerns, the North Carolina Department of Transportation included three wildlife underpasses into the design of a 19.3-km section of the new U.S. Highway 64 in Washington County, North Carolina. We are not aware of any studies on bears that were based on assessment of bear responses before and after road construction. In this paper, we describe a unique opportunity to determine optimal placement of wildlife underpasses and establish a study design to test the impacts of a four-lane highway with wildlife underpasses on black bear ecology.

Study Area

The study area is located in Washington County in eastern North Carolina where the NCDOT is upgrading U.S. Highway 64 from Plymouth to Columbia to a four-lane, divided highway. The section of highway within the treatment area will span approximately 19.3 km (12 miles) for which a new route has been identified south of the current U.S. Highway 64 (figure 1). Construction of the highway and the three wildlife underpasses started during Spring 2001 and is anticipated to be completed in 2004.

The treatment area, the area of the proposed U.S. Highway 64, was approximately 10,750 ha and the control area was approximately 12,270 ha. The control area was chosen to closely resemble the landscape of the treatment area, particularly with regard to the juxtaposition and area of agricultural (38%) and forested lands (62%) (figure 1). Managed pine forests comprised the majority of the forested lands, whereas hardwoods were restricted to natural drainages. Human development was limited to a few large farms within the study areas and several small towns near the study area boundaries. Weyerhaeuser Forest Products Company was the largest landowner within the study area, with private farms and woodlots accounting for the remaining portion.

Both areas included distinct boundaries of forest and agricultural lands. All of Washington County is classified as occupied black bear habitat by the NCWRC, with 17 percent classified as core habitat.

Study Design

Placement of Wildlife Underpasses

The initial goal of our project was to determine placement of three wildlife underpasses. We based our analyses on the premise that areas used most heavily by black bear, coyote (*C. latrans)*, red wolves (*C. rufus*), and white-tailed deer (*Odocoileus virginianus*) were the best potential locations for underpasses. We measured intensity of use by conducting track count and ditch-crossing surveys, and we monitored wildlife trails with infrared cameras. We developed GIS models based on land-cover data to identify potential wildlife travel corridors at the landscape level. Based on a black bear telemetry study by Jones (1996) on the Neuse-Pamlico peninsula, we defined three seasons: spring (April–June), summer (July–September), and fall (October–December). We did not survey the period from January–March because bears are typically denning during this time and movements are limited (Jones 1996).

Track Surveys

We selected six survey routes ranging in length from 1.3–3.6 km to conduct track surveys twice each month (10.7 km total length). These routes included timber and farm roads and a power line right-of-way that were in the immediate vicinity of the proposed highway corridor. The distance from these survey routes to the proposed highway corridor ranged from 0 m, where they crossed, to approximately 860 m. We used a harrow drag one day prior to each survey to improve the substrate for reading tracks and to erase old tracks. Track count surveys were conducted with an all-terrain vehicle. All medium to large mammal species were included if their tracks were identifiable. We measured all canid track lengths if species identification was uncertain.

We used a global positioning system (GPS), with a positional accuracy of 1–3 m, to determine the coordinates of track locations. Tracks that paralleled the survey routes were located but not used because they did not assist in determining crossing points. We developed spatial data layers representing track locations for each species using ArcInfo® (ESRI, Redlands, California, USA), then converted each data layer to raster format with cell values representing the total number of tracks falling within each cell. Cell size was set at 0.75 m^2, below the minimum distance between tracks (e.g., 1 m), to avoid having tracks fall within more than one cell. We used the Spatial Analyst program extension in ArcView® GIS (ESRI, Redlands, California, USA) to locate areas of high animal activity by performing a neighborhood-analysis function on the raster data. Each cell in the input grid was examined to determine the number of tracks within a specified distance and assigned a new value corresponding to the total number of tracks within this radius. We examined these data using 100-m and 200-m radii around each grid cell. We interpolated areas of high animal activity from distributions or clusters of high track counts determined with the GIS. We performed this analysis based on individual species data and in combined data sets. Coyote data were combined with those of red wolves because very few wolf tracks were found and distinguishing tracks of the two species was difficult. We analyzed the track survey data from the non-target species as above and compared the results with the target species.

