I am submitting herewith a thesis written by Matthew Flanders McCollister entitled "Impacts of a 4-lane highway on the spatial ecology of American black bears and the effectiveness of wildlife underpasses in eastern North Carolina." I have examined the final paper copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

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IMPACTS OF A 4-LANE HIGHWAY ON THE SPATIAL ECOLOGY OF AMERICAN BLACK BEARS AND THE EFFECTIVENESS OF WILDLIFE UNDERPASSES IN EASTERN NORTH CAROLINA

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Matthew Flanders McCollister

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DEDICATION

This thesis is dedicated to Hoke, my feist.

“What’re you gonna do if she wants to rassle?” – Jeremy “the worm” Nicholson

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ABSTRACT

From 2001 through 2005, the North Carolina Department of Transportation rerouted and upgraded a section of U.S. Highway 64 in Washington County to a 4-lane divided highway. This new roadway included 3 wildlife underpasses with adjacent wildlife fencing to mitigate the effects of the highway on wildlife, in particular American black bears (*Ursus americanus*). From 2000 to 2001, the University of Tennessee conducted research on the spatial ecology and population demographics of the black bear population at the new highway site and on a nearby control area of similar habitat composition. From 2006 to 2007, after highway construction, data collection was repeated and additional data were collected to document use of the 3 wildlife underpasses and wildlife mortalities from vehicle collisions. I tested several hypotheses to determine if the new highway caused changes in home-range characteristics, spatial responses, habitat use, movement characteristics, and activity patterns of black bears. Using a dataset of 5,775 hourly locations and 4,998 daily locations from 57 bears, I detected no changes in home-range characteristics or movement characteristics of bears because of the new highway. However, the power for several of these analyses was relatively low and my research focused on females. I did detect changes in bear habitat use and activity patterns resulting from the new road. In particular, bears from the new highway area were closer to the road and became more active in morning when highway traffic was low. Underpass monitoring yielded 2,053 photographs of wildlife and 3,622 wildlife crossings based on track counts. The highway surveys recorded 196 animal mortalities from vehicle collisions. I observed an increase in wildlife crossings at the underpass

sites, but no difference in roadkill frequency between protected sections of the highway (underpasses and fencing) compared with unprotected sections. However, substantially fewer animal-vehicle collisions (primarily deer [*Odocoileus virginianus*]) were reported in the study section of U.S. 64 compared with adjacent sections of this highway. Overall, I found few impacts on black bear spatial ecology resulting from the highway and that the 3 wildlife underpasses were effective.

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INTRODUCTION

The expanding transportation network in the United States poses a variety of ecological problems (Evink 2001). In particular, high-speed, divided highways present potential threats to wildlife by changing habitat quality and connectivity. The potential impacts of highways on wildlife can be categorized as direct mortality, direct habitat loss, habitat fragmentation, displacement and avoidance, and associated human development (Ruediger 1998). Large mammals and carnivores may be particularly affected because of relatively large home ranges and extensive movements (Woodruff and Ginsberg 2000). Although collisions may not be a significant source of mortality for all wildlife species (Forman and Alexander 1998), they were a common cause of mortality for several American black bear (*Ursus americanus*) populations in Florida (Wooding and Hardisky 1994, Land et al. 1994). Bears and other large carnivores use habitat at a landscape scale (Clark and van Manen 1993) and may be more vulnerable to such mortality than other wildlife species (Weaver et al. 1996) because of relatively low reproductive rates and large movement patterns. Roads can also fragment habitat, which limits access to resources and reduces genetic exchange (Wooding and Maddrey 1994, Proctor et al. 2002). However, large carnivores may adjust to changes in their environment through a variety of mechanisms at metapopulation, population, and individual levels (Weaver et al. 1996).

Transportation planners are increasingly incorporating design features to mitigate impacts of highways on wildlife. Though warning devices such as mirrors, reflectors, and lighting have been used to reduce animal vehicle collisions (Forman et al. 2003), the effectiveness of these devices is questionable (Pojar et al. 1975, Reed and Woodard 1981). Wildlife crossing structures, such as overpasses, underpasses, culverts, and tunnels have received increased attention (Cramer and Bissonnette 2005) and have been found effective (Falk et al. 1978, Ward 1982, Ludwig and Bremicker 1983, Feldhamer et al. 1986).

In 1992, the North Carolina Department of Transportation (NCDOT) initiated plans for upgrading U.S. Highway 64 from a 2-lane rural roadway to a 4-lane highway between the cities of Plymouth and Columbia. Important reasons for this upgrade were increasing traffic volumes from tourism traffic between Raleigh and the Outer Banks and interest in economic development of this region. NCDOT proposed to improve 45 km (28 miles) of U.S. Highway 64 to improve safety and increase speed limits to 70 mi/hr (113 km/hr). Included in these improvements was a new routing for U.S. Highway 64 in Washington County (Fig. 1). The area for the new 24.1-km route was composed of large forested tracts interspersed with agricultural areas, which provided important habitat for black bears (North Carolina Wildlife Resources Commission, unpublished report).

The potential effect of the new highway on bear movements and genetic exchange was a cause for concern because black bear populations are not continuous across North Carolina's coastal plain, (Jones et al. 1998, Jones and Pelton 2003). Although abundant on the study area, white-tailed deer were also considered in the planning process because of risks associated with deer-vehicle collisions (Conover et al. 1995). Consequently, NCWRC consulted with NCDOT to incorporate 3 wildlife underpasses in the highway design. Additionally, NCWRC requested that NCDOT determine the impact of the new highway on black bears and to assess the effectiveness of the 3 wildlife underpasses.

Large mammals such as the American black bear often act as “umbrella species”, because bear habitat and management can benefit an entire ecosystem (Simberloff 1999). Therefore, black bears represent an appropriate focus for research on the potential impacts of highways on ecological systems at a large scale. Thus, my study was part of a larger research project to determine the short-term impacts of U.S. Highway 64 on black bear ecology (van Manen et al. 2001). This study was designed to assess the potential impacts of the new U.S. Highway 64 route on black bears and other wildlife in Washington County. In this research project, data were collected on a control area to account for potential changes in the study region that were unrelated to the presence of the new highway, but could affect measures used to quantify treatment effects. The treatment area was centered on the new section of U.S. Highway 64, which was completed in September 2005. The control area was to the west of the treatment area and was similar in habitat, but no new highway construction occurred there. Data for the pre-construction phase were collected in 2000 and 2001 by Thompson (2003) and Kindall (2007). Data collection for the post-construction phase of the study occurred during 2006 and 2007. This before-after control-impact study design enabled me to isolate the effect of the highway by comparing the pre-construction with post-construction data (Fig. 2).

Objectives and Hypotheses

My study focused on changes in black bear spatial ecology resulting from the highway and the effectiveness of the wildlife underpasses to mitigate barrier effects. Specifically, the objectives of my study were to:

1. determine whether home-range characteristics, movements, activity levels, and habitat use changed after construction of the new section of U.S. Highway 64, controlling for effects unrelated to the presence of the highway, and
2. determine the effectiveness of the wildlife underpasses by examining wildlife use of the 3 underpasses and the frequency of wildlife vehicle collisions for sections of highway with and without underpasses.

My research hypotheses were:

1a. the home-range area would increase because avoidance of the new highway limited resources available to bears, the area-perimeter ratio of the home range would decrease, and the direction of the primary axis changes as home ranges would become more linear and oriented parallel with the new highway;

1b. movement rates would increase because greater foraging effort would be needed due to habitat degradation from the new highway;

1c. activity would increase during crepuscular time periods due to temporal avoidance of human activity;

1d. habitat use would change to maintain access to resources and increase the remoteness of habitat as a result of the disturbance resulting from the new highway;

2a. wildlife use of the 3 underpass locations would increase after construction of the new section of U.S. Highway 64; and

2b. the frequency of wildlife mortalities due to vehicle collisions would be lower for sections of U.S. highway 64 that contain wildlife underpasses compared with sections without wildlife underpasses.

STUDY AREA

The study area was composed of a treatment and a control area, both located in Washington County, North Carolina (Fig. 3). The treatment area was bordered by Newland Road to the south, the town of Roper to the west, NC highway 32 to the north and the town of Creswell to the east. After completion in September 2005, the new route of U.S. Highway 64 bisected the treatment. The control area was bordered by NC Highway 99 to the south, NC Highway 32 to the west, Plymouth and U.S. Highway 64 to the north, and state roads 1127 and 1125 to the east.

Treatment and control areas were similar in land use and in area (approximately 10,750 ha and 12,270 ha respectively). Land cover in both study areas was similar: percent forest on the control decreased from 62% (2000) forest to 57% (2006) whereas forest on the treatment area changed from 55% (2000) to 53% (2006). Land use was primarily limited to forest and agriculture. Common agricultural crops were wheat, soybeans, corn, cotton, tobacco, peanuts, potatoes, and turf grass. The majority of forested land was owned by Weyerhaeuser Company. Forest land typically had an overstory dominated by loblolly pine (*Pinus taeda*) but also included tulip poplar (*Liriodendron tulipifera*), red maple (*Acer rubrum*), and sweetgum (*Liquidambar styraciflua*). Hardwood forests were limited to small woodlots, farms, conservation easements, and natural drainages. Those forests had an overstory of various oak species (*Quercus* spp.), bald cypress (*Taxodium distichum*), sweetbay (*Magnolia virginiana*), red bay (*Persea borbonia*), and blackgum (*Nyssa sylvatica*). Planted pine and bottomland hardwood forests had similar understory species including river cane (*Arundinaria* *gigantea*), blackberry (*Rubus* spp.), grape (*Vitis rotundifolia*), greenbriar (*Smilax* spp.), and Japanese honeysuckle (*Lonicera japonica*).

Human development, aside from agriculture, was limited to a few homes scattered among private farms and the towns of Roper and Plymouth that bordered the treatment and control areas, respectively. Human population density in Washington County was relatively low with just over 13,500 people (U.S. Census Bureau 2000). An extensive network of unpaved roads and canals occurred throughout the study area. The unpaved roads typically were gated and remained locked, limiting use to forestry and farm equipment operators, hunters, and landowners.

Wildlife was abundant throughout the study sites. Mammal species included black bear, white-tailed deer, eastern gray squirrel (*Sciurus carolinensis*), eastern cottontail (*Sylvilagus floridanus*), gray fox (*Urocyon cinereoargenteus*), red fox (*Vulpes vulpes*), coyote (*Canis latrans*), red wolf (*Canis rufus*), river otter (*Lontra canadensis*), mink (*Mustela vison*), raccoon (*Procyon lotor*), muskrat (*Ondatra zibethica*), beaver (*Castor canadensis*), opossum (*Didelphis virginiana*), and bobcat (*Lynx rufus*). All of Washington County was considered black bear habitat by the NCWRC (Fig. 4). The study area was in close proximity to several areas where black bear hunting was not allowed, including the Roanoke River and Pocosin Lakes National Wildlife Refuges. White-tailed deer were extremely abundant and densities were among the highest in the state (NCWRC, unpublished data)

The section of U.S. Highway 64 within my study area was a 24.1-km, divided, 4-lane paved highway from Plymouth to Creswell. This section crossed a variety of man-made waterways, ranging from ditches to canals. The highway had a posted speed limit of 70 mi/hr (113 km/hr) for the majority of its length. The 3 wildlife underpasses were similar in design but differed in dimensions. The western underpass was approximately 47 m wide and included a small creek, approximately 2–3 m in width, which flooded the underpass on several occasions. The central underpass was approximately 33 m wide and spanned a 1-m wide ditch that contained water throughout the year. The eastern underpass was approximately 29 m wide and remained dry for the most of the year (Fig. 5). Based on research by Foster and Humphrey (1995), visibility to habitat beyond the road was an important factor for underpass use by wildlife. Therefore, vegetation within the 3 underpasses and near the entrances was kept in an early-successional stage, ranging from emergent herbaceous growth to patches of *Rubus* spp. and small woody vegetation. Vegetation was typically <0.5 m high to ensure visibility between the 2 entrances and to provide sufficient cover to prevent wildlife from being overly exposed while crossing (Fig. 6). All wildlife fences were 2.4-m high chain-link and extended a minimum of 800 m in both directions from the underpasses, parallel with the highway. Fencing was continuous underneath the underpasses and connected the sections that paralleled the highway. The entrances to each underpass were blocked by concrete bollards to restrict vehicle access. Multiple gates were incorporated in the wildlife fencing but remained closed and locked. Animal access to the highway via ditches spanned by the fencing was blocked with barbed wire.

METHODS

Study Design

Before-After Control-Impact experiments (Green 1979) can be used to determine whether treatment effects exist while controlling for unrelated changes (Stewart-Oaten et al. 1986). Previous research with similar study designs allowed for strong inference, despite the relatively low sample sizes common among wildlife studies (Janis and Clark 2002, Cain et al. 2008).

My research is specifically focused on behavioral changes of individual bears, which would be more apparent in the short term than population-level responses such as genetic changes due to natural selection caused by the new highway. Behavioral responses of wildlife to changes in their ecosystem may be a function of innate or learned behavior (Wilson 2000) resulting, for example, in avoidance or acclimation. I used existing literature and my own knowledge of black bear behavior and ecology to determine if the responses I observed were biologically significant. Defining biological significance is an inexact task, because biological significance may change with location, time, and a myriad of other factors. Therefore, I limited my focus to black bears in the southeastern U. S. and attempted to derive reasonable estimates from previous research focusing on changes in spatial ecology characteristics due to biologically different circumstances. Determining biological significance is an important aspect of biological research, rather than relying solely on statistical significance, particularly when the power of statistical analyses may be low (Hayes and Steidl 1997). I used biological significance estimates, in addition to the power and minimum detectable effect size of my analyses, to interpret my study findings (Cherry 1998).

Data collection

Livetrapping.—Field personnel conducted livetrapping of black bears from 9 June 2000 to 8 September 2000 during the pre-construction phase and 19 May–14 September 2006 and 20 April–2 July 2007 during the post-construction phase (Fig. 7). Trap sites were established based on bear sign, food sources, and successful trap locations from the first phase of this project. Traps consisted of Aldrich spring-activated foot snares (Aldrich Animal Trap Co., Clallam Bay, Washington, USA) using 3/16” (4.8-mm) diameter steel cable. All snares were modified with an automobile hood spring to reduce injuries (Johnson and Pelton 1980) and stops were placed on the snare to reduce the probability of capturing non-target species, such as red wolves and deer. Periodically, culvert traps were used to capture bears that routinely took bait from snare sites without being captured.

Field personnel immobilized all captured bears with an intra-muscular injection, administered with a pole syringe, of 4.4 mg ketamine hydrochloride (Bristol Laboratories, Syracuse, New York, USA) and 2.2 mg xylazine hydrochloride (Haver-Lockart, Inc., Shawnee, Kansas, USA) per kg of estimated body mass. Field personnel monitored body temperature, respiration, and pulse while the animals were processed. All bears received ear tags with unique ID numbers and corresponding tattoo numbers inside the upper lip and groin. A premolar tooth was extracted from each bear for cementum annuli aging (Willey 1974; Matson Laboratories, Milltown, Montana, USA). For each captured bear, body mass and standard body measurements were collected along with notes on general condition. Female bears weighing >50 kg and males >90 kg received radio collars (MOD-500; Telonics, Inc., Mesa, Arizona, USA) with leather spacers (Hellgren et al. 1988), which were designed to deteriorate and break away in 1 to 2 years. All radio collars contained VHF transmitters with mercury tip-switch sensors that changed the pulse rate depending on the position of the transmitter. Upon completion of data collection, a sublingual, intravenous injection of yohimbine hydrochloride (Spectrum Laboratory Products, New Brunswick, New Jersey, USA) was administered as an antagonist to xylazine hydrochloride at a dosage of 0.2 mg/kg of body mass. All bears were captured and handled according to animal handling protocols approved by the University of Tennessee Office of Laboratory Animal Care (IACUC #1020).

Radiotelemetry.—Field personnel conducted radiotelemetry from 15 July 2000 to June 29 2001 for the pre-construction phase and from 11 June 2006 to 28 November 2007 for the post-construction phase. Azimuths for triangulation were obtained using a 5-element Yagi antenna (Wildlife Materials, Inc., Carbondale, Illinois, USA) from established telemetry stations throughout the 2 study areas. A successful triangulation required 3 azimuths taken within 20 minutes, with pairs of azimuths separated by >30 degrees. Hourly telemetry locations were collected to document short-term movements during 8-hour sessions, either from approximately 0600 until 1400 or from 1400 until 2200. During those sessions, field personnel attempted to locate 2 to 3 bears once every hour. A telemetry cycle with all bears tracked during both shifts was completed approximately every 5 days. Bear movements decreased during the winter season so collection of telemetry data was limited to 1 location/day for each radio-collared bear.

Once bear activity increased in spring, the hourly radio-tracking schedule was resumed. Additional daily locations were obtained between scheduled hourly telemetry sessions for each bear. These daily locations were recorded throughout the day, and all daily locations for a specific bear were >12 hours apart. I entered all azimuths into a database and conducted triangulations using Program Locate III (Nams 2006).

I estimated telemetry error for field personnel based on procedures from the first study phase (Kindall 2004) by placing test collars throughout the areas used by radio-collared bears (Schmutz and White 1990). I compared the locations of test collars obtained from triangulation with those from a global positioning system (GPS) receiver (Garmin International Inc., Olathe, Kansas, USA) to determine the distribution of error distances for each observer (n = 30 observations/observer). I compared telemetry errors with a mixed-model analysis of variance (PROC MIXED; SAS 2005) for each of the 2 study phases to determine if telemetry error was consistent among observers.

Highway Surveys.—Field personnel surveyed a 24.1-km section of U.S. Highway 64 (Fig. 8) from 3 July 2006 to 31 July 2007 to record the locations of wildlife mortalities due to vehicle collisions. The surveys were conducted along the east- and west-bound lanes and started at the junction of highways U.S. Highway 64 and NC Highway 32 east of Plymouth and ended at the junction of U.S. Highway 64 and NC Highway 94, northwest of Creswell. Field personnel recorded species, date, and GPS coordinates of each mortality. All animal carcasses were removed from the highway to prevent double counting.

