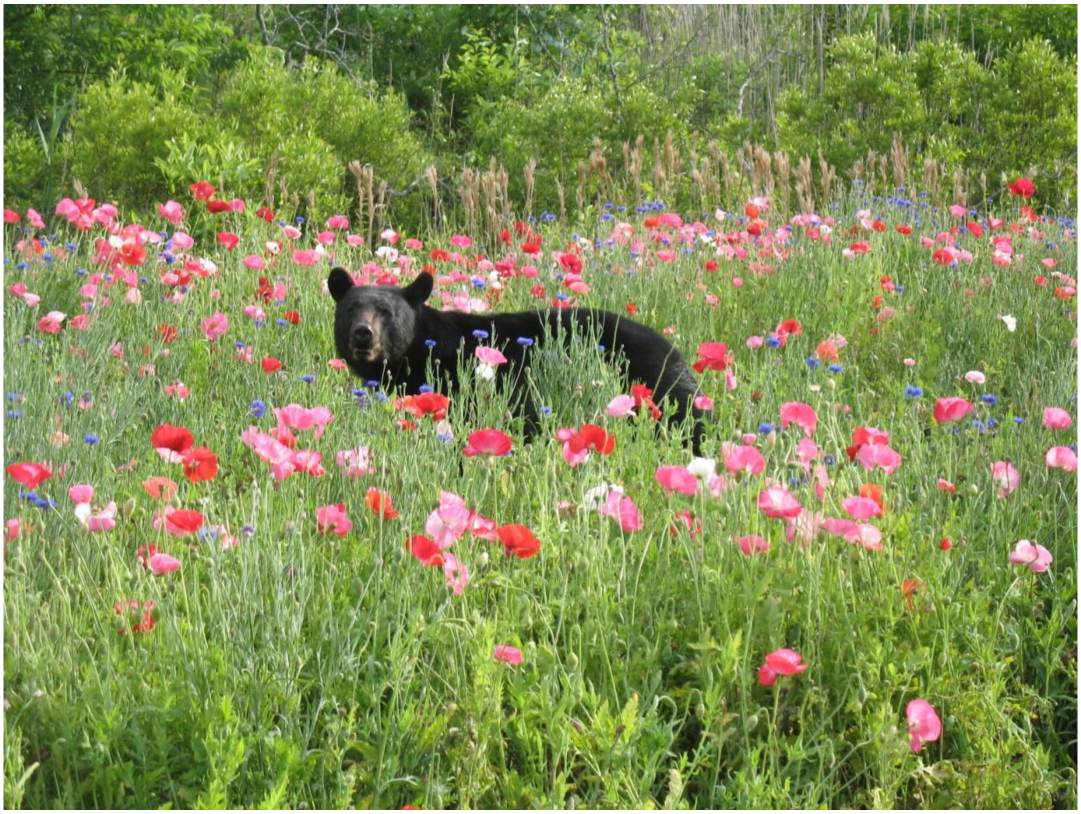
Cost Effective Wildlife Crossing Structures which Minimize the Highway Barrier Effects on Wildlife and Improve Highway Safety along US 64, Tyrrell County, NC



Final Report

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16. Abstract

…This report presents information on research conducted along US 64 from the City of Columbia east to the Alligator River in Tyrell County, NC. The products of the study include a literature review, evaluation of habitat use and wildlife movement patterns, recommendations for need and locations of cost-effective wildlife crossing structures, and recommendations for additional cost effective design and construction measures to minimize adverse impacts to wildlife and increase highway safety The need for wildlife crossing structures and other measures (to improve habitat connectivity and permeability of US 64 for wildlife) was evaluated by monitoring successful and unsuccessful (road-kills) animal movements across the highway. We performed road-kill surveys on the 13 mile segment of US 64. Track monitoring was conducted on 31 tracking strips placed at key locations in adjacent wildlife resource areas and at seven locations on the road right-of-way. Data was collected from April 2009 to July 2011.From all field surveys we documented 134 different species. This included 8 state and federally listed species and 16 other species of conservation interest. Data included a total of 27,886 road-kills and 7,557 tracks. Results of mark-recapture studies of small mammals and herpetofauna included 1,265 individuals along the roadside and 534 individuals at control locations. Several black bear road-kills have been recorded over the last decade and track and photographs documented black bear road crossings at several locations. Few white-tail deer were observed or found as road-kill during this study, however vehicle accident reports provided 10 years worth of data on deer-vehicle accident locations. Large numbers of road-killed frogs, snakes and turtles were recorded throughout the project area, but especially adjacent to forested wetland and marsh impoundment habitat areas. Most can be reduced by using appropriate fencing to reduce the amount of prey species killed on road-sides and altering flight trajectories into traffic. Detailed results including identification of road-kill hotspots and species presence/absence are presented; proposed corrective measures including types and locations for wildlife crossing structures are discussed.…

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EXECUTIVE SUMMARY

This report presents information on research conducted along US 64 from the City of Columbia east to the Alligator River in Tyrrell County, NC. The products of the study include a literature review, evaluation of habitat use and wildlife movement patterns, recommendations for need and locations of cost-effective wildlife crossing structures, and recommendations for additional cost effective design and construction measures to minimize adverse impacts to wildlife and increase highway safety.

The need for wildlife crossing structures or other measures (to improve habitat connectivity and permeability of US 64 for wildlife) was evaluated by monitoring successful and unsuccessful (road-kills) animal movements across the highway. Multiple methods were applied to evaluate activity by different species adjacent to the highway. For instance, remotely operated cameras and tracking stations are effective in capturing presence of medium to large species, and drift fences/pitfall traps are effective in determining presence-absence of small mammals and herpetofauna. Trapping studies were important in determining potential avoidance by certain species to the road right-of-way.

We performed road-kill surveys on the 13 mi segment of US 64. Track monitoring was conducted on 31 tracking strips placed at key locations adjacent to the highway. Mark-recapture studies were performed at four control locations in adjacent wildlife resource areas and at seven locations on the road right-of-way. Data was collected from April 2009 to July 2011.

From all field surveys we documented 134 different species. This included 8 state and federally listed species and 16 other species of conservation interest. Data included a total of 27,886 road-kills and 7,557 tracks. Results of mark-recapture studies of small mammals and herpetofauna included 1,265 individuals along the roadside and 534 individuals at control locations.

The most recent road-killed red wolf was from 2001. More recently, a radio-collared female was documented crossing US 64 several times and tracks of red wolf were documented at several locations. Several black bear road-kills have been recorded over the last decade and track and photographs documented black bear road crossings at several locations. In addition, other carnivores were recorded making successful and unsuccessful road crossings. Few white-tail deer were observed or found as road-kill during this study, however vehicle accident reports provided 10 years worth of data on deer-vehicle accident locations. In addition, deer tracks and photographs provided evidence of locations frequented by deer. Large numbers of road-killed frogs, snakes and turtles were recorded throughout the project area, but especially adjacent to forested wetland and marsh impoundment habitat areas. A wide diversity of avian species was also negatively affected by vehicle strikes. Most can be reduced by using appropriate fencing to reduce the amount of prey species killed on road-sides and altering flight trajectories into traffic.

Detailed results including identification of road-kill hotspots and species presence/absence are presented; proposed corrective measures including types and locations for wildlife crossing structures are discussed.

Cost effective wildlife crossing structures which minimize the highway barrier effects on wildlife and improve highway safety along US 64, Tyrrell County, NC

Final Report

Principal Investigator: Daniel J. Smith

April 2011

INTRODUCTION

Connectivity is well accepted among conservation planners as a critical consideration in the design of reserve networks and multiple-use landscapes (Noss and Cooperrider 1994). Corridors (variably called landscape linkages, connectors, greenways, and other terms) are the most popular means to achieve connectivity. The empirical literature on this topic, though still sparse, is growing rapidly and generally supports the notion that well-designed corridors function to provide demographic connectivity between populations (Beier and Noss 1998). One special type of connectivity is that required to allow animals to move across roads.

Roads are one of the greatest threats to wildlife worldwide (Noss and Cooperrider 1994, Trombulak and Frissell 2000). It is widely recognized by biologists that crossing structures are needed in many cases to allow wildlife to successfully cross highways and maintain connectivity and gene flow within and among populations (Forman et al. 2003, Smith 2003a). However, the construction of large-scale crossing structures can be expensive, costing over one million dollars for a single structure (Beckmann et al. 2010). Therefore it is necessary to perform adequate studies to determine the number and type of structures needed to reduce costs while maximizing the potential for improving road permeability for wildlife.

Baseline conditions need to be established regarding movement, mortality and diversity and abundance of species affected to determine the need, location and design of wildlife crossings. Importantly, monitoring of unsuccessful and successful crossings of highways must encompass multiple species (e.g., amphibians and reptiles as well as mammals), because different structures and landscape/habitat conditions promote movement of different taxa (Clevenger and Waltho 2005, Smith 2003b). It is essential that planners know the places where wildlife are most likely to cross roads so that mitigation measures are best employed in the reduction of collisions and population bisection (Langen et al. 2009).

The North Carolina Department of Transportation (NCDOT) is developing alternative proposals for widening US 64 from Columbia, NC east to the Alligator River. Project planning requirements include the need to evaluate the potential of increased habitat fragmentation and barrier effects on persistence of populations, habitat use, and successful dispersal and other movements by black bear, red wolf, white-tailed deer and other wildlife. The following study evaluates the current impacts to wildlife associated with the existing 2-lane configuration and potential adverse effects related to the proposed widening of this segment to 4-lanes. It combines the use of literature, information and data gathered from previous or ongoing studies both locally and throughout the US with field data collection and GIS analysis for the project area.

BACKGROUND INFORMATION

The North Carolina Department of Transportation contracted with the University of Central Florida (UCF), Department of Biology, Conservation Biology Program to collect baseline data and perform analyses to identify highway hotspots for listed species and other species of conservation interest on US 64 in Tyrrell County, east of the City of Columbia. This project was funded by NCDOT and occurred from February 2009 to May 2011.

Problem or Need Definition

Information was needed to facilitate selection of a preferred alternative that avoids and minimizes adverse barrier effects of the highway on wildlife and improves highway safety by reducing the likelihood of collisions. A comparison of newly compiled information from other relevant studies and collection of data and analysis from this project would increase our understanding of wildlife activity patterns, movement, and habitat use of highway corridors and improve our decision-making ability regarding design and placement of wildlife crossings and other means of improving permeability of roads for wildlife.

This highway project raised several concerns regarding potential negative effects on wildlife including:

- Increased wildlife-vehicle collision risk
- Reduction and fragmentation of wildlife habitat
- Barrier effects of the highway on wildlife—changes in dispersal, movement and land utilization

Research Objective

The objective was to develop solutions regarding potential barrier effects of the road and the need, design and locations for wildlife crossings. An assessment was conducted to determine the most cost-effective means of avoiding or minimizing the impacts of the road including the potential use of wildlife crossing structures as a mitigation measure. The project objective is further outlined by tasks as follow:

1. Conduct a literature review of existing wildlife crossing design and location studies for black bear, white-tailed deer, wolves and other pertinent wildlife

2. Analyze data on vehicle accidents involving wildlife and roadkill in the project area

3. Evaluate wildlife habitat use along the US Hwy 64 corridor from Columbia to the Alligator River including:

    - Evaluate wildlife habitat and identify landscape attributes that promote wildlife use
    - Assess the extent to which the area adjacent to the US Hwy 64 corridor is occupied and utilized by wildlife

- Identify target areas to focus study locations for structure placement
- Refine crossing location sites which will allow continued wildlife dispersal and movement across the highway

4. Coordinate with the NCDOT research steering committee, NC Wildlife Resources Commission, Pocosin Lakes National Wildlife Refuge and the US Fish and Wildlife Service Red Wolf Recovery Team

Comprehensive Approach to Assess Road Impacts

The research team employed several methods to conduct a detailed examination of current and potential impacts of the highway on wildlife resources within and in the area adjacent to the highway corridor from Columbia to the Alligator River. The research team engaged in 5 primary activities:

- consulting and coordinating with NCDOT, resource management agencies and others, as applicable, to assemble information such as habitat inventories and species surveys
- collecting all previously recorded vehicle-wildlife collision data and conducted new roadkill surveys along the entire 13 mi section of US 64
- monitoring of track paths in targeted sections of US 64
- trapping and mark-recapture studies along the right-of-way for small mammals and herpetofauna to determine effects of the existing highway on local movement behavior
- acquiring aerial photographs and GIS data to evaluate spatial patterns of habitat use and movement by wildlife in relation to the US 64 highway corridor with reference to maintaining/restoring regional connectivity between protected conservation areas in Tyrrell County

The scientific information obtained from this broad approach enabled the research team to provide recommendations for facility improvements to US 64 to maintain or improve the ecological integrity of the area and to insure continued or improved permeability of the highway for wildlife.

STUDY AREA AND METHODS

Study Area Description

The project study area included a 13 mi section of US Highway 64 from Columbia to the Alligator River in Tyrrell County, North Carolina (fig. 1). Tyrrell County is a rural area that in 2000 was the least populous county in the state (4,149) with a population density of 11 people per sq. mi. The largest population center, which comprises 20% of the county's residents, is the City of Columbia located at the western end of the project.

Two national wildlife refuges, Alligator River and Pocosin Lakes (fig. 1), are near or adjacent to the pending highway project and wildlife within and surrounding these areas could likely be negatively impacted. Species of particular interest include the black bear and red wolf, but several other species could be impacted as well including white-tailed deer, river otter, and a wide variety of birds, reptiles and amphibians.

Figure 1. Study area location in northeastern North Carolina.

Coordination with Stakeholders

The first step was to assemble all information gathered from various agencies and organizations that would facilitate the research objective. This included information gathered for habitat and species inventories, previous data collected on faunal movements and/or species location records, aerial photos, imagery or digital data, local government and state agency land development and management plans, land ownership and descriptions. This information was used to facilitate GIS and field studies.

Literature Review

We created a literature review of previous and current research on wildlife and roads. This involved searching available indexes and on-line databases of peer-reviewed publications, agency and government reports, and other gray literature. We also reviewed current and previous research projects on black bears and red wolves in the Southeastern Coastal Plain Region to include any relevant information that would assist with achieving the project objectives. In addition to the scientific literature review, we compiled available cost figures for different crossing types and sizes and alternative mitigation measures employed throughout the US.

Site Monitoring

We determined successful and unsuccessful wildlife crossing locations by performing roadkill, track and trapping surveys. We also had access to data from camera stations administered by Virginia Tech. Each task conducted in this project and specific methods are described below.

Road-kill Surveys

We conducted road-kill monitoring surveys (from Columbia City Limits to Alligator River) of all vertebrates by vehicle. US Hwy 64 was checked every other day three days per week by driving 10 mph or less and stopping and recording observed road-kills on the pavement and shoulder of the road. We documented the date, location (using GPS), species (to most precise taxonomic level discernable) and sex and age class (if it could be determined). Recorded road-kills were then marked with orange paint to avoid repeated counting. We recorded road-kill locations in a spatial database.

We coordinated with NCWRC and USFWS for current/historic black bear and red wolf road-kill data and NCDOT for animal-vehicle accident reports and road-kill maintenance and carcass removal information.

Pre-construction Right-of-Way (ROW) Track Monitoring

Track beds were constructed adjacent and parallel to the paved surface of the road at strategic locations (at access trails, roads and canal crossings and at significant habitat ecotones). We coordinated with NCDOT for initial preparation of the 2-m wide track beds that required tilling and herbicide spraying to remove established vegetation. These track beds were constructed from native soils and enhanced by adding sand at locations where tracks were difficult to read. Track beds were checked twice weekly (every third day) for medium to large vertebrates (mammals, turtles, snakes, turkeys). Track beds were maintained by hand raking or tilling with a 1-m wide harrow pulled by an ATV (fig. 2). We documented date, track bed location, species (to most precise taxonomic level discernable) and direction of travel.

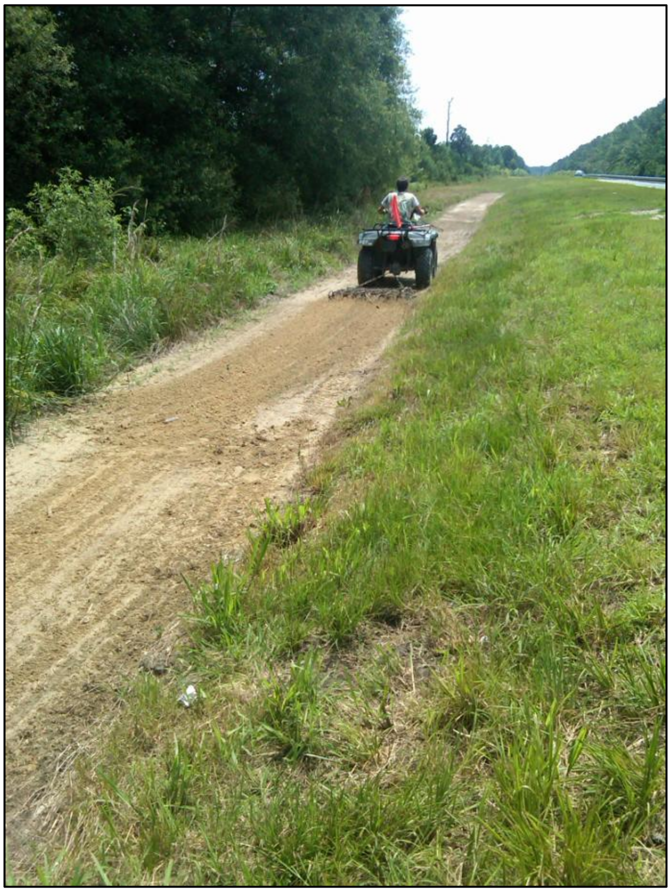


Figure 2. Example of roadside track bed maintenance.

Camera Stations

We signed a data-sharing agreement with the Virginia Tech research team for use of their field camera data for this project. Camera stations were located on canal crossings at adjacent access roads and trails. Many cameras were at locations unsuitable for track beds; in this regard they supplemented the tracking station data. Camera and track data were analyzed separately because of the inherent differences in the data collection methods. For instance, particular species could usually be detected from a photograph, while tracks of similar species were sometimes indistinguishable (e.g, canids, snakes). Conversely, cameras typically only detected larger animals, whereas track beds revealed tracks from small animals. In some cases camera stations and track beds were co-located at the same site.

Presence-Absence Surveys for Small Mammals and Herpetofauna

Drift fence trapping arrays were constructed to perform presence/absence surveys of small mammals and herpetofauna within the right-of-way. Comparable control sites were established beyond 500 m of the right-of-way. Seven roadside trap arrays and four controls were constructed. Chosen locations of the trap arrays corresponded to the major habitat types along the highway corridor. Trap arrays consisted of a 100-ft long silt fence equipped with pitfall and screen funnel traps (fig. 3 and 4). Drift fences were a total of 4 ft wide; they were installed 3 ft above and one ft below ground. Controls had six pitfall traps and four screen funnel traps. Roadside traps had only three pitfall traps (reduced to three to reduce potential as a roadside vehicle hazard) and four screen funnel traps. Shade covers were placed over each trap and wet sponges were used in each trap to prevent desiccation during hot months. Cotton balls were used to provide insulation in the winter. When weather conditions were severe, traps were closed.

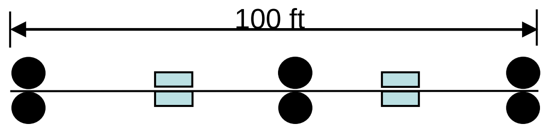


Figure 3. Drift fence array configuration.

Figure 4. Example of a roadside drift fence array.

Trapping was conducted three days per week. Those individuals captured were marked and released and traps replaced. Small mammals (primarily rodents) were marked using uniquely numbered metal ear tags. Frogs and lizards were marked by toe-clipping (Heyer et al. 1994). Snakes were marked by clipping ventral scales (Brown 1976). We documented date, trap location, species, sex and age class (if it could be determined), length and weight.

GIS and Image Analysis

GIS layers for this study included aerial photographs, hydrology, roads, land cover (1996), existing and proposed conservation lands, species location information, etc. These data layers were used in conjunction with results of track, mark-recapture and roadkill surveys to evaluate existing movement patterns and behavior of individual species (and collective groups of taxa) and to predict potential changes in response to the expansion of US 64.

RESULTS

Results are presented in three sections: study area description, species inventories, and road section analyses.

Study Area Characterization

Following Smith (1999), the US 64 road corridor was evaluated in terms of its context and relationship to important wildlife conservation areas identified in Tyrrell County, North Carolina. Physical and biological features of the study area, including land-cover (vegetation and land-use), hydrography, roads, existing and proposed conservation lands, and large scale agriculture and development were identified.

The study area includes the 13 mile 2-lane highway from the City of Columbia east to the Alligator River, the associated road right-of-way clear zones and adjacent lands. An adjacent large canal runs the entire length of the road from old US 64 to the Alligator River (approximately 8.25 mi). Smaller canals and roadside ditches are also common along the western section of the project. Traffic volume on the two-lane alignment peaks at 5,000 – 6,000 vehicles per day in June and July. Traffic levels are lowest from December to February (2,000 – 2,500 vehicles per day). The City of Columbia and the small rural communities of Alligator and Newfoundland are the only local traffic generators. The remaining traffic is associated with trips to and from the much more intensely developed coastal communities.

The only available land cover data for the study area was a 1996 dataset created by the North Carolina Center for Geographic Information and Analysis based on 1995 EOSAT imagery with a 28.5 m pixel resolution (fig. 5a). Given that minimal land conversion to development has occurred in Tyrrell County since 1995, this data should still be acceptable for use in this study. Land cover for the study area consists of a mosaic of 18 different land cover classes (fig. 5b). These include 6 types of natural upland and wetland forest communities (broadleaf evergreens, mixed hardwoods, mixed hardwoods/conifers, other needleleaf evergreens, oak/gum/cypress, and hardwood swamps), 3 types of shrublands (evergreen, deciduous and mixed), managed southern yellow pine forests, unmanaged herbaceous wetland and uplands, managed herbaceous cover, cultivated, unconsolidated sediment (bare ground), low and high intensity development and water bodies. Dominant land cover types include managed southern yellow pine (25,766 ac; 35%), cultivated (11,140; 15%) and hardwood swamps (23,860; 33%). Agriculture and silviculture accounted for 51% of the study area; developed areas were minimal (276 ac, less than 1% of the total area). The area contains valuable natural and managed habitat occupied by red wolf, black bear, white-tail deer, red-cockaded woodpecker, American alligator and many other species of wildlife.

It should be noted that ground-truthing the 1996 land cover revealed large areas designated as "cultivated" that were probably clear-cuts or recently planted "managed southern yellow pine" at the time they were classified. Misclassifications of land cover types of similar reflectance are common in analysis of satellite data, especially when conducted on large scales, in this case a statewide dataset. It isn't typically possible to field verify all locations. In addition, areas that are currently marsh impoundments were classified as cultivated. To evaluate the potential effect of land cover on spatial patterns associated with the field data collected, we corrected these misclassifications within 100 m of each side of the roadway. We reclassified the 1996 land cover into the following 8 major categories: cultivated, development, managed pine forest, marsh impoundment, shrubland, upland forest, water, and wetland forest.

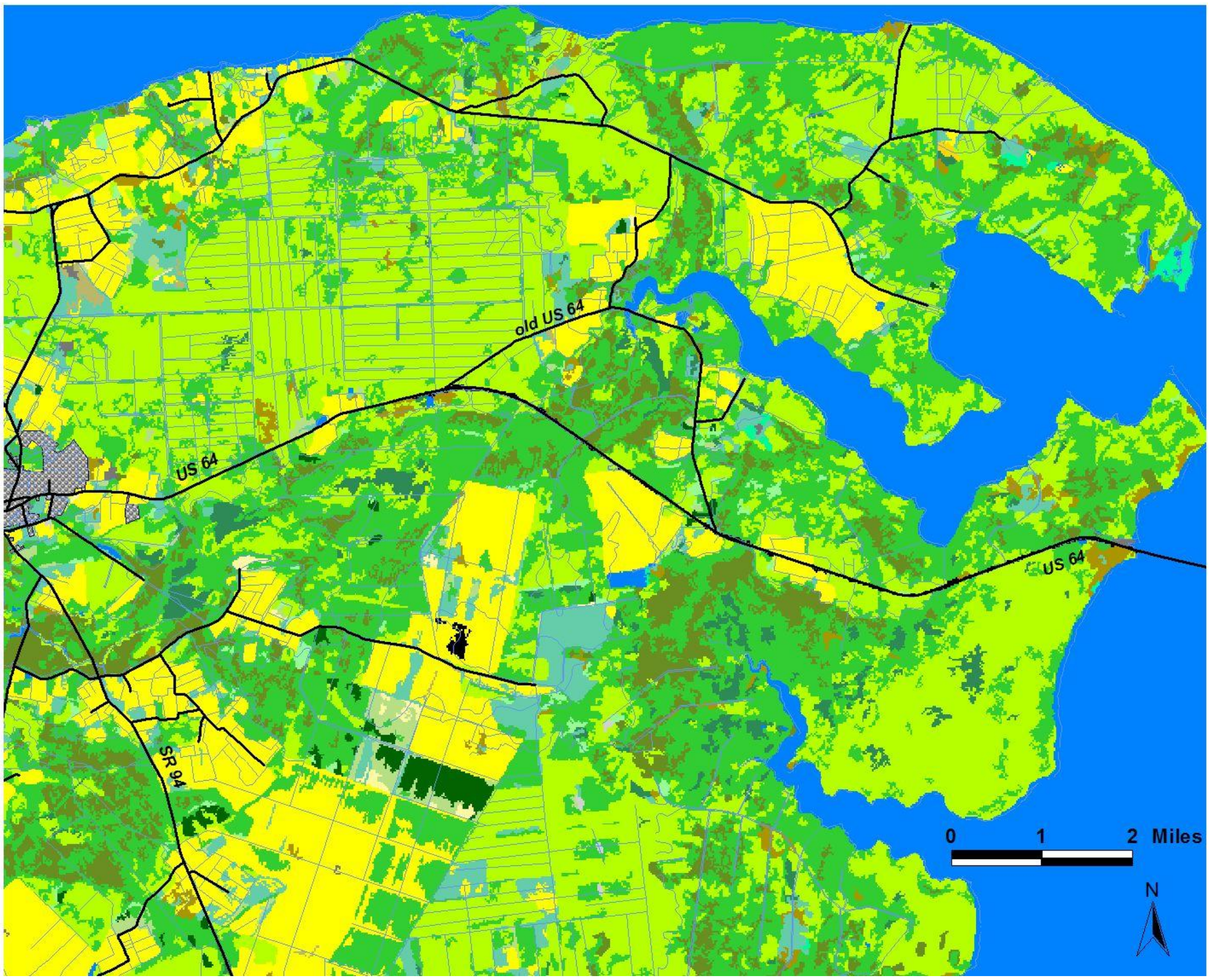


Figure 5a. Surrounding Land Cover (1996) for the US 64 Study Area (see fig. 5b for land cover categories). Source: http://www.nconemap.org.

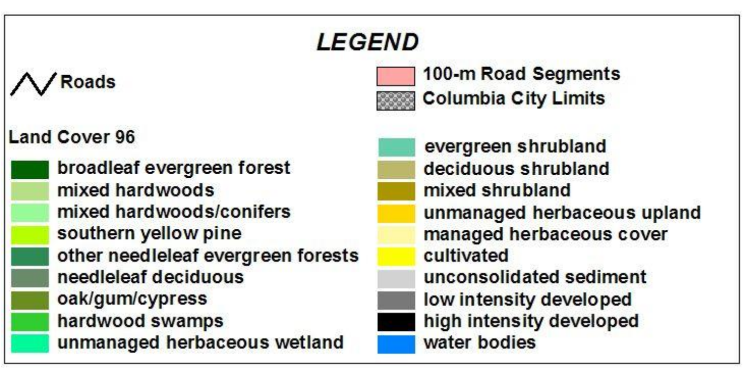


Figure 5b. Key to Land Cover Categories (see fig 6a). Source: http://www.nconemap.org.

Several public and private conservation areas are located in the study area (fig 6). These lands comprise the majority of the eastern half of the project length. These include the Pocosin Lakes National Wildlife Refuge, Alligator River State Game Lands and J. Morgan Futch Waterfowl Impoundment Area, The Conservation Fund's Palmetto-Peartree Preserve and Wetlands America Trust Lands. The Pocosin Lakes NWR (96,700 ac) is south and west of the project area. Most of the protected conservation lands that border US 64 are the Alligator River State Game Lands (14,300 ac). The J. Morgan Futch Impoundment Area (576 ac) is also adjacent to US 64. The Palmetto Peartree Preserve (11,725 ac) occurs primarily on the north side of the existing highway. The Wetlands America Lands consist of 1,519 ac on the north side of Little Alligator Creek. Other Significant Natural Heritage Lands (Scuppernong River Swamp Forest, Palmetto-Peartree Swamp Forest and Alligator/Second Creek Swamp Forest) connect these public and private conservation land holdings and form an ecological network of valuable wildlife habitat across several counties in northeast North Carolina. In the project area only, these proposed conservation lands consist of 8,434 ac.