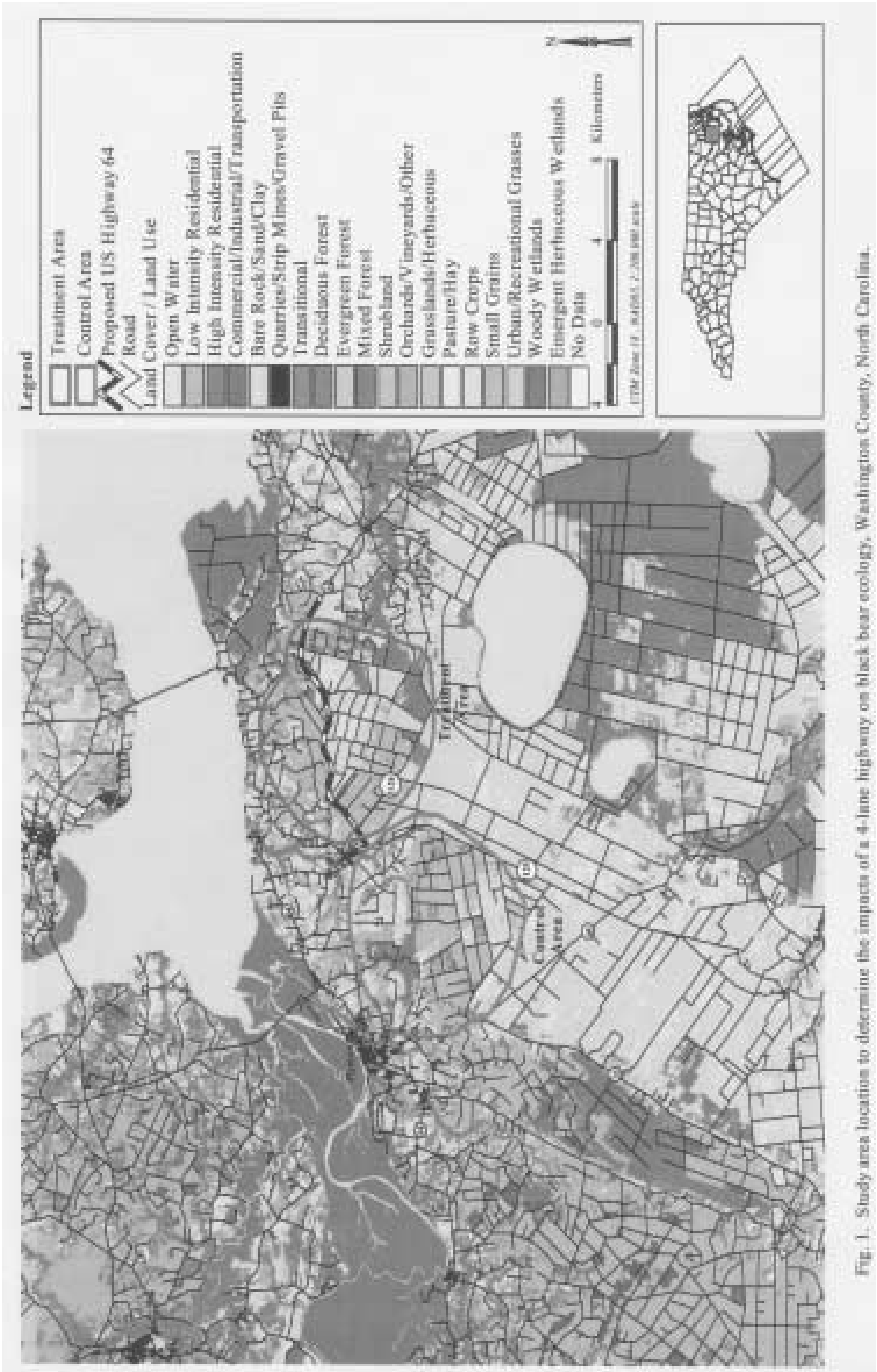

Figure 1: Study area location to determine the impacts of a 4-frame highway on black bear ecology. Washington County, North Carolina.