Underpass Surveys.—During the pre-construction phase of this study, field personnel monitored the 3 proposed underpass sites with actively-triggered infrared camera systems (Trailmaster, Inc., Lenexa, Kansas, USA) from 17 July 2000 to 18 March 2000. During the pre-construction study phase, researchers used 2 camera systems at each of the 3 proposed underpasses, with 1 camera system at the location of both entrances. From 3 July 2006 to 9 August 2007 field personnel conducted camera surveys twice each week for each of the 3 underpasses. Additionally, track surveys were conducted with a 2.5-m wide track pad of bare earth that spanned the width of each underpass, which was raked after each survey. Each set of tracks that crossed the track pad was recorded as a crossing event. I also set up active- and passively-triggered infrared camera systems (Trailmaster, Inc., Lenexa, Kansas, USA) in the same locations as the track pads to acquire photographic records of animals traveling through the underpass (Kucera and Barrett 1993). Eight camera systems were necessary to monitor the entire width of the 3 underpasses: 2 on the eastern underpass and 3 each on both the central and western underpasses. Of these 8 systems, 7 had active infrared sensors and 1 had a passively triggered infrared sensor. I used the passive system to monitor a relatively small span of the western underpass (≈8 m), whereas the active sensors were used to monitor larger distances.

Black Bear Response to New Highway Data Analysis

***Minimum Detectable Effect Size*.—**I performed a post-hoc power analysis to determine the minimum detectable effect size for statistical analysis that I conducted. These analyses were based on an $\alpha = 0.10$ to reduce the probability of Type II errors and a power of 0.80 (power is a function of type I error rate, sample size and effect size; Cherry 1998). I used this minimum detectable effect size to interpret the biological relevance of my results (Steidl et al. 1997).

***Home-range Characteristics*.—**I used the Animal Movement extension (Hooge and Eichenlaub 1997) to ArcView® GIS (ESRI, Redlands, California, USA) to estimate home ranges using the daily locations of radio-collared bears. I used 4 metrics to characterize home ranges: 95% home-range area, 50% home-range area, area-perimeter ratio of the 95% home range, and direction of the primary axis of the 95% home ranges. I chose the 95% area estimate to represent the home range used by each bear and to provide comparisons with other studies. I used the 50% home-range area estimate as a measure of core habitat within the home range and the area-perimeter ratio as a measure of home-range shape. A more elongated or complex-shaped home range has a higher ratio compared with a circular home range.

I used the fixed kernel method to provide an unbiased, non-parametric estimate of home-range size (Powell 2000), which is a better estimate than other home-range techniques (Worton 1989, 1995). This method uses kernels based on probability density functions, which are placed over observed locations. The number and proximity of other locations are then used to determine density estimates. As the concentration of locations increases so does the kernel. I used least-squares cross validation to determine an appropriate smoothing parameter to increase the accuracy of the estimates (Seaman and Powell 1996). I estimated a home range for each bear with $\geq$30 independent locations, which Seaman et al. (1999) recommended as the minimum sample size for the fixed kernel method. I excluded locations collected from January 15 through March 14 because the lack of movement during winter dormancy may bias estimates of home-range size. Except for the directionality of the primary axis, I compared home-range characteristics using a mixed model analysis of variance (PROC MIXED; SAS 2005). I used area (treatment, control), period (pre- and post-construction), and an area x period interaction as fixed terms and sex and age as covariates. For all mixed model analysis of variance tests, I tested that normality and equality of variance were met. In instances where these assumptions were not met, I used transformations to normalize data or used alternative analyses. Power analyses for these mixed model analysis of variance was conducted with SAS (A. Saxton, Univeristy of Tennessee; personal communication).

I determined the primary axis for each 95% home-range estimate based on a 0–180° scale. This measurement quantified the orientation of each home range and allowed statistical comparisons among the 4 different data sets. I made pair-wise comparisons using the Mardia-Watson-Wheeler test (Batschelet 1981) in program Oriana (version 2.00; Kovach Computing Services, Anglesey, Wales) for circular statistics to determine whether the tendency of the primary axes of home ranges to be oriented in an east-west direction increased after completion of the highway.

***Habitat Use*.—** Kindall (2004) and Kindall and van Manen (2007) identified 3 important habitat variables to predict black bear habitat use before U.S. Highway 64 was constructed: forest diversity (Simpson's diversity index; Simpson 1949), forest cohesion, and agriculture-forest edge density. These variables were chosen according to a black bear habitat-use model developed from pre-construction bear locations, tested against a separate subset of these locations, and found to effectively predict black bear habitat use on the study sites during the pre-construction phase (Kindall 2004). To calculate these habitat variables, I used the 2001 National Land Cover Data (Homer et al. 2007) and updated the land-cover data according to silvicultural management records. For both study phases, I classified stands as non-forest if they were harvested within the previous 5 years.

I used the land-cover data for the pre- and post-construction phases with FRAGSTATS 3.3 spatial pattern analysis software (McGarigal et al. 2002) to calculate the 3 habitat variables. I conducted the calculations at 2 different scales with a moving window analysis. I used an analysis window with a 270-m radius to encompass mean telemetry error and mean hourly movement rate and an analysis window with a radius of 1,290 m to represent the mean female home-range size. With this technique, a window is placed over each pixel in the GIS grid and all of the pixels within that window are used to calculate the value of the center pixel. I calculated the mean value of the 3 habitat variables at each scale and for each female bear home range. I excluded male bears from this analysis because of a low sample size (n = 4 for the post-construction phase).

I used dummy regression to determine whether changes in habitat use among female bears indicated a treatment effect (PROC GLM; SAS 2005). Dummy regression, or multi-source regression, compares the relationship between dependent and independent variables for several treatments or data groups and allowed me to test for interactions among the 4 data groups. I compared the data for the 4 experimental groups using each habitat variable as the dependent variable and home-range size as the independent variable. Home-range size varied widely among female bears (0.95–36.0 km^2). Because of the heterogeneous landscape of the study site, home-range size may have influenced the value of the 3 habitat variables. Therefore, I included home-range size in these analyses to determine if the relationship (i.e., the slope of each regression line) of each habitat variable with home-range size was different after construction of the highway, adjusting for any changes that occurred on the control area. I tested for differences in the value of each habitat variable among the 4 data groups using the mean home-range area of all females as the baseline for comparison (i.e., the habitat value at home-range size=4.9 km^2 for each regression line). Power analyses for these dummy regressions were conducted with the GLMPOWER procedure (SAS 2005).

Finally, I included the 3 habitat variables in 2 logistic regression models, one for each scale of analysis, to test if any bear habitat use changes that occurred from the pre- to the post-construction period on the treatment area were different from changes on the control area. Power analyses for logistic regression were conducted with the POWER procedure (SAS 2005).

***Spatial Avoidance of New Highway.*—**Before testing for spatial avoidance on the treatment area, I compared pre- and post-construction trap site distance to the new U.S. Highway 64 with a Kolmogorov-Smirnov test (PROC NPAR1WAY; SAS 1999) to determine if there was potential bias in sampling. To test if bears avoided the new highway, I performed a logistic regression with the 3 habitat variables (forest cohesion, forest diversity, agriculture-forest edge density) that Kindall (2004) used to develop a habitat model for the pre-construction phase. I used the 270-m scale for these variables to include telemetry error and hourly movement rate. To test for avoidance of the new highway, I compared the Akaike's Information Criterion (AIC) for the model with the 3 habitat variables with a logistic regression model that included the same habitat variables but also distance to the new U.S. Highway 64. If the model with the distance variable had a lower AIC value than the model without the distance variable (Burnham and Anderson 2002), the slope estimate for the distance variable was positive, and the 95%

confidence interval (CI) did not include 0, avoidance of the highway would be indicated. I conducted this analysis at the home-range and location scale. At the home-range scale, I used the 95% kernel home ranges for each bear with ≥30 independent locations (n = 49), and calculated the mean value for each of the 3 habitat variables and mean distance to the new route of U.S. Highway 64 within each 95% home-range estimate. For the second scale, I calculated values for the 3 habitat variables and distance to the new highway for all daily locations, excluding winter locations (January 15–March 14).

Movement Rates.—Because highways may affect resource availability and accessibility, I tested whether hourly and daily movement rates changed as a result of the new highway. I used hourly telemetry sessions with ≥3 successful locations during an 8-hour period to calculate hourly movement rates of radio-collared bears. Likewise, I calculated daily movement rates using the daily locations (excluding winter locations from 15 January to 14 March). I tested for the differences in daily or hourly movement rates between the pre- and post-treatment periods, after accounting for changes in the control area, with a mixed model analysis of variance (PROC MIXED; SAS 2005) using area (treatment, control), period (pre- and post-treatment), and an area x period interaction as fixed terms. Individual bears represented the sampling unit (blocking factor) and I used bear(period x area) as a random term. Sex, age, and season were covariates for both analyses. I defined 3 seasons according to food availability and crop production in the study area (Kindall 2004) and the approximate dates that I observed as the beginning (15 January) and end of winter dormancy (14 March): spring (15 March–14 June), summer (June 15–14 September), and fall (15 September–14 January). For the daily movement rate analysis, I used the number of days between each successive location as an additional covariate to account for differences in monitoring frequency between the two study phases.

Movement Linearity.—If bears use areas near the highway but do not cross the highway, movements may become more linear. I chose linearity as a measurement to determine whether bear movement patterns changed. I calculated the linearity for each successful hourly telemetry session (i.e., $\geq$3 successful locations during an 8-hour period) by dividing the distance from the first location in the session to the last location by the total distance the animal was recorded traveling during that session. I tested for the differences in linearity among the pre- and post-treatment periods, after accounting for changes in the control area, with a mixed model analysis of variance (PROC MIXED; SAS 2005). Area (treatment, control), period (pre- and post-treatment), and an area x period interaction were the fixed terms. Individual bears represented the sample unit (blocking factor) and bear(period x area) was a random term. I used sex, age, and season as covariates.

Activity.—I recorded and analyzed activity data to determine whether the highway had an effect on when bears were most active during the day. If the highway was a disturbance to bear movements and foraging, bears may become more crepuscular, as traffic is lower in the early morning or late evening compared with midday traffic. All radio collars contained tip sensors that varied the pulse rate according to the position of the transmitter. Transmitters were programmed to the following specifications: 30 beats per minute (bpm) if the transmitter did not move for 4 hrs, 50 bpm if the transmitter was horizontal or angled upward, and 70 bpm if the transmitter was angled downward (suggestive of feeding or other activities). I classified the observation as inactive when the pulse rate was 50 bpm and the signal strength was consistent. The 50 bpm-signal indicated that the collar was not angled downward and constant signal strength indicated a stationary position. I characterized a signal as active when pulse rate was 50 bpm coupled with varying signal strength, suggesting the bear's position relative to a stationary observer was changing. Using consistency of signal strength to determine activity has been used in many previous studies (Sunquist 1974, Hayes 1976), although, some research has found this to be inaccurate especially in mountains (Lindzey and Meslow 1977). When the collar was angled downward, triggering the tip switch, the pulse frequency changed to 70 bpm. I classified that pulse rate as highly active, regardless of the consistency of signal strength. Similar tip switch criteria have been found to be effective for judging black bear activity by other researchers (Garshelis et al. 1982).

The number of active and highly active records was combined to calculate percent activity (number of active and highly active records/total number of records) of each bear for morning, midday, and evening time periods. I defined those time periods as 04:00–10:00 EST for morning, 10:00–16:00 for midday, and 16:00–22:00 for evening. Data were analyzed using a mixed model analysis of variance (PROC MIXED; SAS 2005) using area (treatment, control), period (pre- and post-treatment), and an area x period interaction as fixed terms to analyze the differences in percent activity between the pre- and post-treatment periods after compensating for changes on the control area. Time periods were separately analyzed with season and sex included as a covariates. I excluded all combinations of bear, season, and time groups with <20 activity records from the dataset.

Underpasses Effectiveness Data Analysis

Highway Surveys.—To evaluate the efficacy of the underpasses in preventing vehicle-wildlife collisions, I compared the frequency of wildlife mortalities among sections of the highway with underpasses and wildlife fencing (protected sections) with the remaining, unprotected sections within the treatment area. For statistical comparisons, I excluded survey records west of the town of Roper to avoid confounding effects due to a large, unfenced bridge that spanned Kendrick Creek, which may have performed a similar ecological function as an underpass. I assigned the remaining survey records to 1 of the 7 sections of the survey route. The 4 sections beyond the wildlife fencing were considered unprotected and the 3 fenced sections near the underpasses were considered protected (Fig. 8). I also measured percent forest cover within a 100-m buffer from the highway to account for variation in land cover among the sections. I tested for differences in wildlife mortalities among protected and unprotected sections of the highway using a generalized linear mixed model (PROC GLIMMIX; SAS 2006), using the length of each section and percent forest cover as covariates. These analyses included the full dataset and a dataset of only medium and large mammals, which were typically too large to fit through the chain links of the wildlife fencing.

I also examined NCDOT and NCWRC data to compare the frequency of vehicle-wildlife collisions from nearby sections of U.S. Highway 64 (Fig. 9) with the section containing the 3 underpasses. I used these additional data to examine whether the frequency of animal-vehicle collisions was different at the scale of the entire section of U.S. Highway 64 where the 3 underpasses were placed compared with other sections where no underpasses were present. I incorporated the length and average annual daily traffic volume to standardize the collision frequencies. Because the majority of animal-vehicle collision reports involved white-tailed deer (A. Braam, North Carolina Department of Transportation, personal communication), I calculated the mean agriculture-forest edge density within 1 km of the highway as an index of deer habitat quality and used that measure to further standardize the collision frequencies.

***Highway Crossings*.—**In addition to the documented black bear crossings through the underpasses, I determined highway crossings by examining all telemetry locations of bears on the treatment area whose 95% home ranges overlapped a portion of the U.S. Highway 64 route. I used the movements between subsequent locations to calculate the minimum number of crossings for each black bear. For the pre-treatment period, I used bears with home ranges overlapping the projected highway route.

RESULTS

Data collection

***Livetrapping*.—**During the pre-construction phase of the study, field personnel captured 23 individual bears (11 females, 12 males) on the treatment area, of which 16 received radio collars (10 females, 6 males). Thirty-two bears (24 females, 8 males) were captured on the control area, of which 16 females and 3 males were radiocollared. I captured 20 individuals on the treatment area and deployed 13 radio collars (11 females, 2 males). Thirty individual bears were captured on the control area and 14 radio collars were deployed; 5 bears removed their collars soon after being released. Of the 9 collars that were successfully deployed, 3 were placed on male and 6 were placed on female bears.

***Radiotelemetry*.—**Field personnel collected 2,572 hourly locations and 2,513 daily locations during the pre-construction phase of the study. The post-construction dataset contained 3,203 hourly locations and 2,485 daily locations (Fig. 10). Kindall (2004) reported no differences in telemetry error among observers ($F_{6, 191} = 1.26$, $P = 0.272$) during the pre-construction phase. Similarly, I found no differences in telemetry error among the post-construction observers ($F_{6, 187} = 1.35$, $P = 0.235$). Mean telemetry error during the pre- and post-construction phases was 253 m and 268 m, respectively.

Black Bear Responses to Highway

***Home-Range Characteristics.*—**The home-range data required a log-transformation for all 3 variables to fit a normal distribution. Sex was an important covariate for the analyses of the 50% home-range area, 95% home-range area, and the area-perimeter ratio of the 95% home-range estimates ($F_{1,44} = 5.24$, $P = 0.027$; $F_{1,44} = 33.16$, $P < 0.001$; and $F_{1,44} = 19.75$, $P < 0.001$ respectively). Because of low sample sizes for male bears, I only conducted these analyses for female home ranges. Age was not a significant covariate for any of the 3 measures ($F_{1, 33} = 0.03$, $P = 0.867$; $F_{1, 33} = 0.01$, $P = 0.917$; and $F_{1, 33} = 0.96$, $P = 0.334$ respectively).

I detected no difference in the core home-range area of female bears between the control and treatment areas ($F_{1, 36} = 0.05$, $P = 0.826$), although there was an increase from the pre- to post-construction phase ($F_{1, 36} = 5.30$, $P = 0.027$). However, the change in core home-range areas of females on the treatment area did not differ from that in the control area (i.e. no interaction effect; $F_{1, 36} = 0.36$, $P = 0.551$) indicating no detectable treatment effect (Table 1). The minimum detectable effect size for this analysis was a 183% change on the treatment area, given no change on the control area between the 2 study phases.

The 95% female home ranges did not differ in size between the control and treatment areas ($F_{1, 36} = 0.57$, $P = 0.456$), but increased in size from the pre- to post-construction phase ($F_{1, 36} = 6.67$, $P = 0.014$). However, no change in the treatment was detected ($F_{1, 36} = 1.91$, $P = 0.176$) after adjusting for changes on the control area (Table 2; Fig. 11). The minimum detectable effect size for this analysis was a 94% change on the treatment area, given no change on the control area.

The area-perimeter ratio was not different between the control and treatment areas ($F_{1, 36} = 0.10$, $P = 0.749$), but ratios increased from the pre- to the post-construction phase ($F_{1, 36} = 6.18$, $P = 0.018$). No change in the treatment was detected ($F_{1, 36} = 0.59$, $P = 0.446$) after adjusting for changes on the control area (Table 3). The minimum detectable effect size for this analysis was a 64% change on the treatment area, given no change on the control area.

The Mardia-Watson-Wheeler test did not demonstrate a difference between the direction of the primary axes of female home ranges on the treatment area for the 2 study phases ($W = 1.231$, $P = 0.54$). The sample size for this test was too low for the control area. The mean direction of the primary home-range axes on the treatment area was 91.2° (53°–130°, 95% CI) and 90.0° (64°–116°, 95% CI) for the pre- and post-construction phases, respectively. The mean direction of those axes were 77.6° (51°–105°, 95% CI) and 115.9° (84°–147°, 95% CI), respectively, for home ranges on the control area. I did not conduct a power analyses for this test.

Habitat Use.—At the 270-m scale, the relationship of agriculture-forest edge density with home-range size for bears on the treatment area was not different before and after construction of U.S. Highway 64, after adjusting for differences on the control area ($F_{1,32} = 1.54$, $P = 0.223$; power = 29%). Similarly, I did not observe a difference in agriculture-forest edge density when comparing the 2 data groups at the mean female home-range size of 4.91 km^2 ($F_{1, 32} = 0.07$, $P = 0.786$; power = 11%).