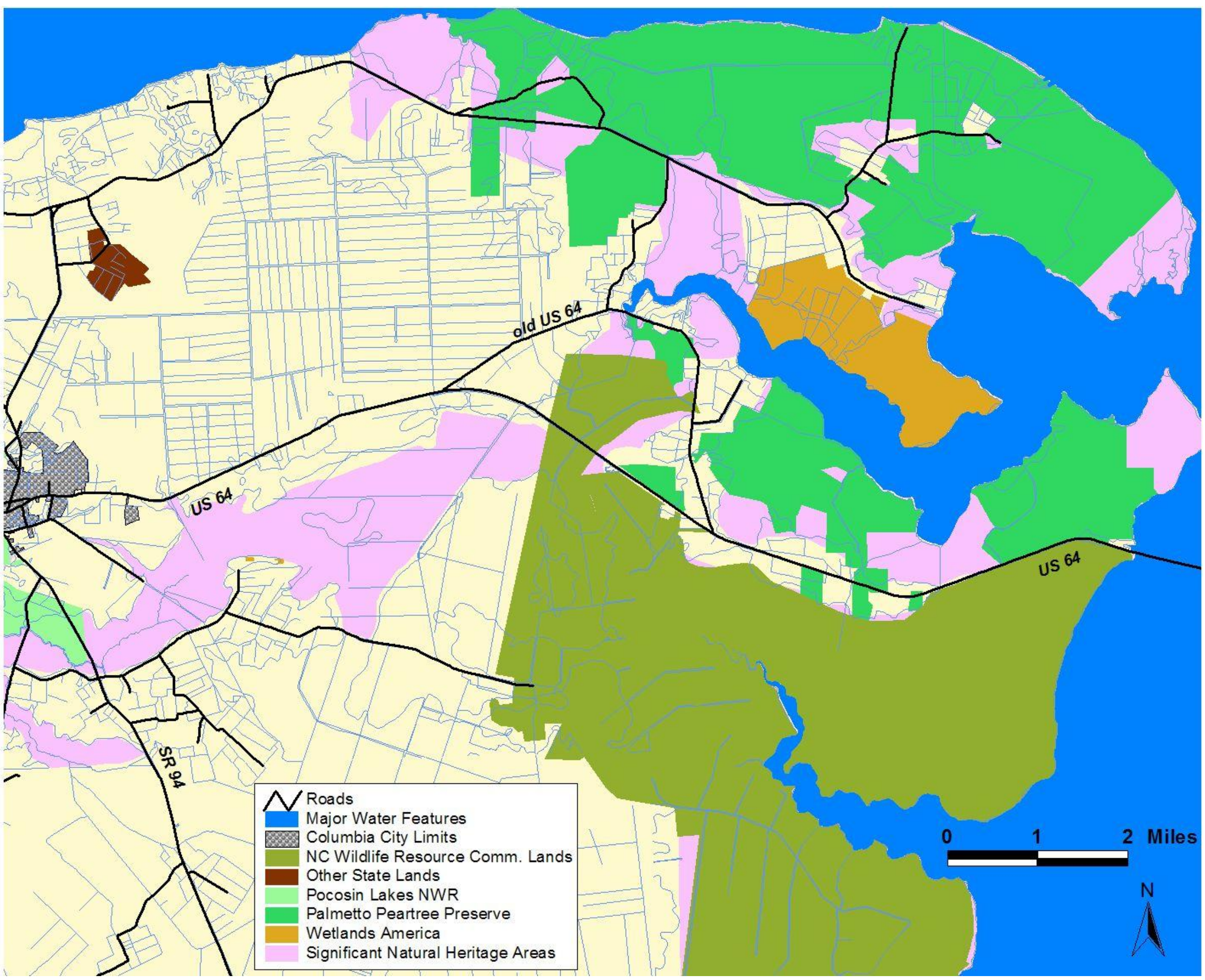


Figure 6. Existing and Proposed Conservation Lands. Source: http://www.nconemap.org.

The western half of the project area is dominated by large-scale silviculture operations. The largest landowner is Weyerhauser Corporation. From aerial photographs, uneven-aged stands of managed pines were digitized (fig. 7). Weyerhauser provided base maps that included year of planting for stands adjacent to US 64. We used these to estimate relative age of remaining stands based on visual similarity from the aerial photographs (fig. 7). Bounded to the north and south by Sound Side Road and Mills Road and east of Columbia and west of old US 64 there is approximately 6,500 ac of managed pinelands. Those areas shown in fig. 7 greater than 50 yrs old consist of natural forest types, typically hardwood swamps or mixed hardwoods/conifers. Not shown in fig. 7 are much smaller patches of these same natural forest types contained within many of the managed stands. This area of Tyrrell County is extremely low in elevation and is dominated by wetlands. As a result, development of commercial forestry areas includes a large network of canals and artificial waterways for water control and drainage.

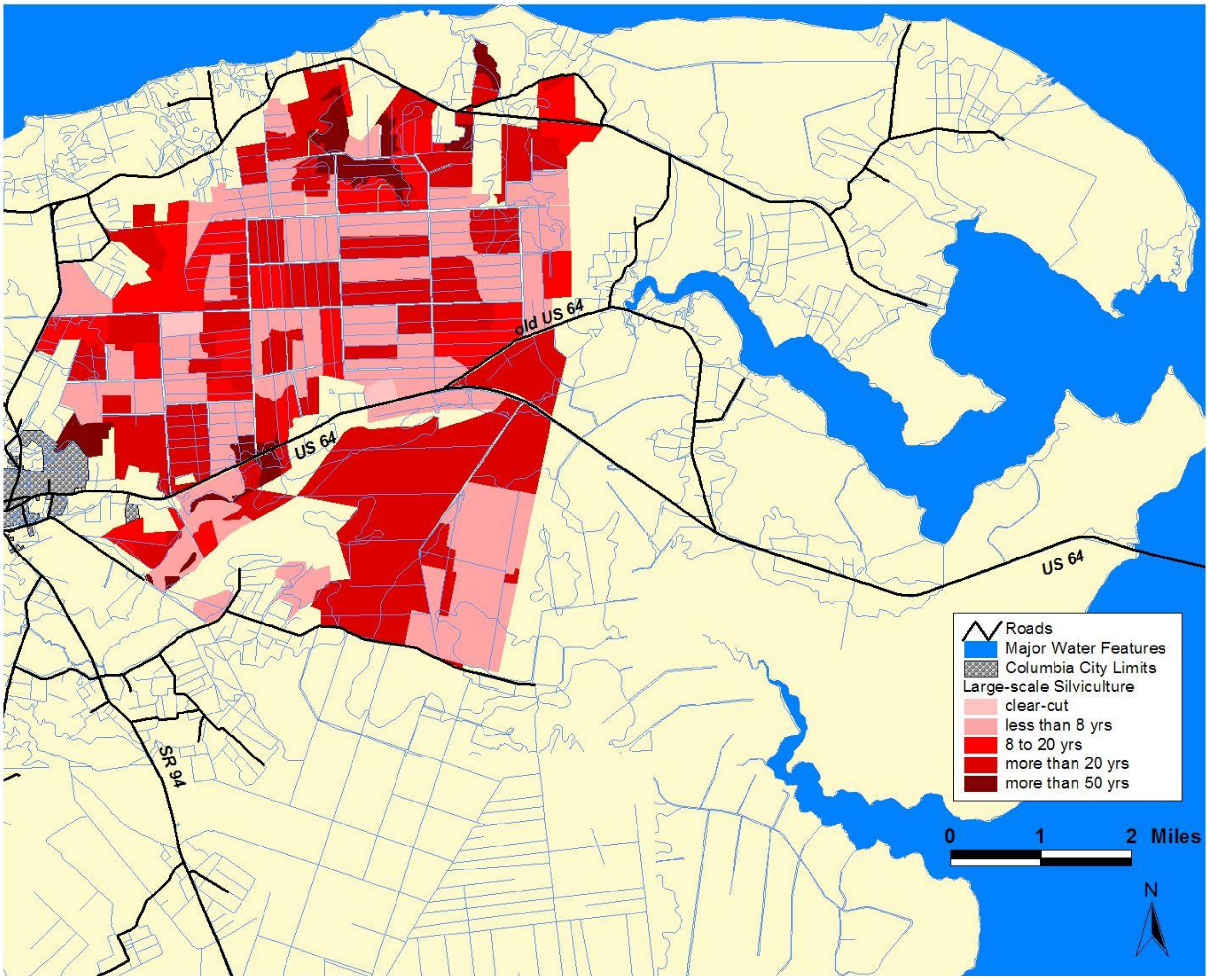


Figure 7. Relative Stand Ages on Large-scale Silviculture Lands in the US 64 Study Area. Source: Weyerhauser and http://www.nconemap.org.

Based on the nature of commercial forestry operations in this area, most stands rotate on a 25 to 40 year cycle. This fluidity likely results in shifting wildlife movement paths over time as individual animals and populations adapt to changing stand height/density and understory characteristics associated with preferred cover for movement or foraging. This lack of stability in cover characteristics at specific locations within this type of landscape must be taken into account when considering locations for wildlife crossings; hotspots for wildlife-vehicle collisions and preferred movement paths will likely change on the same 25 to 40 year cycle.

Species Inventories

For the entire length of the study area we recorded 133 different species (Table 1). These were categorized by faunal groups that include birds (n=43), carnivores (n=7), domesticated (n=2), invertebrates (n=1), meso-mammals (n=2), small mammals (n=18), ungulates (n=2) and herpetofauna (n=58).

Table 1. Species List from the US 64 Study Area, 2009 – 2010.

Group Name	Scientific Name	Common Name	Roadkill	Track/photo	Live Observation	Trap
Avifauna	*Aix sponsa*	wood duck	X			
Avifauna	*Archilochus colubris*	ruby-throated hummingbird	X			
Avifauna	*Ardea herodias*	great blue heron	X	X	X	
Avifauna	*Bubo virginianus*	great horned owl	X			
Avifauna	*Buteo lineatus*	red-shouldered hawk	X	X		
Avifauna	*Cardinalis cardinalis*	northern cardinal	X	X		
Avifauna	*Cathartes aura*	turkey vulture	X			
Avifauna	*Catharus fuscescens*	veery	X			
Avifauna	*Catharus guttatus*	hermit thrush	X			
Avifauna	*Coccyzus americanus*	yellow-billed cuckoo	X			
Avifauna	*Colaptes auratus*	northern flicker	X			
Avifauna	*Colinus virginianus*	northern bobwhite	X		X	
Avifauna	*Corvus brachyrhyynchos*	American crow		X		
Avifauna	*Corvus corax*	common raven		X		
Avifauna	*Cygnus columbianus*	tundra swan	X			
Avifauna	*Dendroica coronata*	yellow-rumped warbler	X			
Avifauna	*Dendroica pinus*	pine warbler	X			
Avifauna	*Dryocopus pileatus*	pileated woodpecker	X			
Avifauna	*Dumetella carolinensis*	gray catbird	X			
Avifauna	*Halieatus leucocephalus*	bald eagle			X	
Avifauna	*Leucophaeus atricilla*	laughing gull	X			
Avifauna	*Melanerpes erythrocephalus*	red-headed woodpecker	X			
Avifauna	*Meleagris gallopavo*	wild turkey	X	X	X	
Avifauna	*Melospiza georgiana*	swamp sparrow	X			
Avifauna	*Otus asio*	eastern screech owl	X		X	
Avifauna	*Passerella iliaca*	fox sparrow	X			
Avifauna	*Passerina caerulea*	blue grosbeak	X			
Avifauna	*Picoides pubescens*	downy woodpecker	X			
Avifauna	*Pipilo erythrophthalmus*	eastern towhee	X			
Avifauna	*Poecile carolinensis*	carolina chickadee	X			
Avifauna	*Protonotaria citrea*	prothonotary warbler	X			
Avifauna	*Quiscalus quiscula*	common grackle	X			
Avifauna	*Regulus calendula*	ruby-crowned kinglet	X			

Table 1. (continued).

Group Name	Scientific Name	Common Name	Roadkill	Track/photo	Live Observation	Trap
Avifauna	*Sialia sialis*	eastern bluebird	X			
Avifauna	*Spizella passerina*	chipping sparrow	X			
Avifauna	*Sturnella magna*	eastern meadowlark	X		X	
Avifauna	*Sturnus vulgaris*	european starling	X			
Avifauna	*Tachycineta bicolor*	tree swallow	X		X	
Avifauna	*Thryothorus ludovicianus*	carolina wren	X			
Avifauna	*Troglodytes aedon*	house wren	X			
Avifauna	*Turdus migratorius*	American robin	X			
Avifauna	*Zenaida macroura*	mourning dove	X			
Avifauna	*Zonotrichia albicollis*	white-throated sparrow	X			
Carnivore	*Canis latrans*	coyote	X	X		
Carnivore	*Canis rufus*	red wolf		X		
Carnivore	*Lutra canadensis*	North American river otter	X	X	X	
Carnivore	*Lynx rufus*	bobcat	X	X	X	
Carnivore	*Mustela vison*	American mink	X	X		
Carnivore	*Urocyon cinereoargenteus*	gray fox	X	X	X	
Carnivore	*Ursus americanus*	American black bear	X	X	X	
Domestic	*Canis lupus familiaris*	domestic dog		X		
Domestic	*Felis catus*	domestic cat		X		
Herpetofauna	*Acris gryllus*	southern cricket frog	X		X	X
Herpetofauna	*Agkistrodon c. contortix x mokasen*	copperhead	X		X	
Herpetofauna	*Agkistrodon p. piscivorus*	cottonmouth				X
Herpetofauna	*Amphiuma means*	two-toed amphiuma				X
Herpetofauna	*Anolis carolinensis*	green anole	X		X	X
Herpetofauna	*Bufo americanus*	American toad	X	X		X
Herpetofauna	*Bufo terrestris*	southern toad	X			X
Herpetofauna	*Bufo woodhousei*	Woodhouse's toad	X			X
Herpetofauna	*Carphophis a. amoenus*	eastern wormsnake	X			X
Herpetofauna	*Chelydra s. serpentina*	common snapping turtle	X		X	
Herpetofauna	*Chrysemys p. picta*	painted turtle	X	X	X	X
Herpetofauna	*Chrysemys scripta*	red-eared slider	X			
Herpetofauna	*Clemmys guttata*	spotted turtle	X	X	X	X
Herpetofauna	*Coluber c. constrictor*	northern black racer	X		X	X
Herpetofauna	*Crotalus horridus*	timber rattlesnake	X			
Herpetofauna	*Deirochelys reticularia**	chicken turtle*	X			
Herpetofauna	*Desmognathus auriculatus*	southern dusky salamander				X
Herpetofauna	*Diadophis p. punctatus*	southern ringneck snake	X			X
Herpetofauna	*Elaphe g. guttata*	cornsnake	X			X
Herpetofauna	*Elaphe o. obsoleta*	black rat snake	X		X	
Herpetofauna	*Eumeces fasciatus*	five-lined skink				X
Herpetofauna	*Eumeces inexpectatus*	SE five-lined skink			X	X
Herpetofauna	*Farancia a. abacura*	eastern mud snake	X		X	X

Table 1. (continued).

Group Name	Scientific Name	Common Name	Roadkill	Track/photo	Live Observation	Trap
Herpetofauna	*Heterodon platirhinos*	eastern hognose snake	X			
Herpetofauna	*Hyla chrysoscelis*	Cope's grey treefrog	X			X
Herpetofauna	*Hyla cinerea*	green treefrog	X			X
Herpetofauna	*Gastrophryne carolinensis*	narrowmouth frog	X			X
Herpetofauna	*Hyla femoralis*	pine woods treefrog	X			X
Herpetofauna	*Hyla squirella*	squirrel treefrog				X
Herpetofauna	*Kinosternon s. subrubrum*	eastern mud turtle	X		X	X
Herpetofauna	*Lampropeltis g. getula*	eastern kingsnake	X			X
Herpetofauna	*Lampropeltis t. triangulum x elapsoides*	scarlet kingsnake	X			
Herpetofauna	*Nerodia e. erythrogaster*	redbelly watersnake	X			
Herpetofauna	*Nerodia f. fasciata*	banded watersnake	X		X	X
Herpetofauna	*Nerodia s. sipedon x pleuralis*	midland/northern watersnake	X			
Herpetofauna	*Nerodia taxispilota*	brown watersnake	X			
Herpetofauna	*Notophthalmus viridescens*	eastern newt	X			
Herpetofauna	*Opheodrys a. aestivus*	rough green snake	X			X
Herpetofauna	*Plethodon chlorobryonis*	AC slimy salamander				X
Herpetofauna	*Pseudacris brimleyi*	Brimley's chorus frog				X
Herpetofauna	*Pseudacris c. crucifer*	northern spring peeper	X			X
Herpetofauna	*Pseudemys c. concinna*	eastern river cooter	X			
Herpetofauna	*Pseudemys f. floridana*	Florida cooter	X			
Herpetofauna	*Pseudemys r. rubriventris*	northern red-belly cooter	X		X	
Herpetofauna	*Rana catesbeiana*	American bullfrog	X			X
Herpetofauna	*Rana clamitans melanota*	northern green frog	X			X
Herpetofauna	*Rana sphenocephala*	southern leopard frog	X		X	X
Herpetofauna	*Rana virgatipes*	carpenter frog	X			X
Herpetofauna	*Regina r. rigida*	glossy crayfish snake	X			
Herpetofauna	*Scincella lateralis*	ground skink			X	X
Herpetofauna	*Seminatrix pygaea paludis*	carolina swamp snake	X			X
Herpetofauna	*Sternotherus odoratus*	common musk turtle	X			X
Herpetofauna	*Terrapene c. carolina*	eastern box turtle	X			X
Herpetofauna	*Thamnophis s. sauritus*	eastern ribbon snake	X			
Herpetofauna	*Thamnophis s. sirtalis*	common garter snake	X			X
Herpetofauna	*Trachemys s. scripta*	yellow-belly slider	X	X	X	
Herpetofauna	*Virginia striatula*	rough earth snake	X			
Herpetofauna	*Virginia v. valeriae*	smooth earth snake	X			X
Invertabrate	*Danaus plexippus*	monarch butterfly		X		
Meso mammal	*Didelphis marsupialis*	Virginia opossum	X	X	X	
Meso mammal	*Procyon lotor*	raccoon	X	X	X	
Small mammal	*Blarina brevicauda*	northern short-tailed shrew				X
Small mammal	*Condylura cristata*	star-nosed mole	X			X
Small mammal	*Cryptotis parva*	least shrew				X
Small mammal	*Lasiurus borealis*	red bat	X			

Table 1. (continued).

Group Name	Scientific Name	Common Name	Roadkill	Track/photo	Live Observation	Trap
Small mammal	*Microtus pennsylvanicus*	meadow vole				X
Small mammal	*Myocastor coypus*	nutria	X	X	X	
Small mammal	*Ochrotomys nuttalli*	golden mouse				X
Small mammal	*Ondatra zibethicus*	muskrat		X		
Small mammal	*Oryzomys palustris*	marsh rice rat	X			
Small mammal	*Peromyscus leucopus*	white-footed mouse	X			X
Small mammal	*Corynorhinus rafinesquii*	Rafinesque's big-eared bat	X			
Small mammal	*Reithrodontomys humulis*	eastern harvest mouse	X			X
Small mammal	*Scalopus aquaticus*	eastern mole	X			
Small mammal	*Scuirus carolinensis*	gray squirrel	X	X	X	
Small mammal	*Sigmodon hispidus*	hispid cotton rat	X			X
Small mammal	*Sorex longirostris*	southeastern shrew				X
Small mammal	*Sylvilagus floridanus*	eastern cottontail	X	X		
Small mammal	*Sylvilagus palustris*	marsh rabbit	X			
Ungulate	*Odocoileus virginianus*	white tailed deer	X	X	X	
Ungulate	*Sus scrofa*	wild boar		X		

*denotes unverified records.

Imperiled and/or Focal Species

Several imperiled and/or focal species were identified within the study area. Imperiled species are those Federally or State listed (Table 2). Focal species include those, though not listed, that are of particular conservation interest because of rarity, ecological importance (e.g., keystone or wide-ranging species) or special management needs including game species (Table 3). Special recognition of these species was afforded in the analysis.

Table 2. List of Imperiled Species Recorded (road-kill records 04/09 – 06/10).

Type	Imperiled Species	Common Name	State Status	Federal Status	# Road kills
Aves	*Halieatus leucocephalus*	bald eagle	T	BGPA	
Aves	*Picoides borealis*	red-cockaded woodpecker		E	
Carnivore	*Canis rufus*	red wolf	SR	E	
Chiroptera	*Corynorhinus rafinesquii*	Rafinesque's big-eared bat	SC	SC	1
Small mammal	*Condylura cristata*	star-nosed mole	SC		2
Herpetofauna	*Alligator mississippiensis*	American alligator		T (S/A)	
Herpetofauna	*Crotalus horridus*	timber rattlesnake	SC		1
Herpetofauna	*Deirochelys reticularia*	chicken turtle	SC		2*

Notations: E – endangered, T – threatened, SC – special concern, BGPA – Bald and Golden Eagle Protection Act, T(S/A) – threatened due to similarity of appearance, SR – significantly rare; *denotes unverified records.

Table 3. Other Species of Conservation Interest (road-kill records 04/09 – 06/10).

Type	Scientific Name	Common Name	Status	# Road kills
Aves	*Meleagris gallopavo*	wild turkey		1
Aves	*Colinus virginianus*	northern bobwhite		6
Carnivore	*Urocyon cinereoargenteus*	gray fox		5
Carnivore	*Ursus americanus*	black bear		7*
Carnivore	*Lynx rufus*	bobcat		1
Carnivore	*Lutra canadensis*	river otter		4
Carnivore	*Mustela vison*	American mink		8
Ungulate	*Odocoileus virginianus*	white-tail deer		1*
Herpetofauna	*Lampropeltis t. triangulum x elapsoides*	scarlet kingsnake	W1	4
Herpetofauna	*Regina rigida*	glossy crayfish snake	SR	25
Herpetofauna	*Seminatrix pygaea paludis*	carolina swamp snake	SR	35
Herpetofauna	*Virginia v. valeriae*	smooth earth snake	W2	1
Herpetofauna	*Clemmys guttata*	spotted turtle	W1	201
Herpetofauna	*Pseudemys r. rubriventris*	northern red-belly cooter	W1	30
Herpetofauna	*Terrapene c. carolina*	eastern box turtle		39
Herpetofauna	*Pseudacris brimleyi*	Brimley's chorus frog	W1	

Notations: SR – significantly rare, W1/W2 – watch list; *only includes road-kills recorded as part of this study.

Field Surveys

Wildlife survey results are presented by monitoring activity. These include road-kill, track/photograph, and mark-recapture surveys. Road-kill monitoring was performed for all species. Track monitoring was performed for carnivores, mesomammals, ungulates, wild turkey, and large snakes and turtles. Mark-recapture studies were performed on small mammals and herpetofauna at selected locations along the road right-of-way and within adjacent habitat areas. Field surveys were conducted from April 2009 to July 2010.

Road-kill

Diversity and Abundance. Road-kill data was subdivided into five categories: mammals, birds, snakes, turtles and amphibians. A total of 202 mammals from 22 different species were recorded (fig. 8). Virginia opossum (78) and raccoon (29) were most abundant. Other key carnivores recorded included American mink (8), black bear (7), bobcat (1) and gray fox (5). Eleven road-kill bats were found. Only one white-tail deer was recorded during the study period, though we learned that many carcasses were likely removed prior to the opportunity for us to record these for use in this study. From NCDOT animal-related crash reports covering 2000 to 2010, approximately 3.27 vehicle collisions with white-tail deer per year were reported on US 64 east of Columbia in Tyrrell County.

Bird road-kills consisted of 262 individuals of 40 different species (fig. 9). This included 175 passerines and 14 raptors. Only three species were recorded of more than 10 individual road-kills, eastern screech owl (11), swamp sparrow (28) and yellow-rumped warbler (91). Bird road-kills are listed in table 4. Other species of interest found as road-kill included tundra swan (1), wood duck (1), northern bobwhite (6) and wild turkey (1).

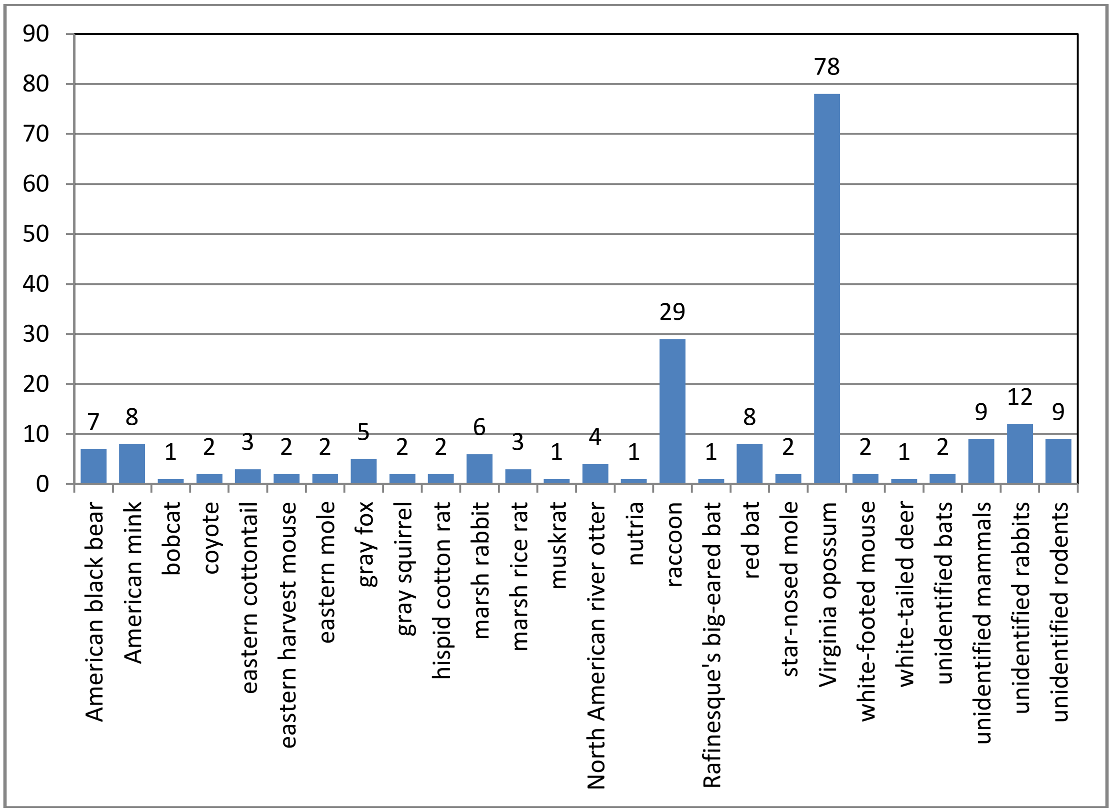


Figure 8. Mammal road-kill totals by species, April 2009 – July 2010.

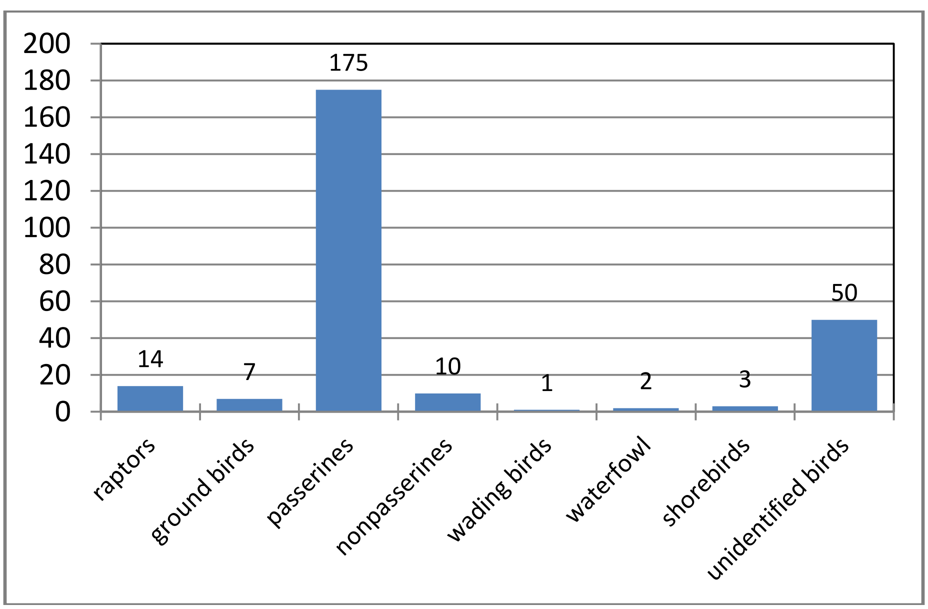


Figure 9. Bird road-kill totals by taxa, April 2009 – July 2010.

Table 4. Total bird road-kills by species, April 2009 – July 2010.

Species	Common Name	No.
Turdus migratorius	American robin	6
Passerina caerulea	blue grosbeak	1
Poecile carolinensis	carolina chickadee	1
Thryothorus ludovicianus	carolina wren	3
Spizella passerina	chipping sparrow	1
Quiscalus quiscula	common grackle	5
Picoides pubescens	downy woodpecker	1
Sialia sialis	eastern bluebird	1
Sturnella magna	eastern meadowlark	6
Otus asio	eastern screech owl	11
Pipilo erythrophthalmus	eastern towhee	2
Sturnus vulgaris	european starling	4
Passerella iliaca	fox sparrow	1
Dumetella carolinensis	gray catbird	3
Ardea herodias	great blue heron	1
Bubo virginianus	great horned owl	1
Laridae	gulls/terns	2
Catharus guttatus	hermit thrush	2
Troglodytes aedon	house wren	1
Leucophaeus atricilla	laughing gull	1
Zenaida macroura	mourning dove	1
Colinus virginianus	northern bobwhite	6
Cardinalis cardinalis	northern cardinal	1
Colaptes auratus	northern flicker	2
Columbidae	pigeons/doves	2
Dryocopus pileatus	pileated woodpecker	1
Dendroica pinus	pine warbler	2
Protonotaria citrea	prothonotary warbler	1
Melanerpes erythrocephalus	red-headed woodpecker	1
Buteo lineatus	red-shouldered hawk	1
Regulus calendula	ruby-crowned kinglet	1
Archilochus colubris	ruby-throated hummingbird	1
Melospiza georgiana	swamp sparrow	28
Tachycineta bicolor	tree swallow	4
Cygnus columbianus	tundra swan	1
Cathartes aura	turkey vulture	1
Catharus fuscescens	veery	7
Zonotrichia albicollis	white-throated sparrow	3
Meleagris gallopavo	wild turkey	1
Aix sponsa	wood duck	1
Coccyzus americanus	yellow-billed cuckoo	1
Dendroica coronata	yellow-rumped warbler	91
Aves	unidentified birds	50

We documented a total of 1,071 snake road-kills of 23 different species (fig. 10). Nine species were recorded of more than 20 road-kills – banded water snake (459), brown water snake (22), Carolina swamp snake (35), copperhead (22), eastern mud snake (60), glossy crayfish snake

(25), midland/northern water snake (51), northern black racer (102) and redbelly water snake (117). Of special note, we observed one road-killed timber rattlesnake.