Ditch-crossing Surveys

Much of the proposed highway route followed a forest-cropland edge with pine plantations to the north and large farms to the south. Because these farms lacked suitable roads that paralleled the proposed route, most of the track routes were north of the proposed highway corridor. Therefore, we conducted ditch-crossing surveys on the south edge of the proposed highway along the forest-farmland boundary. This ditch was continuous except for two breaks, a property line and a road. We searched for trails worn into ditch banks at crossing points. We differentiated crossings of large mammals from erosion or beaver and otter slides by counting only trails that clearly crossed the ditch or if we observed deer or black bear tracks. These surveys provided a general view of which areas were used most during a given season because it takes many animals to create a trail. We surveyed ditches once at the midpoint of each season. Methods of collection and analysis of the crossing survey data were identical to those used for the track surveys.

Infrared Cameras

Unlike the track and ditch-crossing surveys, which were conducted to find travel corridors, infrared cameras were set up in eight areas already identified as travel routes. These included trails and creeks that were perpendicular to the proposed highway. We used active-infrared (TM1500) and passive-infrared (TM550) TrailMaster® 35-mm camera systems with Yashica T-4 Super D Weatherproof automatic-flash cameras (Goodson and Associates, Inc., Lenexa, Kansas, USA). We used the photographs to identify species and document frequency of trail use. Infrared monitors were set 56 cm above the ground and were continuously operable. The monitors counted how often the infrared beam was broken (an 'event'), or whether a camera took a photograph. We assumed that additional events tallied after a photograph of an animal were either the same animal or a second animal of the same species. Multiple photographs containing several deer supported this assumption. We standardized the activity results of target species to obtain a comparable index between sites by dividing the number of photographs of each target species by the number of days that the cameras were functional.

GIS Analyses

We evaluated land-cover data for the Albemarle-Pamlico peninsula to delineate landscape characteristics preferred by black bears and white-tailed deer. Potential travel corridors were identified by ranking each land-cover type (Excellent, Good, Fair, Poor, and Very Poor) according to its level of use based on a study by Jones (1996) of radio-collared bears on the Neuse-Pamlico peninsula. We then reclassified the land-cover data according to these ranks.

Data from surveys, monitors, and modeling were analyzed separately and results were spatially combined. Sites selected by multiple survey methods were given more weight in determining the three underpass locations. Finally, we adjusted underpass locations if the data analyses placed them within 200 m of the proposed interchanges.

	Pre Construction 2000-2001	**Post Construction 2005-2006**
Treatment Area (Highway Construction)	Group 1	Group 2
Control Area (No Highway Construction)	Group 3	Group 4

Fig. 2. Experimental design to determine effects of a 4-lane highway with underpasses on black bear ecology in eastern North Carolina.

Effects of the Highway on Black Bears and Effectiveness of Underpasses
The overall objectives for this portion of the study are to determine whether spatial ecology, population demographics, and genetic exchange of black bears differ before and after highway construction. We are collecting data on a wide variety of variables to measure those aspects of black bear ecology. We also will determine whether the three underpasses mitigate the potential barrier effect of the highway to bear movements.

Construction of U.S. Highway 64 started during the spring of 2001 and is anticipated to be completed in 2004. Because of the length of the highway construction phase, it is unlikely that all bears captured before construction began will still be alive and in the study area after the highway is completed. Thus, establishment of a control area was necessary to adjust for any effect caused by a different sample of bears in the post-construction group and because of potential changes in environmental conditions. Our analysis will be based on four groups of bears: (1) treatment area, pre-construction; (2) treatment area, post-construction; (3) control area, pre-construction; and (4) control area, post-construction (figure 2). Treatment effects occur only if differences exist between groups 1 and 2, after adjusting for differences between the control groups 3 and 4.

The primary reason for inclusion of a control area is to isolate any effects that may not be associated with the new highway. Suppose, for example, that the bear population in the project area gradually increases during the next 10 years. This increase may result in changes in the measurements we will use (e.g., home range sizes, movements, etc.). Without a control area, we will not be able to isolate the impacts of the new highway from the effects caused by the population increase. As another example, different weather conditions during the second phase of our study may indirectly contribute to changes in food resources and, in turn, affect our measures (e.g., bear movements, habitat use). These effects should be separated from highway impacts. Thus, in our statistical analysis, we are essentially looking for an 'interaction effect' (figure 3). In the example of figure 3, we show a decrease in movement rate on the treatment area but a much smaller decrease on the control area. In statistical terms this would show an interaction, which would indicate that the impact of the highway is real. Had the line for the control area been parallel to the treatment area line, the conclusion would follow that there is a change in the movement rate but that it is likely caused by something other than the highway. In this latter case, without the control area, one could arrive at the false conclusion that the treatment did affect bears.