I found an interaction for the relationship of agriculture-forest edge density with home-range size at the 1,290-m scale ($F_{1, 32} = 4.08$, $P = 0.052$; power = 38%). The slope parameters indicated that agriculture-forest edge density, relative to home-range size, increased on the treatment area (pre: -4.83; post: 0.23) and decreased on the control area (pre: -0.58: post: -1.22). However, at the mean female home-range size of 4.91 km^2, no interaction effect was detected ($F_{1, 32} = 0.53$, $P = 0.472$; power = 14%; Table 4; Fig. 12).

At the 270-m scale, I detected no difference in the relationship of forest cohesion to home-range size for the pre- and post-construction phases on the treatment area, after adjusting for control area differences ($F_{1, 32} = 0.01$, $P = 0.922$; power = 10%). I observed no difference in forest cohesion when compared at 4.91 km^2 ($F_{1, 32} = 0.54$, $P = 0.468$; power = 10%). Likewise, the 1,290-m scale did not show a relationship of forest cohesion with home-range size nor for the mean female home-range size comparison ($F_{1, 32} = 0.72$, $P = 0.404$, power = 10%; and $F_{1, 32} = 1.86$, $P = 0.182$, power = 10%, respectively; Table 5; Fig. 13).

At the 270-m scale, I did not detect a difference for the relationship of forest diversity to home-range size ($F_{1, 32} = 1.82$, $P = 0.187$; power =20%; Table 6). However, a decrease in forest diversity occurred at the mean home-range size for bears on the treatment area from the pre- to the post-construction phase (0.51 to 0.35), after adjusting for changes on the control area (0.32 to 0.41; $F_{1,32} = 6.09$, $P = 0.019$; power = 40%; Table 7). The 1,290-m scale showed a marginal difference in the relationship of forest diversity to home-range size for the pre- and post-construction phases on the treatment area that was not apparent on the control area ($F_{1, 32} = 2.75$, $P = 0.107$; power = 0.16). However, I observed no difference in forest diversity at the mean female home-range size for the pre- and post-construction phases on the treatment area ($F_{1, 32} = 1.68$, $P = 0.204$; power = 14%; Fig. 14).

Based on the logistic regression model of all 3 habitat variables, only forest cohesion showed a change in use between the 2 sampling periods at both the 270-m and 1,290-m scales ($P = 0.017$ and $P = 0.016$; respectively). However, that change was not different from the change I observed on the control area so I did not consider this to be a treatment effect. Power to determine a significant treatment effect was greater than 0.54 for all habitat variables at the 270-m scale and greater than 0.92 for all habitat variables at the 1290-m scale.

***Spatial Avoidance of New Highway.*—**The Kolmogorov-Smirnov test indicated that trap-site distance from the new highway route was not different between pre- and post-construction periods on the treatment area ($P = 0.660$). At the home-range scale, male home ranges were excluded from analysis because of low sample sizes. AIC values did not improve with the addition of distance to the new highway to the model (AIC = 27.3 without the distance term and AIC = 28.9 with the distance term). Therefore, this variable was not useful in predicting black bear home ranges. However, at the location scale, distance to the highway did improve the AIC value substantially (ΔAIC = 46.3). Despite this improvement and significance of the distance term ($P < 0.001$), this analysis does not indicate black bear avoidance of the new U.S. Highway 64. The parameter estimate for the distance variable was -0.00025 (-0.00032 – -0.00018, 95% CI), suggesting that bear locations were more likely to be closer to the highway during the post-construction period.

***Movement Rates.*—**I used a log transformation to approximate a normal distribution for the hourly movement data. Sex and age were not significant covariates and were removed from the model ($F_{1,\,56.2} = 1.08$, $P = 0.302$; and $F_{1,\,38.4} = 0.34$, $P = 0.564$, respectively), but there was a season effect ($F_{2,\,4112} = 33.43$, $P < 0.001$) so this covariate remained in the model. Hourly movements did not change on the treatment area between the 2 study phases, after accounting for changes on the control area ($F_{1,\,47.3}$

= 0.20, P = 0.658; Table 8). The minimum detectable effect size for this analysis was a 7% change on the treatment area, given no change on the control area.

I used a square-root transformation to normalize daily movement rates. The daily movement rate differed by sex, season, and the number of days between locations ($F_{1, 58.6}$ = 22.55, $P < 0.001$; $F_{2, 3612}$ = 24.49, $P < 0.001$; and $F_{1, 3616}$ = 330.92, $P < 0.001$, respectively) but not by age ($F_{1, 44.4}$ = 0.70, P = 0.409). Because of low sample sizes for males, I conducted seasonal analyses for female bears only, using the number of days between successive locations and season as covariates. Daily movement rates of females showed no treatment effect ($F_{1, 49}$ = 0.25, P = 0.620; Table 9). The minimum detectable effect size for this analysis was a 31% change on the treatment area, given no change in movement rates on the control area.

Movement Linearity.—Age and sex were not significant covariates for this analysis ($F_{1, 38.6}$ = 0.28, P = 0.602 and $F_{1, 71.3}$ = 0.64, P = 0.427, respectively). But season was significant ($F_{2, 1043}$ = 5.86, P =0.003) and I included it in the model. The mixed model analysis of variance indicated that the linearity of movements of bears on the treatment area did not change between the 2 sampling periods, after accounting for changes on the control area ($F_{1, 47.3}$ = 1.57, P = 0.217). The minimum detectable effect size for this analysis was a 23% change on the treatment area, assuming no changes occurred on the control.

***Activity*.—**Analysis of variance showed that season was a significant covariate ($F_{2, 342}$ = 10.30, $P < 0.001$) but not sex ($F_{1, 342}$ = 0.34, P =0.560). Percent activity for the morning period changed more on the treatment area compared with the control area ($F_{1, 100}$ = 14.18, P = 0.0003); the minimum detectable effect size was a 43% change on the treatment area, assuming no changes occurred on the control. Morning activity increased from 45% to 68% activity on the treatment area, compared with a slight decrease on the control area from 63.7% to 59.8% (Table 10). I detected no interaction effect for the midday (minimum detectable effect size was a 42% change; $F_{1, 123} = 0.44$, $P = 0.507$) or evening periods ($F_{1, 108} = 0.89$, $P = 0.348$; minimum detectable effect size was a 38% change).

Effectiveness of Highway Underpasses

Highway Surveys.—Within the study section of U.S. Highway 64, field personnel recorded 196 animal mortalities from vehicle collisions during July 2006–July 2007 (Table 11). The frequency of mortalities did not differ between protected and unprotected sections of the new highway ($F_{1, 3} = 0.98$, $P = 0.395$), after accounting for the length and percent forest of each section. I obtained similar results considering medium and large mammal mortalities only ($F_{1, 3} = 1.51$, $P = 0.307$). The minimum detectable effect sizes for these analyses were a 66% change in all mortalities and a 68% change in medium and large mammal mortalities.

Comparison of NCDOT animal-vehicle collision reports from 2 sections of U.S. Highway 64 west of the study section (Tarboro to Williamston and Williamston to Plymouth) and one section to the east (Creswell to Columbia), suggested fewer animal-vehicle collisions for the study section from Plymouth to Creswell, after accounting for differences in agriculture-forest edge density, section length, and traffic associated with each section (Table 12). The section furthest from the study section (Tarboro to Williamston), had a 37% greater frequency of reported animal-vehicle collisions. However, the 2 sections of U.S. Highway 64 adjacent to the study section had even greater frequencies of such collisions: 105% greater for the Williamston–Plymouth section and 165% greater for the Creswell–Columbia section.

***Underpass Surveys.*—**The remote cameras recorded 243 photographs of wildlife at the proposed underpass sites during the pre-construction phase and 2,053 photographs of wildlife using the underpasses during the post-construction phase of the study (Table 13). Track-count surveys in the underpasses indicated of 3,622 animal crossings representing 20 different species (Table 14). Of those crossings, 3,183 (87.9%) were from white-tailed deer; the ratio of observed deer mortalities to deer crossings in the 3 underpasses was 7:3,183 (0.2%). Based on track counts and underpass camera surveys between July 2006 and July 2007, black bears crossed U.S. Highway 64 using the wildlife underpasses on at least 17 occasions. Judging by photographs and date these represent a minimum of 10 individuals. The ratio of mortalities to crossings was 2:17 (12%), indicating the underpasses and fencing were less effective for black bears compared with white-tailed deer.

***Highway Crossings*.—**Based on telemetry data, 5 pre-construction and 8 post-construction bears had home ranges that overlapped the proposed and the new route of U.S. Highway 64, respectively (Table 15). All 5 bears during the pre-construction phase were confirmed crossing the proposed highway route, totaling 16 crossing events. After the highway was completed, the telemetry data indicated that 4 of the 8 bears crossed the highway (n = 36 crossing events). All of those 4 bears were females, 2 were killed by vehicles on U.S. Highway 64 (1 November 2007 and 18 August 2008). Both mortalities occurred about 3.5 km west of the western underpass after highway monitoring ended. The fate of the 2 other bears is unknown. Field personnel recorded one of these females crossing the highway in the immediate vicinity of the western underpass when telemetry monitoring was still being conducted, but when underpass monitoring had already ceased. The remaining female (# 64) was still active in the area at the end of telemetry data collection.

In addition to these females that I monitored, 3 other mortalities of bears captured during post-construction research were documented on U.S. Highway 64 within the treatment area. One was a yearling male killed on 26 May 2007. The other was bear # 42, a 90-kg male. This male was captured on the control area as a yearling in August 2006 and killed by a vehicle on 5 May 2007. This mortality occurred within sight (<200m) of the eastern underpass; it appears that this bear crossed from the north side of the highway by crawling under the wildlife fence and was struck by a vehicle in the east-bound lane. The third was bear # 101, a 125 kg male which was captured in the treatment area on 1 June 2007 and killed on 11/19/2008. This bear was struck by a vehicle at the eastern end of the western underpass's wildlife fence.

DISCUSSION

Black Bear Responses to New Highway

Overall, my findings did not support a change in the spatial ecology of black bears as a result of the construction of U.S. Highway 64. Except for a few individual tests, I did not detect changes on the treatment area that were different from observed changes on the control area. However, the power of my analyses and what is biologically significant should be considered in the interpretation of my results.

I estimated a biologically significant change in home-range characteristics based on differences in 95% home-range size between solitary adult females and adult females with cubs (Benson and Chamberlain 2007); as well as differences between this same measure during mast-crop failure and normal-mast conditions for a black bear population (Kasbohm et al. 1998). Research comparing two biologically different situations like these suggests that a 50% change in home-range characteristics, like size, could indicate biological significance. Given the large minimum detectable effect sizes of my home-range characteristic analyses, it is possible that the highway had a biologically significant effect on black bear home-range characteristics that I did not detect.

Home-range characteristics changed from the first to second study phase, although these changes occurred on both study areas. Previous research has attributed home-range characteristics, particularly size, to a variety of factors, most importantly food availability and reproductive status (Moyer et al. 2007; Pelton 1982; Rogers 1977, 1987). Black bear home ranges can be small in highly productive habitats (Smith and Pelton 1990, Oli et al. 2002, Koehler and Pierce 2003) and this was the case on both study areas during the pre-construction phase (Kindall 2004). However, home-range size has also been shown to vary inversely with competitor density (Hixon 1980). More importantly, home-range size of solitary carnivores tends to be inversely related to population density, particularly among females (Sandell 1989). Findings based on genetic sampling indicate that population density was high during the pre-construction phase (Thompson 2003) but decreased substantially on both study areas after the highway was completed (J. Nicholson, University of Tennessee, personal communication). Because habitat was relatively consistent for both study phases, the change in home-range size likely was a function of the change in bear density. Preliminary population analyses show changes in abundance have occurred for both areas but it is unclear at this point whether there was a treatment effect (Nicholson, personal communication). The increase in home-range size may have caused other, indirect changes as well. For example, the area-perimeter ratio of home ranges increased on both study areas, which simply may have been a function of larger home ranges. However, other measures that were not related to home-range size also did not show a treatment effect, such as the orientation of the primary axes of home ranges.

My results did not indicate that bears avoided the new highway; in contrast, I found a weak attraction to roads as evidenced by the logistic regression analysis. Many studies have been conducted on black bear avoidance of roads and different responses have been reported, in part because of differences in road and habitat types being studied (Beringer et al. 1990, Brody and Pelton 1989). Chruszcz et al. (2003) reported that distances of grizzly bears (*Ursus arctos*) to roads with high traffic volumes in Banff National Park, Alberta, Canada were not different from random. Furthermore, they found bears were closer to roads with low traffic volumes than expected by chance. In a study on Marine Corps Base Camp Lejeune in North Carolina, Brandenburg (1996) found that black bear avoidance was most obvious within 100 m of primary roads (83%, 34 of 41 seasonal tests comparing observed and expected crossing patterns) but this response decreased as distance to roads increased (i.e., at distances 100–200 m from primary roads, 16 of 31 [52%] seasonal tests showed an avoidance response). Although studies report differing results concerning avoidance of roads, black bears generally seem reluctant to cross divided, 4-lane highways or roads with high traffic volumes similar to U.S. Highway 64 (Brody and Pelton 1989, Beringer et al. 1990).

Although I detected a treatment effect for forest diversity within bear home ranges at the 270-m analysis scale, the analysis explicitly accounted for home-range size, so I speculate that increased use of areas with lower forest diversity was not a function of changes in home ranges. Greater use of areas with lower forest diversity on the treatment area likely reflects use of commercial pine plantations. Regardless of decreased use of forest diversity, habitat use of black bears seemed to show little effect of the new highway. Research in Alberta, Canada indicated that grizzly bears, particularly males, will use areas adjacent to paved roads when high-quality habitat is available, and human activity was lowest (Gibeau et al. 2002). Research on grizzly bears in Montana indicated that bears avoid roads with >10 vehicles/day, but show no or positive selection for low-traffic roads (<10 vehicles/day) where important habitat resources occur (Mace et al. 1996). These studies indicate that the benefits of accessing good habitat resources may outweigh the risk of using areas near roads. In my study, bears did not avoid the new highway or alter habitat use, and home ranges were often directly adjacent to U.S.

Highway 64. Although, this may be an indication that home-range placement was affected by the highway. I speculate that most bears limited their activities to one side of the highway and adjacent habitat instead of abandoning a productive area after the road was constructed

The strongest evidence for a treatment effect was that activity of black bears increased during the morning period (0400–1000 hrs). Again, I estimated a biologically significant change in activity based on differences between solitary adult females and adult females with cubs. Previous bear research in the Great Smoky Mountains National Park suggests that 20% changes in activity can be found between adult females with and without cubs (Garshelis and Pelton 1980). The effect I detected for morning activity is likely biologically significant, given a minimum detectable change of 43%. Furthermore, a biologically significant effect could have been present for midday and evening periods as well, given that the minimum detectable effect was relatively high (40%).

Black bear activity has been described as diurnal and crepuscular (Amstrup and Beecham 1976, Garshelis and Pelton 1980, Masters 2002), and I originally hypothesized that bear activity would become more active in morning and evening when human activity was low. The increase in morning activity is likely a response to disturbance associated with the highway. Weaver et al. (1996) included behavioral plasticity as 1 of 3 mechanisms used by large carnivores for coping with environmental disturbances. The traffic on U.S. Highway 64 increased throughout the day until 1500 as commercial and vacation traffic used this route to the Outer Banks and traffic levels were highest from 1000-1700. In response to this, bears near the highway may have increased their activity during periods of lower, morning traffic. Although the existence of the highway represents a change in habitat and habitat connectivity, the traffic associated with the highway may represent an important disturbance factor for wildlife. Studies focusing on wildlife underpasses and wildlife behavior near roads show that human activity can be an important characteristic influencing whether or not animals use wildlife crossing structures (Clevenger and Waltho 2000). Although I did not detect a treatment effect for midday or evening activity, a change in morning activity would not necessarily require a change during these periods. Furthermore, if bear activity was slow to increase as traffic decreased at the end of the day, my evening monitoring period (1600-2200) may have been too early to detect a highway effect. Although Brandenburg (1996) focused on road crossings instead of general activity of black bears on Marine Corps Base Camp Lejeune, he found that the majority of crossings of primary roads occurred when traffic was low from sunset to midmorning (177 of 179 crossings). A similar increase in movement during late-night hours may have occurred in my study area, although my methods do not allow for comparisons of these times.

The experimental design for the study was chosen to allow the identification of impacts from the highway by using pre- and post-construction periods, but environmental or population changes that were different for the 2 study areas could have affected study inference. Bear harvests on timber company lands in 2000 were limited for each hunting club and methods were mainly based on still hunting. In 2007, methods included hunting with dogs and harvest was limited by state regulations, which were more liberal than previous hunting club quotas. Anecdotal and incomplete harvest records show similar harvest trends for both areas for the pre- to the post-construction phase. Therefore, my conclusions should not have been affected by a change in hunting pressure. The treatment area had a farm located southwest of the eastern underpass that was planted in row crops (e.g., corn, soybeans) during the first study phase, but was converted to turf grass by the second phase. Although this change would decrease the amount of forage available on the treatment area, it did not appear to be significant because agricultural crops remained abundant throughout the study area. One difference that should be noted is that researchers during the first phase were able to capture bears along a corridor of privately owned forests on the eastern portion of the treatment area, which was not accessible during the second study phase. However, only 1 home range from the first phase was located in this area; therefore, the effect of those sampling differences was probably inconsequential.

Although my study included 57 radio-collared animals, females were the focus for many of my analyses. Home-ranges of males were larger and dispersal in black bears is primarily restricted to males (Pelton 1982, Elowe and Dodge 1989, Swartz and Franzmann 1992). Consequentially, male movements may be more likely to be disrupted given their greater spatial scale and the demographic consequences of this highway may have been more detectable had the focus been upon males.

Given the lack of a consistent treatment effect for the majority of factors I examined, I cannot reject the overall null hypothesis that the highway had no effect on the spatial ecology of black bears. However, there did appear to be a behavioral shift because of the increase in morning activity on the treatment area. I note that the data for my study were collected on bears that were in the treatment area after highway construction but no determination could be made of how bears responded in the interim between the 2 study phases. None of the live-captured or DNA-sampled bears from the second phase were recaptures from the first study phase. Additionally, site occupancy on the treatment area was reduced substantially and more so than on the control area (F. T. van Manen, U.S. Geological Survey, personal communication), suggesting that bears moved out of the treatment area. It is important to recognize that my results only apply to the impact of the highway on the spatial ecology of those black bears that remained in the treatment area. Additionally, given the few males, low sample sizes, and low power associated with much of my analysis, there is potential for highway effects to exist that are not shown in my results. Therefore, my statistically significant findings should correctly identify actual changes in bear ecology, but insignificant results do not necessarily indicate that the highway had no effect on black bears.