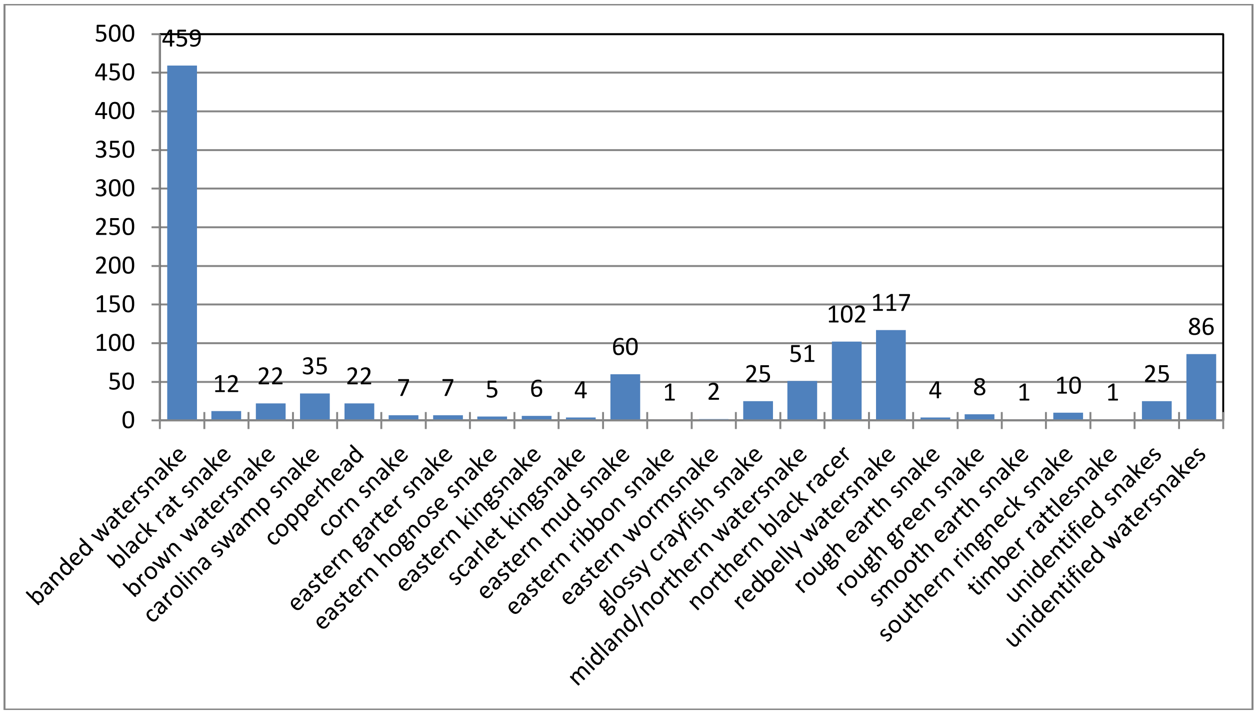


Figure 10. Snake road-kill totals by species, April 2009 – July 2010.

Turtle road-kills consisted of 885 individuals of 12 different species (fig. 11). Dominant species included common snapping turtle (158), eastern mud turtle (163), painted turtle (126), spotted turtle (201) and yellow-bellied slider (78).

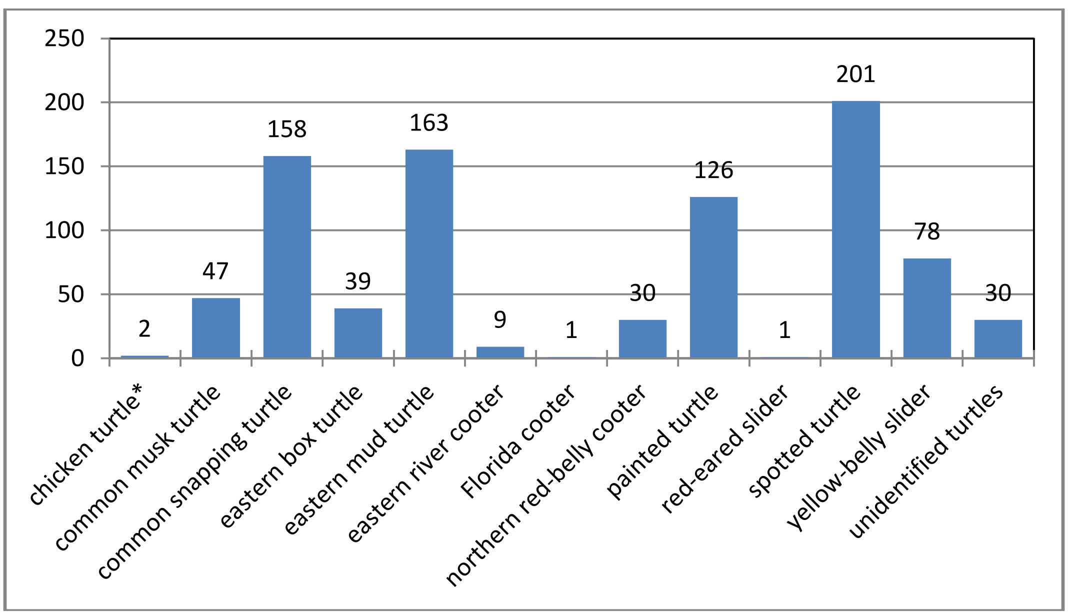


Figure 11. Turtle road-kill totals by species, April 2009 – July 2010. *denotes unverified records.

We found 25,427 amphibians, 13 species of frogs and one species of salamander (fig. 12). The most abundant species included American bullfrog (147), green treefrog (197) and southern leopard frog (103). Because of the poor quality of specimens, frogs were difficult to identify to species. We recorded 8,350 unidentifiable ranids and 16,556 other unidentifiable anurans.

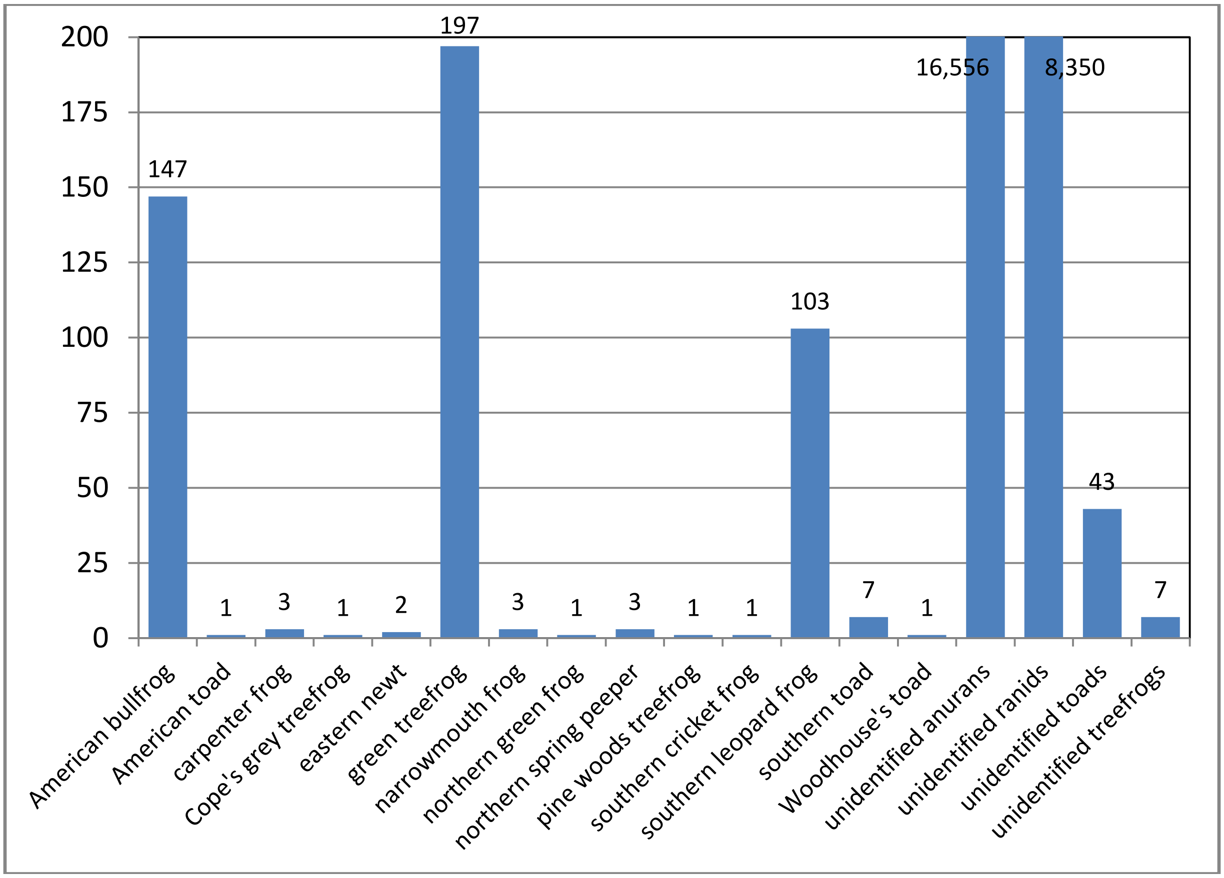


Figure 12. Amphibian road-kill totals by species, April 2009 – July 2010.

Temporal Trends. Temporal variability of recorded road-kills is shown in fig. 13. Mammal road-kills varied little on a month to month basis; however a significant number of road-killed mammals occurred in November (20% of recorded mammal road-kills). Very few avian road-kills were recorded monthly except for late winter – early spring. Sixty-nine percent of bird road-kills were recorded from January to March. Ninety-four percent (n=23,931) of road-killed frogs occurred in three seasonal spikes, April – June 2009, August – October of 2009 and June 2010. Road-killed snakes were more abundant in spring and summer months. We recorded 93% of snakes from May – October 2009 and April to June 2010. Turtles followed this same seasonal pattern. From May to September 2009 and April to June 2010 we documented 70% of road-kill turtles.

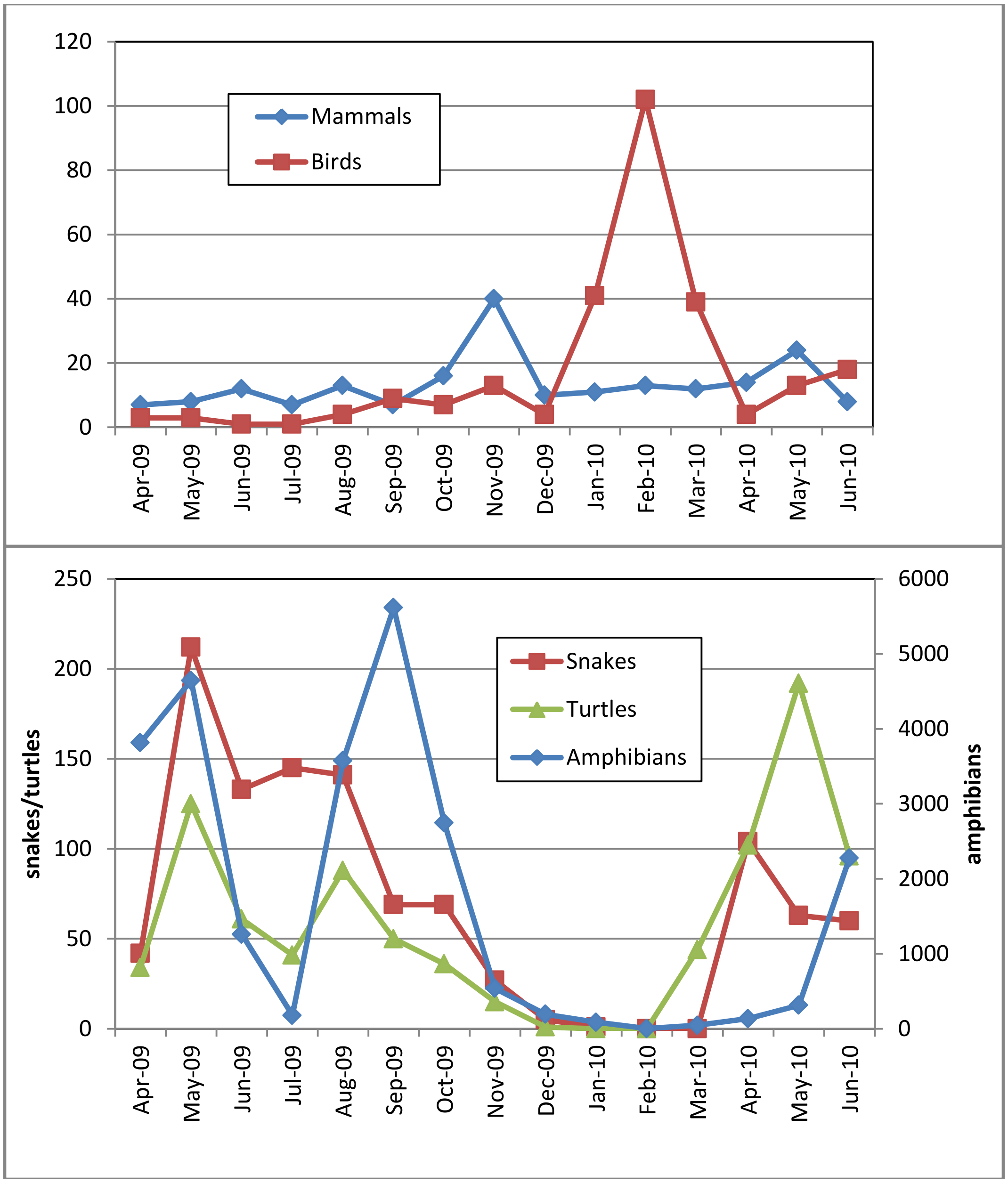


Figure 13. Temporal variation in recorded road-kills.

For comparison, fig. 14 shows monthly rainfall and average daily temperature by month. Average daily temperature was lowest in February 2010, corresponding to the highest number of avian road-kills and the lowest number of herpetofauna road-kills. Average temperatures of approximately 70 degrees F or higher occurred from May to September of 2009 and May to June 2010. This is consistent with greater quantities of herpetofauna road-kills. Significant rainfall (approximately 6 in or more per month) occurred from May to August 2009, November to January 2010 and again in March and June of 2010.

We compared temporal trends in abundance of road-kills with average daily rainfall and temperature for each month. Snakes were positively correlated to rainfall and temperature, r = 0.75 and 0.74 respectively. Turtles were somewhat positively correlated to temperature, r = 0.64.

Birds were somewhat negatively correlated to average monthly temperature, r = -0.65. No other taxonomic groups showed a significant correlation to rainfall. Different results may occur with a longer study period and further manipulation of the parameters (e.g., monthly temperature extremes instead of average daily temperature by month, considering lag times in response to rainfall).

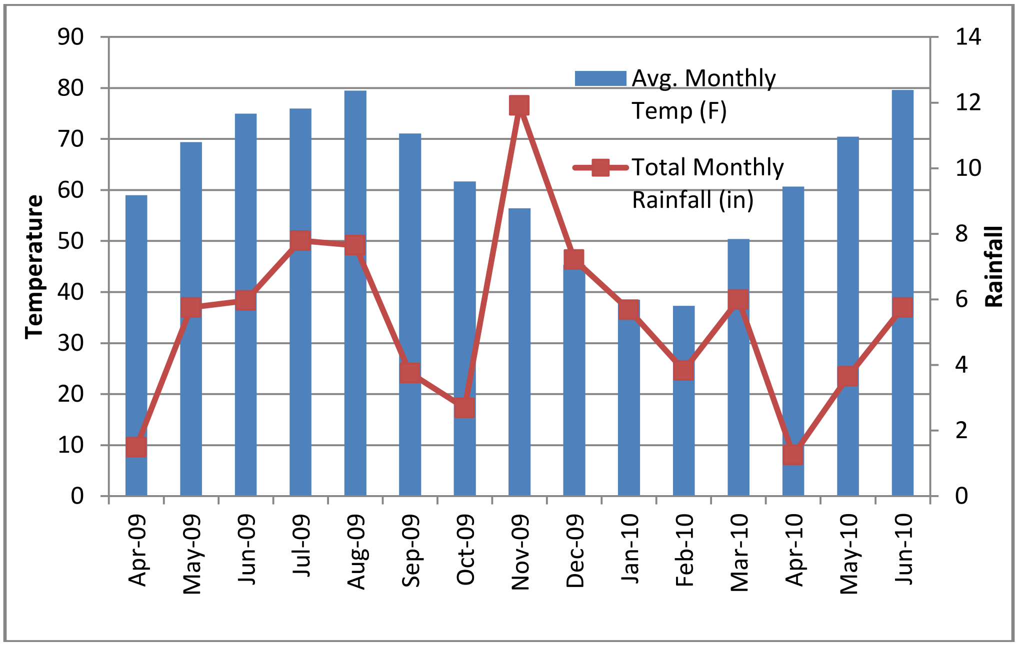


Figure 14. Monthly precipitation (total) and temperature (average daily) for City of Columbia, Tyrrell County, NC (April 2009 – July 2010).

Spatial Patterns. To examine the spatial distribution of road-kills on US 64, we divided the road into 100 m long segments (fig. 15). The entire project area comprises a total of 204 100-m wide segments. Results are presented in three sections, west section (Columbia city limits to old US 64), central section (between the two old US 64 intersections), and east section (old US 64 to Alligator River). Appendix A displays section maps for all road-kills with land cover for comparison purposes. The west section extends from segment no. 1 to segment no. 70. The central section starts at segment no. 71 and ends at segment no. 126. The east section begins at segment no 127 and ends at segment no. 204.

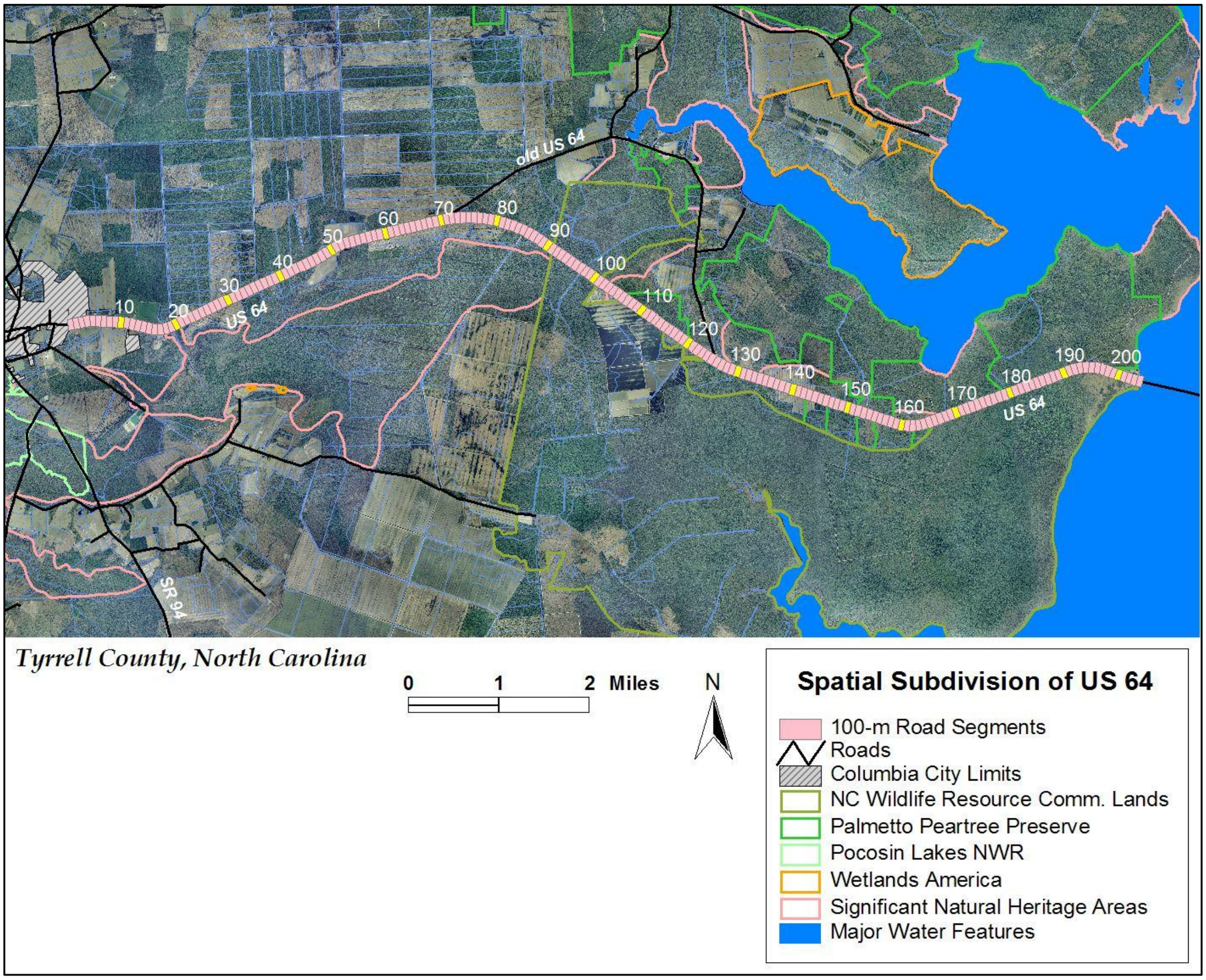


Figure 15. Spatial subdivision of US 64 into 100-m wide road segments for spatial analysis of road-kills.

Spatial distribution of mammal road-kills for the entire study area is shown in fig. 16. Mammal road-kill locations by road section are shown in Appendix A (figs. A-1 to A-3). We recorded 202 mammals in all three road sections (west – 38, central – 58, east – 106). When averaged, there was approximately two mammals per 100 m for the entire project length (west – 1, central – 2 and east – 2). The maximum number per 100 m was 6 individuals at road segment no. 132. The distribution of road-killed mammals is dispersed somewhat uniformly across the entire road length except for the first 1,200 m east of the City of Columbia.

When compared to land cover type, one-way ANOVA test detected no significant differences in location of road-kills. However, student's *t* test ($p = 0.017$) identified a significant difference between number of mammal road-kills found in cultivated vs. marsh impoundment areas.

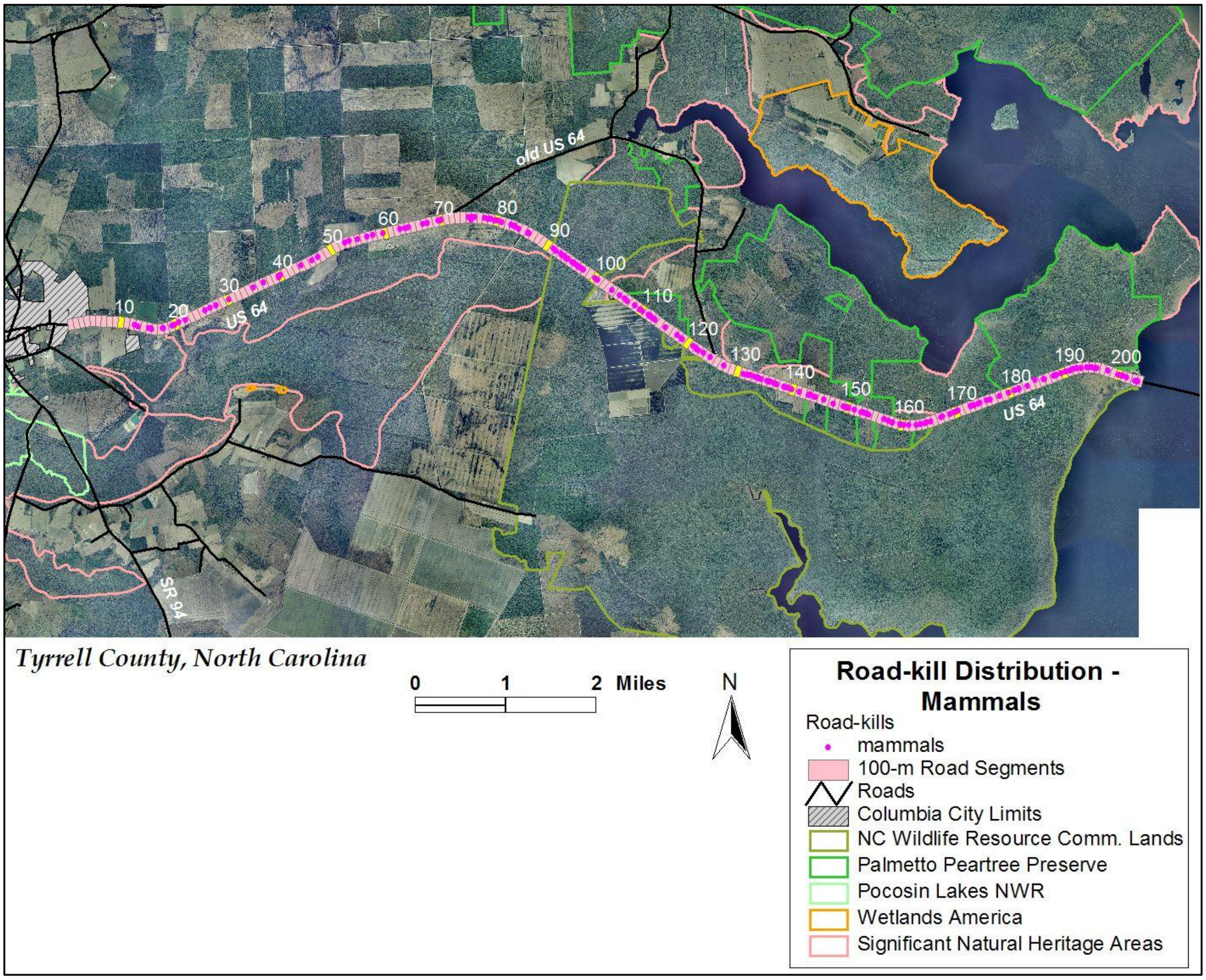


Figure 16. Location of road-killed mammals on US 64, Tyrrell County, April 2009 – July 2010.

Location of all bird road-kills is shown in fig. 17. Bird road-kill locations by road section are shown in Appendix A (figs. A-4 to A-6). We recorded 262 birds in all three road sections (west – 46, central – 34, east – 182). Road-killed birds were found in greater numbers in the wetter, eastern section of the project area. In the central and western sections, fewer road-killed birds were found and appear random in location. When averaged, there was approximately 2.2 birds per 100 m for the entire project length (west – 1.6, central – 1 and east – 3). The maximum number per 100 m was 9 individuals at road segment no. 191.

A one-way ANOVA test detected no significant difference in location of road-kills by land cover type. The student's *t* test, on the other hand identified a significant difference between number of bird road-kills found in wetland forest vs. cultivated areas (p = 0.039) and wetland forest vs. managed pine forest (p = 0.025).

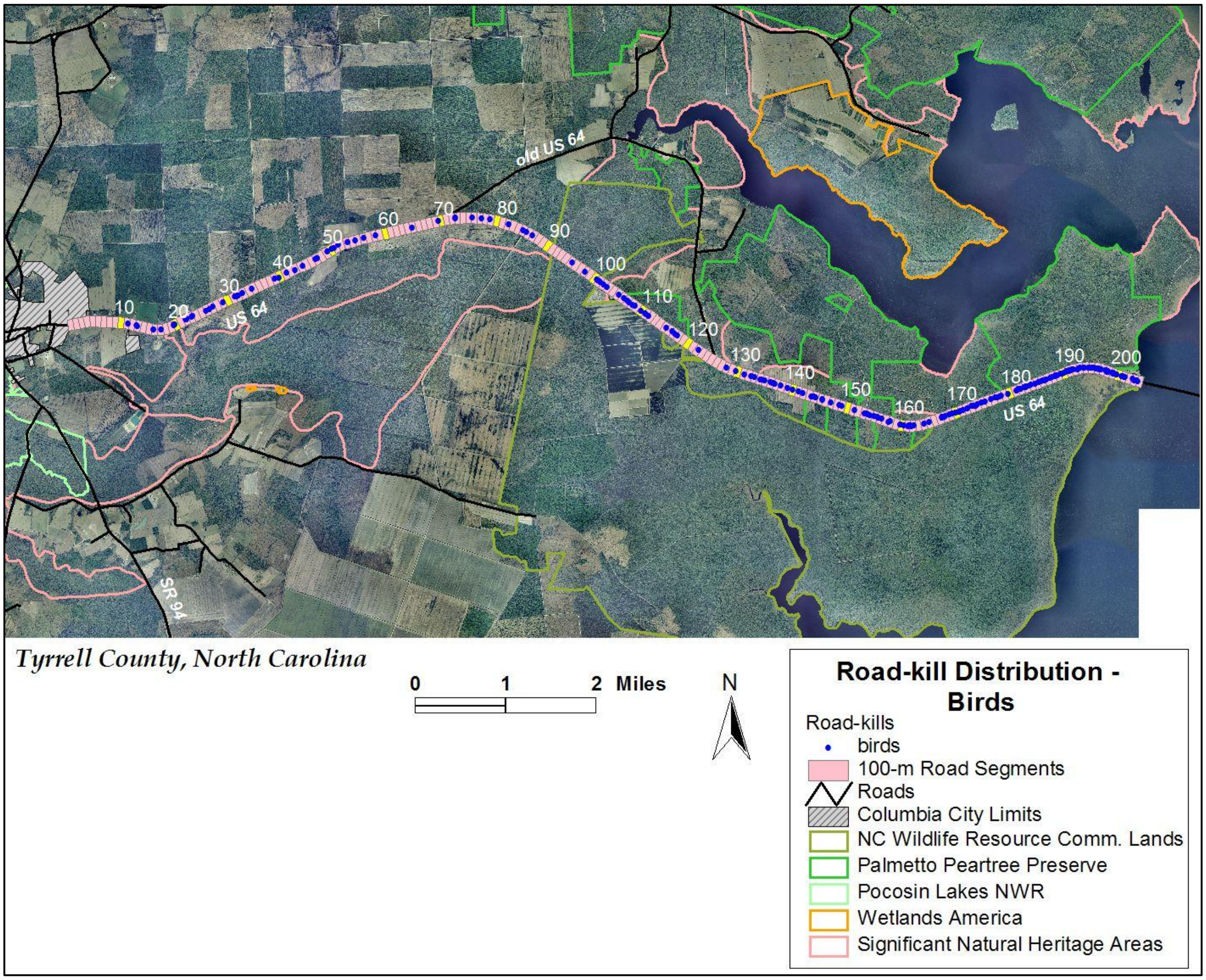


Figure 17. Location of road-killed birds on US 64, Tyrrell County, April 2009 – July 2010.