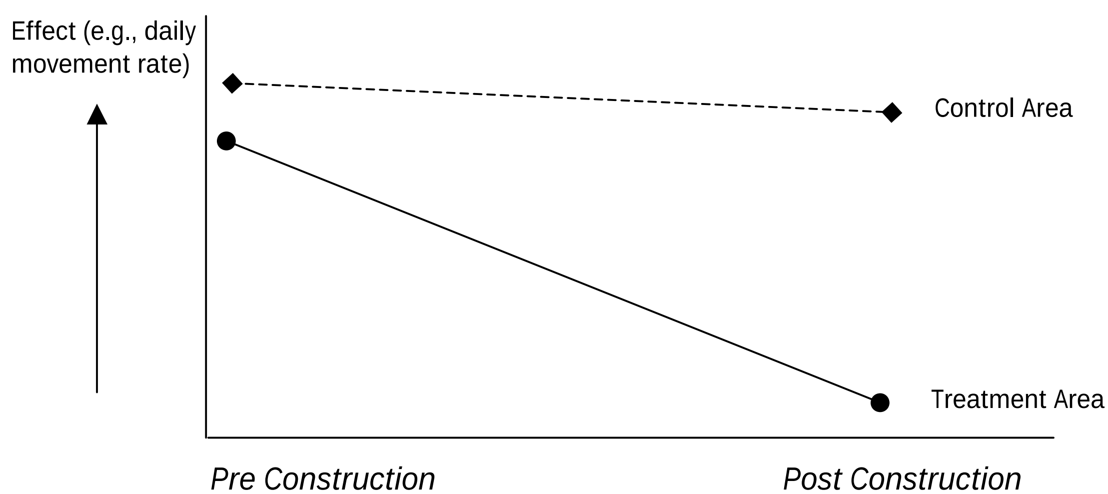

Fig. 3. Example of 'interaction' effect necessary to determine the effects of a four-lane highway with wildlife underpasses on black bear ecology.

It is important that the 'driving forces' of black bear ecology are similar for the treatment and the control area. Thus, we chose the control area based on relatively similar land-cover composition, forest-agriculture juxtaposition, agricultural crops, road network, human settlement, and bear harvest regime. Although the treatment and control areas are not exactly the same, we speculate that similarity in these primary factors will be adequate for detecting effects caused by the highway. The two study areas were relatively close for logistical reasons but the spatial separation was enough so that study animals could be assigned to only the treatment or the control area.

Our experimental design should allow relatively strong inference because it was set up to isolate effects in response to the highway itself. As such, the results of the study should be clearly interpretable and should be applicable to eastern North Carolina and beyond. This study should allow us to establish general principles of how black bears respond, if at all, to four-lane highways and how underpasses may mitigate such impacts.

Field Methods and Preliminary Findings

Placement of Wildlife Underpasses

Study Findings

Track surveys revealed 6,056 individual tracks from nine mammal species: black bear, deer, red wolf, coyote, bobcat (*Lynx rufus*), domestic dog (*C. familiaris*), gray fox (*Urocyon cinereoargenteus*), raccoon (*Procyon lotor*), and opossum (*Didelphis virginiana*) (table 1). The GIS analysis of the combined target species data revealed several clusters of activity (figure 4). Deer accounted for most track activity (84%); black bears and canids (i.e., red wolves and coyotes) represented 3% and 2%, respectively. Repeated GIS analysis with data separated by species indicated that the high proportion of deer tracks did not mask the overall outcome.

Table 1
Results of track surveys from the U.S. Highway 64 wildlife underpass placement study, Washington County, North Carolina, 1999.