Effectiveness of Highway Underpasses

I did not detect a difference in wildlife mortalities between protected and unprotected sections of the highway. However, taking into consideration that these underpass sites were chosen because of the high frequency of animal crossings in these locations, before highway construction (Scheick and Jones 1999), these observations should not be interpreted to suggest that the underpasses and fencing were not effective. Clearly, areas near the underpass sites provided better wildlife habitat conditions. Additionally, scale also is an important consideration. For example, Clevenger et al. (2001) used a large scale to determine the effects of wildlife fencing on wildlife-vehicle collisions. Comparisons of U.S. Highway 64 animal collision reports from my study section (Plymouth to Creswell) with nearby sections of the highway indicated substantially fewer wildlife-vehicle collisions within the study section. This difference was particularly evident based on comparisons with the sections immediately west

(Williamston to Plymouth) and east (Creswell to Columbia) of U.S. Highway 64. Although these counts include all reported wildlife collisions, the vast majority represent vehicle collisions with white-tailed deer (A. Braam, North Carolina Department of Transportation; personal communication).

The effectiveness of the underpasses to reduce the barrier effect of the highway is substantiated by the remote camera and track surveys. Although the number of remote cameras and area covered was not exactly the same for the 2 sampling phases, the large number of crossings I documented based on camera and track surveys shows a high volume of wildlife crossings within the underpasses. The data on white-tailed deer provide the best evidence of the effectiveness of the underpasses in preventing deer-vehicle collisions. I speculate that the volume of deer traffic in the underpasses may be attributable to the ease with which deer movements can be guided by fencing. In several instances, mortalities occurred as a result of deer attempting to cross the highway where the fencing ended (4 of 7 deer mortalities were within 280 m of the fencing edge). Clevenger et al. (2001) observed similar mortality events at fencing edges and suggested that deer typically walk along the fence until it ends and then cross the highway.

Medium to small mammals, particularly bobcat, coyote, fox, opossum, and raccoon may have experienced the lowest benefit of the underpass design. Many of these species are capable of climbing the fence or finding a way through the fencing. Land and Lotz (1996) found that otter, fox, raccoon, and bobcat used smaller, box-culvert structures in greater proportion than larger mammals such as deer and puma (*Puma concolor*), which are more likely to cross at larger underpasses. Research by Clevenger and Waltho (2005) indicated that a variety of attributes contribute to wildlife use of a crossing structure and, more importantly, that the characteristics are different for each species. They suggested that underpasses that were high, wide, and short in length influenced use by grizzly bears, wolves (*Canis lupus*), elk, and deer, whereas black bears and pumas used less open structures.

Although the accounts of highway crossings and underpass usage by black bears are relatively few and anecdotal, they provide important insights into the barrier effect of the highway and the effectiveness of the underpasses. The highway may represent a barrier for some bears. Moreover, the bears that do attempt to cross the highway may have lower survival. Over the course of 1 year of monitoring, I confirmed black bears using the underpasses on 17 occasions, likely representing at least 10 different bears. I conclude that although the highway seems to be a barrier for black bears, infrequent use of the underpasses and a limited number of crossings indicate that it is not impermeable. Previous research from the pre-construction phase identified the eastern and western underpasses as potentially important habitat linkages for bears (Kindall and van Manen 2007). The western underpass provides a connection from Big Swamp (Bull Neck) to the control area and on to the Roanoke River, whereas the eastern underpass connects Big Swamp with habitat southeast of the treatment area and Pocosin Lakes National Wildlife Refuge (Fig. 15). Consequently, even if use of the underpasses is relatively infrequent, that permeability may be crucial to maintain population and genetic exchange on a regional scale (i.e., Albemarle-Pamlico peninsula).

The second study phase started <1 year after the highway was opened for traffic. Although some species quickly adapt to the presence of the underpasses, consistent use by black bears may require more time. Researchers monitoring wildlife underpasses in

Collier County, Florida suggested that, for some mammals like puma, use of underpass structures may be a learned behavior (Foster and Humphrey 1995, Land and Lotz 1996). As female bears using the underpasses on the treatment area raise cubs and other bears learn the underpass locations, bear use of these structures may increase over time. Clearly, future monitoring would provide additional, valuable insights regarding underpass effectiveness.

MANAGEMENT AND RESEARCH IMPLICATIONS

Other than a shift in activity, black bears in my study did not show biologically important spatial responses to the presence of U.S. Highway 64. However, I note that the demographic and genetic findings of parallel studies are focused on changes that may have occurred at the population level, rather than the individual level and discrete time periods that I examined.

The number of bears that used the underpasses was sufficient to suggest that the highway was at least semi-permeable. Thus, the underpasses represent an important tool for transportation planners to maintain permeability of the highway, which, in turn, would be important to maintain demographic and genetic exchange among black bear populations. However, black bears did not make exclusive use of the underpasses. Therefore, transportation planners should consider other measures to improve underpass effectiveness.

Potential improvements for wildlife crossing structures that I noted during my study are similar to those suggested by other researchers (e.g., Clevenger et al. 2001, Ruediger et al. 2005). Barbed-wire outriggers at the top of fencing and burying the fencing to prevent animals from accessing the roadway may improve underpass effectiveness, specifically for animals like bears with the ability to climb or push underneath most chain-link fencing. Constructing fences in a more funnel-shape array and continuous fencing between underpasses would also decrease the tendency of deer to walk along the fence away from the underpass and cross the road once the fencing ends.

Planning and implementing wildlife underpasses in transportation infrastructure is expensive. However, vehicle collisions with wildlife, particularly deer, result in significant property damage and human injury each year (Conover et al. 1995, Romin and Bissonette 1996). From 2005 through 2007, Washington County reported 297 wildlife-vehicle collisions. These accidents included $638,460 in damages, 15 human injuries, and 2 fatalities. Because the cost of the 3 underpasses was <2% of the overall highway project cost (Jones et al., in press), the cost-benefit ratio seems favorable.

Future research is needed to determine the long-term effects of this highway and the effectiveness of the underpasses. The long-term impact of U.S. Highway 64 will be of particular interest if and when development associated with the highway begins. The data collected for this study would provide a crucial benchmark for longer-term studies. The study site could also provide additional research opportunities regarding underpass and fencing design. Because long-term collision data already exist, changes and improvements in underpass design and maintenance and fence design could be compared to optimize the effectiveness of highway passageways.

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TABLES

Table 1. Mean 50% home-range area of female black bears for pre-construction (2000–2001) and post-construction (2006–2007) phases of U.S. Highway 64 on control and treatment areas, Washington County, North Carolina.

Period[a]	**Area**	***n***	$\bar{x}$ **(km²)**	**95% confidence interval**
Pre-construction	Treatment	9	0.41	0–1.40
Pre-construction	Control	14	0.41	0–1.20
Post-construction	Treatment	11	1.40	0.51–2.30
Post-construction	Control	6	1.19	0–2.40

[a] No period x area effect; $F_{1, 36} = 0.36$, $P = 0.551$

Table 2. Mean 95% home-range area of female black bears for pre-construction (2000–2001) and post-construction (2006–2007) phases of U.S. Highway 64 on control and treatment areas, Washington County, North Carolina.

Period[a]	**Area**	***n***	$\bar{x}$ **(km^2)**	**95% confidence interval**
Pre-construction	Treatment	9	3.86	0–7.77
Pre-construction	Control	14	2.70	0–5.84
Post-construction	Treatment	11	7.97	4.44–11.51
Post-construction	Control	6	7.37	2.58–12.16

[a] No period x area effect; $F_{1,36} = 1.91$, $P = 0.176$

Table 3. Area-perimeter ratio of 95% home ranges of female black bears for pre-construction (2000–2001) and post-construction (2006–2007) phases of U.S. Highway 64 on control and treatment areas, Washington County, North Carolina.

Period[a]	**Area**	***n***	$\bar{x}$ **(km²/km)**	**95% confidence interval**
Pre-construction	Treatment	9	0.293	0.178–0.407
Pre-construction	Control	14	0.231	0.140–0.323
Post-construction	Treatment	11	0.389	0.285–0.492
Post-construction	Control	6	0.414	0.274–0.554

[a] No period x area effect; $F_{1, 36} = 0.59$, $P = 0.446$

Table 4. Agriculture-forest edge density estimates for pre-construction (2000–2001) and post-construction (2006–2007) phases of U.S. Highway 64 on control and treatment areas analyzed at 270- and 1,290-m scales (relative to home-range size) and statistical analysis of a treatment effect for female black bear home ranges in Washington County, North Carolina.

		Agriculture-forest edge density (m/ha)					
Scale	**Group**	**Slope[a]**	***F***	***P***	**Value[b]**	***F***	***P***
270 m			1.54	0.22		0.07	0.79
	Pre-treatment	-2.99			15.2		
	Pre-control	0.4			15.2		
	Post-treatment	0.02			24		
	Post-control	-1.74			21.1		
1,290 m			4.08	0.05		0.53	0.47
	Pre-treatment	-4.83			15		
	Pre-control	-0.59			16.2		
	Post-treatment	0.23			22.1		
	Post-control	-1.22			18.2		

[a] Slope of the regression line to represent the change in the habitat variable, as black bear home-range size (km^2) increases

[b] Value for habitat variable at mean female black bear 95% home-range size of 4.9 km^2

Table 5. Forest cohesion estimates for pre-construction (2000–2001) and post-construction (2006–2007) phases of U.S. Highway 64 on control and treatment areas analyzed at 270- and 1,290-m scales (relative to home-range size) and statistical analysis of a treatment effect for female black bear home ranges in Washington County, North Carolina.

		Forest cohesion index (0-100)					
Scale	**Group**	**Slope[a]**	***F***	***P***	**Value[b]**	***F***	***P***
270 m			0.01	0.92		0.54	0.47
	Pre-treatment	0.07			98.9		
	Pre-control	-0.39			97.5		
	Post-treatment	-0.19			95.9		
	Post-control	-0.55			96.3		
1,290 m			0.72	0.40		1.86	0.18
	Pre-treatment	0.07			99.6		
	Pre-control	-0.04			99.7		
	Post-treatment	-0.01			99.4		
	Post-control	-0.01			99		

[a] Slope of the regression line to represent the change in the habitat variable, as black bear home-range size (km^2) increases

[b] Value for habitat variable at mean female black bear 95% home-range size of 4.9 km^2

Table 6. Forest diversity estimates for pre-construction (2000–2001) and post-construction (2006–2007) phases of U.S. Highway 64 on control and treatment areas analyzed at 270- and 1,290-m scales (relative to home-range size) and statistical analysis of a treatment effect for female black bear home ranges in Washington County, North Carolina.

		Forest diversity, Simpson's index (0–1)					
Scale	**Group**	**Slope[a]**	***F***	***P***	**Value[b]**	***F***	***P***
270 m			1.82	0.19		6.09	0.02
	Pre-treatment	0.1			0.506		
	Pre-control	0.02			0.316		
	Post-treatment	0			0.345		
	Post-control	-0.03			0.407		
1,290 m			2.75	0.11		1.68	0.20
	Pre-treatment	0.09			0.626		
	Pre-control	0.02			0.515		
	Post-treatment	0			0.568		
	Post-control	-0.01			0.571		

[a] Slope of the regression line to represent the change in the habitat variable, as black bear home-range size (km^2) increases

[b] Value for habitat variable at mean female black bear 95% home-range size of 4.9 km^2

Table 7. Forest diversity (270 m) estimates and 95% confidence intervals for pre-construction (2000–2001) and post-construction (2006–2007) phases of U.S. Highway 64 on control and treatment areas at mean female black bear home-range size in Washington County, North Carolina.

Group	**Forest diversity**	**95% confidence interval**
Pre-treatment	0.51	0.39–0.62
Pre-control	0.32	0.22–0.41
Post-treatment	0.35	0.26–0.42
Post-control	0.41	0.29–0.53

Table 8. Mean hourly movement rates (m/hr) of radio-collared black bears from pre-construction (2000–2001) and post-construction (2006–2007) phases of U.S. Highway 64 on control and treatment areas, Washington County, North Carolina.

Group [a]	**Movement rate (m/hr)**	**95% confidence interval**
Pre-treatment	213	180–246
Pre-control	246	218–273
Post-treatment	218	186–250
Post-control	272	235–309

[a] No interaction effect; $F_{1,\,47.3} = 0.20$, $P = 0.658$

Table 9. Mean daily movement rates (m/24 hrs) of radio-collared, female black bears from pre-construction (2000–2001) and post-construction (2006–2007) phases of U.S. Highway 64 on control and treatment areas, Washington County, North Carolina.

Group [a]	**Movement rate (m/24 hrs)**	**95% confidence interval**
Pre-treatment	455	336–574
Pre-control	351	246–455
Post-treatment	795	677–914
Post-control	691	542–841

[a] No interaction effect; $F_{1,\,49} = 0.25$, $P = 0.620$

Table 10. Percent activity of radio-collared black bears by time of day from pre-construction (2000–2001) and post-construction (2006–2007) phases of U.S. Highway 64 on control and treatment areas, Washington County, North Carolina.

Time	**Group**	**% activity**	**95% confidence interval**	**Significance of treatment effect (*P*-value)**
Morning [a] (04:00–09:59)	Pre-treatment	45.4	38–53	<0.001
	Pre-control	63.7	58–70	
	Post-treatment	67.8	60–75	
	Post-control	59.8	49–71	
Midday [b] (10:00–15:59)	Pre-treatment	37.5	32–43	0.507
	Pre-control	40.3	36–45	
	Post-treatment	54.1	49–60	
	Post-control	53.1	46–61	
Evening [c] (16:00–21:59)	Pre-treatment	58.1	51–65	0.348
	Pre-control	59.5	54–65	
	Post-treatment	72.3	66–79	
	Post-control	67.0	56–78	

[a] No interaction effect; $F_{1,\,100} = 14.18$, $P = 0.0003$

[b] No interaction effect; $F_{1,\,123} = 0.44$, $P = 0.507$

[c] No interaction effect; $F_{1,\,108} = 0.89$, $P = 0.348$

Table 11. Frequencies of wildlife mortalities due to vehicle collisions for section of U.S. Highway 64 with 3 wildlife underpasses, Washington County, North Carolina, 2006–2007.

Species	**Outside fencing**	**Within fencing**
Barred owl	2	
Black vulture		1
Bufo sp.	1	
Buteo sp.	1	
Chrysemys picta	1	
Canada goose	1	
Canis domesticus	1	
Canis latrans	1	
Chelydra serpentina	13	1
Chrysemys picta	4	
Clemmys guttata	2	1
Coluber constrictor	7	1
Crow	1	
Didelphis virginiana	43	18
Elaphe obsoleta	2	1
Felis domesticus	1	1
Green heron	1	
Kinosternon subrubrum	2	
Mephitis mephitis	1	
Mustela vison	2	
Myocastor coypus	1	
Nerodia erythrogaster	2	1
Odocoileus virginianus	3	4
Procyon lotor	23	5

Table 11, cont.

Species	**Outside fencing**	**Within fencing**
Pseudemys floridana	2	
Rana catesbeiana	3	2
Red shoulder hawk	1	
Red-tailed hawk		1
Seagull	2	
Sigmodon sp.	1	
Storeria occipitomaculata	2	
Sylvilagus palustris	6	2
Terapene carolina	2	2
Turkey	1	
Turkey vulture	2	1
Urocyon cinereoargenteus	8	1
Unknown bird	1	
Unknown rodent	1	
Ursus americanus	1	1
Vulpes vulpes	2	

Table 12. Animal-vehicle collision report data from 4 sections of U.S. Highway 64 within Edgecombe, Martin, Tyrrell, and Washington Counties, North Carolina, January 2006–June 2008.

U.S. Highway 64 section	Km	2006 Average Annual Daily Traffic	Reported crashes	Reports/(km x vehicle traffic)	Mean ag/forest edge w/in 1 km of highway	% vs. study section
Plymouth to Creswell (Study Site)	36.4	5,268	10	5.22×10^{-5}	12,435	100
Tarboro to Williamston	40.2	9,161	29	7.87×10^{-5}	13,602	138
Williamston to Plymouth	29	8,417	33	0.00014	15,717	205
Creswell to Columbia	13.5	5,794	7	8.94×10^{-5}	8,035	265

Table 13. Frequencies of wildlife species recorded with remote cameras within 3 wildlife underpasses of U.S. Highway 64, Washington County, North Carolina, from 17 July 2000 to 18 March 2001 (pre-construction) and 3 July 2006 to 9 August 2007 (post-construction).

Pre-construction	**West underpass**	**Central underpass**	**East underpass**
Ursus americanus	0	0	0
Odocoileus virginianus	47	152	43
Other mammals	0	0	1
Post-construction			
Ursus americanus	7	2	6
Odocoileus virginianus	580	934	364
Other mammals	114	44	2

Table 14. Frequencies of wildlife species recorded inside 3 wildlife underpasses of U.S. Highway 64 based on track surveys, Washington County, North Carolina, 2006–2007.

Species	**East underpass**	**Central underpass**	**West underpass**
Canis spp.	1	8	12
Castor canadensis	1	0	0
Didelphis virginiana	3	14	13
Lynx rufus	4	1	8
Felis spp.	2	2	4
Mustela vison	1	2	1
Myocastor coypus	0	0	3
Odocoileus virginianus	621	1, 604	958
Ondontra zibethicus	0	3	10
Procyon lotor	39	79	115
Sus scrofa	0	1	0
Sylvilagus spp.	0	9	5
Ursus americanus	6	0	6
Unknown fox	5	4	13
Turkey	1	0	1
Great blue heron	0	1	1
Unknown bird	0	1	1
Unknown mole	0	0	2
Unknown snake	6	20	26
Unknown turtle	1	1	2

Table 15. U.S. Highway 64 crossing data for all black bears with 95% home ranges that overlapped the new section of highway, treatment area, Washington County, North Carolina, 2000–2001 and 2006–2007.