Location of all frog road-kills is shown in fig. 18. A total of 25,425 frog road-kills were recorded in all three road sections (west – 274, central – 4,574, east – 20,577). Average turtle road-kills in the western, central and eastern sections averaged 4, 82 and 264 road-kills per 100 m, respectively. The maximum number per 100 m was 1,742 individuals at road segment no. 130.

The eastern half of the study area was considerably wetter and frog road-kills were more prevalent. Of special interest were seven mass frog kills (fig. 19). These were instances where we encountered hundreds to thousands of frog road-kills in a single visit on stretches of road from 100 to 1,000 m long. These seven two-night events accounted for 60% (n=15,303) of total frog mortalities recorded.

Frog road-kill distribution appear clumped, see Appendix A (figs. A-7 to A-9). The majority of frog road-kills are concentrated in the central and east sections in road segments 98 – 110 (n=1,756), 112 – 122 (n=1,959), 125 – 152 (n=18,591). Eighty-eight percent of road-killed frogs were recorded between these segments, a total distance of 3.2 mi. This equates to about 6,970 road-kills per mi. In the west section most frog road-kills occurred in road segment nos. 20 – 40 (n=173), 10 to 100 times less than the clumps in the central and east sections.

A one-way ANOVA test detected no significant difference in location of road-kills by land cover type. The student's *t* test, however identified significant differences between number of frog road-kills found in marsh impoundments vs. cultivated areas ($p = 0.013$) and wetland forest vs. cultivated areas ($p = 0.036$). This supports the generally accepted notion that wetland areas are more valuable habitat than lands cultivated for row crops.

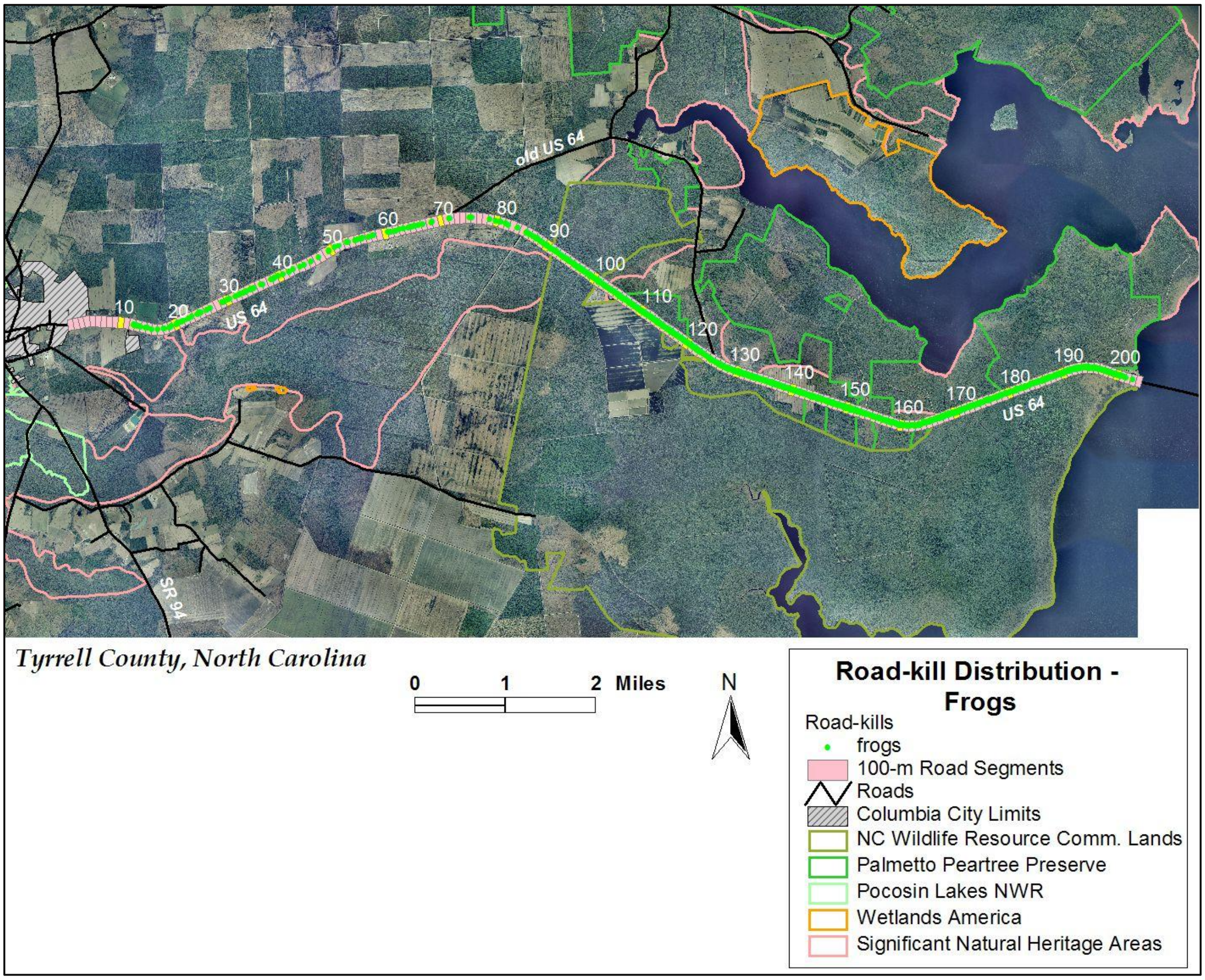


Figure 18. Location of road-killed frogs on US 64, Tyrrell County, April 2009 – July 2010.

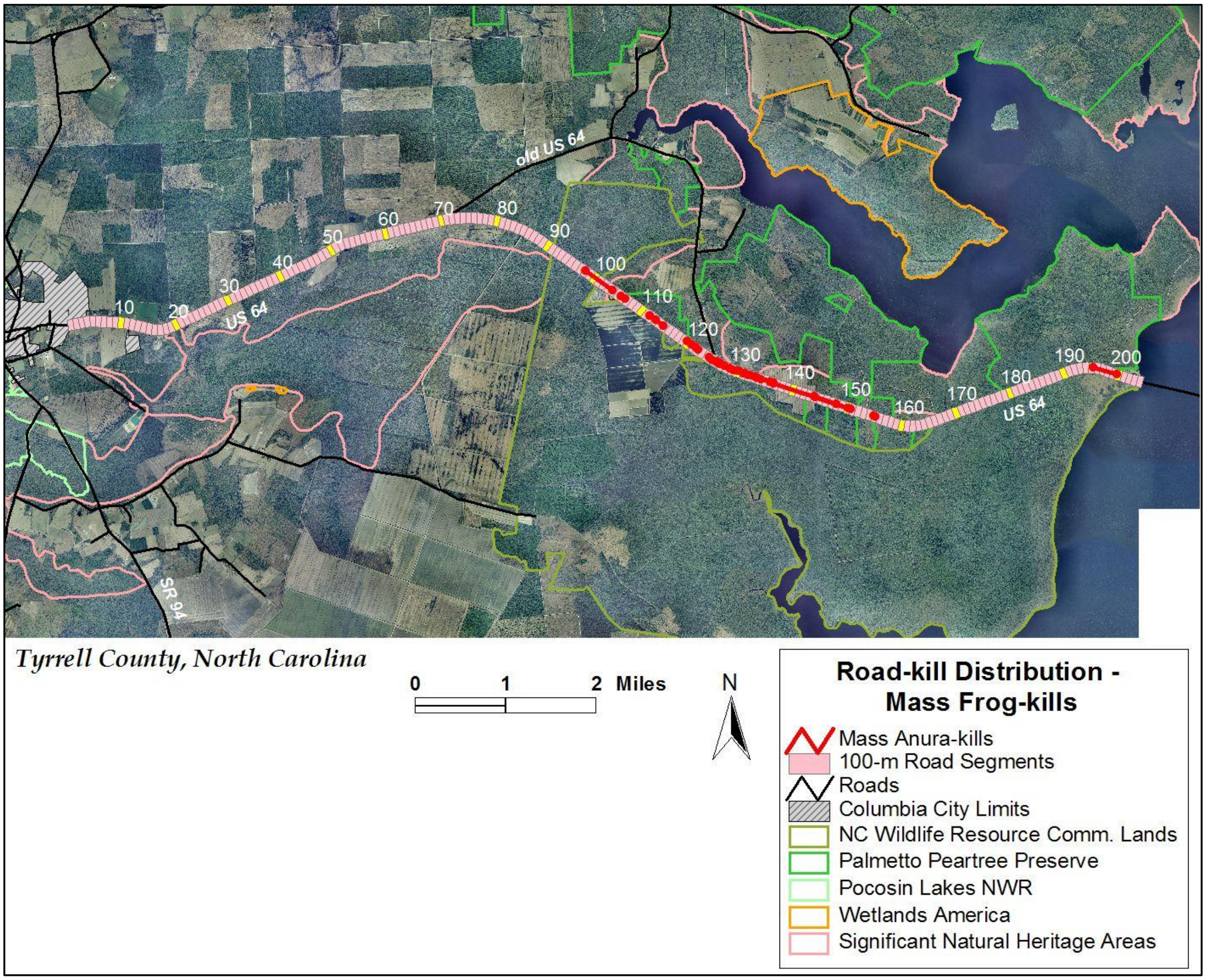


Figure 19. Location of mass frog road-kills on US 64, Tyrrell County, April 2009 – July 2010.

Spatial distribution of all snake road-kills is shown in fig. 20. The number of road-kills increase as you move east through the project area, Appendix A (figs. A-10 to A-12). This makes sense as the majority of road-killed snakes are aquatic or wetland dependent species and the road corridor becomes wetter toward the eastern end. We recorded 1,701 snakes in all three road sections (west – 130, central – 237, east – 708). Snake road-kills in the western, central and eastern sections averaged 2, 4 and 9 road-kills per 100 m, respectively. Two clumps may be evident in the eastern section where several road segments had 15 – 25 road-kills per 100 m (road segment nos. 127 – 139 and 190 – 198). The highest number of snake road-kills (n=26) occurred in segment no. 174.

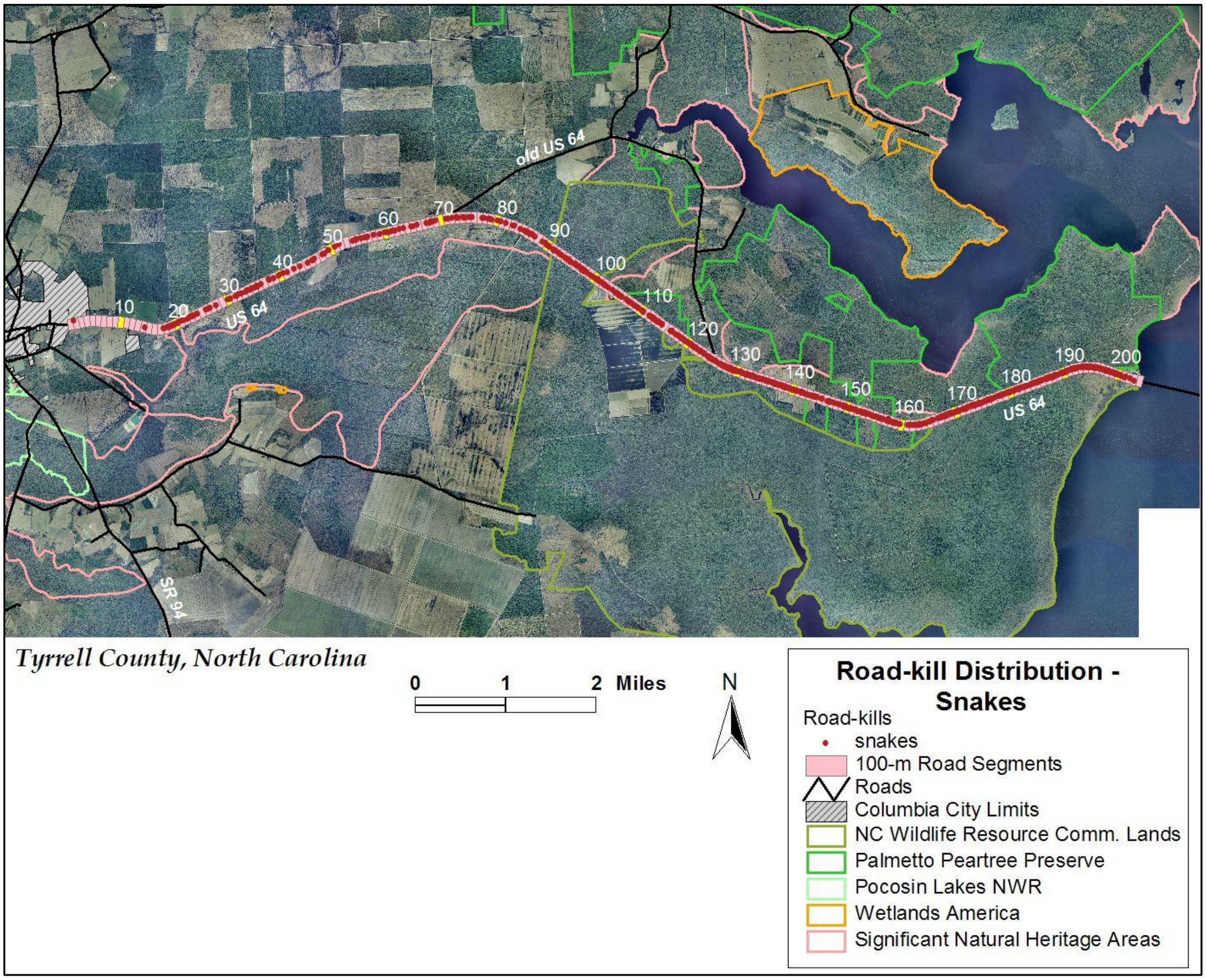


Figure 20. Location of road-killed snakes on US 64, Tyrrell County, April 2009 – July 2010.

Spatial distribution of all turtle road-kills is shown in fig. 21. The pattern of road-killed turtles is similar to that of snakes, Appendix A (figs. A-13 to A-15), numbers increase moving eastward. Since most turtles observed were aquatic, we recorded greater numbers along the eastern half of the study area where it was much wetter. We recorded 885 turtles in all three road sections (west – 82, central – 214, east – 589). Average turtle road-kills in the western, central and eastern sections averaged 1, 4 and 8 road-kills per 100 m, respectively. The maximum number per 100 m was 27 individuals at road segment no. 128. Potential clumps of road-killed turtles are present at road segment nos. 125 – 137, 151 – 153, and 194 – 199.

A one-way ANOVA test detected a significant difference in location of reptile road-kills by land cover type ($F = 5.29$, $p = 0.00015$). The student's t test identified significant differences between number of reptile road-kills found in marsh impoundments vs. cultivated areas ($p = 0.00014$), marsh impoundments vs. managed pine forests ($p = 0.0039$), wetland forest vs. managed pine forest ($p = 0.000027$), wetland forest vs. cultivated areas ($p = 0.0000083$), wetland forest vs. water ($p = 0.039$) and managed pine forest vs. cultivated areas ($p = 0.034$). In general, this explains that marsh impoundments and wetland forest areas are important habitat areas for the reptiles we recorded.

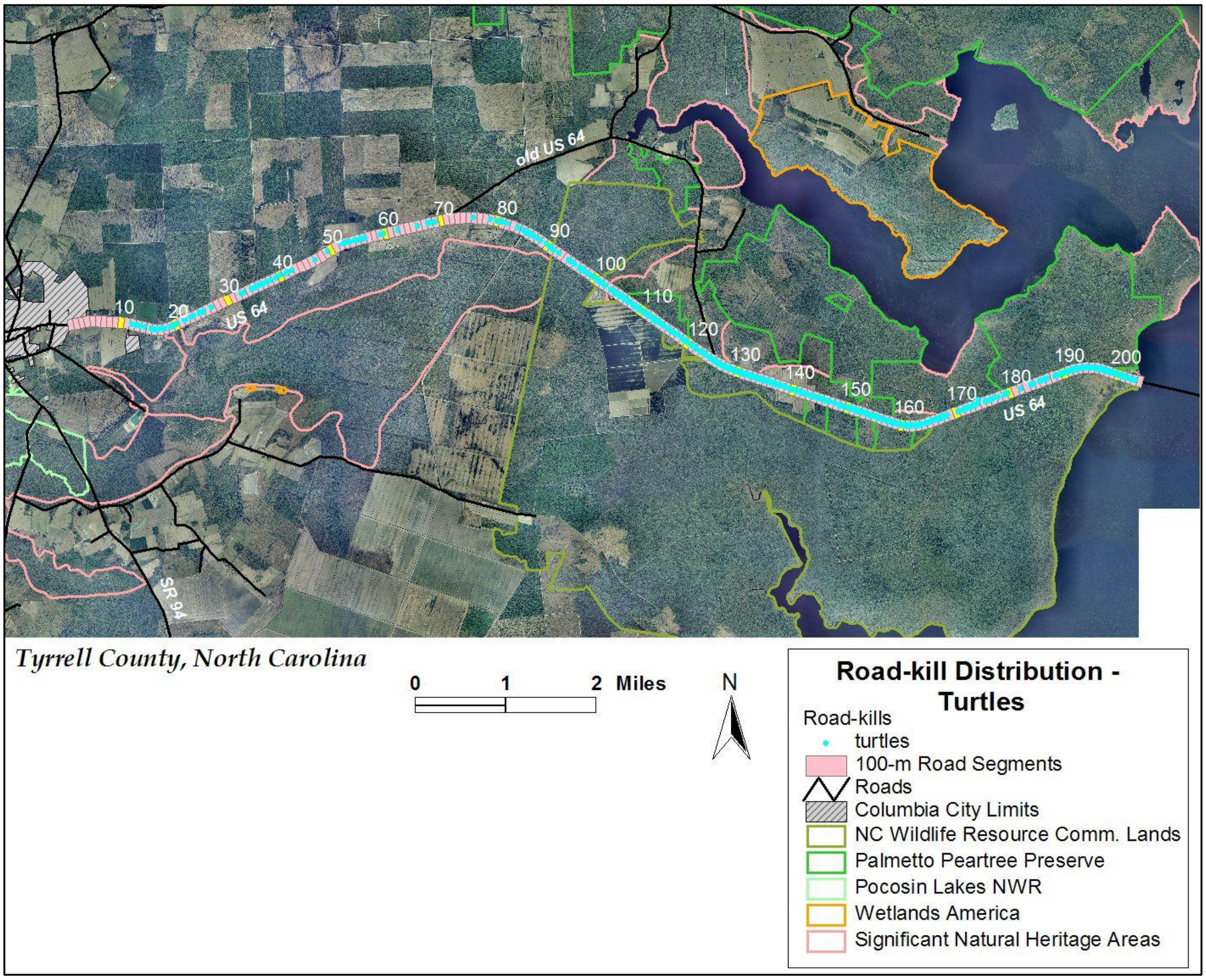


Figure 21. Location of road-killed turtles on US 64, Tyrrell County, April 2009 – July 2010.

Species of Conservation Interest. Certain road-killed focal species were tracked during the project (Appendix B, figs. B-1 to B-8). Consult fig. 15 for location of road segment numbers. Species presented in this section include, but are not limited to, those listed by the NC Natural Heritage Program as Federally or State- protected, or rare or at risk of decline for this area.

Black bear road-kill data was available from two sources. Records we could confirm were provided by NCWRC or documented from field activities we conducted. Other records we could not confirm were compiled from NCDOT vehicle-wildlife crash reports. From 2000 to 2010, there were 32 confirmed and 39 unconfirmed records (fig. 22). Duplicate records were removed, so this makes a possible 71 potential black bear road-kills on US 64. That equates to approximately 6.5 per year on the 13 mi length of road. Relative effort and consistency in data collection by both sources over the history of this dataset is unknown. Therefore we cannot say whether the combined numbers represent a low or high estimate of the actual number of black bears killed on this stretch of US 64. With high confidence we can say that the confirmed numbers represent a minimum average of three deaths per year from collisions with vehicles. A safe approximation of annual collisions lies somewhere between the two averages of 2.9 – 6.5.

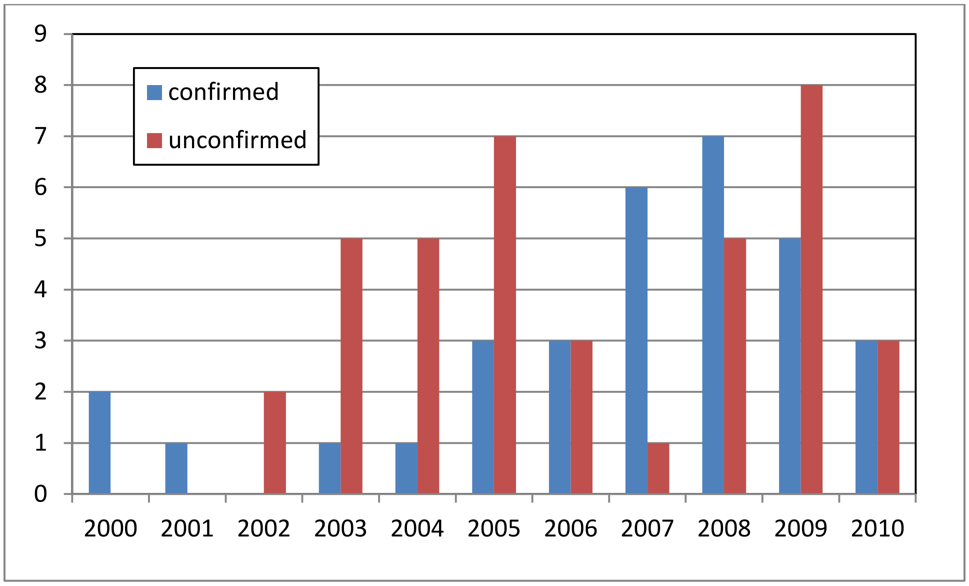


Figure 22. Black bear road-kill records from 2000 to 2010. Notes: confirmed records are those collected by NCWRC; unconfirmed records are from NC vehicle accident reports.

Location of documented bear road-kills is shown in Appendix B, fig. B-1. When combining both datasets, at least one bear-related crash occurred on average every 0.25 mi in the project area beginning at road segment no. 12 and ending at road segment no. 199. Maximum number of bear road-kills occurred in segment no. 119 (n=6). A cluster of 5 bear road-kills occurred around road segment nos. 12 – 19. This location corresponds to the interface between managed pine forest and rural development and cultivated areas just east of Columbia. Another cluster of bear road-kills (n=14) was evident between road segment nos. 70 – 92, a distance of approximately 0.75 mi. This location is at and just east of the western intersection with old US 64 (SR 1229). Mature forest is present on the northside of the highway at this location. Twelve bear road-kills were reported in a 0.68 mi long stretch of US 64 just west of the eastern intersection with old US 64 (SR 1229). This is located near the small community of Alligator and the J. Morgan Futch impoundments. From road segment nos. 139 to 151 (0.75 mi), 8 more collisions with bears were reported. This location corresponds to an area containing cultivated marsh impoundments and mature pinelands. Six additional collisions occurred from road segment nos. 157 – 165 (0.50 mi). This location is on a significant curve in the road adjacent to mature pinelands and hardwood swamp. Several scattered data points of bear road-kills were located east from road segment no. 175 (location of entrance to NC Alligator River Game Lands; 2 road-kills right across from access road). At the access road to the east tract of the Palmetto-Peartree Preserve (road segment no. 191), four bear road-kills have been documented.

Only two road-killed red wolves have been documented on this section of US 64 (Appendix B, fig. B-2); both were females. One occurred in 1996 and the other occurred in 2001. These were found on road segments 98 and 191 (see fig. 15 for location reference). These locations were both characterized as forested wetlands consisting of hardwood swamps or cypress/gum/oak land cover. Both occurred adjacent to NC Wildlife Resource Commission managed game lands. Two other road-kills occurred in proximity to US 64. One was found on SR 94 in 2008, about 3 mi. SW of the project area along the Scuppernong River Swamp Forest Natural Heritage Area that connects Pososin Lakes NWR to the NC Alligator River Game Lands adjacent to US 64. The other road-kill was documented in 2006 on a forest road about 1 mi. north of US 64 within the Weyerhauser commercial forestry area.

We only documented one white-tail deer road-kill during this study (at road segment no. 132, see fig 15). Carcass removal is a standard practice conducted by NCDOT for safety purposes and USFWS will collect carcasses to use as bait for red wolf trapping. In addition, when fresh carcasses are encountered, deer hunters have been known to remove them. As a result we estimate that many more deer road-kills likely occurred. This conclusion is supported by vehicle-animal crash data collected by law enforcement at accident scenes. From 2000 to 2010, 37 vehicle collisions with white-tail were reported (fig. 23). The most reported was 7 in 2008; on average 4 collisions per year were reported in the last decade. It is probable also that these numbers are low as it is recognized that not all deer collisions with vehicles are reported. Location of reported deer collisions are shown in Appendix B, fig. B-3. The spatial distribution more strongly reflects sections of US 64 where deer-vehicle collisions were absent rather than areas where they were concentrated. Thirteen deer-vehicle collisions occurred in the first 24 road segments (see fig. 15 for reference), within 1.5 mi of the City of Columbia. Another collection of collision sites is more dispersed from segment no. 55 to 106 (n=12). Two other clusters were found in segment nos. 120 – 132 (n=5) and 154 – 173 (n=5).

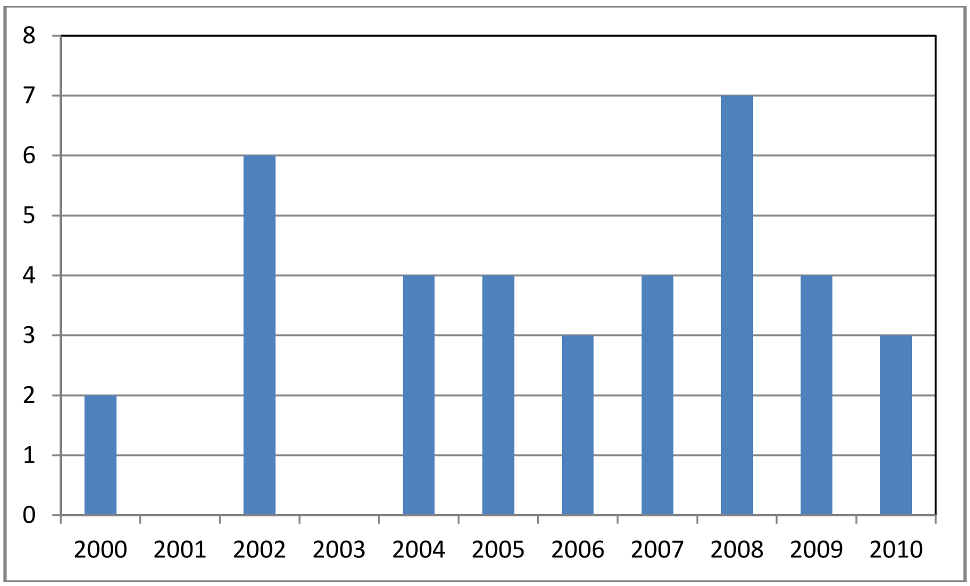


Figure 23. Vehicle-deer collisions reported on the US 64 project area, 2000 – 2010. Source: NCDOT.

Road-kills of other mammals of conservation interest found included carnivores (Appendix B, fig. B-4) and certain small mammals (Appendix B, fig. B-5). Other carnivore road-kills included coyote (2), gray fox (5), bobcat (n=1), river otter (n=4), and American mink (n=8). Coyote and gray fox road-kills were found adjacent to managed pine forests or near rural development areas. River otter and American mink road-kills were found in the eastern section of the project where a large canal adjacent to the road is prominent. Small mammal road-kills included star-nosed mole (n=2), Rafinesque's big-eared bat (n=1), red bat (n=8) and unidentified bats (n=2). Of special note is that the star-nosed mole and Rafinesque's big-eared bat are listed as Special Concern

Species. Seven of the red bat road-kills were clustered in two locations in the eastern section of US 64 adjacent to Palmetto-Peartree Preserve lands. These locations were comprised of hardwood swamp and mature pinelands.

Road-kills of birds of conservation interest (in this case birds of prey and game birds) found on US 64 are shown in Appendix B, fig. B-6). Birds of Prey included red-shouldered hawk (n=1), turkey vulture (n=1), great horned owl (n=1) and eastern screech owl (n=11). Except for eastern screech owl, we encountered few individuals of these species. Raptor road-kills usually are much higher when an abundant prey base is available along the roadsides. Game birds included wild turkey (n=1) and northern bobwhite (n=6). We also recorded one tundra swan on the roadside, though this was an injured animal, potentially from a vehicle collision.