Species	**Number of Tracks**	**Percent of Total**
Black Bear	189	3.1
White-tailed Deer	5,111	84.4
Red Wolf	1	<0.1
Red Wolf/Coyote	4	0.1
Coyote	138	2.3
Domestic Dog	108	1.8
Gray Fox	313	5.2
Raccoon	114	1.9
Opossum	72	1.2
Bobcat	6	0.1
Total	6,056	100.0

Ditch crossing surveys revealed 548 crossing points along the major agricultural ditches. Based on tracks and frequent sightings, these crossings were used mainly by deer, although black bear and raccoon sign were also found. The GIS analysis of crossing points showed strong clustering (figure 4). Heavy clusters from the track surveys were close to crossing clusters suggesting travel routes, and these areas became candidates for underpasses.

Monitoring trails with infrared-operated camera systems documented use of travel routes by seven species: black bear, deer, domestic dog, gray fox, raccoon, opossum, and rabbit (*Sylvilagus* sp.). These monitors yielded 112 photographs of 125 animals with 112 additional events (without photographs) assumed to be animals (table 2). There were 331 empty photographs caused by unknown sources (244), a defective infrared monitor (44), vines growing over the infrared sensor (22), hurricane winds (17), and bear disturbance (4).

Table 2
Results of infrared-operated camera systems from the U.S. Highway 64 wildlife underpass placement study, Washington County, North Carolina, 1999.

Subject	Number of Photographs	Number of Animals in Photographs	Number of Events
White-tailed Deer	75	84	61
Black Bear	12	13	38
Domestic Dog	3	4	0
Gray Fox	3	3	0
Raccoon	14	16	13
Rabbit	4	4	0
Opossum	1	1	0
Total	112	125	112

Our GIS modeling based on the ranking of land-cover types provided a better understanding of where blocks of preferred habitats were in relation to each other and to the proposed highway. This ranking of land-cover types revealed three potential travel corridors. Two followed creeks and the third connected a large swamp to a large forest block.

Recommendations

We selected three wildlife underpass sites after comparing the results of the track surveys, ditch crossing surveys, infrared cameras, and land-cover maps (figure 4). The western-most site is not located at an area of high animal activity. However, the presence of a stream, identified as a wildlife travel corridor through habitat ranking, and the proximity to an area of high activity support its present location. The central site is located near a major concentration of track and ditch crossings, but we moved it slightly east to keep it away from a proposed interchange and existing residential houses. The eastern underpass site connects two large blocks of contiguous forestland.

These three structures will be the first wildlife passages suitable for large mammals built in North Carolina and among the first in the eastern United States outside of Florida. The underpass design we recommended was similar to the structures built on Interstate Highway 75 in Florida (Evink 1994) because of high use by black bear, white-tailed deer, and several other species (Foster and Humphrey 1995, Land and Lotz 1996). Moreover, the geography and habitat between the two areas are similar. The open-span, bridge-type underpasses will be 2.4 m tall and 36.6 m wide. We recommend varying lengths (ranging from 0.8 to 1.6 km) of 3-m tall wildlife-proof fencing be installed parallel to the highway. We suggested one-way escapes (e.g., gates or deer leaps; Putnam 1997) every 200–300 m to provide an exit for animals that enter the highway.

Based on results from recent research in Canada, "jump-outs" may be the most effective design (J. Jorgenson, Alberta Natural Resources Service, personal communication). Provisions were made for the NCDOT to maintain the area in front of and underneath the underpasses in early successional vegetation (i.e., woody vegetation <1.2 m tall). We suggest the placement of 0.61-m tall cement columns, 0.9 m apart, across each underpasses to prevent use of the structures as ATV routes, which would likely disturb wildlife. Each underpass structure and adjacent land will be enrolled in the NCWRC "Registered Lands" program to empower NWRC wildlife officers to enforce no hunting or trespassing at these sites.

The wildlife underpasses will be constructed between privately owned parcels of land. The potential benefits of the underpasses could be substantially reduced if future development or land clearing is allowed in close vicinity to the underpasses. Therefore, we suggest that the NCDOT purchase land at each underpass opening. We also recommend that land purchase options from future mitigation efforts be used for the purchase of additional lands to connect the areas near the underpasses with important wildlife habitats in the region. Finally, the location and frequency of vehicle collisions with large mammals should be documented systematically so that the requirements for further modifications, such as lengthening the fences, can be determined.