Study phase	**Bear ID #**	**Length of highway in 95% home range (m)**	**No. of crossings**
Pre-construction			
	8	925	2
	10	0	2
	13	0	2
	17	0	4
	19	1,570	6
Post-construction			
	51	9,296	12
	54	4,531	0
	56 [a]	675	15
	58 [a]	1,550	7
	64	2,325	2
	65	1,594	0
	66	78	0
	102	834	0

[a] Killed in a vehicle collision on U.S. Highway 64

FIGURES

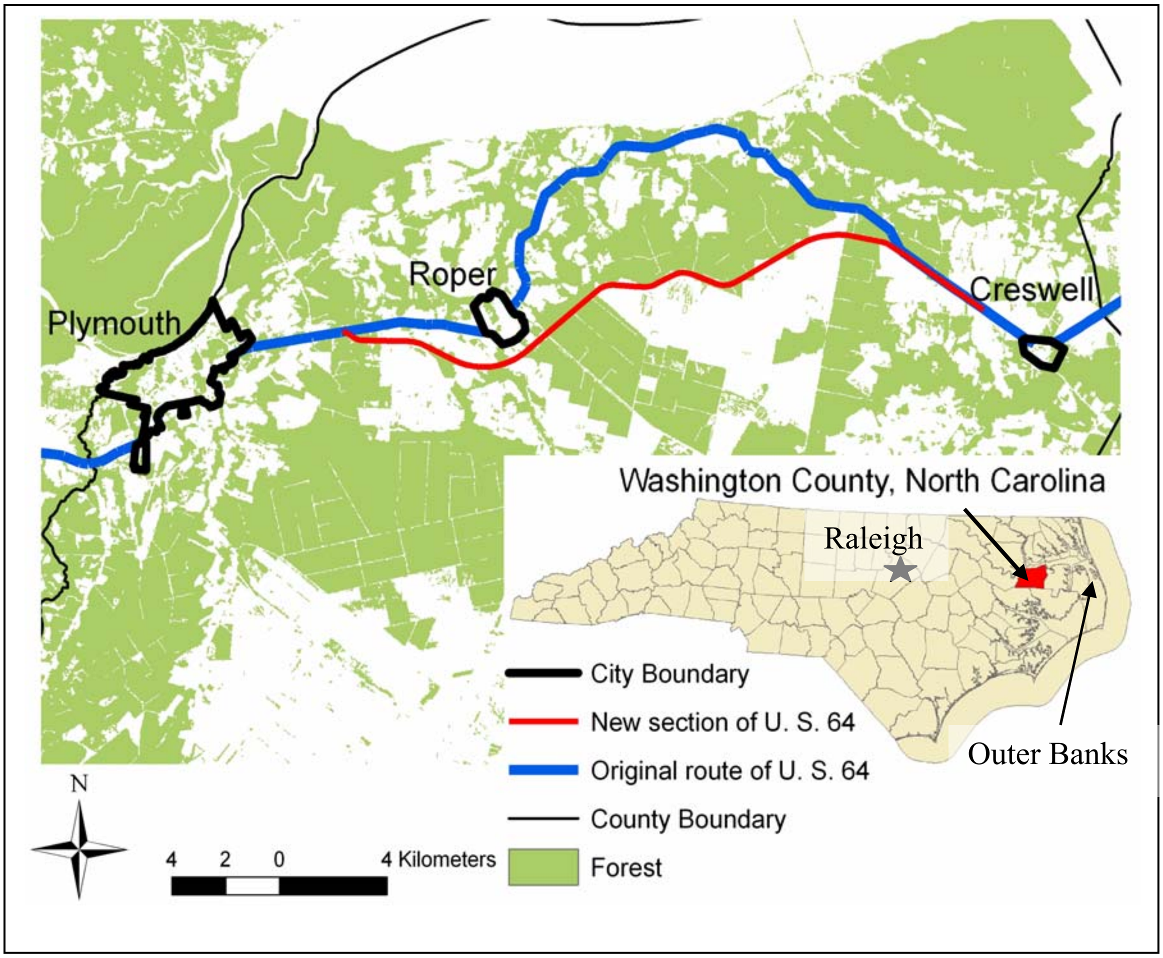


Fig. 1. Original and new route of U. S. Highway 64 in Washington County, North Carolina.

	Pre-construction 2000–2001	**Post-construction** 2006–2007
Treatment area (Highway construction)	Group 1	Group 2
Control area (No highway construction)	Group 3	Group 4

Fig. 2. Experimental design to determine short-term impacts of a highway with underpasses on the spatial ecology of black bears in Washington County, North Carolina 2000–2008.

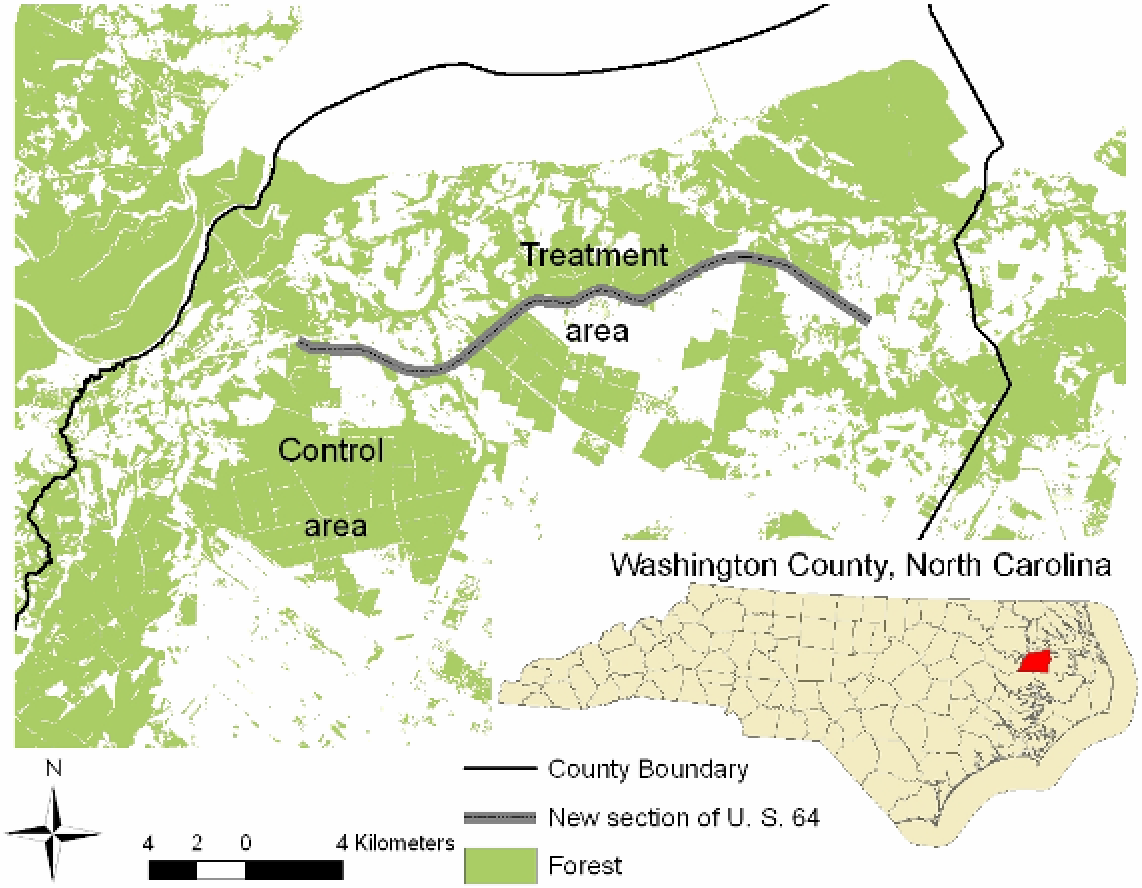


Fig. 3. Control and treatment areas studied to determine short-term impacts of a new section of U.S. Highway 64 on black bear ecology, Washington County, North Carolina 2000–2008.

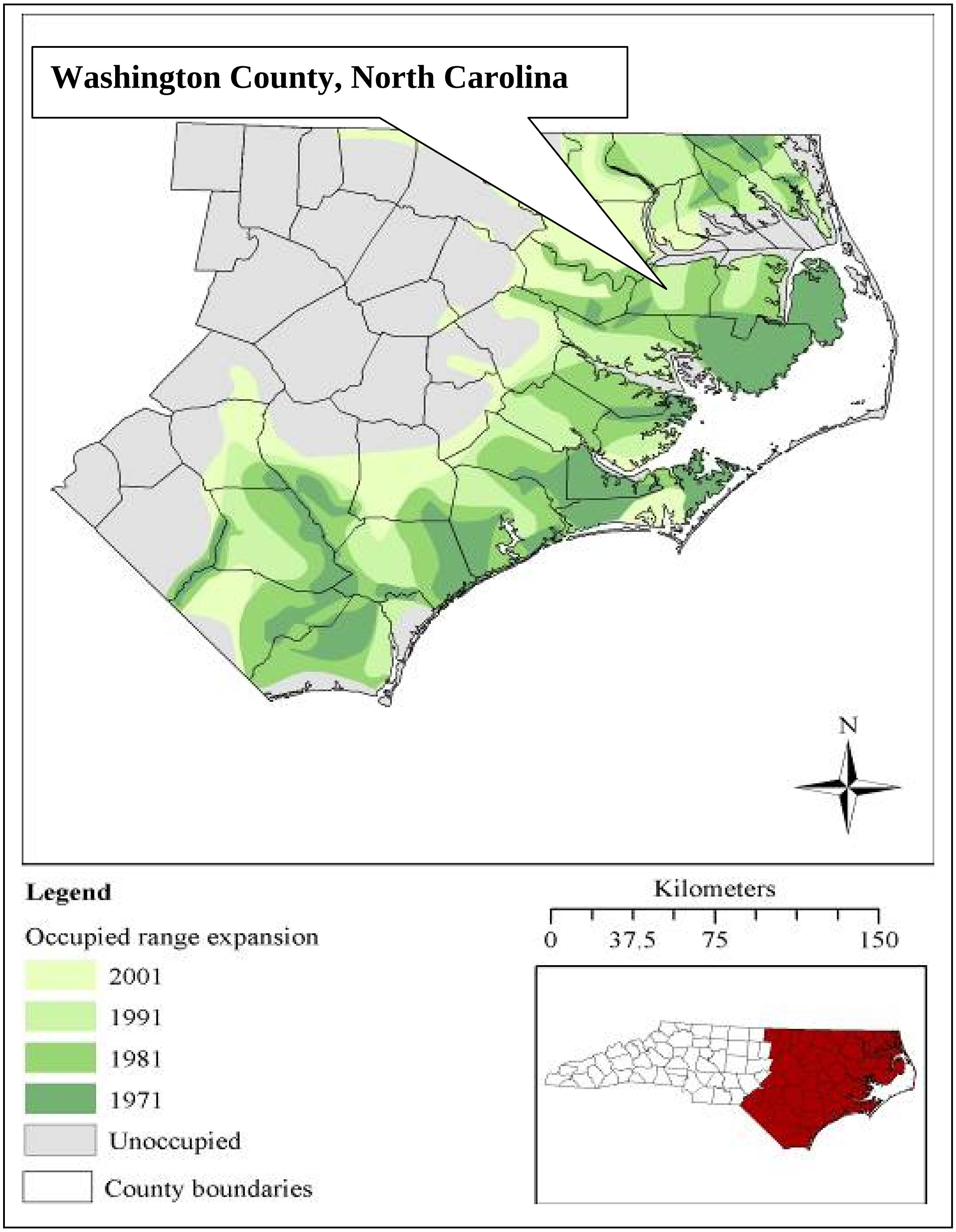
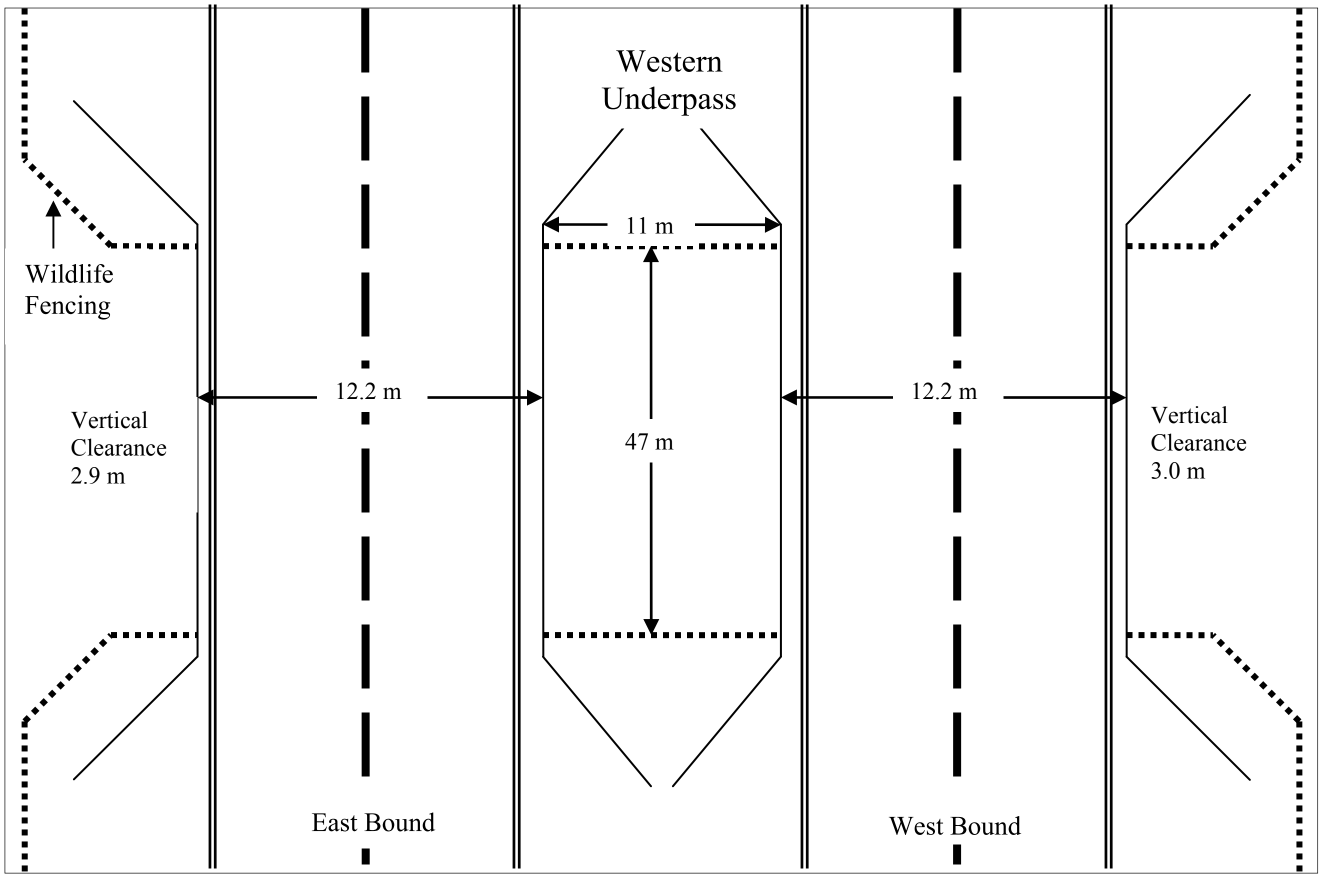
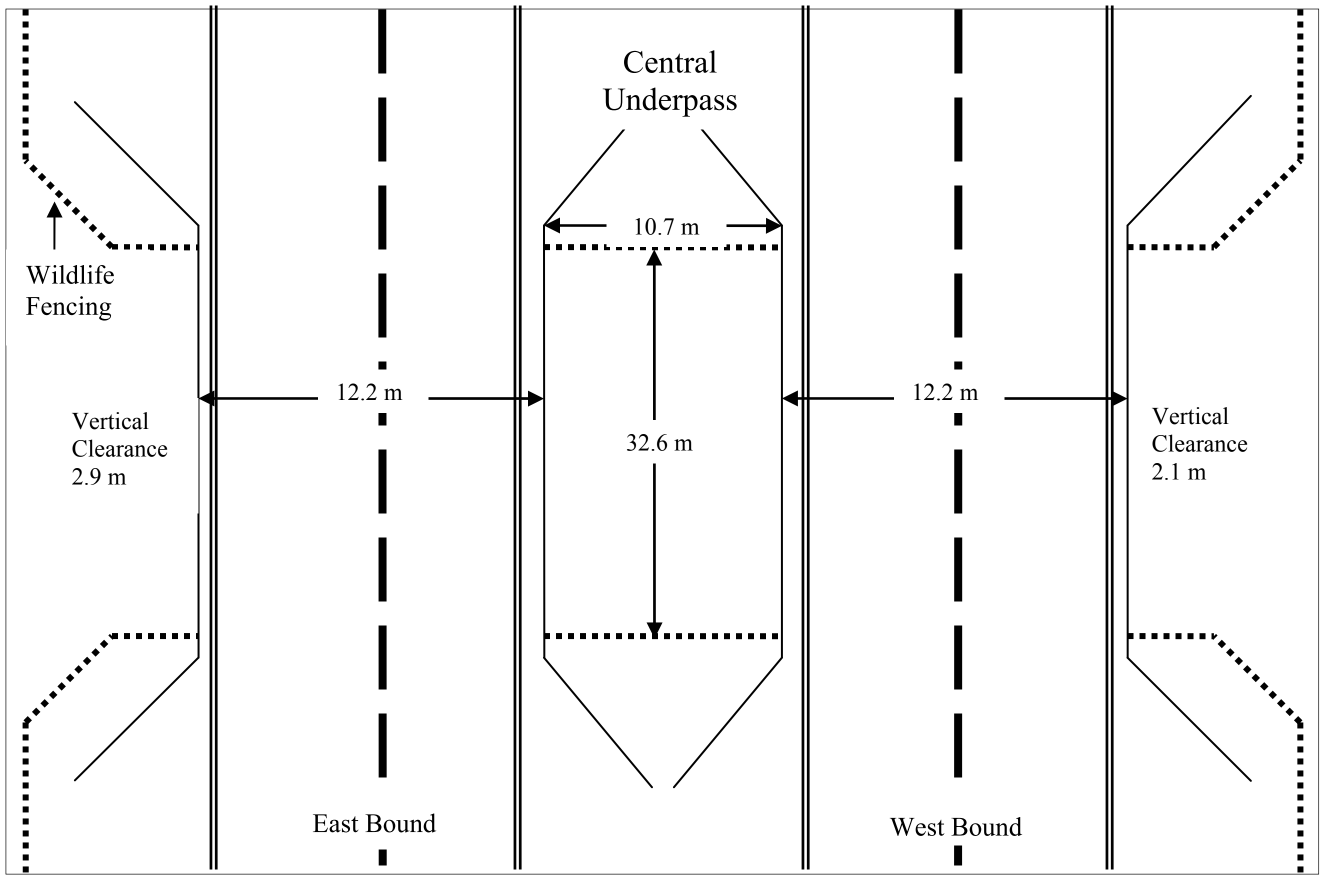