Snake road-kills of conservation interest are shown in Appendix B, fig. B-7. Five species of snakes were listed as rare or at risk of decline for this area. These included timber rattlesnake (n=1), scarlet kingsnake (n=4), smooth earth snake (n=1), glossy crayfish snake (n=25) and Carolina swamp snake (n=35). All of these species were found in the eastern section of the project area. The former two species were within ecotones between forested wetlands or impoundment areas and mature pine forests or rural development. The latter two species were more common as road-kills and were found adjacent to forested wetland habitats only. Two continuous clusters are evident near the eastern intersection with old US 64 (SR 1229) and at the along easternmost tract of Palmetto-Peartree Preserve.

Appendix B, fig. B-8 displays turtle road-kills of conservation interest. These were also species listed as rare or potentially experiencing population declines. We found chicken turtle (n=2), eastern box turtle (n=39), northern redbelly cooter (n=30) and spotted turtle (n=201). The chicken turtles are unconfirmed records, though many individuals of the same species were encountered across the Alligator River along US 64 in Dare County. The eastern box turtles were recorded in several locations on US 64; areas comprised of different habitat types including managed pine forests, hardwood swamp, impoundment marshes and oak/gum/cypress. Northern redbelly cooters and spotted turtles were found near hardwood swamps and impoundment marshes. All aquatic turtles were observed using the canals parallel to the pavement.

In their totality, snakes, turtles and frogs were quite abundant near all wetland and aquatic habitats, especially in the central and eastern sections of the roadway (see fig. 15).

Track Stations

The character of the right-of-way for US 64 from the City of Columbia east to the Alligator River includes canals and ditches that run parallel for nearly the entire length of the project. A deep water canal along the southside of the road begins at road segment no. 69 and extends eastward all the way to the Alligator River. Smaller drainage swales exist along the northside of the road from road segment no. 126 to the Alligator River. Drainage ditches exist on either one or both sides of the road between road segment nos. 11 and 70 (see fig. 15 for road segment locations). The canal was a permanent water body; drainage ditches and swales were ephemeral, though during our field work they always contained water. Crossing over these canals and ditches were several dirt access roads. Our reconnaissance survey revealed that these access roads were used regularly by wildlife to cross over the canal to get to the other side of US 64.

We prepared and monitored track beds at all of these access points where soil and vegetation conditions were suitable; those that were not were monitored with cameras. In addition, we established and monitored 300 ft track stations at all ecotones between major land cover types. Figure 24 shows the location of all track bed and/or camera locations. Track beds were established at 31 of these sites. Table 5 provides a description of each of these sites.

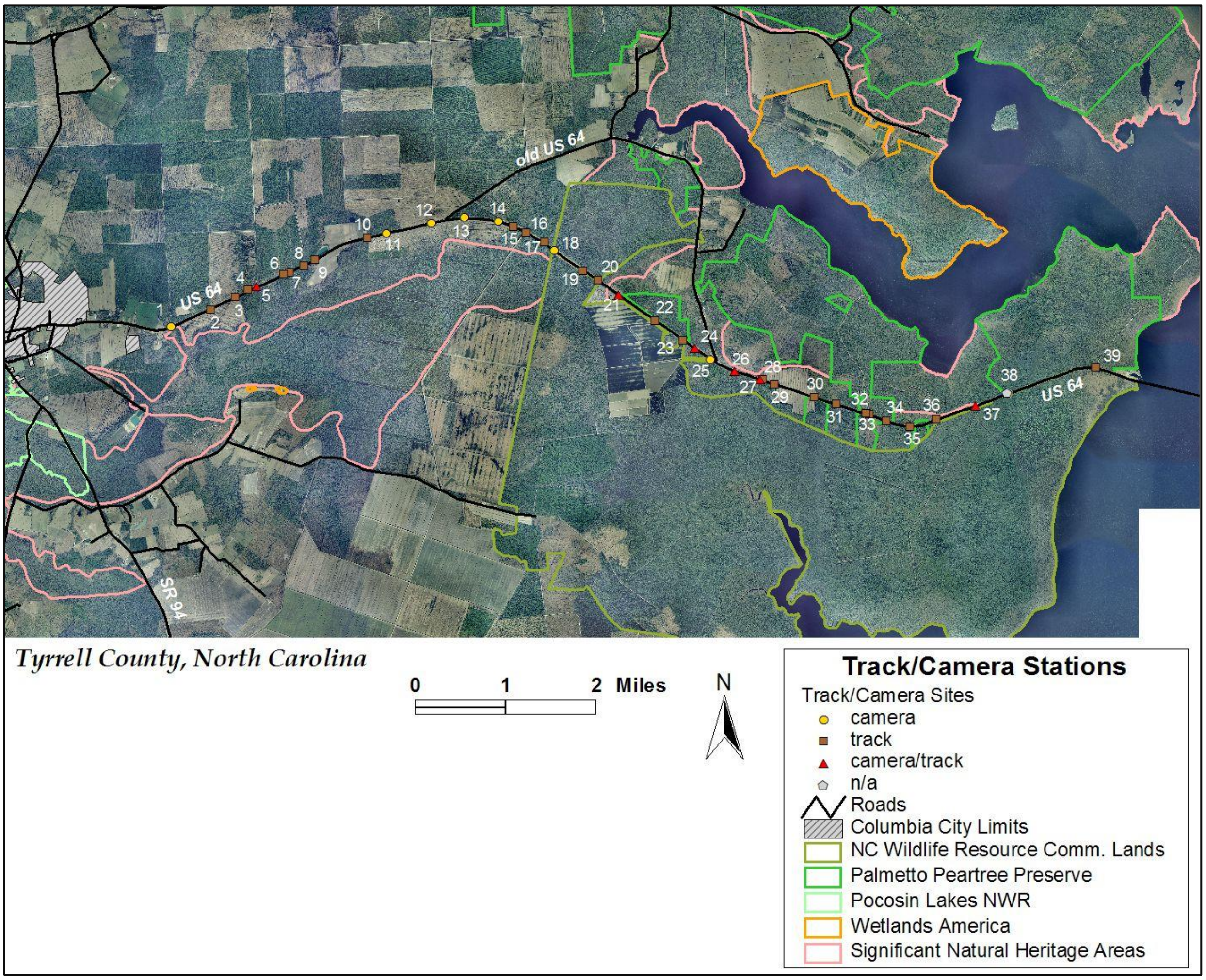


Figure 24. Track bed and/or camera locations on US 64 in Tyrrell County.

Table 5. Description of track bed and camera stations on US 64 in Tyrrell County.

ID	Site Description	Special Feature	Track/ Camera	Track Bed Length (ft)	Road Segment
1	hardwood swamp, managed pine forest	gravel/limerock road	camera		19
2	hard edge; managed pine forest	trail	track	300	27
3	hard edge; managed pine forest, hardwood swamp		track	300	31
4	hardwood swamp	paved road	track	300	34

Table 5. continued.

ID	Site Description	Special Feature	Track/ Camera	Track Bed Length (ft)	Road Segment
5	hardwood swamp	dirt road	both	20	36
6	managed pine forest	paved road	track	300	41
7	managed pine forest	dirt road	track	300	42
8	managed pine forest	powerline easement	track	50	45
9	hard edge; farmland, managed pine forest	pond, dirt road	track	20	47
10	farmland, managed pine forest-clearcut	treeline	track	50	57
11	managed pine forest	gravel/limerock road	camera		60
12	managed pine forest	gravel/limerock road	camera		68
13	managed pine forest	trail/natural bridge	camera		74
14	managed pine forest	gravel/limerock road	camera		80
15	hard edge; managed pine forest		track	300	83
16	managed pine forest	gravel/limerock road	track	50	86
17	hardwood swamp, managed pine forest		track	300	89
18	oak/gum/cypress wetland forest	trail/natural bridge	camera		91
19	hardwood swamp	dirt road	track	20	97
20	hard edge; managed pine forest, hardwood swamp		track	300	101
21	managed pine forest	dirt road	both	20	105
22	marsh impoundment, managed pine forest	gravel/limerock road	track	50	113
23	hard edge; marsh impoundment, managed pine forest	dike	track	300	119
24	broadleaf evergreen forest	dirt road	both	20	121
25	broadleaf evergreen forest, rural development	gravel/limerock road	camera		125
26	hardwood swamp, managed pine forest	dirt road	both	20	129
27	managed pine forest	trail/natural bridge	both	20	134
28	hard edge; managed pine forest, old farm structures	dike	track	20	134
29	marsh impoundments, old farm structures	dirt road	track	20	137
30	marsh impoundments, old farm structures	dirt road	track	20	144
31	stand age transition, managed pine forest		track	300	148
32	managed pine forest, P3 access	dirt road	track	20	153
33	managed pine forest	trail/natural bridge	track	20	154
34	stand age transition, managed pine forest		track	300	157
35	managed pine forest, P3 access	dirt road	track	20	162
36	managed pine forest, private tree farm	dirt road	track	20	166
37	managed pine forest, game lands access	dirt road	both	20	174
38	managed pine forest, private access	dirt road	n/a		180
39	hardwood swamp, P3 access	dirt road	track	300	196

Notes: Fig. 15 displays locations of each road segment; we could not get permission to monitor site no. 38.

Worth noting was conditions at certain track beds that hindered detection of tracks. The high clay content in the soil at track beds nos. 16, 17, 20, 22 and 23 rendered these track beds less effective during moisture extremes. When very dry, these track beds essentially turned to stone and track imprints were undetectable in some sections. When very wet, they turned to slush; in some areas water would pool preventing our ability to read tracks entirely. Where the moisture content was moderate, imprints were generally good. During both extremes they were very difficult to maintain with the ATV and this led to reestablishment of vegetation that also hampered our efforts. We had scheduled to spray and re-till these track beds and supplement with sand to improve their condition in early December 2009; however these plans were delayed for four months because of continuous and extreme rainfall that softened the road shoulders and prevented access by heavy equipment. As a result track records from November 2009 to May 2010 under-represent wildlife activity at these specific sites.

Diversity and Abundance. We recorded tracks of 18 different taxa/species (fig. 25). A total of 7,477 tracks were recorded. White-tail deer were the most numerous (4,492, 60%). Canids (728), coyote (96), red wolf (211) and gray fox (231) accounted for 17% of total tracks recorded. We recorded 277 bobcat and 331 black bear tracks.

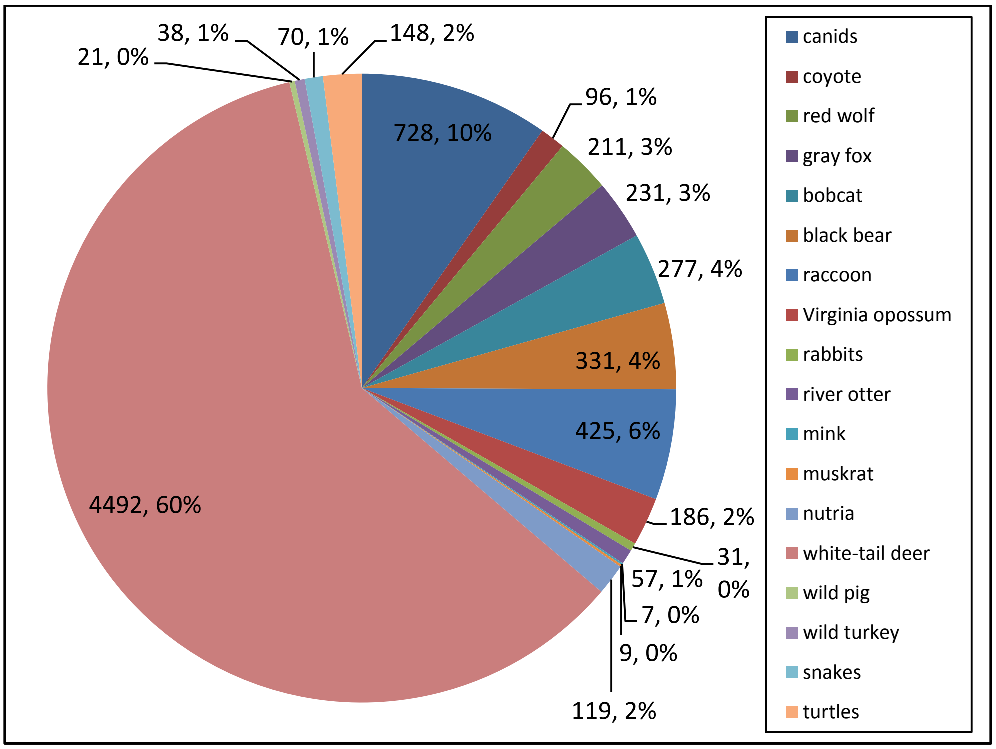


Figure 25. Total amount and percent of tracks by taxa/species.

Spatial Pattern. Differences in number of tracks observed at each track station are presented in figs. 26 – 34. Refer to fig. 24 and table 5 for location and description of each track station. Total tracks recorded by site number are shown in fig. 26; the most was at track bed no. 20 (n=726), followed by track bed nos. 16 and 22 (554 and 572 respectively). Six sites had more than 300 tracks; eight more sites had more than 200 tracks.

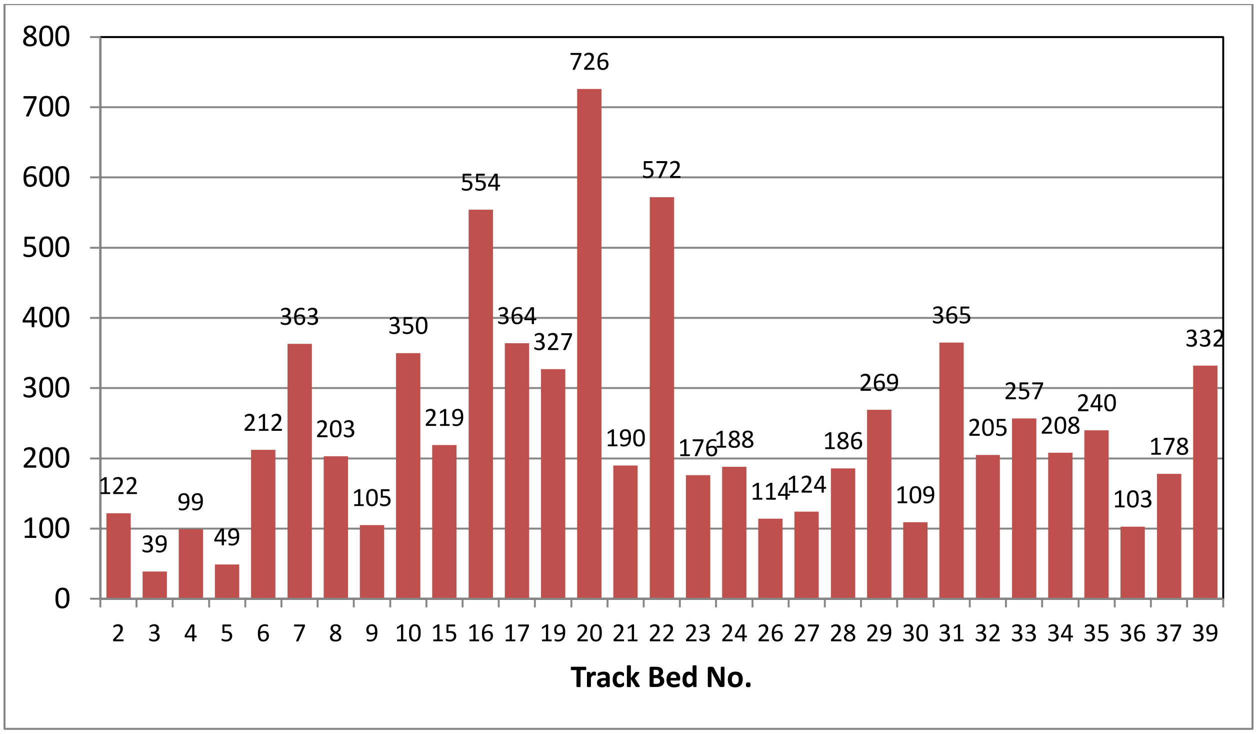


Figure 26. Total tracks recorded by track bed location.

Figure 27a provides a comparison of all canid track locations recorded. Track bed nos. 7, 10, 15, 19, 22, 23, 24, and 29 had over 60 combined canid tracks. Figure 27b displays the total tracks by location for each individual canid species. The greatest number of unidentified canid tracks was found in track bed nos. 7, 10, 15, 19, 21, 24, 26, 28 and 29. Coyote tracks were most abundant at track bed nos. 19 and 22. Red wolf tracks (represented primarily by one radio-collared female) were recorded most often at track bed nos. 7, 10, 15, 22, 23 and 31. We found the most tracks of gray fox at track bed nos. 15, 34 and 39.

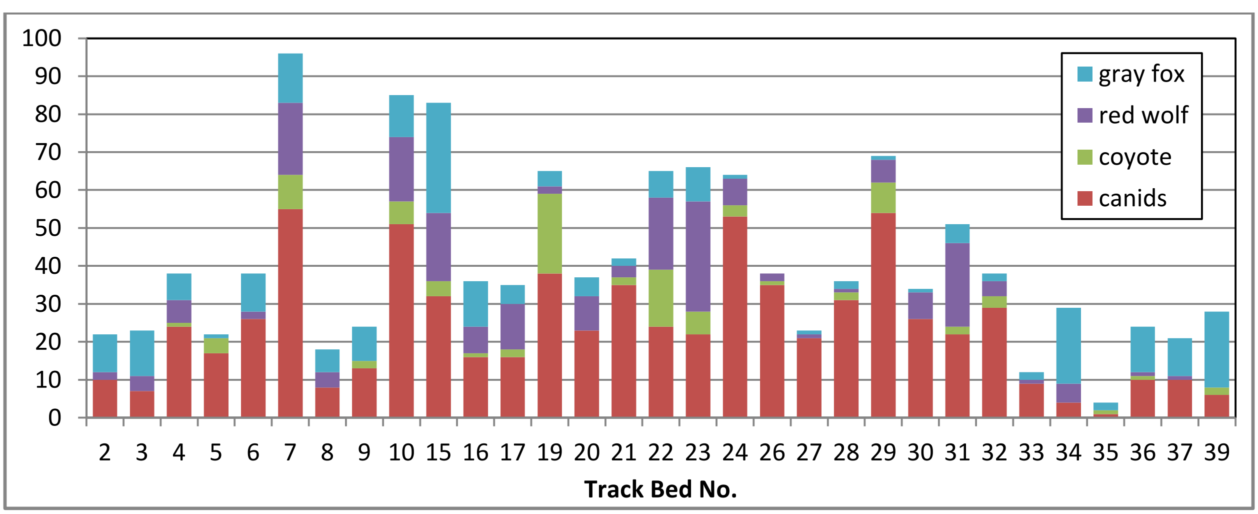


Figure 27a. Combined canid tracks recorded by track bed location.

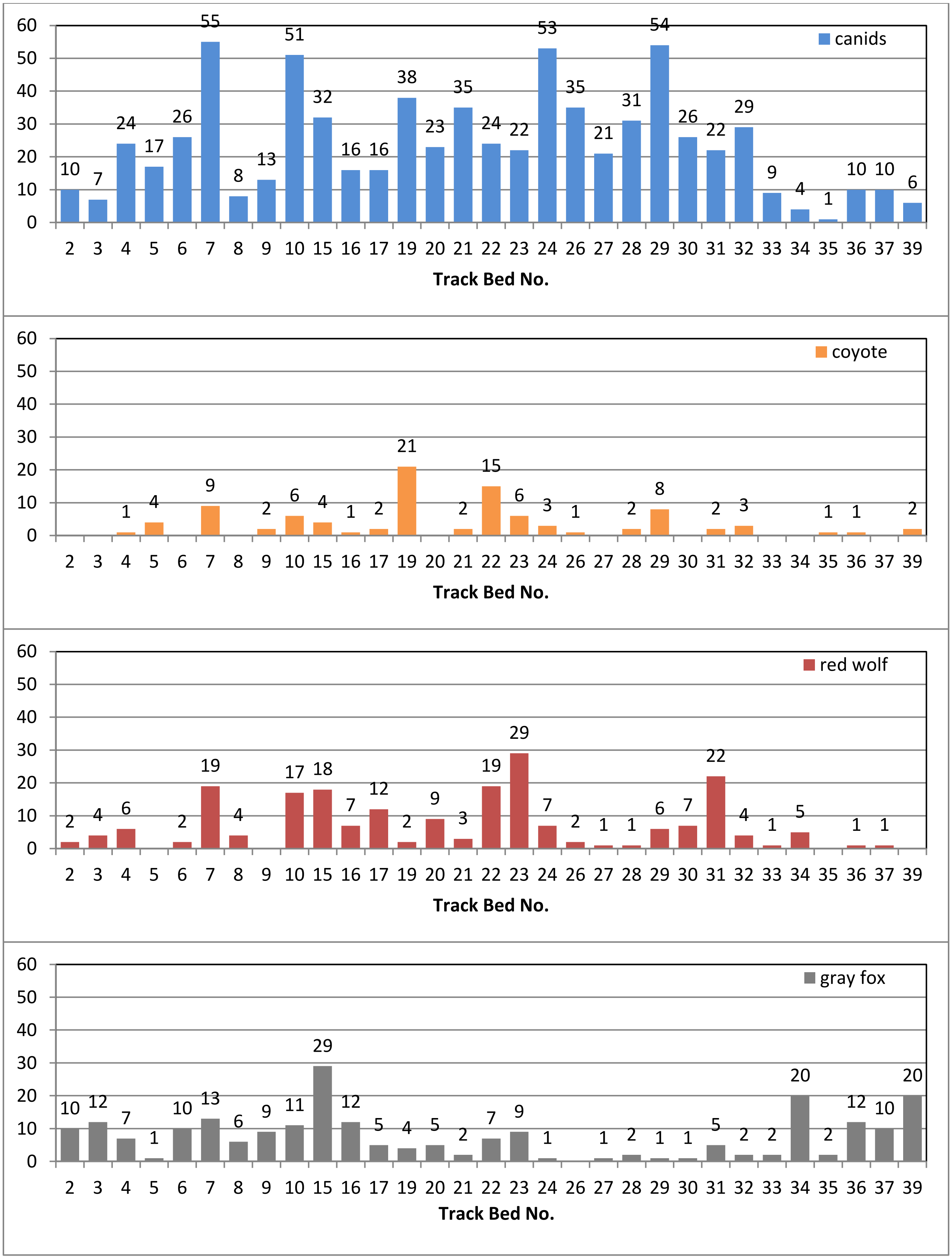


Figure 27b. Total tracks by individual canid species.

Bobcat tracks were found at all track bed locations except for track bed no. 35 (fig. 28); the greatest number of bobcat tracks was found at track bed nos. 4, 10, 19, 20, 21, 24 and 39.

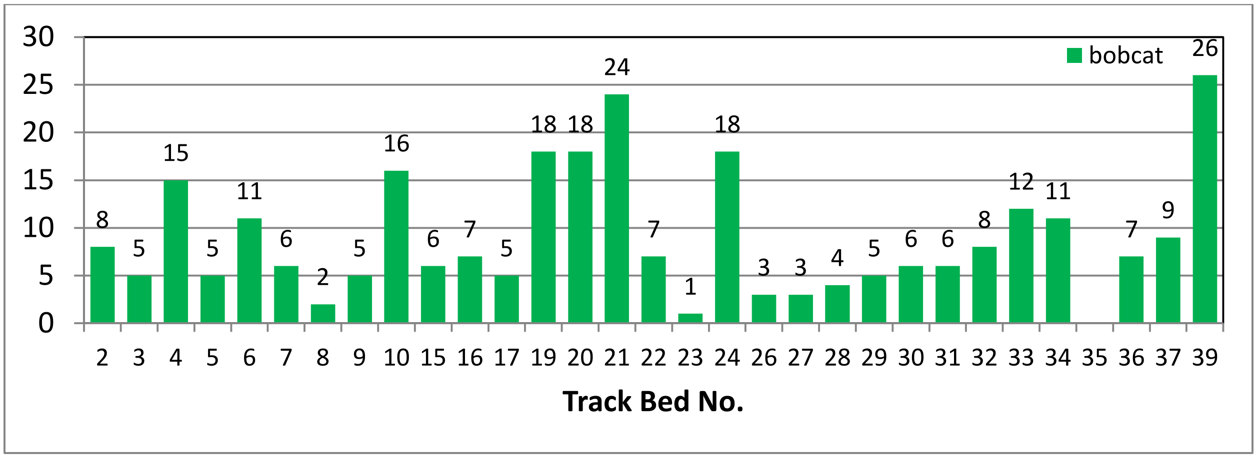


Figure 28. Bobcat tracks recorded by track bed location.

Black bear tracks were recorded at all but two track bed locations (fig. 29). They were most abundant at track bed nos. 16, 19, 21, 22, 24, 30 – 32, 37 and 39.

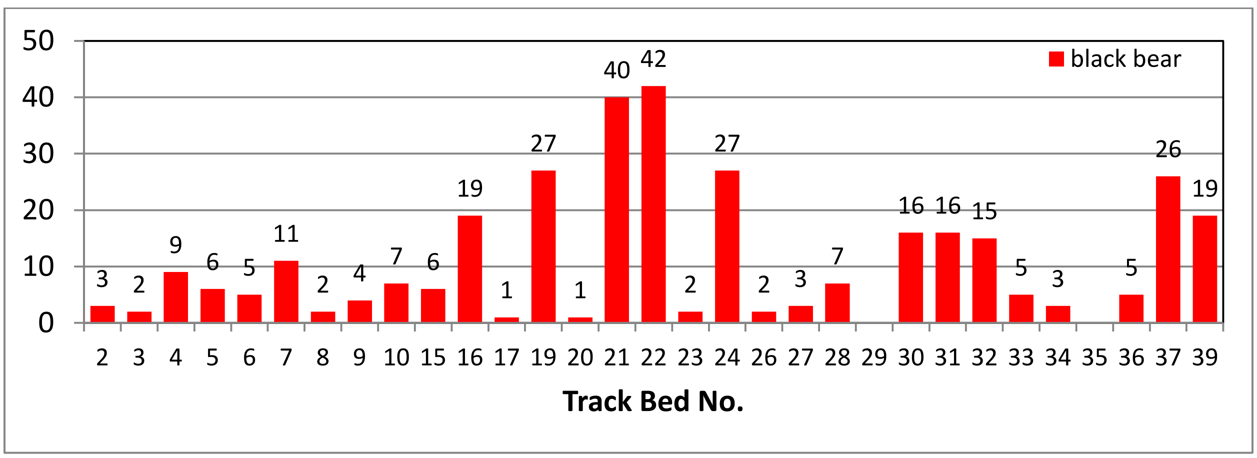


Figure 29. Black bear tracks recorded by track bed location.

Mesomammal track locations are shown in fig. 30. Raccoons were found in all but one track bed; they were most abundant at track bed nos. 2, 19, 20 and 33. Virginia opossum was also found in all but one track bed, but their abundance was low when compared to raccoons; they were most common at track bed nos. 9, 19 and 20.

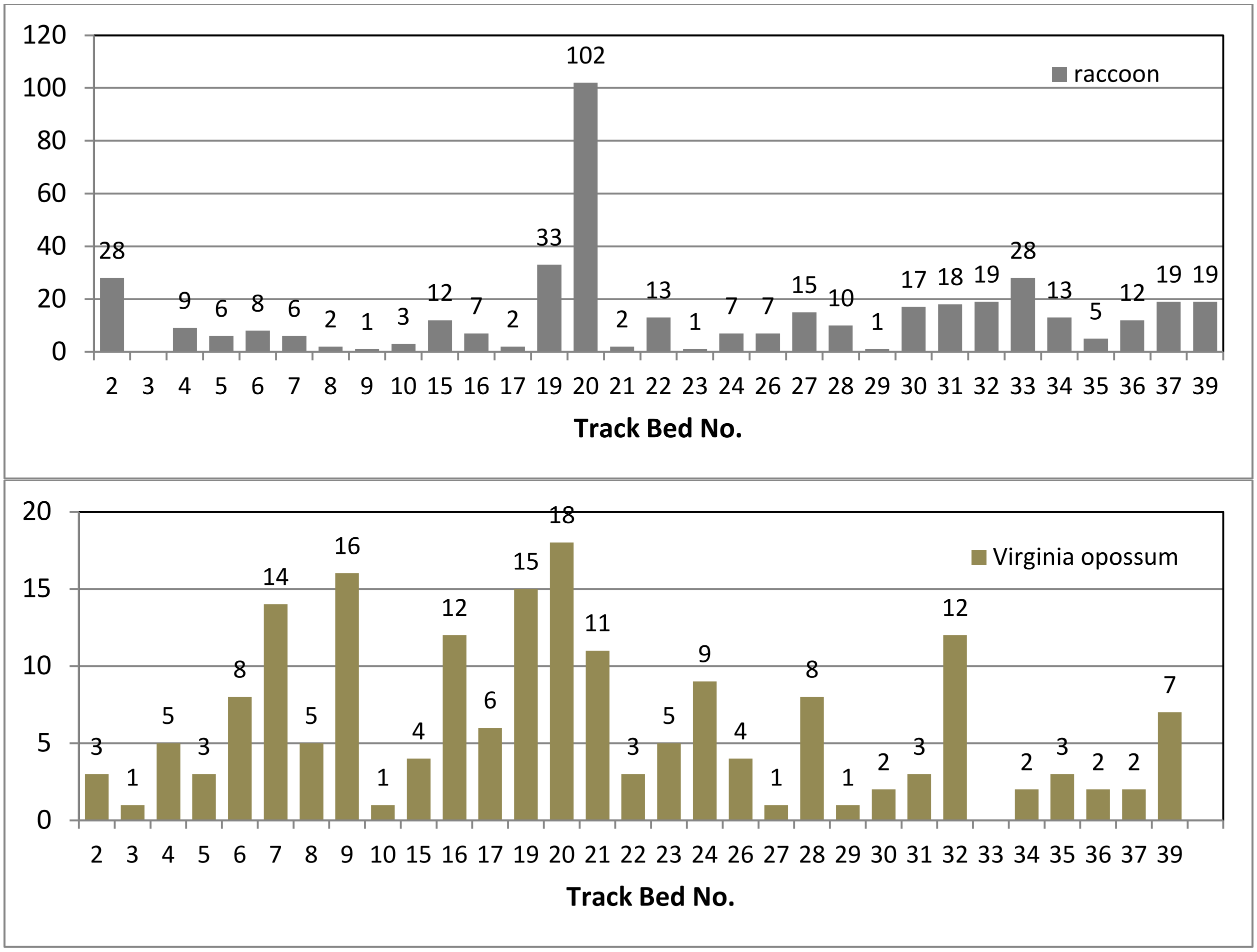


Figure 30. Mesomammal tracks recorded by track bed location.