Effects of Highway on Black Bear and Effectiveness of Underpasses

Phase 1

Field work was initiated during the summer of 2000. We used spring-activated foot snares (modified with automobile hood springs to prevent injuries) to capture 23 bears (12 males, 11 females) on the treatment area and 32 bears (8 males, 24 females) on the control area. Captured bears were immobilized, measured, weighed, eartagged, and lip tattooed. A premolar tooth was extracted for aging based on cementum annuli and tissue samples were collected for DNA analysis. Sixteen bears were fitted with radiocollars on the treatment area and 19 bears on the control area. All radio transmitters were equipped with motion-sensitive activity and mortality monitors. Captured bears were handled according to animal handling protocols approved by the University of Tennessee Office of Laboratory Animal Care.

Locations of radio-collared bears were estimated by ground triangulation with additional aerial surveys to locate bears moving out of the study areas. The study design required observations of short-term bear movements. Therefore, we mostly located bears at hourly intervals during 8-hour sampling periods throughout the 24-hour period. Activity data were collected in conjunction with location estimation. Specific behavior associated with different activity signals can be predicted based on techniques used with Florida panthers (Janis et al. 1999). The telemetry data will be used to determine habitat use, activity patterns, movements, and to delineate home ranges and activity centers.

A reliable population estimate must be obtained during both phases of the study so that the effects of the highway on black bears can be fully understood. Conventional mark-recapture techniques based on capture-and-release often provide population estimates with relatively low precision and poor accuracy because of low sample sizes and sampling biases. A relatively new technique is to "mark" animals based on microsatellite analysis of DNA collected from hair samples; this technique has many advantages over livetrapping, including increased capture probability, no tag loss, lower bias, and decreased intrusiveness of research (Woods et al. 1999, Mills et al. 2000). Traditional mark-recapture models (Seber 1982) can be applied to these data to estimate population abundance and density. We established 70 hair sample sites each on both study areas. Each hair-trap station consisted of a barbed-wire enclosure with a bait in the center. Hair samples, snagged by the barbed wire from visiting bears, were collected over seven weekly sampling periods, resulting in 686 hair samples for the treatment area and 1,240 hair samples for the control area. A random subsample will be used for microsatellite analysis.

Microsatellite analysis also can be used to determine genetic relatedness among different animal populations (Paetkau et al. 1995, Warrillow et al. 2001) and thus to identify potential barriers to genetic exchange (Paetkau et al. 1998). Comparisons of genetic relatedness among black bears before and after highway construction will be useful to determine whether the highway serves as a barrier to genetic exchange.

Two passive infrared camera units (Trailmaster®, Goodson and Associates, Inc., Lenexa, Kansas) were placed at each of the entrances of the 3 proposed highway underpass sites (6 cameras total; figure 4). We collected 243 photographs of wildlife, which will be used to compare the frequency of use of these travel corridors before highway construction with use of the wildlife underpasses once construction is completed.

Phase 2

The field research scenario of Phase 1 will be repeated after the anticipated completion of the highway in 2004. Pre- and post-construction data will then be compared for a wide variety of variables, such as hourly movement rates, home range size, population density, and genetic relatedness.

Potential Management Implications

The results of this research project will be used to determine whether placement of wildlife underpasses can be optimized with the help of field reconnaissance studies. Furthermore, we will be able to document whether short-term survival, gene flow, movements, home ranges, activities, and habitat use of black bears are different before and after construction of the four-lane highway and whether wildlife underpasses can mitigate such effects. This study will provide detailed data on when and how frequently bears use wildlife underpasses. We will also be able to determine which bears use the underpasses and estimate 'effective areas' for each underpass. Finally, this study will provide baseline data regarding use of underpasses by many other wildlife species.

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Biographical Sketch: Frank van Manen is a research ecologist with the U.S. Geological Survey's Southern Appalachian Field Laboratory in Knoxville, Tennessee. He holds an adjunct assistant professor appointment with the Department of Forestry, Wildlife, and Fisheries at the University of Tennessee. Frank blends his interest in mammals with landscape ecology. Much of his research is devoted to predicting species distributions, determining wildlife responses to landscape perturbations, and modeling metapopulation dynamics. The effects of our changing landscape on large carnivores have particularly drawn his attention. He currently supervises six M.S. candidates working on a variety of species, ranging from rare plants and trees to black bears and elk. Frank earned his M.S. degree from Wageningen University in the Netherlands and his Ph.D. from the University of Tennessee.

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