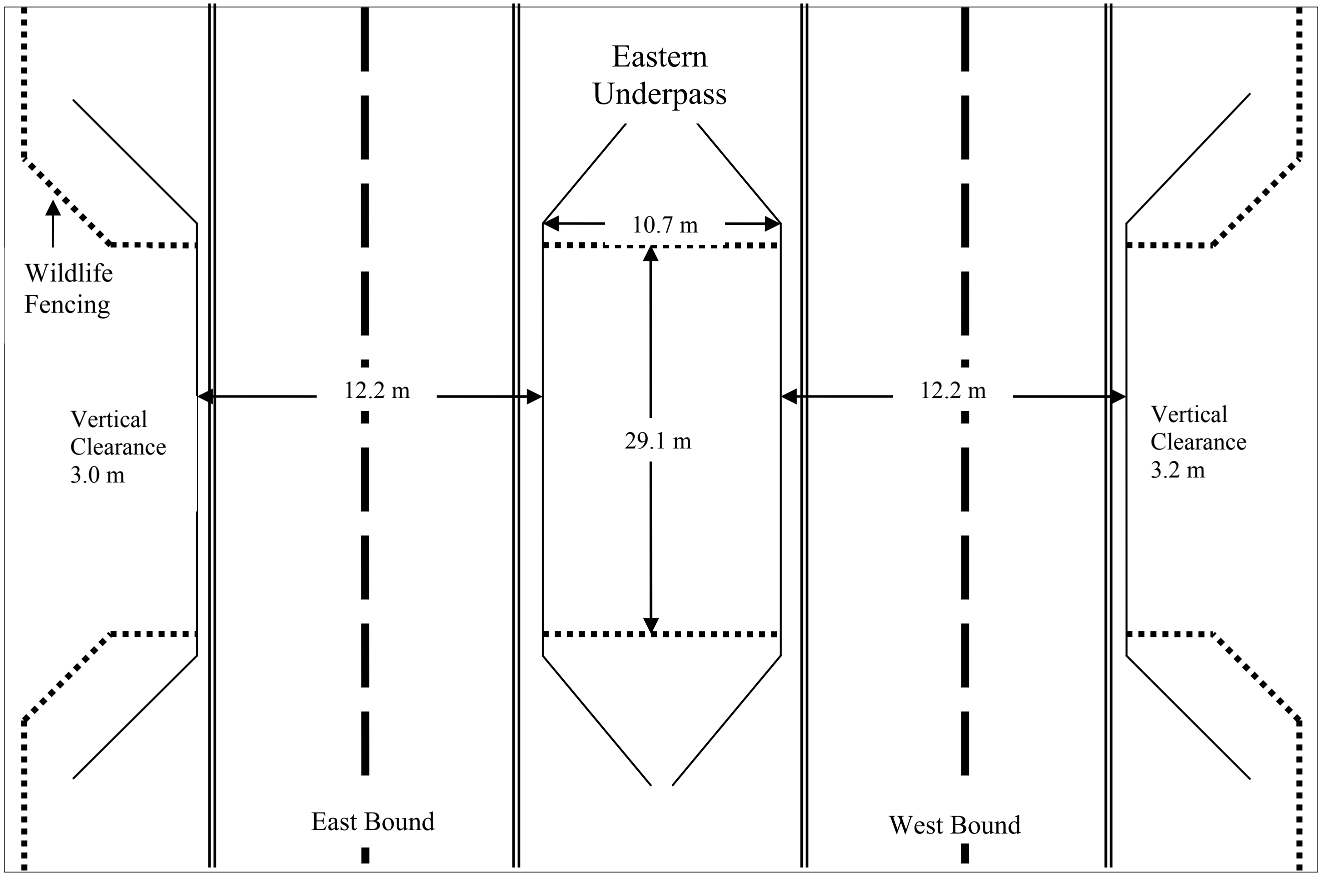
Fig. 4. Occupied black bear range and range expansion in North Carolina, 1971–2001 (North Carolina Wildlife Resources Commission, unpublished data).



(a)

Fig. 5. Dimensions of western (a), central (b), and eastern (c) wildlife underpasses on U.S. Highway 64 in Washington County, North Carolina; measurements taken by Anne Burroughs and Dennis Herman of the NCDOT.


Central
Underpass
10.7 m
Wildlife
Fencing
12.2 m
12.2 m
32.6 m
Vertical
Clearance
2.9 m
Vertical
Clearance
2.1 m
East Bound
West Bound
(b)

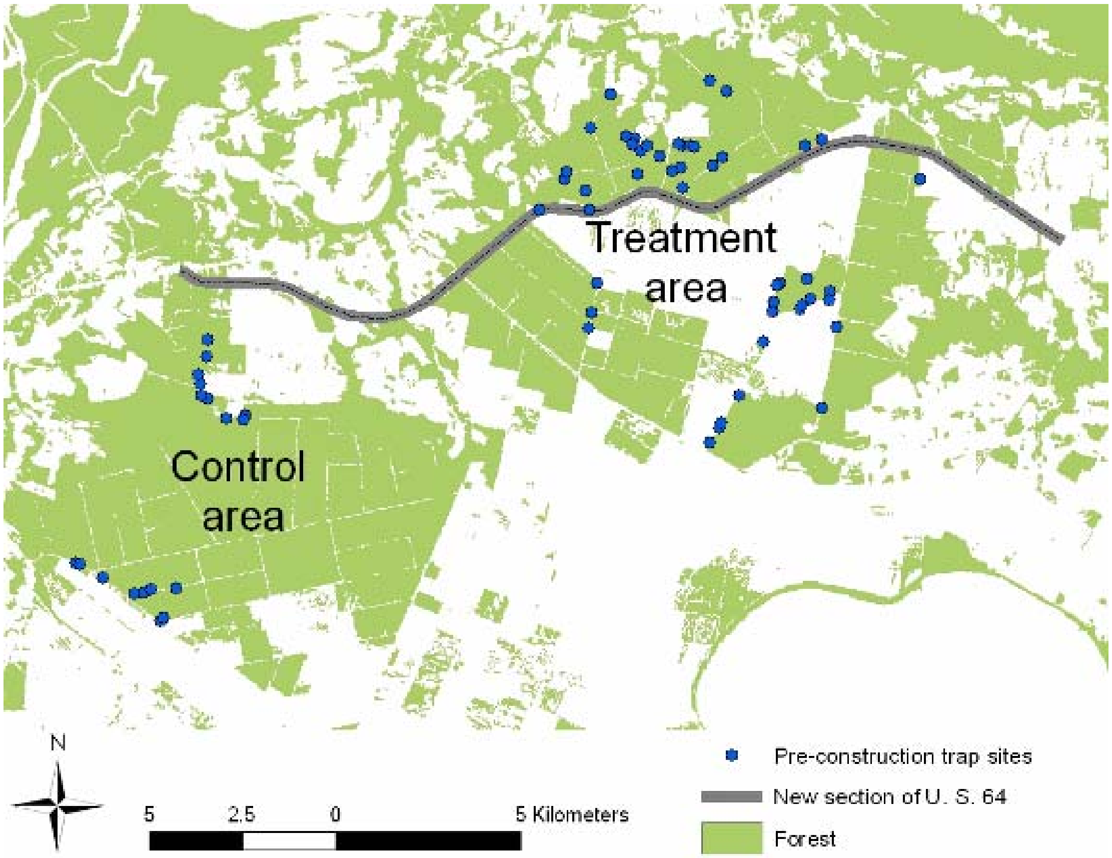

Eastern
Underpass
10.7 m
Wildlife
Fencing
12.2 m
12.2 m
Vertical
Clearance
3.0 m
29.1 m
Vertical
Clearance
3.2 m
East Bound
West Bound
(c)


(a)

Fig. 6. Western (a), central (b), and eastern (c) wildlife underpasses on U.S. Highway 64, Washington County, North Carolina, 2007.

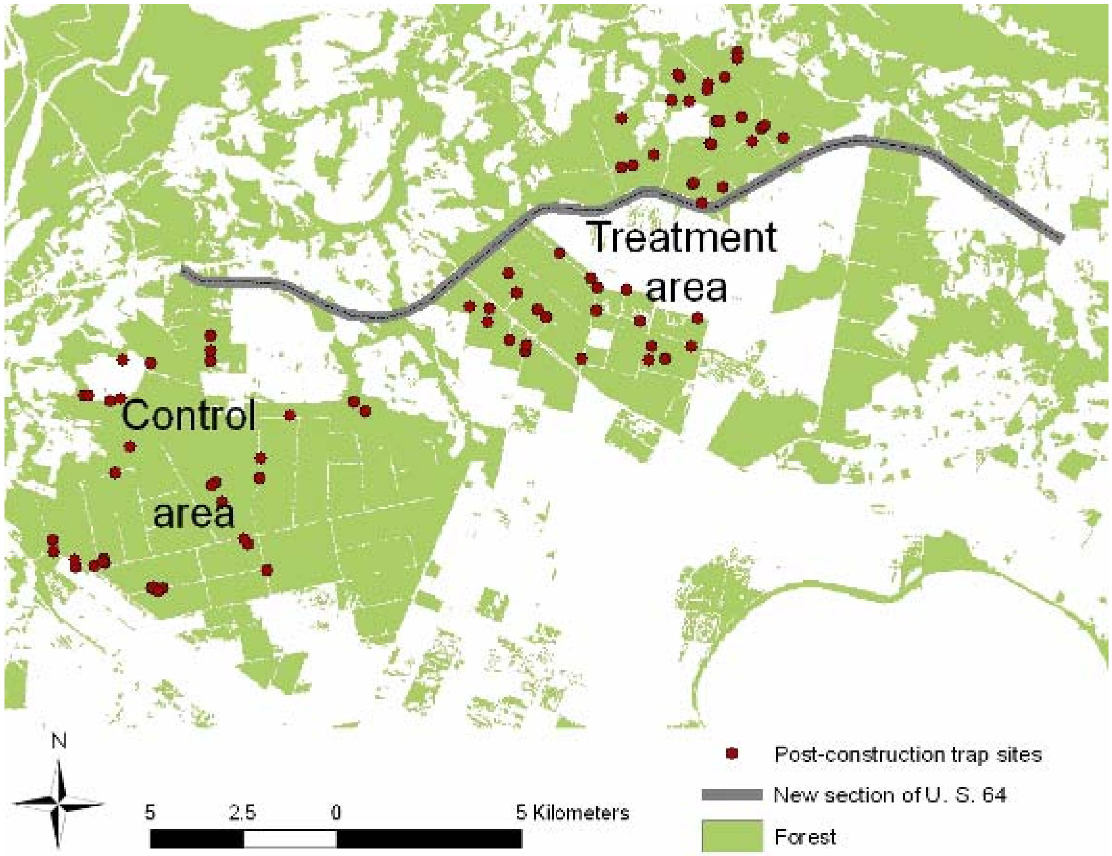

(b)

 (c)



(a)

Fig. 7. Live trapping sites for pre-construction (a) and post-construction phase (b) of research to determine short-term impacts of a new section of U.S. Highway 64 on black bears, Washington County, North Carolina, 2000-2007.



Treatment
area
Control
area
N
5
2.5
0
5 Kilometers
Post-construction trap sites
New section of U. S. 64
Forest

(b)

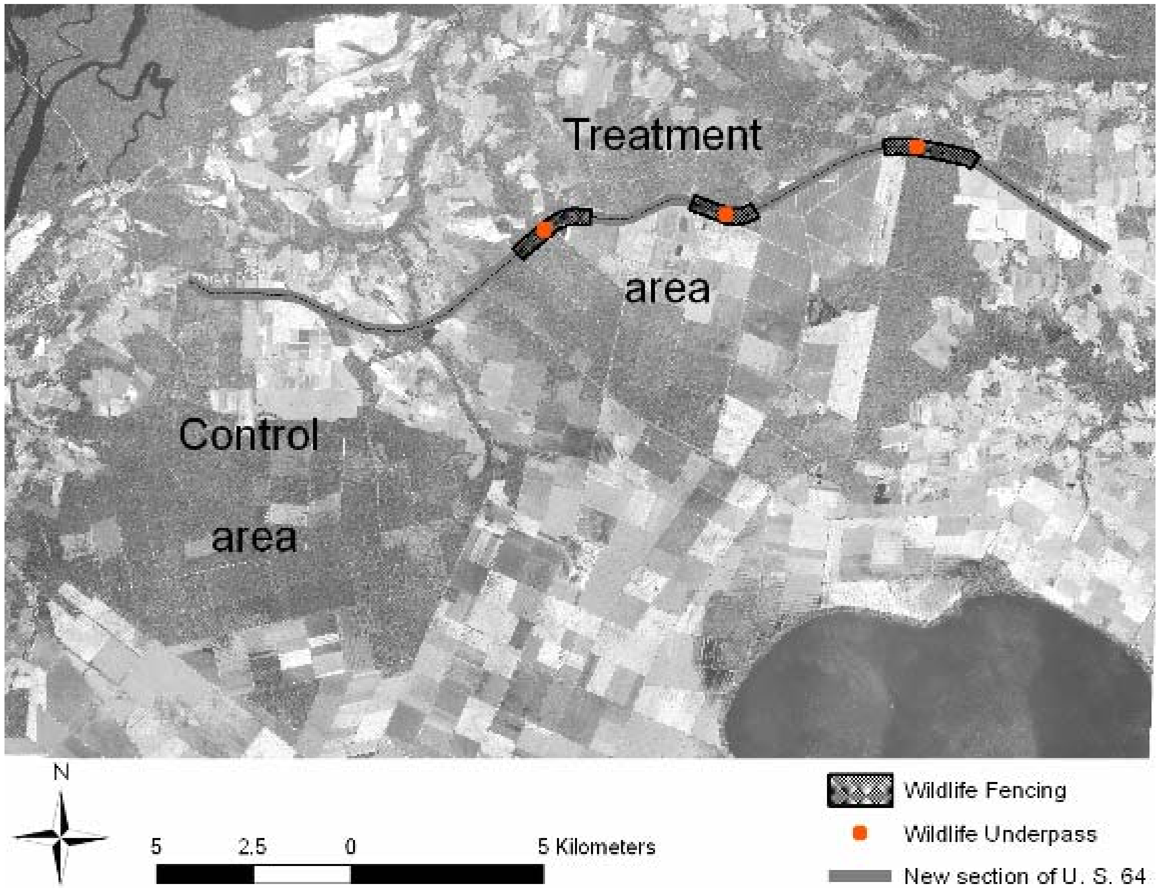


Fig. 8. Study section of U.S. Highway 64 to determine the effectiveness of wildlife fencing and underpasses in Washington County, North Carolina 2006–2007.

Fig. 9. Nearby and adjacent sections to study section (Plymouth to Creswell) of U.S. Highway 64, North Carolina.