White-tail deer track locations are displayed in fig. 31. We recorded deer tracks in every track bed. They were most abundant (>400) in track bed nos. 16, 20 and 22. Track bed nos. 7, 10, 17, 31, 35 and 39 had more than 200 tracks. An additional 7 other track beds had more than 100 deer tracks. Abundant forage on the open verges adjacent to the road is a significant attractant that draws the deer out of the forested habitat that predominantly occurs along the entire project length.

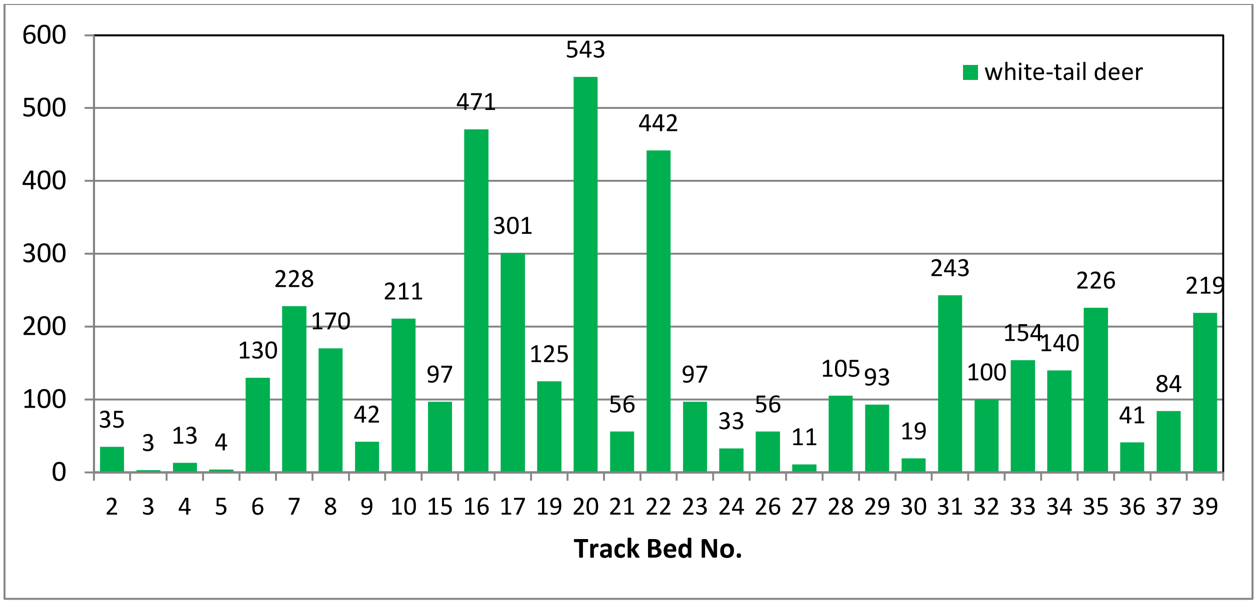


Figure 31. White-tail deer tracks recorded by track bed location.

Aquatic dependent mammal track locations are shown in fig. 32. River otters were found at 10 track stations; they were most abundant at track bed nos. 19, 29 and 33. Few American mink tracks were recorded; they were observed at track bed nos. 10, 16, 27, 33 and 36. Muskrat was also rarely detected. Nutria was the most common of this group; they were observed in 12 track beds. Tracks were most prevalent at track station nos. 27 and 29 where a nutria was frequently observed in the adjacent canal and marsh impoundment. These species utilized the adjacent canals and ditches as primary habitat; as a group they were most common at five locations associated with the deep water canal that connects to the Alligator River – track station nos. 19, 24, 27, 29 and 33.

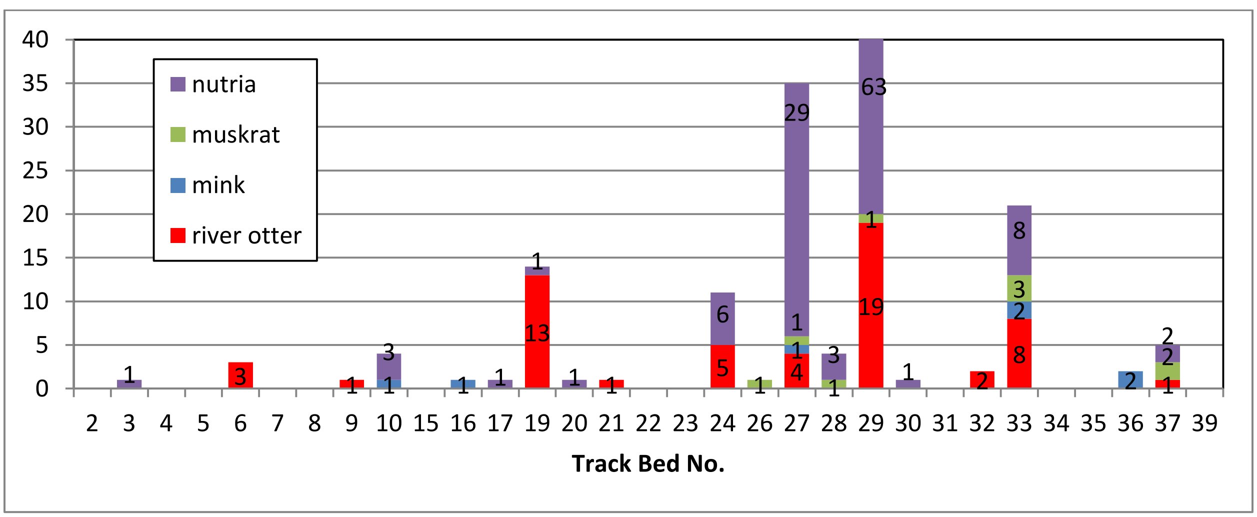


Figure 32. Aquatic-dependent mammal tracks recorded by track bed location.

Wild turkey tracks were not encountered at many track stations in the project area. They were only detected at 7 of the 31 track beds (fig. 33). They were most abundant at track stations either adjacent to an open farmland area (track station nos. 9 and 10) or where the clear zone on the north side of the road was wider and more open containing suitable forage (track station nos. 15 to 23).

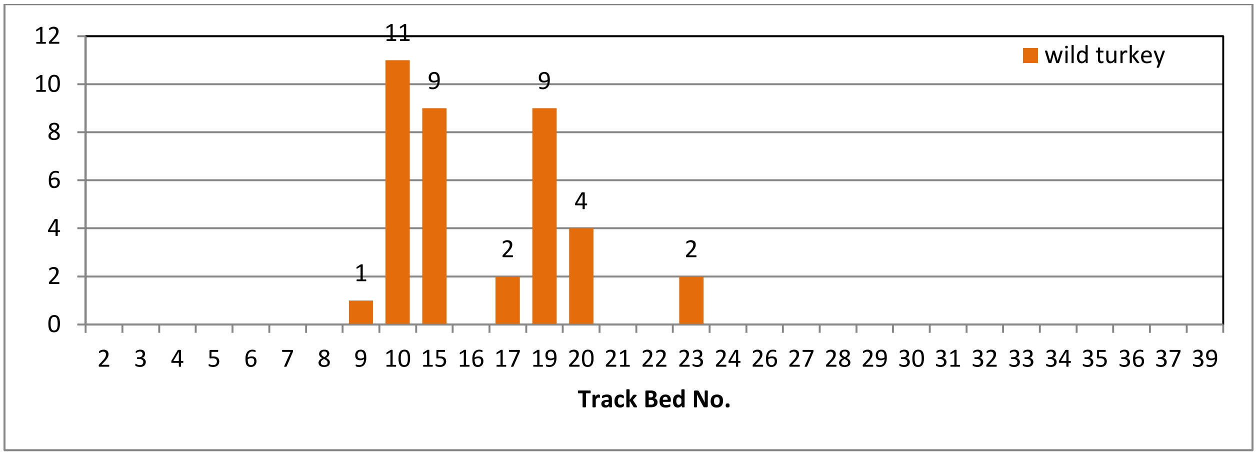


Figure 33. Wild turkey tracks recorded by track bed location.

Reptile tracks recorded included snakes and turtles. In general it appears that snakes were more commonly recorded in the western half of the project area, while turtles were more common in the eastern half of the project area (fig. 34). Snakes were most common (43 of 69, 62%) in track beds adjacent to the managed pine forests and agriculture lands (track bed nos. 2 – 10) to the far west. The exception was track bed no. 31 (n=8), a transitional area of managed pine forest, hardwood swamp and marsh impoundments. Turtles were more common at track bed sites adjacent to the marsh impoundment and forested wetland areas in the eastern section of the project area. In reference to the road-kill data, most turtle tracks were likely from aquatic-dependent species. The deepwater canal in this section probably contributes to the presence of more turtle activity.

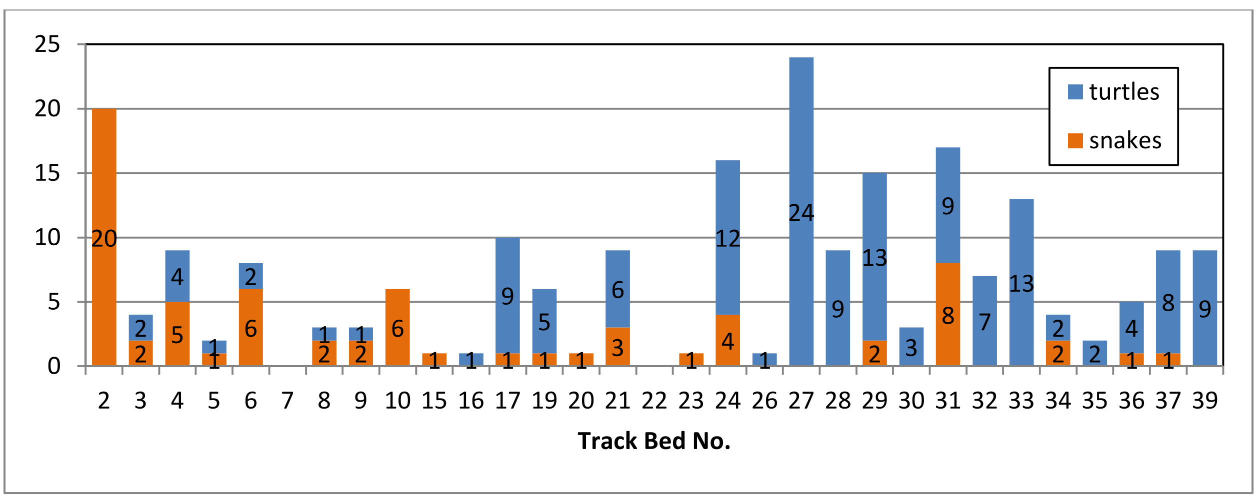


Figure 34. Reptile tracks recorded by track bed location.

We compared abundance of tracks to land cover type at track stations (ANOVA and Student's *t* test). Faunal groups evaluated included carnivores (canids, bobcat, black bear), aquatic-dependent mammals (river otter, American mink, muskrat and nutria), meso-mammals (raccoon and Virginia opossum), ungulates (white-tail deer and wild pig), reptiles (turtles and snakes) and wild turkey. Only the aquatic-dependent mammal group was statistically significant. Abundance was greater in marsh impoundments than wetland forest ($p = 0.019$) or managed pine forest (0.020).

Camera Stations

Proposed monitoring locations where substrate and/or vegetation were unsuitable for track beds, cameras were used. Virginia Tech conducted the camera study. Figure 24 shows the location of all camera stations included in this study. Seven sites included cameras only; six additional sites included cameras and track monitoring stations. The combined sites included sites where vehicle use frequently disturbed the integrity of the track beds. Table 5 provides a description of each camera site.

Cameras were set up at these sites at different dates and certain sites experienced some down-time (table 6). Cameras were checked regularly (once every one to two weeks) but were unreliable at station nos. 12, 21, 27 and 37 and certainly under-represented actual wildlife use of these access roads. Camera malfunctions were attributable to various issues, e.g., mechanical or electrical failure and weather conditions.

Table 6. Range of Operation by Camera Station.

Station No.	2009		2010	
	Start	Stop	Start	Stop
1			02/07/10	05/13/10
5*	10/30/09			04/23/10
11			04/15/10	06/22/10
12	07/07/09	09/30/09	01/18/10	05/20/10
13			04/18/10	06/17/10
14	10/08/09			06/30/10
18			04/17/10	07/17/10
21*	09/14/09	11/09/09	04/14/10	04/21/10
24*	07/15/09			04/19/10
25			04/15/10	05/18/10
26*	07/08/09			04/13/10
27*	12/16/09	02/09/10	04/10/10	04/22/10
37*	07/17/09	09/07/09	04/14/10	04/21/10

*indicates sites where cameras and track beds were used

Track surveys (where track bed conditions were good) were reliable and captured a greater range of smaller species; normally camera sensitivity is set to capture only larger wildlife species (if sensitivity is set too high, many false positives will result from movement of vegetation and wind-blown debris that trip the sensor). Disadvantages of tracks include the inability to determine abundance (e.g., several tracks of the same species could be from the presence of one or many individuals) and accuracy of identification that is dependent on quality of imprints (e.g., coyote and red wolf are difficult to distinguish from tracks). Relative abundance is better determined from photographs and identification is generally easier (depending on the quality of the photographs taken). To avoid duplication with track data at combined camera/track monitoring sites, camera data was analyzed separately.

Diversity and Abundance. Tabulation of photographic images from all camera sites is shown in fig. 35. A total of 594 individuals from 17 species/taxa were documented. As with the track data, white-tail deer were the most numerous (162, 28%). Black bear was the next most common (86, 14%). The meso-mammals, raccoon and Virginia opossum, accounted for 106 (18%) of the images recorded. Several bobcats were also recorded (64, 11%). Canids (6), coyote (38), red wolf (62) and gray fox (14) represented 19% of total images.

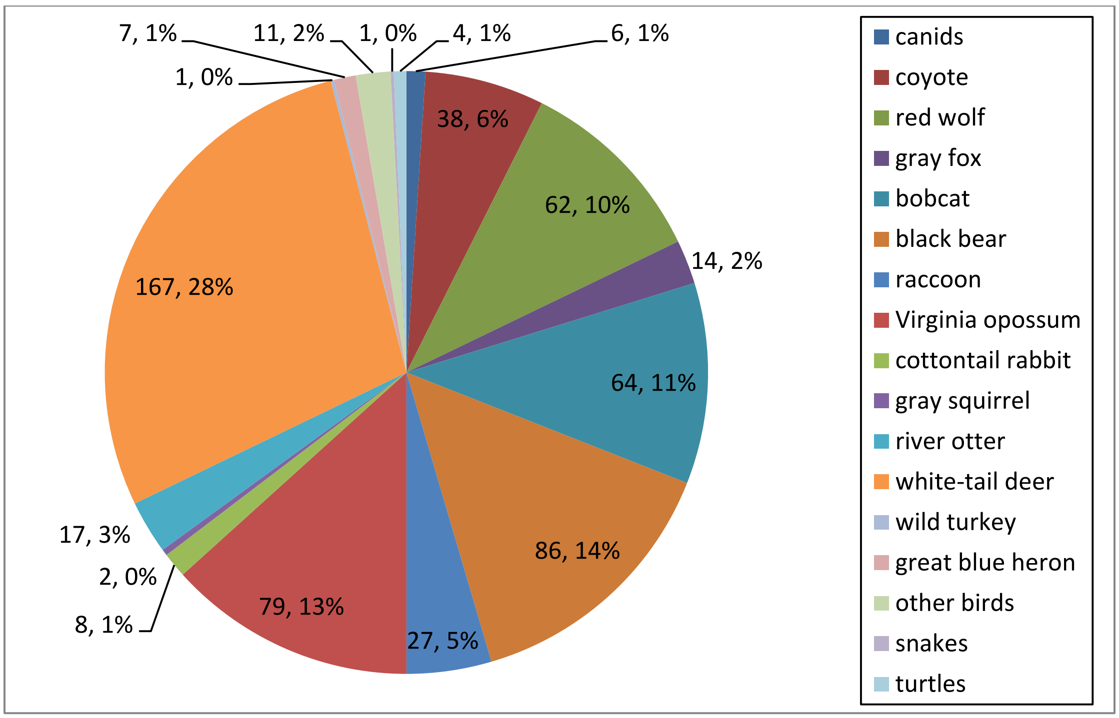


Figure 35. Total amount and percent of photographs by taxa/species.

Spatial Pattern. Differences in number of images taken at each camera station are presented in figs. 36 – 44. Refer to fig. 24 and table 5 for location and description of each camera station. Total wildlife images by site number are shown in fig. 36. Camera station nos. 5, 14, 24 and 26 were active the longest (table 6); three of these four recorded the most images (no. 14 – 114, no. 24 – 119 and no 26 – 75). Camera station no. 37 provided 67 images, but was active only a short period of time (approximately 2 months). Camera station nos. 12, 21 and 27 each recorded approximately 40 wildlife observations.

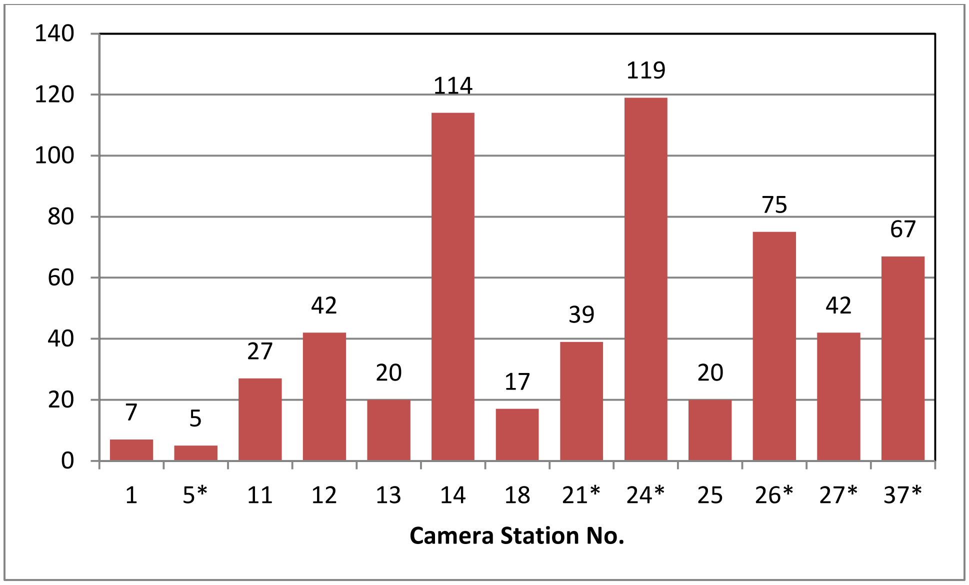


Figure 36. Total wildlife images documented by camera station. Note: asterisk indicates sites where tracks were also recorded.

Figure 37 provides a comparison of all canid images recorded. When combined, camera station nos. 14, 24 and 26 had over 86 images. Only a few canids were unidentified, these were recorded at camera station nos. 12, 24 and 26. Red wolf was most abundant among all canid images; photographs were captured at all sites except camera station no. 25. Red wolf tracks (represented primarily by one radio-collared female) were recorded most often at track bed nos. 24 and 26. Coyotes were next most common among the canids. Only camera station nos. 1, 27 and 37 did not capture photographs of coyotes. Camera station no. 24 had the most photographs of coyote. Many of these were from one individual that was following the female red wolf at the same sites. We documented the most images of gray fox at camera station no. 14.

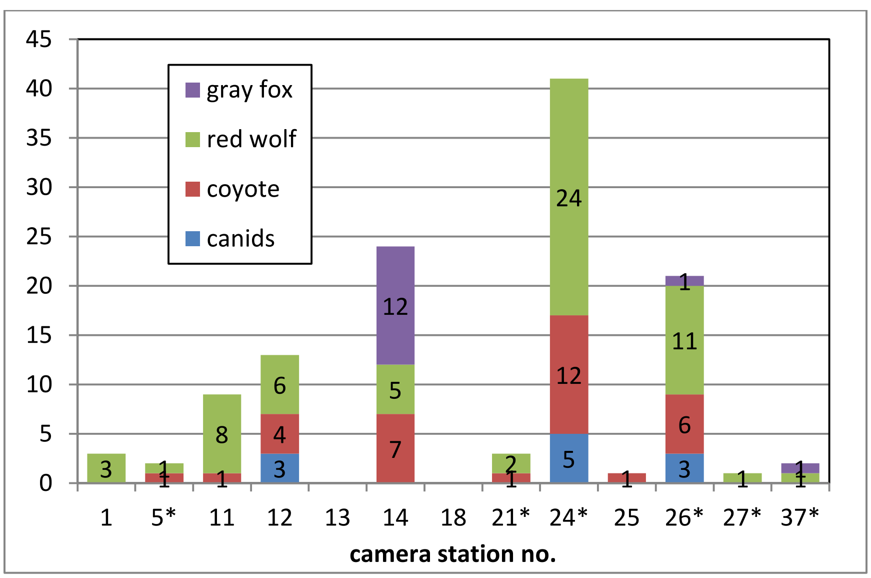


Figure 37. Combined canid images documented by camera station. Note: asterisk indicates sites where tracks were also recorded.

Bobcats were found at all camera stations except for no. 5 (fig. 38); the greatest number of bobcats was documented at camera station nos. 14 and 24.

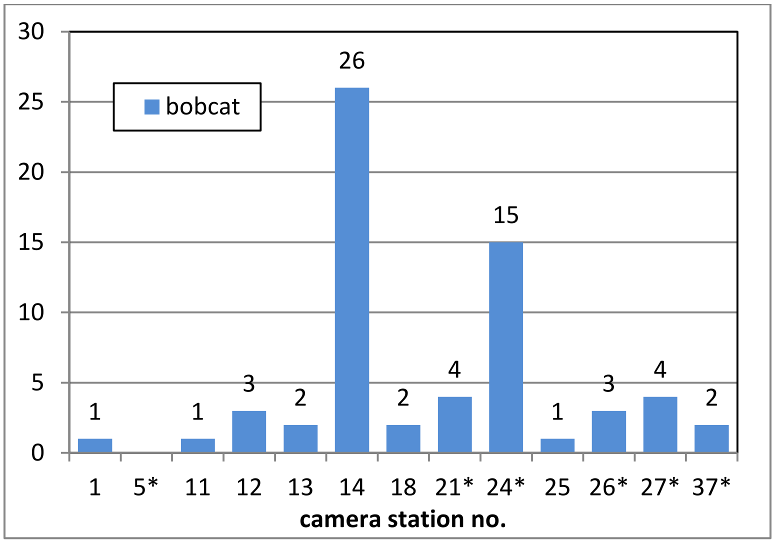


Figure 38. Bobcat images documented by camera station. Note: asterisk indicates sites where tracks were also recorded.

Images of black bears were taken at 9 of 13 locations (fig. 39). They were most abundant at camera station nos. 14, 21, 24 and 37.

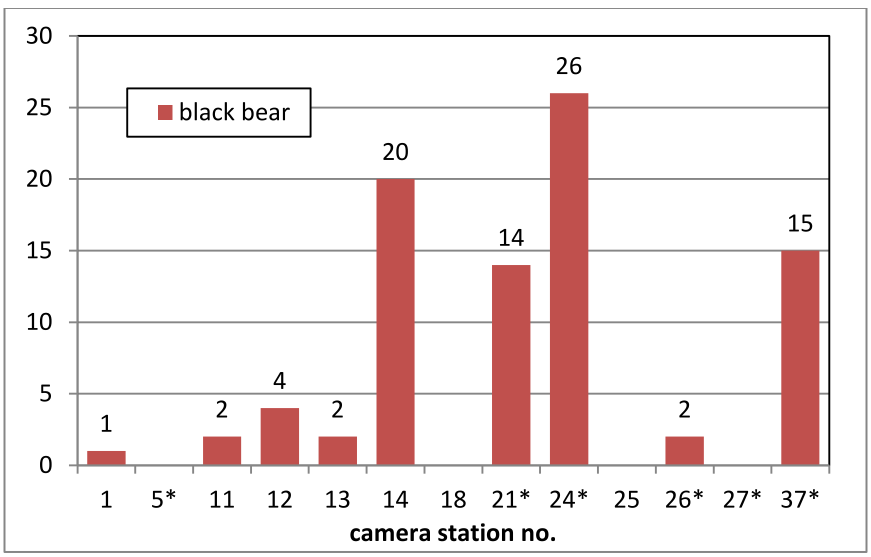


Figure 39. Black bear images documented by camera station. Note: asterisk indicates sites where tracks were also recorded.

Mesomammal locations are shown in fig. 40. Images of raccoons were captured at all the central and eastern section camera sites; but only two locations had more than five raccoons, camera station nos. 14 and 37. Virginia opossum was found at 8 of 13 camera locations, their abundance was high when compared to raccoons; they were most common at camera station nos. 14 and 24.

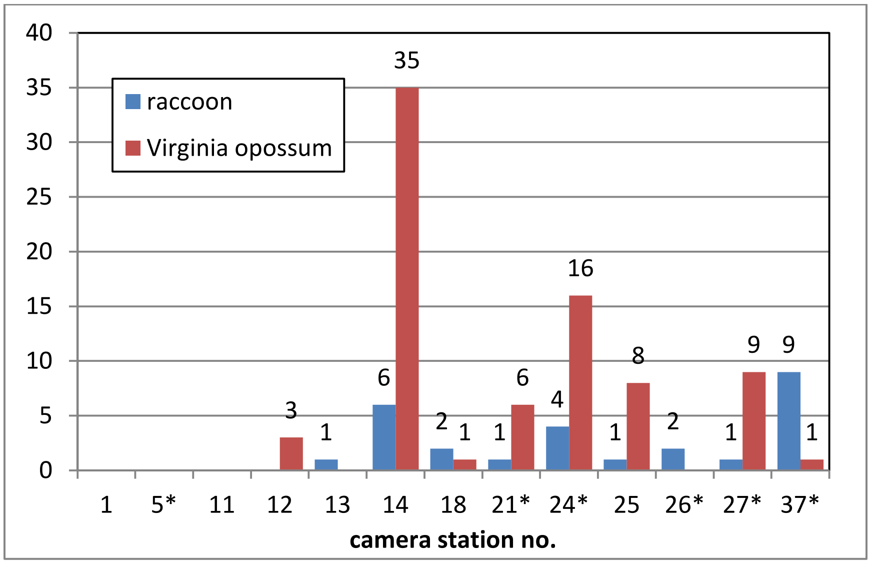


Figure 40. Mesomammal images documented by camera station. Note: asterisk indicates sites where tracks were also recorded.

Location of images taken of white-tail deer are displayed in fig. 41. White-tail deer were documented at all but the two most western sites. They were most abundant at camera station nos. 26 (n-42) and 37 (n=38). Camera station nos. 11 – 13, 18, 21 and 24 had 9 or more images.

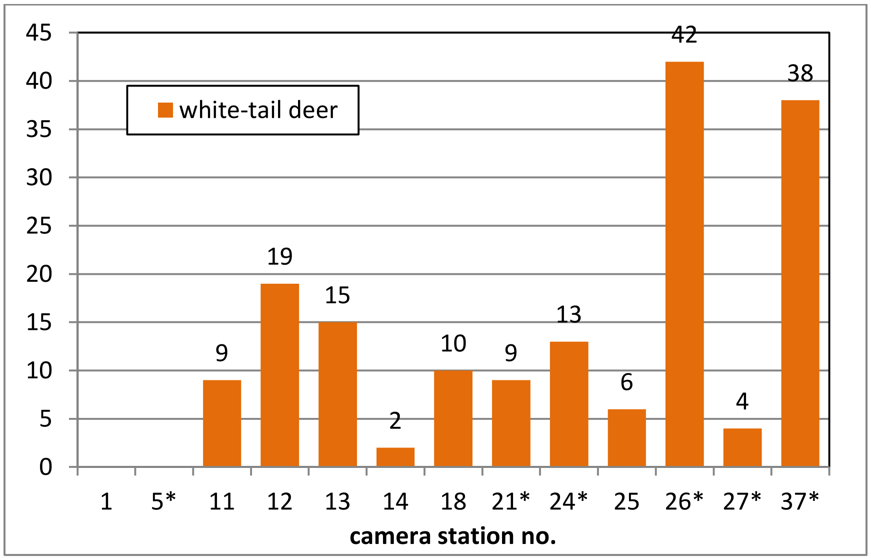


Figure 41. White-tail deer images documented by camera station. Note: asterisk indicates sites where tracks were also recorded.

Photographs of birds included wild turkey and great blue heron (fig. 42). Only one wild turkey was caught on camera, at station no. 24. A few herons were documented at camera station nos. 5, 26 and 27. Smaller birds (e.g., crows, cardinal, raven, red-shouldered hawk) tripped sensors, on occasion, at 7 of the 13 camera locations.