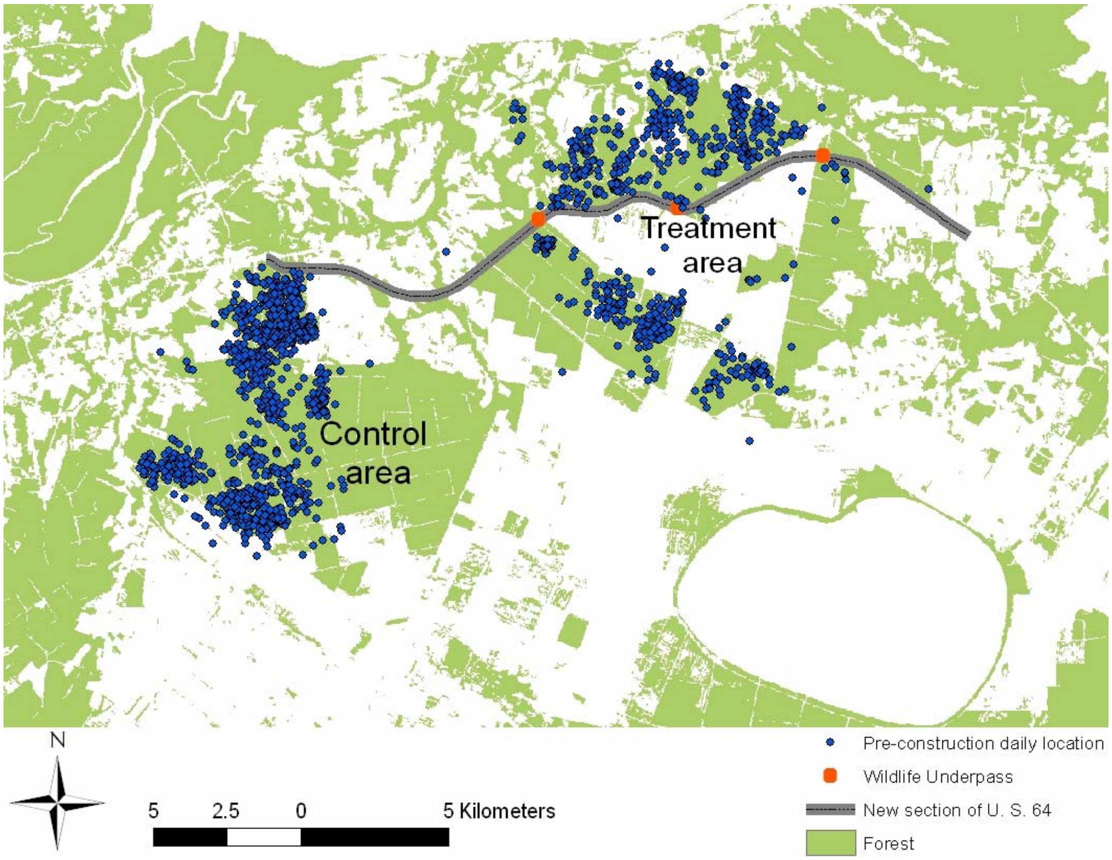
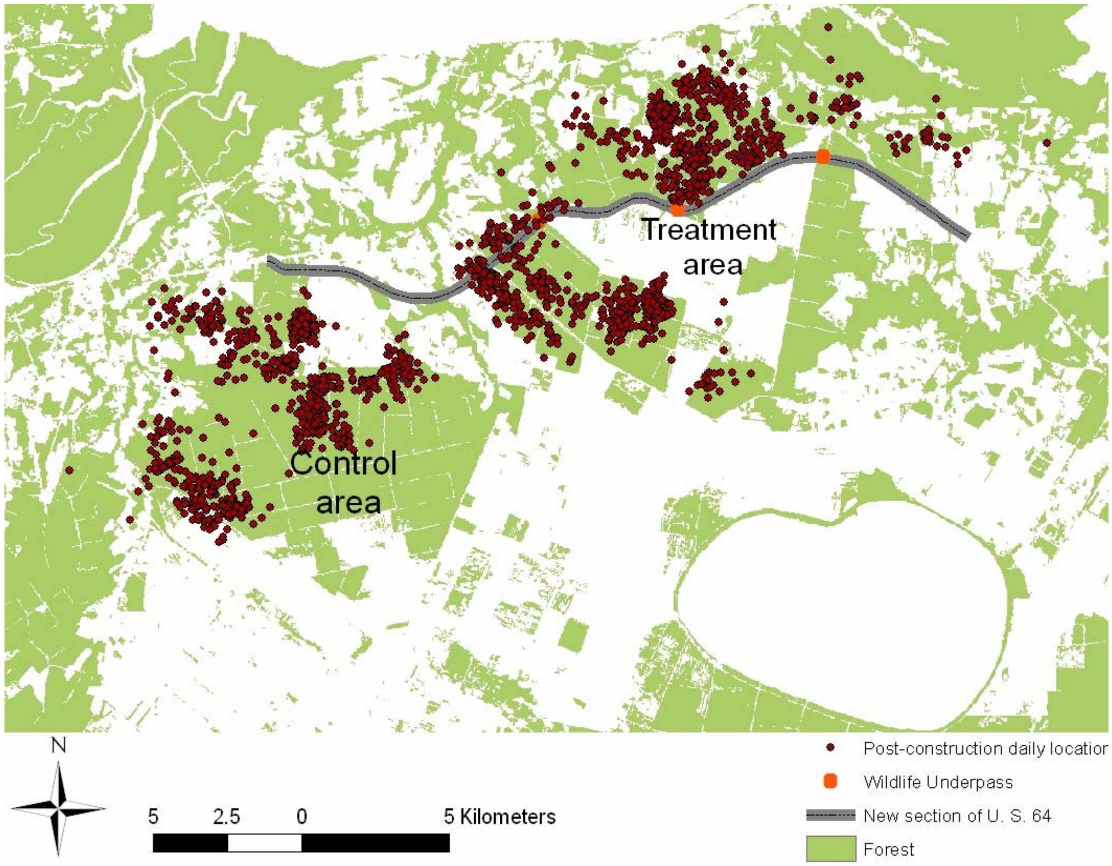
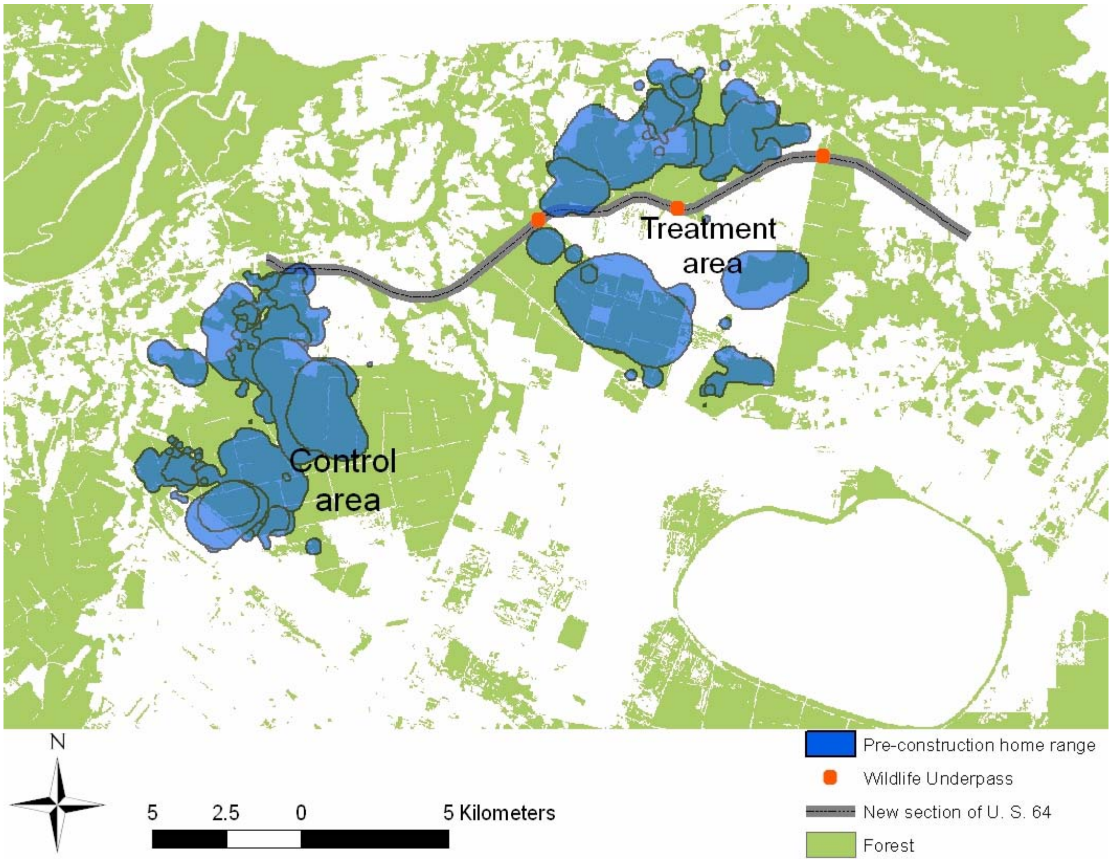


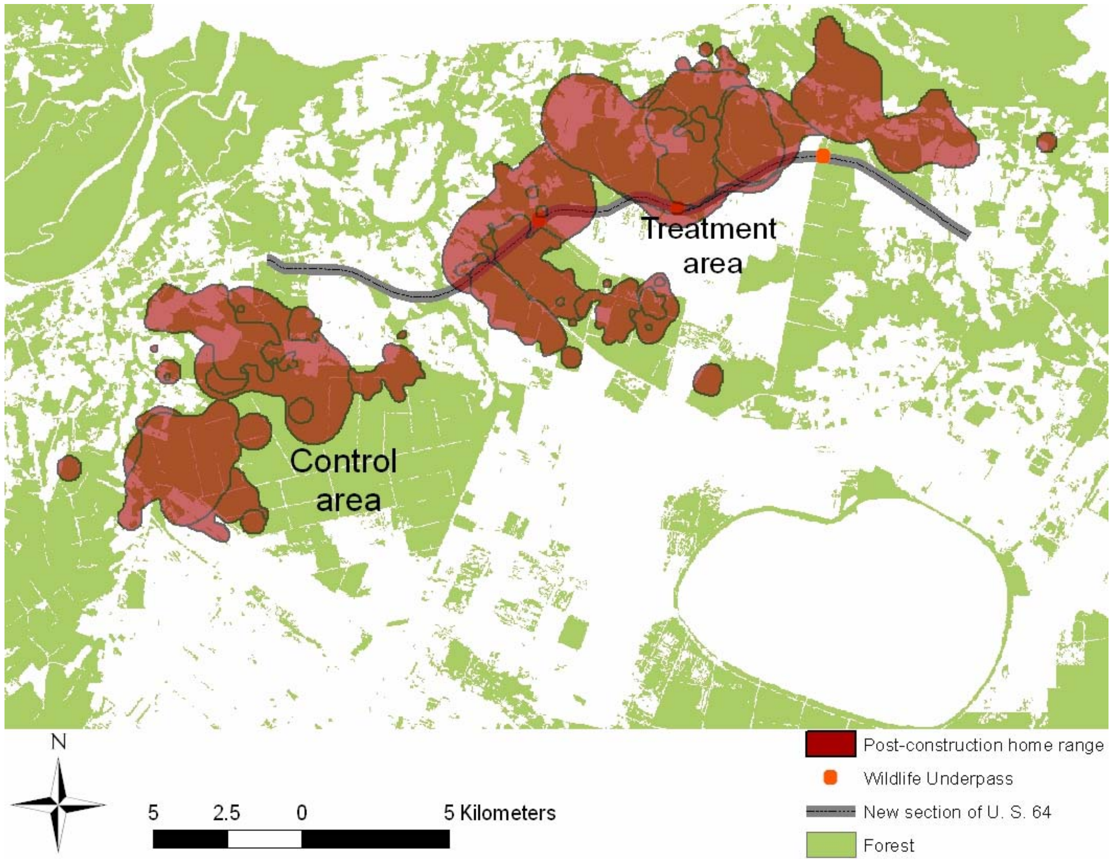
Fig. 10. Daily locations for pre-construction (a) and post-construction phase (b) of research to determine short-term impacts of a new section of U.S. Highway 64 on black bears, Washington County, North Carolina, 2000-2007.


Treatment area
Control area
N
5 2.5 0 5 Kilometers
Post-construction daily locatior
Wildlife Underpass
New section of U. S. 64
Forest
(b)



(a)

Fig. 11. Home ranges (95% fixed kernel) for pre-construction (a) and post-construction phase (b) of research to determine short-term impacts of a new section of U.S. Highway 64 on black bears, Washington County, North Carolina, 2000-2007.


Treatment
area
Control
area
N
5 2.5 0 5 Kilometers
Post-construction home range
Wildlife Underpass
New section of U. S. 64
Forest
(b)

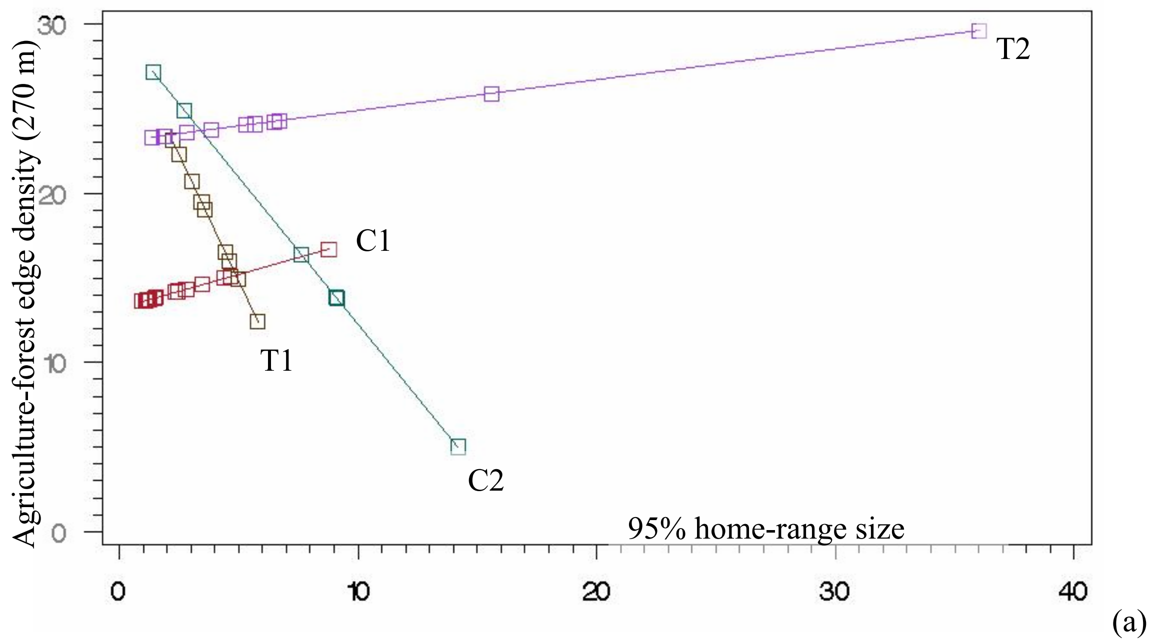
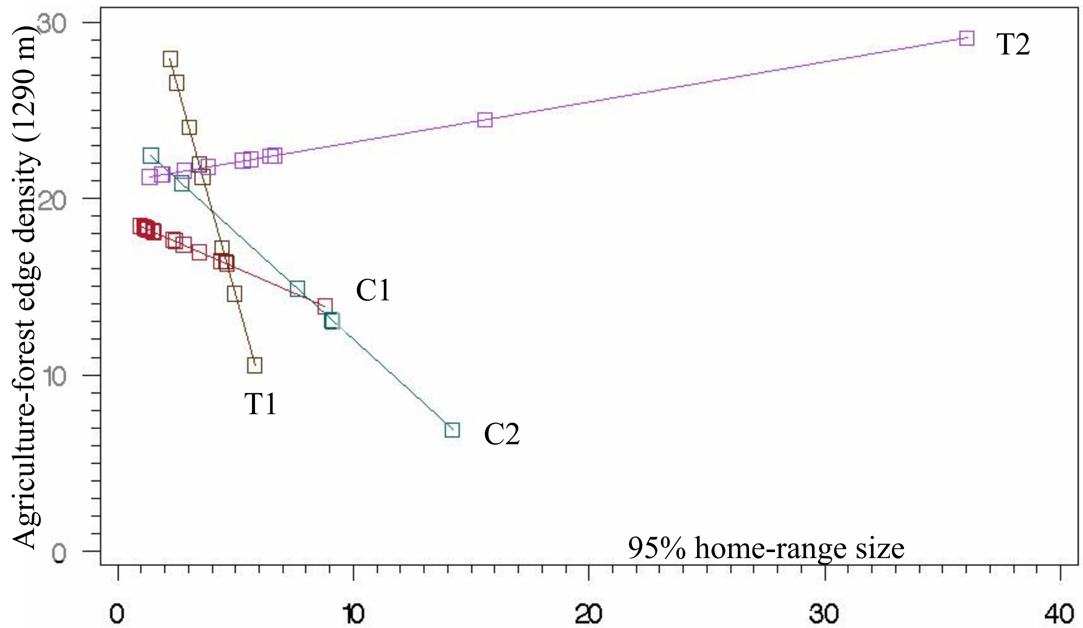
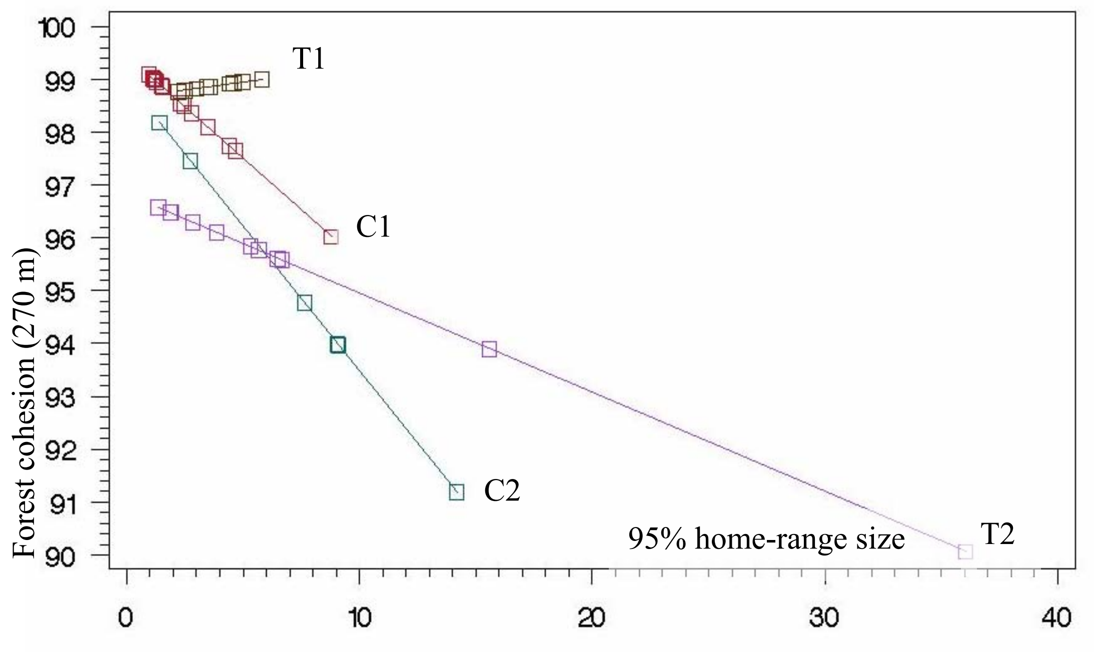


Fig. 12. Dummy regression of agriculture-forest edge density, calculated at a 270-m scale (a) and a 1290-m scale (b), of female black bear home ranges from the pre-construction treatment area (T1), pre-construction control area (C1), post-construction treatment area (T2), and post-construction control area (C2) datasets from Washington County, North Carolina.



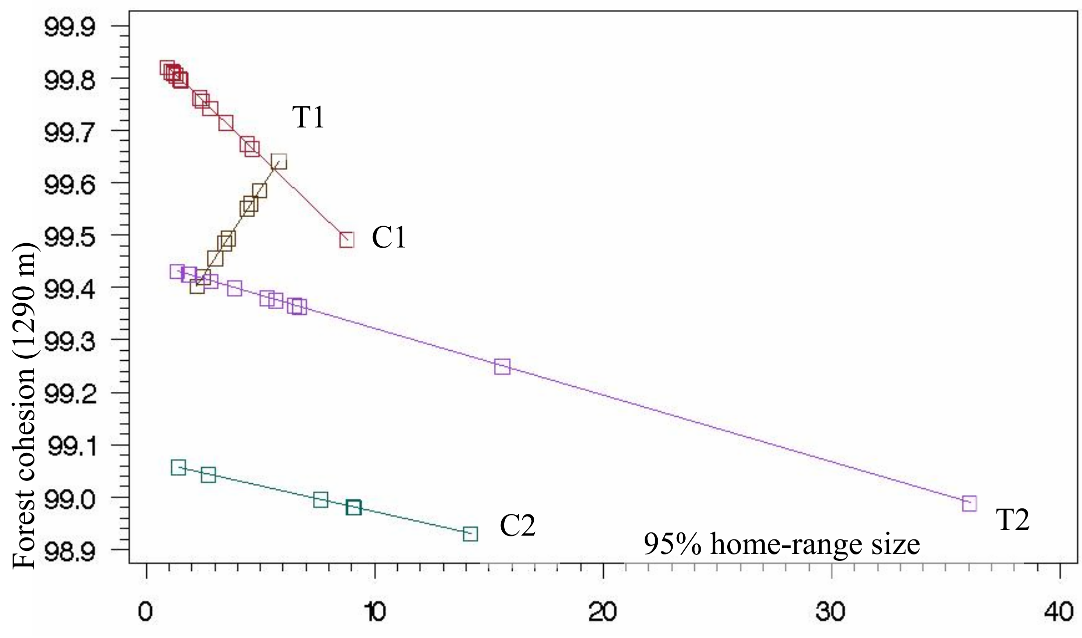
Agriculture-forest edge density (1290 m)
95% home-range size
T2
C1
T1
C2
0
10
20
30
40

(b)



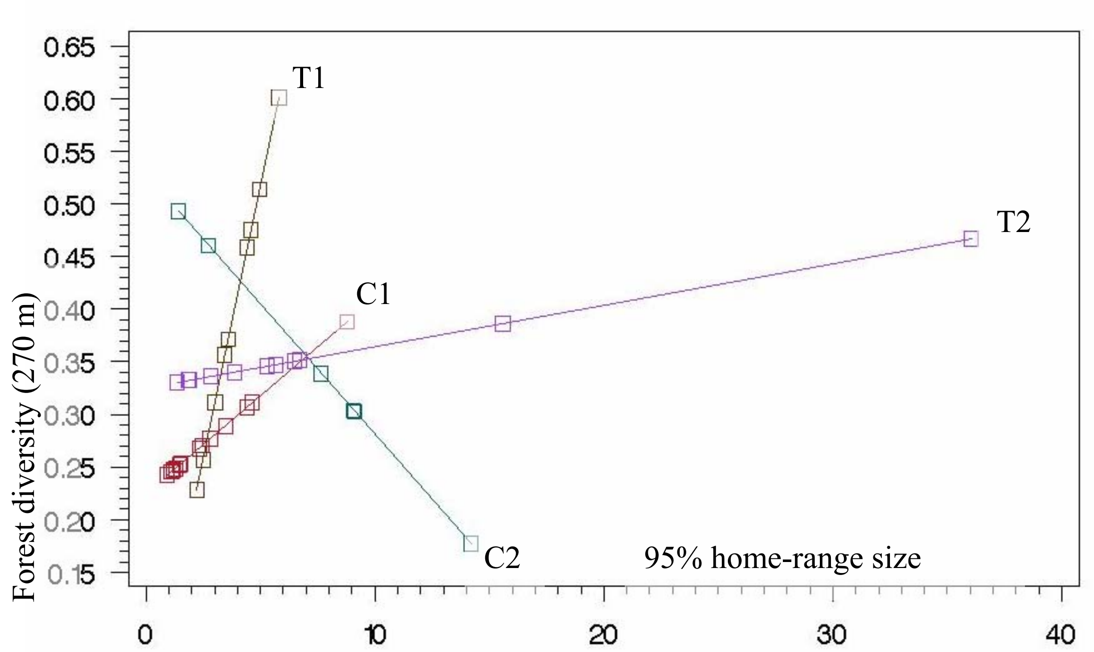
(a)

Fig. 13. Dummy regression of forest cohesion, calculated at a 270-m scale (a) and a 1290-m scale (b), of female black bear home ranges from the pre-construction treatment area (T1), pre-construction control area (C1), post-construction treatment area (T2), and post-construction control area (C2) datasets from Washington County, North Carolina.



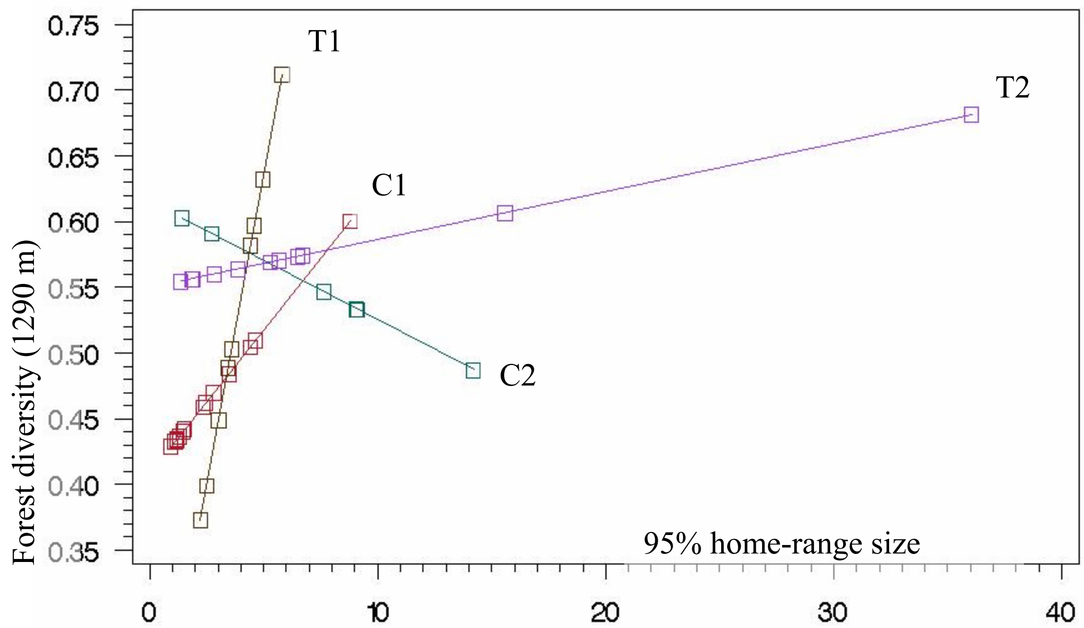
Forest cohesion (1290 m)
99.9
99.8
99.7
99.6
99.5
99.4
99.3
99.2
99.1
99.0
98.9
T1
C1
T2
C2
95% home-range size
0
10
20
30
40

(b)



(a)

Fig. 14. Dummy regression of forest diversity, calculated at a 270-m scale (a) and a 1290-m scale (b), of female black bear home ranges from the pre-construction treatment area (T1), pre-construction control area (C1), post-construction treatment area (T2), and post-construction control area (C2) datasets from Washington County, North Carolina.


T1
T2
C1
C2
Forest diversity (1290 m)
95% home-range size
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0
10
20
30
40

(b)

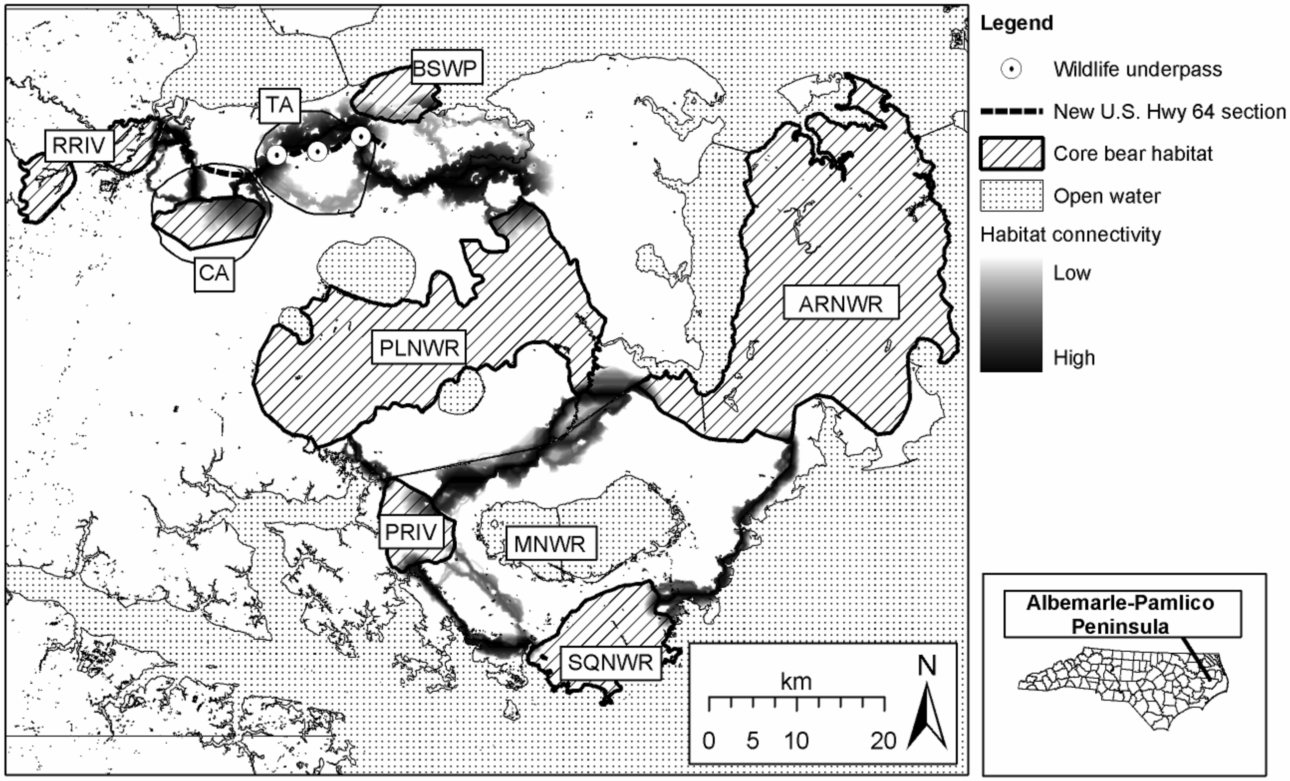


Fig. 15. Habitat connectivity based on a least-cost-path analysis between areas of core black bear habitat, Albemarle-Pamlico Peninsula, North Carolina. Abbreviations for areas: BSWP = Big Swamp, CA = control area, PRIV = Pungo River, RRIV = Roanoake River, ARNWR = Alligator River National Wildlife Refuge (NWR), MNWR = Lake Mattamuskeet NWR, PLNWR = Pocosin Lakes NWR, and SQNWR = Swanquarter NWR (from Kindall 2004).

APPENDIX

Table 1. Capture date, physical characteristics, and number of locations used to determine short-term impacts of a new section of U.S. Highway 64 on black bears, treatment area, Washington County, North Carolina, 2000-2001.

Date	**Bear ID #**	**Sex**	**Mass (kg)**	**Age**	**Radio collar**	**No. of hourly locations**	**No. of daily locations**
16-Jun-00	WT 001	M	69[a]	3	Yes	42	17
17-Jun-00	WT 002	M	77	3	No		
19-Jun-00	WT 003	F	48	2	Yes	77	48
21-Jun-00	WT 004	F	64[a]	5	Yes	81	50
23-Jun-00	WT 005	M	147[a]	3	No		
5-Jul-00	WT 006	M	60[a]	1	No		
9-Jul-00	WT 007	F	39	1	Yes	40	15
11-Jul-00	WT 008	F	61	4	Yes	92	51
12-Jul-00	WT 009	F	70	3	Yes	102	61
14-Jul-00	WT 010	F	61[a]	3	Yes	95	47
14-Jul-00	WT 011	M	155[a]	3	Yes	12	22
18-Jul-00	WT 012	M	136[a]	6	Yes	51	66
27-Jul-00	WT 013	F	66	7	Yes	74	36
30-Jul-00	WT 014	M	118[a]	2	No		
31-Jul-00	WT 015	M	74[a]	2	No		
5-Aug-00	WT 016	F	27	1	No		
13-Aug-00	WT 017	M	102[a]	2	Yes	85	48
16-Aug-00	WT 018	M	133	3	Yes	15	18
18-Aug-00	WT 019	F	73	3	Yes	87	51
18-Aug-00	WT 020	F	48	2	Yes	87	55
20-Aug-00	WT 021	M	68	1	No		
25-Aug-00	WT 022	F	64[a]	7	Yes	102	68
4-Sep-00	WT 023	M	114	2	Yes	19	13

[a] Estimated with regression equation (Eason and van Manen, University of Tennessee, unpublished data).

Table 2. Capture date, physical characteristics, and number of locations used to determine short-term impacts of a new section of U.S. Highway 64 on black bears, control area, Washington County, North Carolina, 2000–2001.

Date	**Bear ID #**	**Sex**	**Mass (kg)**	**Age**	**Radio collar**	**No. of hourly locations**	**No. of daily locations**
10-Jul-00	WT 100	F	80	-	Yes	86	59
12-Jul-00	WT 098	F	57[a]	3	Yes	111	73
12-Jul-00	WT 099	F	57[a]	5	Yes	77	63
15-Jul-00	WT 097	F	59	7	Yes	60	49
16-Jul-00	WT 094	F	77[a]	5	Yes	87	75
16-Jul-00	WT 095	F	25[a]	2	No		
16-Jul-00	WT 096	F	24	1	No		
18-Jul-00	WT 093	M	73	1	No		
19-Jul-00	WT 092	F	75	4	Yes	80	31
20-Jul-00	WT 090	F	64	9	Yes	97	79
20-Jul-00	WT 091	F	35	2	No		
21-Jul-00	WT 088	F	66	6	Yes	72	71
21-Jul-00	WT 089	M	167[a]	-	Yes	97	84
22-Jul-00	WT 085	F	55	5	Yes	75	58
22-Jul-00	WT 086	F	63	3	Yes	26	5
22-Jul-00	WT 087	F	36	1	No		
23-Jul-00	WT 081	F	36	2	No		
23-Jul-00	WT 082	M	52	1	No		
23-Jul-00	WT 083	F	49	2	Yes	99	66
23-Jul-00	WT 084	F	32	2	No		
24-Jul-00	WT 080	F	80	5	Yes	74	70
25-Jul-00	WT 078	F	70	4	Yes	97	66
25-Jul-00	WT 079	F	27	1	No		

Table 2.cont.

Date	Bear ID #	Sex	Mass (kg)	Age	Radio collar	No. of hourly locations	No. of daily locations
29-Jul-00	WT 077	F	25	1	No		
30-Jul-00	WT 076	M	36	2	No		
31-Jul-00	WT 072	M	86	1	No		
31-Jul-00	WT 073	M	98	2	Yes	82	67
31-Jul-00	WT 074	F	66	7	Yes	98	72
31-Jul-00	WT 075	M	177	8	Yes	76	32
6-Aug-00	WT 071	F	75	-	Yes	49	12
7-Aug-00	WT 069	M	41	1	No		
7-Aug-00	WT 070	F	48	9	Yes	65	55

[a] Estimated with regression equation (Eason and van Manen, University of Tennessee, unpublished data)

Table 3. Capture date, physical characteristics, and number of locations used to determine short-term impacts of a new section of U.S. Highway 64 on black bears, treatment area, Washington County, North Carolina, 2006–2007.

Date	**Bear ID #**	**Sex**	**Mass (kg)**	**Age**	**Radio collar**	**No. of hourly locations**	**No. of daily locations**
24-Jun-06	WT 060	M	32	1	No		
2-Jul-06	WT 061	F	73	6	Yes	258	153
17-Jul-06	WT 062	M	45	2	No		
10-Aug-06	WT 064	F	68	7	Yes	260	181
17-Aug-06	WT 066	F	66	4	Yes	268	182
28-Aug-06	WT 059	F	55	5	Yes	303	171
29-Apr-07	WT 052	M	36	1	No		
30-Apr-07	WT 053	F	80	>5	Yes	101	59
7-May-07	WT 054	M	175	5	Yes	46	51
10-May-07	WT 055	M	81	2	No		
16-May-07	WT 051	F	57	2	Yes	102	102
23-May-07	WT 065	M	127	3	Yes	21	42
24-May-07	WT 057	M	66	2	No		
24-May-07	WT 058	F	61	2	Yes	88	81
27-May-07	WT 056	F	95	7	Yes	104	97
29-May-07	WT 050	F	45	2	Yes	102	87
31-May-07	WT 049	M	83	3	No		
1-Jun-07	WT 101	M	82	3	No		
2-Jun-07	WT 102	F	77	3	Yes	106	90
16-Jun-07	WT 105	F	91	-	Yes	95	85

Table 4. Capture date, physical characteristics, and number of locations used to determine short-term impacts of a new section of U.S. Highway 64 on black bears, control area, Washington County, North Carolina, 2006–2007.

Date	**Bear ID**	**Sex**	**Mass (kg)**	**Age**	**Radio collar**	**No. of hourly locations**	**No. of daily locations**
20-May-06	WT 024	F	34	2	No		
23-May-06	WT 025	M	89	3	Yes		
5-Jun-06	WT 026	M	68	2	No		
8-Jun-06	WT 027	F	45	2	No		
8-Jun-06	WT 028	M	45	-	No		
8-Jun-06	WT 029	F	100	14	Yes	201	175
9-Jun-06	WT 030	F	89	7	Yes	221	182
9-Jun-06	WT 031	M	13	0	No		
9-Jun-06	WT 032	M	82	2	No		
9-Jun-06	WT 033	M	73	3	No		
10-Jun-06	WT 034	F	64	16	Yes	198	137
11-Jun-06	WT 035	M	84	3	No		
1-Jul-06	WT 036	M	91	3	Yes	82	80
6-Jul-06	WT 037	M	120	5	Yes	141	83
16-Jul-06	WT 038	F	41	3	No		
2-Aug-06	WT 039	F	55	6	Yes	122	150
10-Aug-06	WT 063	F	21	1	No		
10-Aug-06	WT 040	M	118	4	Yes	18	6
12-Aug-06	WT 041	F	68	6	Yes	238	174
13-Aug-06	WT 042	M	57	1	No		
14-Aug-06	WT 043	F	54	3	Yes		
20-Aug-06	WT 044	M	210	10	Yes		
27-Aug-06	WT 045	M	64	2	No		

Table 4 cont.

Date	Bear ID	Sex	Mass (kg)	Age	Radio collar	No. of hourly locations	No. of daily locations
8-Sep-06	WT 047	M	30	1	No		
11-Sep-06	WT 048	F	105	14	Yes		
10-May-07	WT 103	F	44	2	Yes	128	87
12-May-07	WT 104	M	23	1	No		
26-May-07	WT 106	M	80	2	No		

VITA

Matthew F. McCollister was born in Montgomery, Alabama on 20 February 1983. He graduated from the Montgomery Academy in 2001. He received a Bachelor of Science degree in Biology in May 2005 from Furman University in Greenville, South Carolina. While an undergraduate student, he worked seasonally for the U.S. Forest Service in New Mexico and the U.S. Fish and Wildlife Service in Alaska. After graduating, he briefly studied at Clemson University and then worked for 6 months with puma and desert bighorn sheep in New Mexico. In June 2006, he began work as a Graduate Research Assistant for the Department of Forestry, Wildlife and Fisheries at the University of Tennessee, Knoxville.