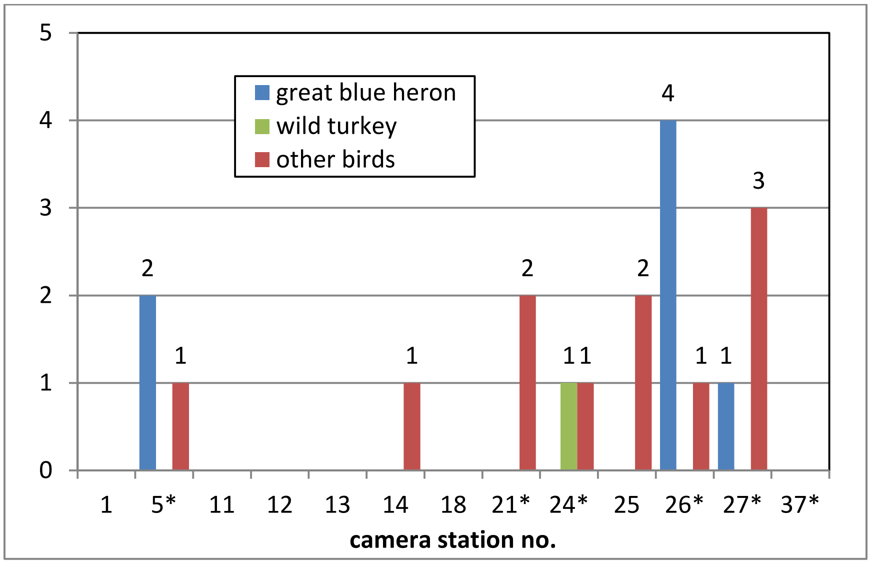


Figure 42. Bird images documented by camera station. Note: asterisk indicates sites where tracks were also recorded.

Curiously, river otters (n=17) were only documented by the cameras at one location, site no. 27 (fig. 24, table 5). This camera location was adjacent to a marsh impoundment and a deep water canal. A few small mammals (n=10; including 6 eastern cottontails at camera station no. 11), turtles (n=4) and even one snake tripped camera sensors. These numbers should not be considered indicative of the abundance of these species at these sites since animals of this size rarely trip the sensors of the cameras.

We compared abundance of taxonomic groups in photographic images to land cover type at camera stations (ANOVA and Student's *t* test). Faunal groups evaluated included carnivores (canids, bobcat, black bear), meso-mammals (raccoon and Virginia opossum), white-tail deer and birds (7 spp.). Difference in abundance by land cover type was not statistically significant for any of these taxonomic groups.

<u>Presence-absence Surveys</u>

Trapping efforts began in May 2009 and continued through June 2010. Traps were activated for at least three consecutive days weekly. Trap locations are shown in fig. 43. We established 4 control sites and 7 roadside sites. Over the course of the project each trap site was checked approximately 125 times. About 58% of the time, no animals were captured. Six trap arrays had to be closed entirely because of severe flooding on one occasion; on 7 separate visits, certain trap arrays were partially closed from flooding. Capture results were subdivided into amphibians, reptiles and small mammals.

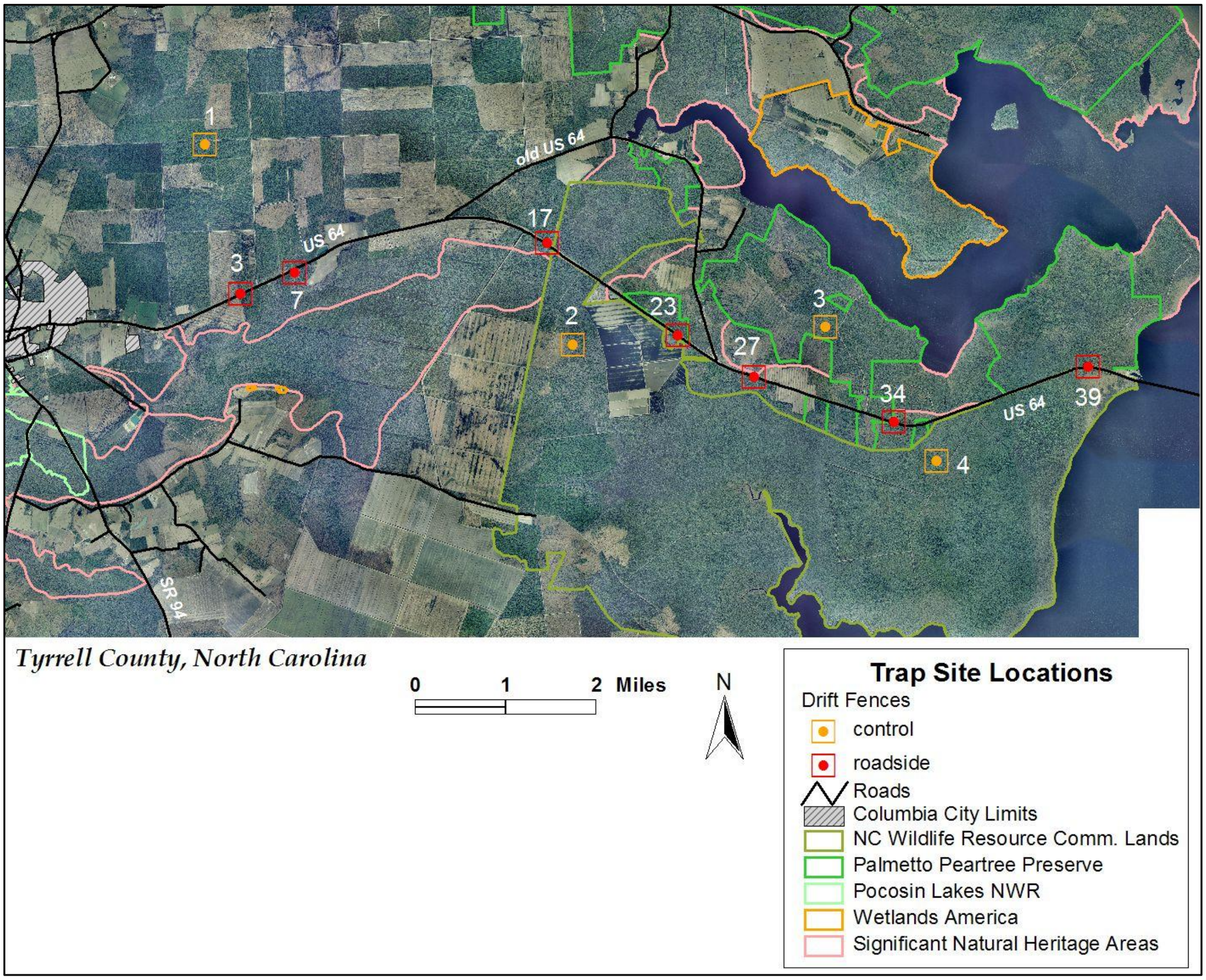


Figure 43. Roadside and control drift fence trap array locations.

We captured individuals from 19 different amphibian species (fig. 44). Diversity (and abundance) of captures in control and roadside traps were 13 (720) and 19 (767), respectively. If adjusted for number of traps, controls produced 180 captures per trap and roadside produced 110 captures per trap. On a per trap basis, total captures by taxa was a ratio of about 1.1 to 1 roadside to control for frogs and a ratio of 1.4 to 1 control to roadside for salamanders. The most abundant amphibians in control sites were southern leopard frog (266), eastern narrowmouth frog (110) and carpenter frog (102). In roadside traps, southern leopard frog (325), eastern narrowmouth frog (224) and carpenter frog (95) were most commonly captured. Atlantic Coast slimy salamander (42) and eastern newt (12) were the most commonly captured salamanders in control and roadside traps, respectively. Those species present in roadside traps but absent from control traps were bullfrog, Cope's grey treefrog, squirrel treefrog, eastern newt, southern dusky salamander and two-toed amphiuma. No species captured in control traps were absent from roadside traps.

Reptiles captured in control and roadside traps included 23 different species (fig 45). Number of species included 4 lizards, 13 snakes and 6 turtles. Abundance (and number of species) of reptiles found in control and roadside traps were similar, 78 (16) and 79 (16) respectively. This included 55 and 34 lizards, 15 and 24 snakes, and 8 and 21 turtles. Most common lizards were green anole (27-control, 13-roadside), ground skink (15-control, 4-roadside) and SE five-lined skink (12-control, 16-roadside). Number of snakes captured was low; most species included three captures or less except northern black racer (4-control, 14-roadside). Turtle captures was also low; most abundant was spotted turtle (control-4, roadside-8). Reptiles present in roadside traps and absent in control traps included five-line skink, corn snake, eastern mud snake, rough green snake, smooth earth snake, common musk turtle and painted turtle. Reptiles present in control traps and absent in roadside traps included black rat snake, Carolina swamp snake, cottonmouth, eastern garter snake, eastern worm snake, southern ring-neck snake and eastern box turtle.

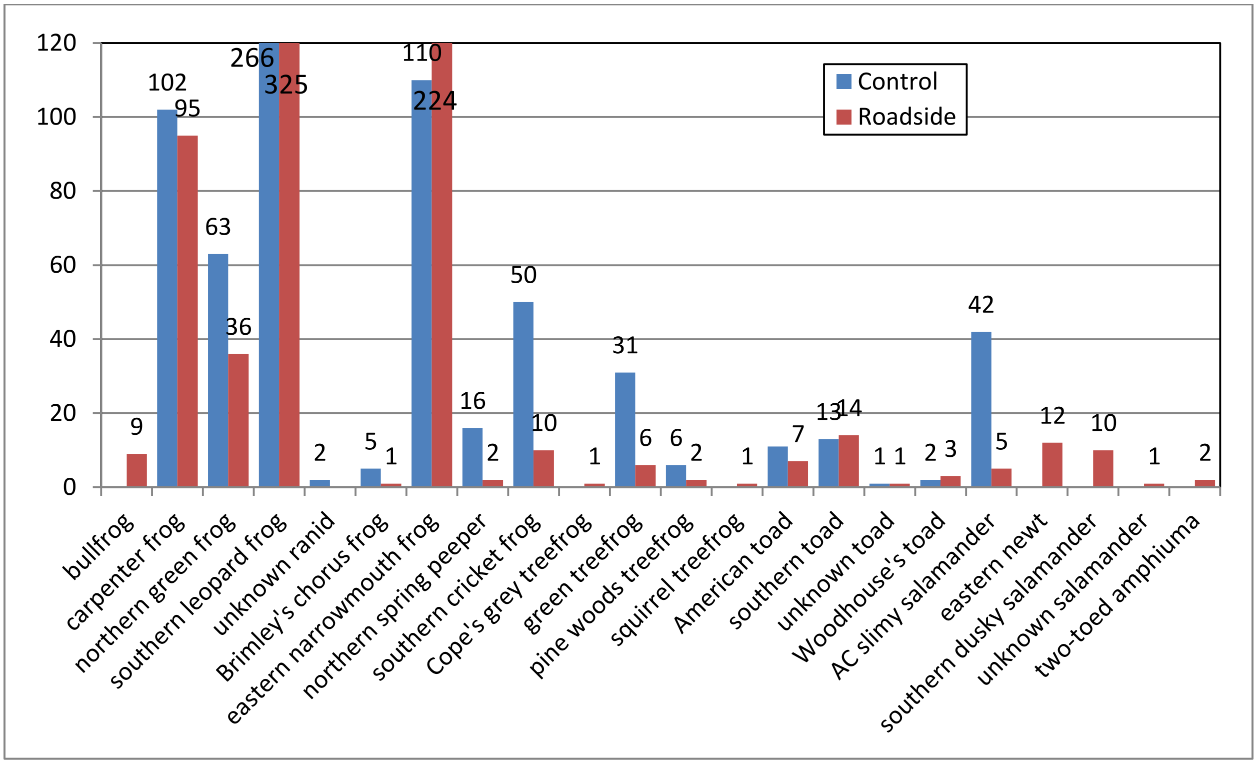


Figure 44. Comparison of amphibians captured in control and roadside trap arrays.

We captured 10 species of small mammals in drift fence trap arrays (fig. 46). This included 56 in control and 64 in roadside traps. We recorded 9 and 31 mice/rats in control and roadside traps, respectively. We also documented 47 (control) and 33 (roadside) shrews/moles. The most abundant mouse/rat was eastern harvest mouse (3-control, 17-roadside); the most abundant shrew/mole was southeastern shrew (35-control, 8-roadside). Small mammals absent from controls but present in roadside traps included golden mouse, hispid cotton rat, northern short-tailed shrew and star-nosed mole. Small mammals absent from roadside traps but present in control traps included meadow vole.

Control and roadside trap arrays were paired in the three road sections, west, central and east (see figs. 43 and 15 [and text on pg. 24]). The west section included control trap no. 1 and roadside trap nos. 3 and 7; control trap no. 1 and roadside trap no. 7 were located in managed pine forest habitat. Trap no. 3 was located at an ecotone of managed pine forest and wetland forest. The central section included control trap no. 2 and roadside trap nos. 17 and 23. Land cover included: wetland forest and managed pine forest at control trap site no. 2, wetland forest at roadside trap site no. 17 and managed pine forest and marsh impoundment at trap site no. 23. The east section included control trap nos. 3 and 4 and roadside trap nos. 27, 34 and 39. Control trap nos. 3 and 4 were located at transition zones between wetland forest and managed pine forest. Roadside trap no. 27 was adjacent to wetland forest and marsh impoundment; roadside trap no. 34 was adjacent to managed pine forest; and roadside trap no. 39 was adjacent to wetland forest and managed pine forest. All trap arrays were adjacent to swales, ditches or canals typical of this landscape.

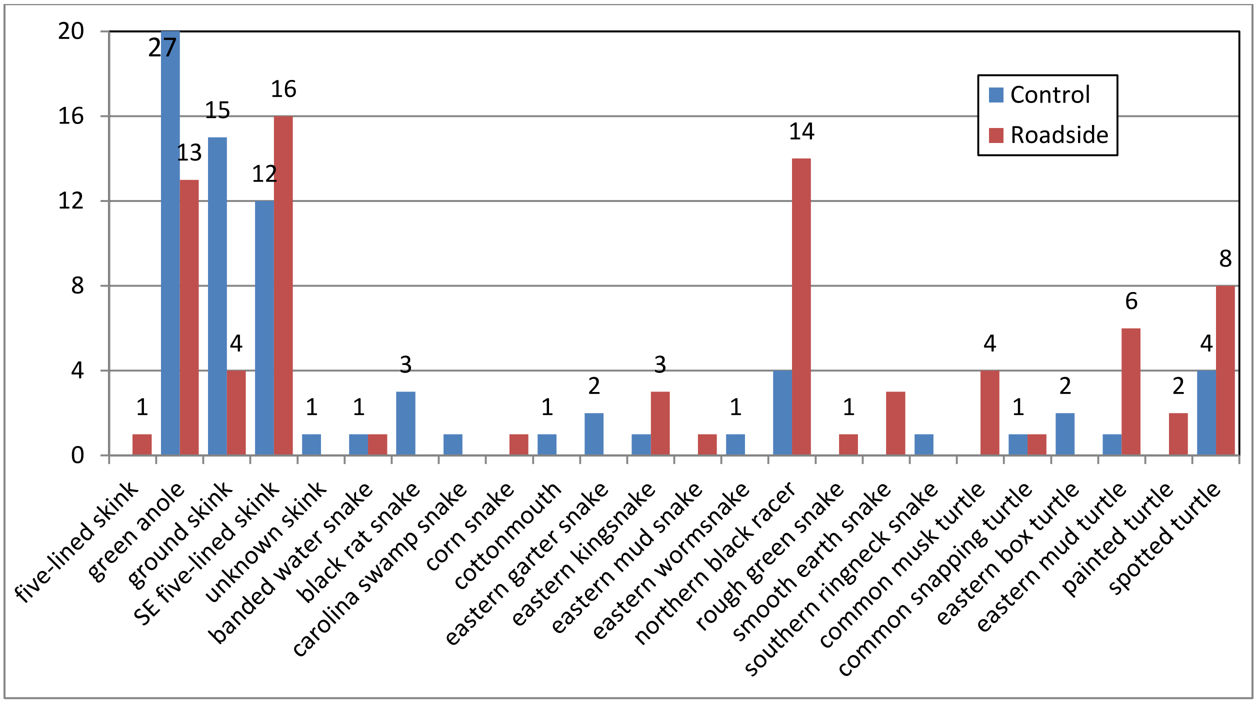


Figure 45. Comparison of reptiles captured in control and roadside trap arrays.

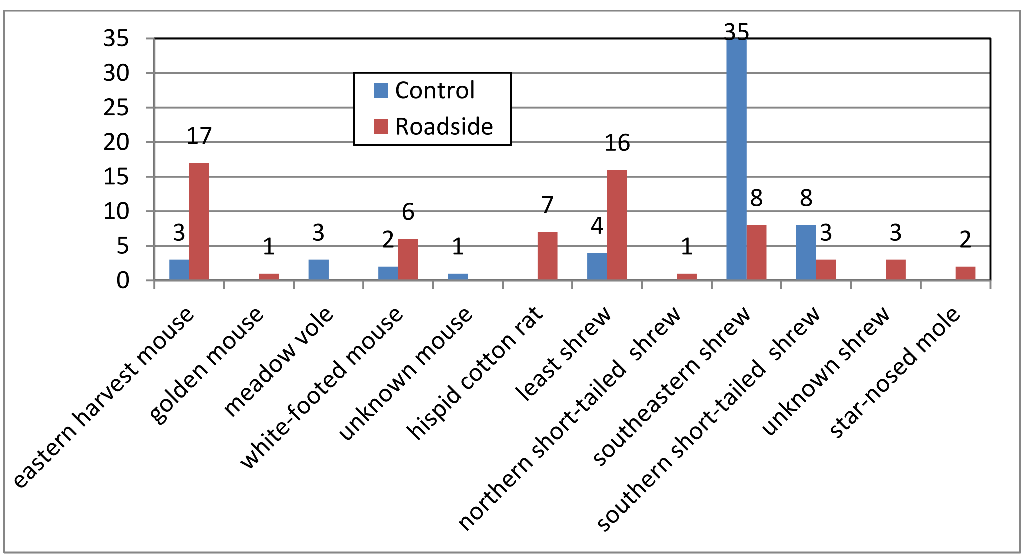


Figure 46. Comparison of small mammals captured in control and roadside trap arrays.

Table 7 includes capture data by taxa and trap number. The most frogs were captured at control trap no. 3 (n=436) and roadside trap no. 27 (n=232). Salamanders were more common at control trap nos. 1 and 2; very few were captured in roadside traps. Snakes were infrequent captures at control and roadside traps. Turtles were most abundant in roadside trap no. 27 (n=13). Lizards, primarily green anoles, were common at control trap no. 2. The most mice/rats and shrews were captured at roadside trap no. 17 (n=10) and control trap no. 1 (n=35).

Table 7. Number of individuals captured at each site by taxa.

Trap No.	Type	Frogs	Salamanders	*Amphibians*	Snakes	Turtles	Lizards	*Reptiles*	Mice/Rats	Shrews	*Mammals*	Total
1	c	48	24	72	1	0	4	5	1	35	36	113
2	c	150	18	168	4	1	43	48	2	2	4	220
3	c	436	0	436	6	6	5	17	1	4	5	458
4	c	44	0	44	5	1	3	9	5	6	11	64
3	r	111	3	114	1	1	3	5	3	7	10	129
7	r	190	4	194	6	1	6	13	3	9	12	219
17	r	70	1	71	3	1	3	7	10	5	15	93
23	r	53	1	54	5	0	4	9	7	8	15	78
27	r	232	7	239	3	13	8	24	3	3	6	269
34	r	40	6	46	3	2	3	8	1	0	1	55
39	r	41	8	49	2	3	7	12	4	1	5	66
Total		**1415**	**72**	**1487**	**39**	**29**	**89**	**157**	**40**	**80**	**120**	**1764**

Notes: c = control, r = roadside; see fig. 43 for location.

We performed a one-way ANOVA on number of species and abundance by control vs. roadside trap locations for all taxonomic groups. No significant differences were detected for the mean number of species or abundance between the combined control and roadside datasets. However, when compared to land cover, difference in abundance was significant. Roadside wetland forest sites were significantly more productive than roadside managed pine forest sites (student's *t* test, $p = 0.016$).

Sightings and Observations

Live sightings were recorded along the US 64 project area (Appendix C, figs. C-1 to C-5). These included black bear, bobcat, gray fox, river otter, white-tail deer, bald eagle, wild turkey, spotted turtle and northern redbelly cooter.

DISCUSSION

This discussion includes a summary of the results and sections on location and design of wildlife crossings and planning and management implications.

Summary of Results

This section provides a summary of the extensive findings of the different research activities conducted in the project. The application of these findings is discussed with regard to adverse impacts of the road and potential changes that may occur if road widening takes place. Most road-kill, track, and mark-recapture will be discussed with reference to fig. 47, the segmented road grid.

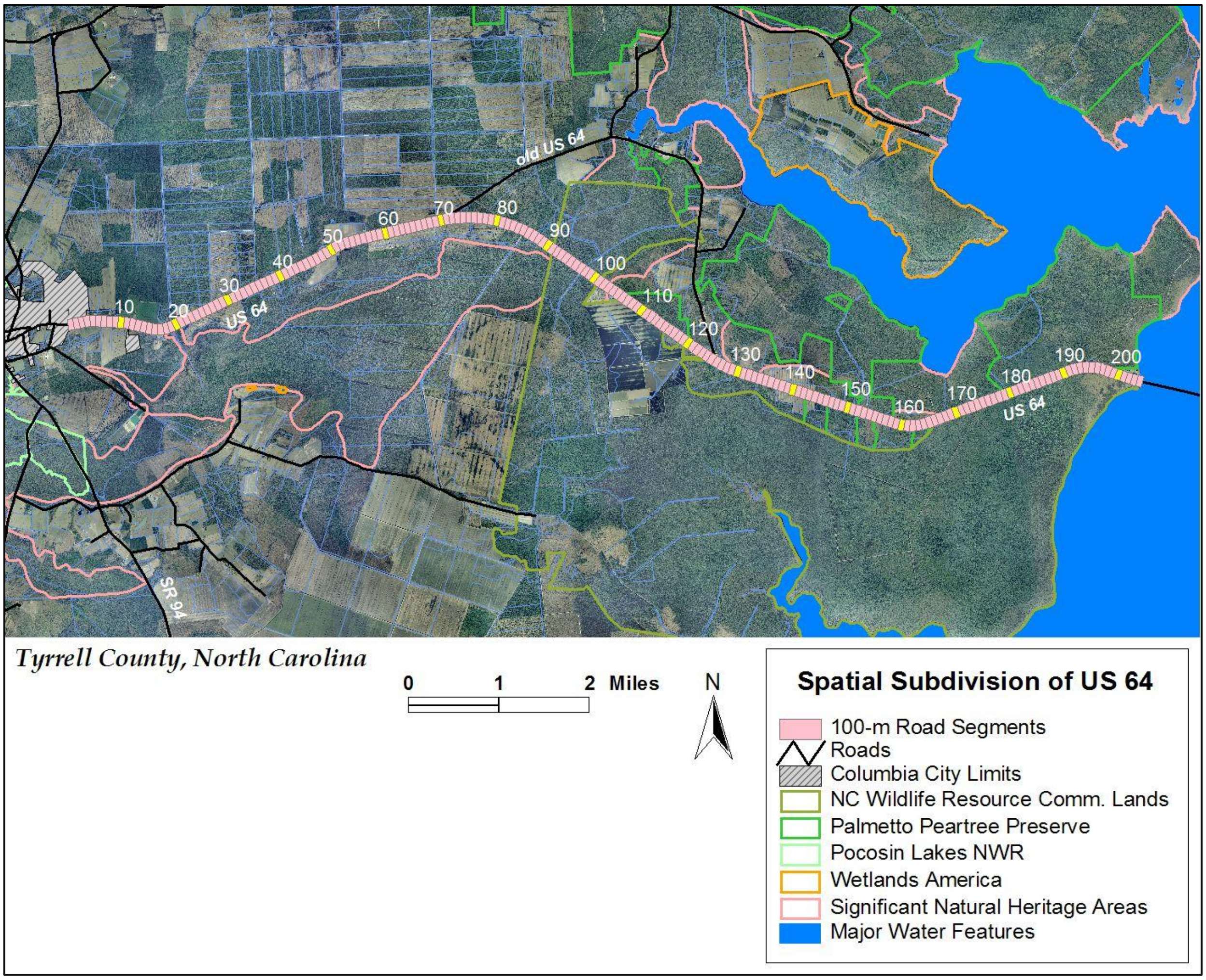
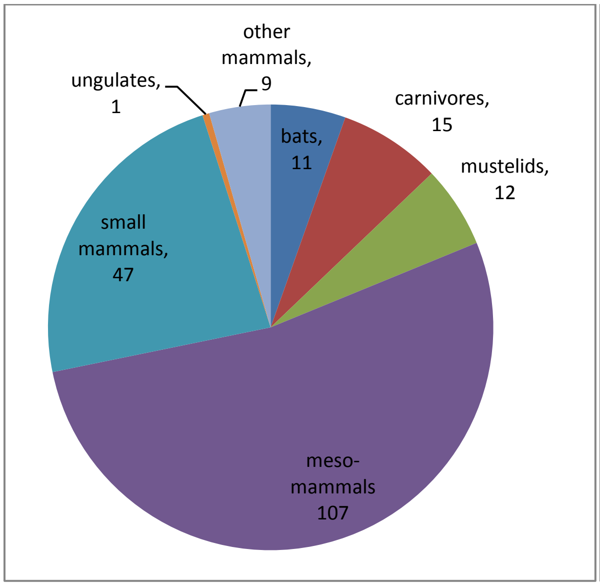


Figure 47. US 64 Segmented Road Grid. Each grid cell is 100 m wide.

<u>Road-kill Summary</u>

From April 2009 to July 2010, 27,886 individual animals were found on 13 mi of US 64 between the City of Columbia and the Alligator River. There was 113 identifiable species. The majority were anurans followed by snakes, turtles and meso-mammals (Figure 48). Two types of road-kills are notable, focal species and those that were killed in large numbers (table 8).



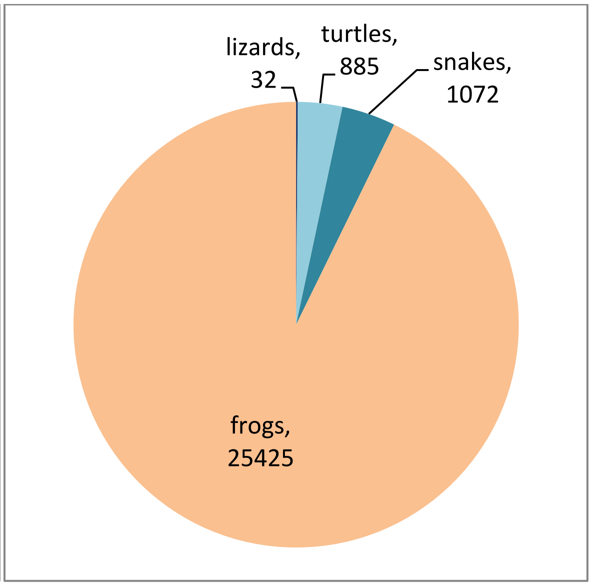


Figure 48. Total road-kills (mammals and herpetofauna).

Table 8. Focal species road-kills and those species killed in large numbers.

Focal Species	No.	Numerous Species	No.
black bear	7	banded watersnake	459
American mink	8	northern black racer	102
bobcat	1	redbelly watersnake	117
gray fox	5	common snapping turtle	158
Rafinesque's big-eared bat	1	eastern mud turtle	163
river otter	4	painted turtle	126
star-nosed mole	2	spotted turtle	201
white-tail deer	1	bullfrog	147
carolina swamp snake	35	green tree frog	197
glossy crayfish snake	25	southern leopard frog	103
scarlet kingsnake	4	yellow-rumped warbler	91
smooth earth snake	1		
timber rattlesnake	1		
chicken turtle	2		
eastern box turtle	39		
northern redbelly cooter	30		
bobwhite quail	6		
wild turkey	1		

Note: see tables 2 and 3 for explanation and significance of focal species.

Not reflected in fig. 48 is that most frogs were unidentifiable to the species level (n=24,956), therefore the amounts listed by species in table 8 are considered significantly low estimates. Similarly, we also documented 86 unidentified snakes. Few lizard and rodent road-kills were recorded. Road crossing avoidance by certain species of mice and rats has been documented in previous studies (Fahrig and Rytwinski 2009).Twenty-eight of the 32 lizards were green anoles. On one occasion a successful road crossing by a green anole was witnessed by field technicians. Some factors that could explain few lizards in the road-kill data: aversion to roads and roadside habitat by other species of lizards, high roadside predation rates, depredation of carcasses, and rapid disintegration deterring identification of carcasses. We also recorded 262 birds killed on the road. Notable birds included great-horned owl (1), eastern screech owl (11), red-shouldered hawk (1) and turkey vulture (1) preying upon other road-kill and were also killed. Lastly, single occurrences of wood duck and tundra swan road-kills were recorded.

In addition to our field surveys, we compiled other sources of road-kill data for black bear, red wolf and white-tail deer (table 9). Only one red wolf roadkill was reported by the USFWS in the last decade on US 64 in the study area. One additional red wolf road-kill occurred in 1996. Confirmed black bear data was collected by or reported to NCWRC by reliable sources.

Table 9. Current and previous road-kill data for red wolf, black bear and white-tail deer

	confirmed occurrences*		unconfirmed occurrences***	
Year	red wolf*	black bear**	black bear	white-tail deer
2000		2		2
2001	1	1		
2002			2	6
2003		1	5	
2004		1	5	4
2005		3	7	4
2006		3	3	3
2007		6	1	4
2008		7	5	7
2009		5	8	4
2010		3	3	3
	1	32	39	37

Notes: *Data was provided by US Fish and Wildlife Service, Red Wolf Recovery Team
**Data was provided by the North Carolina Wildlife Resources Commission
***Data was provided by North Carolina DOT

Unconfirmed road-kill occurrences of black bear and white-tail deer are from compiled vehicle-animal crash reports. These reports are filed by law enforcement officers. When detected, duplicates of occurrences that corresponded to NCWRC data were removed from this analysis. A few issues define the reliability of this data. First, some of the records report that the animal survived the collision and immediately fled the location, so the report relies on the driver's ability within a few seconds under stress to identify the species of animal that was struck. Second, locations of these records are estimates based on nearest landmark. The inaccuracy in location may result in double counting some of these records with confirmed records collected by NCWRC. This obviously creates some ambiguity with the black bear as we think it reasonable that not all accidents with black bears are reported to NCWRC. When confirmed and unconfirmed black bear road-kill records are combined, the maximum killed in any one year (2009) was 13 animals. White-tail deer road-kill numbers per year from unconfirmed records are likely low estimates as many of the collisions with deer are probably not reported to law enforcement or NCWRC (table 9).

Important locations (Figure 47 [road segment nos.]; Appendices A and B) of significant numbers of road-killed herpetofauna by taxa included anurans (road segment nos. 98-106, 109, 112-115, 117-118, 121, 125-152, 189, 195-200), snakes (road segment nos. 18-19, 97-98, 113-114, 127-130, 132-134, 137-140, 150-153, 168-170, 174, 187-188, 190-198) and turtles (road segment nos. 113-114, 125-137, 151-153, 194-199). Those locations identified represent the upper quartile for anurans (n = 97.7 or more) and the upper quartile (8-snakes, 6-turtles) and a minimum of 20 individuals combined in adjacent cells for snakes and turtles. When these groups are combined, locations with a minimum of 110 individuals represent the upper quartile (road segment nos. 98-106, 109, 112-115, 117-118, 121, 125-153, 155, 168, 189, 191, 195-200).

Critical sites where large carnivore road-kills occurred included red wolf (road segment nos. 98, 191) and black bear (road segment nos. 12-19, 70-92, 113-123, 139-151, 157-165, 175, 191). The stack graph in fig. 49 displays road segments where multiple black bear/red wolf carnivore road-kills occurred and clusters of consecutive road segments with road-kills (also see map in fig. 47).

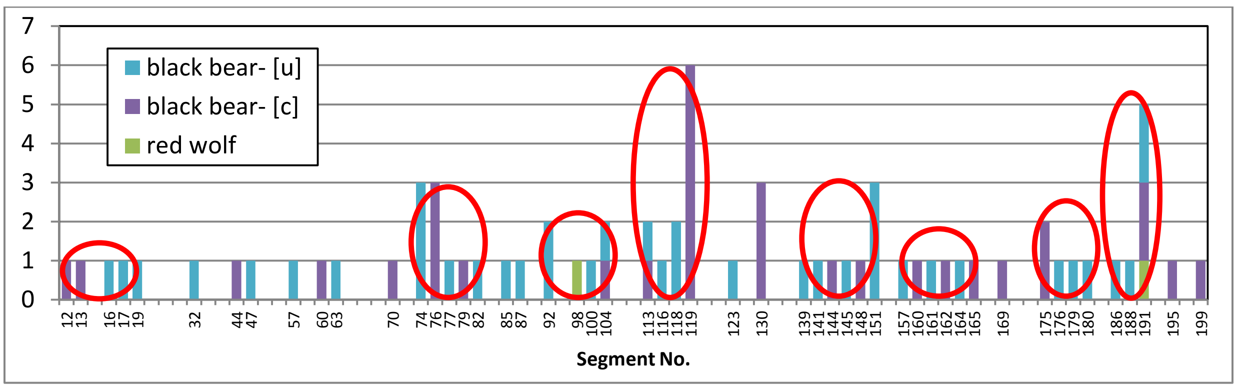


Figure 49. Location of road-kill black bear and red wolf road-kills on US 64, 2000 – 2010.

When other carnivore road-kills from the 2009-2010 surveys were combined, many locations overlap or are adjacent with the long-term black bear/red wolf road-kill data (fig. 50, and 49 above).

Data was insufficient to denote any particular road segments with considerable numbers of white-tail deer road-kills. From 2000 to 2010, only five segments were documented with at least 2 road-kill white-tail deer (road segment nos. 11, 14, 19, 58, 132; see fig. 47). These overlap or are adjacent with locations of large carnivore road-kills (fig. 49). Track and camera surveys were more informative regarding locations where repeated crossings of white-tail deer may occur.

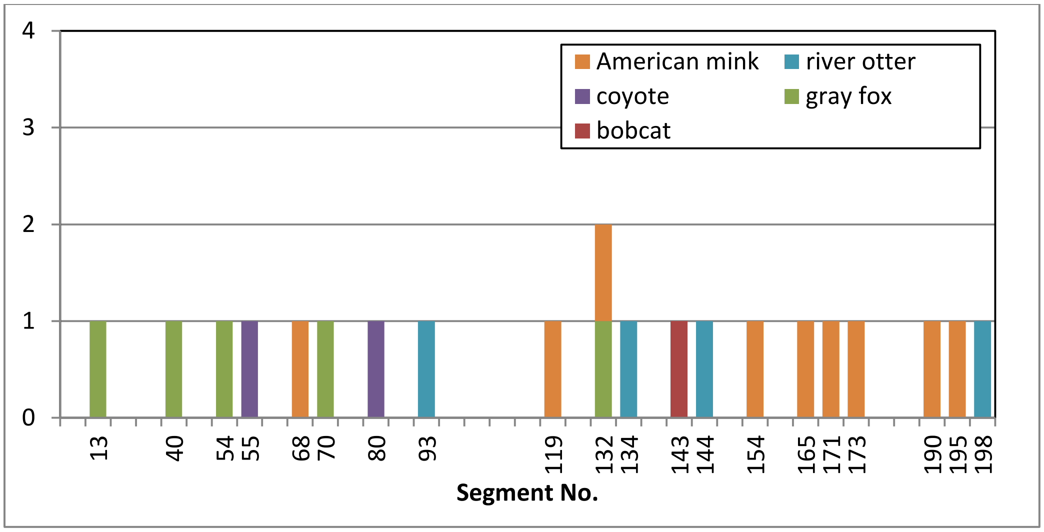


Figure 50. Other road-kill carnivore locations on US 64, 2009 – 2010.

Track and Camera Summary

A total of 4,492 sets of whitetail deer, 728 sets of canids, 211 sets of red wolf, 96 sets of coyote, 231 sets of gray fox, 277 sets of bobcat and 331 sets of black bear tracks were recorded from 31 track stations on US 64 (fig. 24). Tracks of other species of conservation interest included river otter (57), American mink (7), wild turkey (38), snakes (70) and turtles (148). We did not assume that presence of tracks on one side of the road equaled a successful crossing. Several factors contributed to this: 1) possibility of aborted crossing attempts, 2) members of the three faunal groups we monitored (certain carnivores [primarily coyote and fox], ungulates and snakes) use the right-of-way for foraging, and 3) track paths could not be constructed on the south side because of space limitations and safety concerns—this prevented us from matching tracks on either side of the highway to confirm successful road crossings. Because of these factors we reported tracks as the degree of activity on the right-of-way.

Overall, much fewer camera images were recorded than track imprints. Nevertheless, we did capture several images of red wolf, coyote, gray fox, bobcat, black bear and river otter at a few monitoring locations. It is important to note that canid, red wolf and coyote tracks/photographs at road segment nos. 83, 113, 119, 121, 137 and 148 represent to a large degree one radio-collared female red wolf and one male coyote/red wolf (unconfirmed) that repeatedly moved through these locations over a period of several months.

As with the road-kill, significant hotspots of activity are evident from track and camera data. These hotspots were identified by track/camera station. Track/camera stations where the highest activity occurred are shown in Table 10 (also fig. 24). Station numbers are cross-referenced to road segment number. In most instances these track/camera stations correspond to the same road segments identified as road-kill hotspots. Highlighted cells indicate those track/camera stations where numerous tracks/photographs were recorded. Minimum number of tracks/photographs for inclusion in table 10 included those sites with values in the fourth quartile or a minimum of ten, whichever was highest for the following species: white-tail deer (215), canids (31.5), red wolf (10), coyote (10), gray fox (10.5), bobcat (11.5), black bear (16) and river otter/mink (10). Canid tracks represent those that could not be identified and/or verified to the species level. Exclusion from the table does not mean that no tracks/photographs were recorded for any of these species at each respective location, only that the amount was below the specified threshold.

Table 10. Track/camera stations exhibiting the greatest number of tracks.

Site No	Road Segment No.	canids	coyote	red wolf	gray fox	bobcat	black bear	river otter/ mink	white-tail deer	Total
1*	19	2	0	(3)	0	(1)	1 (1)	0	3	6 (5)
2	27	10	0	2	10	8	3	0	35	68
3	31	7	0	4	12	5	2	0	3	33
4	34	24	1	6	7	15	9	0	13	75
5**	36	17	4(1)	(1)	1	5	6	0	4	37
6	41	26	0	2	10	11	5	3	130	187
7	42	55	9	19	13	6	11	0	228	341
8	45	8	0	4	6	2	2	0	170	192
9	47	13	2	0	9	5	4	1	42	76
10	57	51	6	17	11	16	7	1	211	320
11*	60	0	1	8	0	1	2	0	9	21
12*	68	3	4	6	0	3	4	0	19	39
13*	74	0	0	0	0	2	2	0	15	19
14*	80	0	7	5	12	26	20	0	2	72
15	83	32	4	18	29	6	6	0	97	192
16	86	16	1	7	12	7	19	1	471	534
17	89	16	2	12	5	5	1	0	301	342
18*	91	0	0	0	0	2	0	0	10	12
19	97	38	21	2	4	18	27	13	125	248
20	101	23	0	9	5	18	1	0	543	599
21**	105	35	2 (1)	3 (2)	2	24 (4)	40 (14)	1	56 (9)	163 (30)
22	113	24	15	19	7	7	42	0	442	556
23	119	22	6	29	9	1	2	0	97	166
24**	121	53 (5)	3 (12)	7 (24)	1	18 (15)	27 (26)	5	33 (13)	147 (95)
25*	125	0	1	0	0	1	0	0	6	8
26**	129	35 (3)	1 (6)	2 (11)	(1)	3 (3)	2 (2)	0	56 (42)	99 (68)
27**	134	21	0	1 (1)	1	3 (4)	3	5 (17)	11 (4)	45 (26)
28	134	31	2	1	2	4	7	0	105	152
29	137	54	8	6	1	5	0	19	93	186
30	144	26	0	7	1	6	16	0	19	75
31	148	22	2	22	5	6	16	0	243	316
32	153	29	3	4	2	8	15	2	100	163
33	154	9	0	1	2	12	5	10	154	193
34	157	4	0	5	20	11	3	0	140	183
35	162	1	1	0	2	0	0	0	226	230
36	166	10	1	1	12	7	5	2	41	79
37**	174	10	0	1 (1)	10 (1)	9 (2)	26 (15)	1	84 (38)	141 (57)
38***	180									
39	196	6	2	0	20	26	19	0	219	292
subtotal tracks		728	96	211	231	277	331	64	4492	6430
subtotal cameras		13	33	62	14	64	87	17	167	457

Notes: refer to fig. 24 for track/camera station locations; *indicates camera location only, **indicates camera and tracks, ***indicates no monitoring occurred. Dark pink indicates value fell within the upper quartile; light pink indicates value is at the threshold of the upper quartile; blue indicates four or more species above the upper quartile; and light blue indicates less than three species above the upper quartile, but includes at least one species of concern (black bear or red wolf).

Snake tracks were only numerous at one location, track station no. 2 (n=20). Turtle tracks were more commonly found at more sites than snakes, though the number of tracks recorded was not reflective of the number of road-kills documented. This was attributed to poor quality substrate for reading tracks. Track station nos. 17 (n=9), 24 (n=12), 27 (n=24), 28 (n=9), 29 (n=13), 31 (n=9), 33 (13) and 39 (n=9) had the greatest number of turtle tracks. Wild turkey tracks were most common at track station nos. 10 (n=11), 15 (n=9) and 19 (n=9). In general, smaller (low weight) species were unable to leave a significant imprint in the high clay content soil unless it was moist.

<u>Trapping Summary</u>

A total of 846 individuals of 35 species of herptiles were captured in right-of-way drift fence traps. The highest number of captures occurred at control trap location nos. 2 and 3 and roadside trap location nos. 7 and 27 (see fig. 43, table 7; trap nos. correspond to track station numbers), indicating significant population densities of these species in adjacent habitat areas. Herptiles present in control traps, but absent in roadside traps included pinewoods treefrog, black rat snake, Carolina swamp snake, cottonmouth, eastern garter snake, eastern worm snake, southern ring-neck snake and eastern box turtle. Despite the lack of captures of these species in roadside traps, their presence is evident due to the presence of road mortalities. Only the cottonmouth was not recorded as road-kill. Consistent with findings by Means (1999) and Aresco (2005a), the current level of road-kills likely have not threatened the population with extinction, but changes in highway configuration and intensity could affect long-term presence and population size if sufficient measures are not taken to insure successful recruitment and dispersal to/from the wetlands. Aresco (2005b) and Steen and Gibbs (2004) documented skewed sex ratios in turtles as a result of extreme highway mortality rates.

Of 64 small mammals caught in roadside traps, 31 were mice/rats and 33 were shrews/moles. Highest densities of small mammals occurred in roadside trap nos. 7, 17 and 23. Twenty small mammals were found as road-kills, all of these were captured in roadside traps as well. Apparently, the road is a significant barrier to small mammal movement. Several factors influencing this barrier effect are artificial substrate (pavement), road surface and clearance width, right-of-way vegetation management, vehicle traffic, emissions, noise and vibration (Garland and Bradley 1984, Mader 1984, Wilkins 1982, Kozel and Fleharty 1979, and Oxley et al. 1979).

Highway Improvement Recommendations

Absence of wildlife underpasses and cross-drainage structures associated with the current configuration of US 64 translate into high levels of mortality, especially for smaller species with poor mobility. The US 64 Project Area in Tyrrell County provides an opportunity to improve upon the current 2-lane configuration with a design that restores habitat connectivity between adjacent conservation lands (Figure 47) and is more cost-effective to implement than retrofitting the existing two-lane highway. Wildlife crossing structures and other measures will be needed to provide necessary levels of permeability for wildlife once the highway is expanded to four lanes.

The low elevation of the existing 2-lane highway from old US 64 east to the Alligator River and presence of the parallel canal along the southside of the road limits the ability to design and construct a system of structures that function in all hydrologic conditions. If crossing structures were installed under the road at the current elevation, the low clearance would result in the structures being severely inundated during high water periods. This would prevent most air-breathing animals from using the culverts. The roadbed in this section may need to be raised to accommodate structures that provide for movement of terrestrial species. Higher elevation would give highway engineers more flexibility in design and implementation.

The following parameters (from Smith 2003a) were considered in making recommendations for improvements to the US 64 corridor:

- Context Sensitivity—vegetation consistent with surrounding habitat
- Environmental variability—provide for terrestrial passage at semi-aquatic sites during periods of high water levels
- Directional fencing—funnel wildlife through passages and away from road surface
- Berming—reduce effects of traffic noise and lights
- Topography—road should be designed to "fit into" the landscape (e.g., minimize alteration in slope of underpass/ overpass approaches)
- Substrate—consistent with adjacent area
- Lighting—reduce tunnel effects by increasing openness value (height*width/length) and providing light penetration in medians of divided highways
- Human presence—reduce human access associated with crossing sites

To improve habitat connectivity within the US 64 Project Area in Tyrrell County, we propose a system of culverts, bridges, roadside animal detection devices and barrier fences to eliminate road-kills and increase permeability of the road for the wide diversity of wildlife in the area. We recommend installing eight bridges or bridge culverts in the central and east sections for large wildlife, a series of box culverts in all road sections designed to increase permeability for smaller wildlife species, and a roadside animal detection system in the west section. All large structures in the central and east sections will require 10 ft barrier fencing with 3 ft herptile excluding mesh at the base of the fence. Smaller structures will require standard 4-5 ft field fence with attached 3 ft herptile excluding mesh. Recommended dimensions of structures are consistent with structure preferences of the target species (or surrogates of) identified in previous studies (Clevenger et al. 2001, Smith 2003b).

Large Crossing Structures

Eight potential areas for large crossing structures were identified from analysis of road-kill and track/camera data in the central and east sections. These areas are separated by approximately 1,000 m and each area has one or more existing access roads to resource areas or private lands (table 11). Maintaining access to adjacent public resource areas and private lands will need to be addressed. Where possible wildlife crossings should be placed in a location separate from access roads; when they must be co-located, proper design considerations are necessary to enhance use by wildlife. These measures would include resident soil substrates and native landscaping/cover adjacent and parallel to unpaved access roads. In cases where an unimproved access road is associated with a wildlife crossing, a land bridge (ramp) over the southside canal would already be required so no additional measures to cross over the canal would be necessary to enhance use by wildlife.

Table 11. Candidate areas for large wildlife crossing structures in central and east study area sections.

Potential Large Crossings	Road Segment Range	No. of Access Roads
Area 1	74-89	2
Area 2	97-105	2
Area 3	113-121	2
Area 4	129	1
Area 5	139-151	3*
Area 6	157-166	2
Area 7	174-180	2
Area 8	186-196	1

*two of these access roads are just outside this range
Note: see fig. 47 for road segment locations; road segment width is 100 m.

Several other access roads to US 64 occur at other locations within the central and east sections besides those identified as highway hotspots for crossings by large wildlife. The highway design will need to accommodate these. If these locations are bridged, then infrequent crossings by larger wildlife could benefit by using these structures to cross under the highway.

Although we didn't identify wildlife crossing locations for larger wildlife in the west section that were as important as those in the central and east sections, evidence of less frequent crossings by black bear and red wolf was apparent. Road-kill of black bears and photographs of black bear and red wolf were recorded at road segment no. 19 (westernmost access road to Weyerhauser lands). In addition, many crossings by large canids were recorded between road segment nos. 34-42 and 57. Also, several red wolf tracks were recorded at road segment nos. 42 and 57; numerous black bear tracks were recorded at road segment no. 42. Again access roads to adjacent lands are present at these locations and will require design considerations. Accommodations for unimproved (non-paved) access roads (e.g., bridges or bridge culverts) at road segment nos. 19, 42 and 57 would promote safe crossings for red wolf and black bear in these areas. Depending on highway design for access to adjacent lands, (i.e., the configuration does not include bridges for access roads), an alternative consideration for these three locations would be use of a roadside animal detection system (Huijser and McGowen 2004). The open right-of-way for these locations is conducive to successful implementation of these devices to promote safer highways and increased road permeability for larger wildlife. Many types of these systems are now available at a range of costs and sophistication (Huijser et al. 2009a and 2009b).

Recommended bridge or bridge-culverts for large wildlife crossings that do not include access roads should have a minimum opening of 24 ft wide (at ground-level) by 10 ft high (center clearance) with an open median to increase openness and light penetration. We further recommend that land bridges (or ramps) be constructed over canals, ditches or swales to create a continuous terrestrial connection for these wildlife crossings. If the bridge includes an unpaved access road, the structure should be a minimum of 45 ft wide and 10 ft high with the same median specifications. It would be preferable to place the access road on one side to accommodate a wider, undisturbed and vegetated strip on the other side for wildlife use only. Approaches of these structures need to be landscaped with native shrub and ground cover vegetation; and final elevation within the structure and the adjacent approaches needs to be higher than adjacent areas to prevent pooling of water and buildup of sand and silt within the structure. These structure types have proven highly functional for a wide variety of wildlife species including black bear and surrogates for red wolf (coyote, fox, bobcat) (Chasez et al. 2007, Smith 2003b, Smith and Noss 2011).

Small Crossing Structures

Locations where small wildlife crossing culverts are needed include 13 areas (table 12). Several of these overlap with candidate sites for large crossings. If large crossings are implemented at any of these locations, then smaller crossings would be unnecessary. All of these locations exhibited significant levels of reptile and amphibian road-kills.

Table 12. Candidate areas for small wildlife crossing structures.

Potential Small Crossings	Road Segment Range
Area 1	18-19
Area 2	86
Area 3	97-106
Area 4	109
Area 5	112-115
Area 6	117-118
Area 7	121
Area 8	125-153
Area 9	155
Area 10	158
Area 11	168
Area 12	189-191
Area 13	195-200

Note: see fig. 47 for road segment locations; road segments are 100 m wide.

Recommended small wildlife crossing structures should include an opening from 5 – 8 ft wide (at ground-level) by 3 – 5 ft high (center clearance). This range allows some variation for specific site conditions. Amount of light available within culverts can help counter tunnel effects. Certain amphibian species will not use culverts when sufficient light is not present (Krikowski 1989, Langton 1989). These structures should include lighting grates (not drainage grates) within the median and on the shoulders to maximize light penetration. For those structures adjacent to marsh impoundments and wetland habitats, the crossings can be designed to include a gallery of trickle-irrigation tubes throughout the length of the culvert that maintain moisture within from drainage water contained in road-side or median swales. Three-sided (concrete walls and ceiling, natural soil floor) box culverts or arches are recommended in drier areas where scour or high velocity drainage is not an issue. In areas where rapid drainage or scour is likely, then oversized standard four-sided box culverts or oval pipes should be used and backfilled with native soils to the recommended clearance height range. If erosion at the entrances is a concern, rip-rap should not be used (Smith 2003a); if soil substrates cannot be maintained, then the approaches should be paved with porous concrete, tiles or other substitute materials. These structures are targeted toward herpetofauna and small mammals, though Hewitt et al. (1998), Smith (2003b) and Smith and Noss (2011) demonstrated infrequent use of similar-sized structures by ocelot and bobcat. Comparable structures were monitored for several species of herpetofauna and produced good results (Barichovich and Dodd 2002, Boarman and Sazaki 1996, Smith 2003b, Smith and Noss 2011).

Spacing of structures should be approximately one every 1,000 ft which addresses limited home range and dispersal distance for most species that would use the crossings. Most of the habitats in the central and east sections are expansive wetlands of low-elevation. The best solution to improve habitat connectivity in this type of landscape is to install several of these smaller structures distributed along the natural topographic gradient of the wetland basin (see example in Adair et al. 2002). The center of the basin nearly always maintains surface water but the water recedes as one moves toward the wetland-upland ecotones. We suggest these smaller culverts be spaced out along this gradient that will flood and dry at different times as the water levels naturally increase and decrease. As this wet/dry interface fluctuates seasonally and inter-annually, wildlife movement patterns will also adapt. This will allow for road crossing opportunities by upland species that occur along these margins. Road-kill data suggests that high numbers of road-kills occur throughout most of the wetland basins. By providing multiple culverts, more crossing opportunities are afforded during reptile and amphibian breeding seasons.

Fencing

Lastly, two types of road-kill barriers are suggested. In association with large crossings, a 10 ft high fence that extends the length of the road segment range of each respective area in table 11. Length of each area varies, but the fencing is needed to keep larger species off the road and direct them toward the wildlife crossing structure. At the base of the fence we recommend installation of a 3 ft high mesh-screen herpetofauna barrier. Pepper et al. (2006) provides examples of this fence configuration. The mesh screen should extend below the ground surface approximately 1 ft to prevent any openings. Fencing should terminate at all culvert and bridge openings to aid in funneling wildlife through the crossing structures. One-way gates/earthen ramps may be needed to allow escape for wildlife trapped in the fenced enclosure within the right-of-way (see Bank et al. 2002).

Small crossing structures should be accompanied by a standard field fence 4-5 ft high with the same attached screen-mesh as specified above. The length of this fence should also be extended throughout the impact zone (road segment range) identified for each small crossing area in table 12.

Even with these measures the long-term effects of road expansion may be detrimental and can take decades to determine (Findlay and Bourdages 2000). Following construction we recommend that funding be earmarked to monitor crossing structure performance and population stability of representative focal species.

Planning Considerations

To preserve the character of the Tyrrell County project area of US 64 we strongly support a context-sensitive approach to land-use planning and highway design (see Moler 2002 and Gesing 2003). Palmetto Peartree Preserve and the Alligator River State Game Lands provide valuable wildlife habitat for black bear and red wolf and numerous species of mammals, reptiles, amphibians, birds and invertebrates. This area is connected to the much larger Pocosin Lakes NWR and forms a critical regional wildlife habitat node in NE North Carolina. Although not threatened by significant land development pressure, this area faces other challenges. Based on models of sea-level rise, Coastal North Carolina faces significant threats from inundation in the next 100 yrs (Overpeck and Weiss 2009). A one meter rise in sea level would essentially cover the project area (Overpeck and Weiss 2009, Weiss et al. 2011). Most of the conservation lands in Tyrrell County are not scheduled for specific protection measures from sea-level rise (Clark et al. 2010). It is important therefore, that this road project accommodate movement and migration by wildlife to the west as this area transitions from freshwater to saline-influenced environments.

2-lane vs. 4-lane configuration: aversion factors and negative edge effects

Two lane and four lane highways can produce varying negative effects on wildlife in adjacent areas. The extent of these effects is regulated by width and traffic volume. Consider that traffic volume is equal. In this case, two lane highways generally produce more road-kills, but are more permeable (Smith 2003a). Four lane highways would have fewer road-kills, but have been demonstrated to become aversion zones for many species and therefore are greater habitat fragmenting forces (Smith 2003a, Carr and Pelton 1984, and Garland and Bradley 1984). Seiler (2003) determined thresholds of the effect of traffic on deer road crossings. Three distinct traffic-level zonal effects were identified: when traffic was approximately 3,000 vehicles per day or less, road crossings were frequent with fewer collisions; when traffic was more than 3,000 and less that 10,000 vehicles per day, road crossings continued to occur but collisions increased significantly; and when traffic was greater than 10,000 vehicles per day, the road became an aversion zone where few crossing attempts were made.

Langton (1989) and Tyning (1989) documented the obstruction of normal migratory patterns of amphibian populations by roads. Mortality rates increased as mobility of various species decreased (Hels and Buchwald 2001). For populations of slower amphibian species (many of which occur in along US 64), wider, high-traffic roads become an interminable barrier, effectively disrupting the breeding process.

Widening of highways increases the potential magnification of negative edge effects, including the absence or reduction of species sensitive to noise or visual disturbance and increased presence of predators and weedy species (e.g., birds, rodents, and omnivores) (Forman and Alexander 1998; Gibbs 1998; Reijnen et al. 1997, 1995; Bennett 1991; Andrews 1990; Garland and Bradley 1984; Adams and Geis 1983; Wilkins 1982; Ferris 1979; Kozel and Fleharty 1979; and Oxley et al. 1974). In summary, roads seem to increase the richness of species that are competitively advantaged in disturbed environments, while decreasing the abundance and richness of area-sensitive or forest-interior species.

Reijnen et al. (1997, 1995) attributed forest breeding bird's aversion to road verges to reduced habitat quality (primarily caused by traffic noise; and to a much lesser extent, visual disturbance or pollutants). These studies examined the effect of proximity to roads on breeding-bird density and found a 60% reduction in species diversity in plots adjacent to roads. The threshold where bird densities decline was defined as the distance from the highway where traffic noise is 42 decibels (dB) or higher (Reijnen et al. 1995).

Increased edge can impact interior species by increasing predation from edge predators as far as 300 to 600 m into a forested patch (Norse et al. 1986). Disruption of normal behavior, communication skills, and mating success can also result, as was shown for nocturnal frogs by artificial lighting (Buchanan 1993) and for anurans and birds by traffic and other technogenous noise pollution (Il'ichev et al. 1995, and Barrass 1985). For these reasons we discourage placement of artificial lighting along the highway adjacent to public wildlife management areas and rural areas.

Habitat fragmentation

Habitat isolation and fragmentation by linear structures such as roads may have drastic effects on biological diversity. Human influence threatens native biological diversity through loss of species from genetic inbreeding, elimination of large uninterrupted habitat, and invasion of alien species (Forman and Alexander 1998, Andrews 1990, and Harris and Gallagher 1989). Though this area is not currently experiencing significant land development or growth, the widening of US 64 could influence construction or improvement to secondary roads that may lead to residential and commercial development.

Rapid fragmentation of landscapes by roads and urbanization result in loss of normal dispersion patterns and population instability (Rosen and Lowe 1994, Harris and Scheck 1991, and Andrews 1990). Prior to the construction of US 64 and associated canals, this area once was a continuous landscape of mixed forested wetlands and uplands that animals regularly moved through. The same movement phenomenon appears to be occurring with the exception that the animals now have to cross two significant barriers (the road and canal) at great risk due to high-speed traffic flow. What once was a simple 75-100 m movement event across uniform habitat now involves an abrupt dense habitat edge, a section of grass or bare ground, a canal or ditch of varying depth and width and a section of pavement with periodically dense high-speed traffic. This presents a daunting task to a slow moving spotted turtle, carpenter frog or eastern kingsnake. The result is significantly high road mortality, fewer successful crossings and habitat fragmentation for those species that are not well adapted to artificial landscape features. We recorded very few small mammal road-kills indicating a reluctance to cross the road; this could mean segregation of local populations. Negative effects of the road on long-term population genetics, though unknown, may be significant (Steen and Gibbs 2004, Aresco 2005a).

Extent of habitat fragmentation and isolation caused by increasing road densities is critical for determining the persistence of disturbance-sensitive species. Based on numerous studies that have documented these impacts for various species (Bowers and Matter 1997, Rodgers and Smith 1996, Van Dyke et al. 1986, and Opdam et al. 1985), the best prescription for retaining disturbance-sensitive species would include conservation reserve designs that maintain contiguous large reserves. Ideally these reserves would contain wetland-upland gradients of suitable habitat (high landscape structural complexity preferred) and network connections that contain similar characteristics and that minimize negative edge effects. We strongly recommend that State and private conservation organizations purchase remaining inholdings around the Palmetto-Peartree Preserve and Alligator River State Game Lands. In addition it is critical to improve the linkage between these areas and Pocosin Lakes NWR by acquiring fee-simple or obtaining conservation easements on identified significant natural heritage areas to maintain the current ecological function of this area. The two areas most critical are the Scuppernong river Swamp Forest and Palmetto Peartree Swamp Forest.

Regional landscape connectivity

Along with the encroachment of roads and development, isolation and fragmentation of ecosystems and associated wildlife populations has occurred with varying detrimental effects, as previously discussed. Coordination between transportation agencies and resource conservation agencies is essential to the development of effective policies that protect ecological systems, while simultaneously providing safe and efficient transportation systems.

North Carolina WRC, USFWS and several private conservation organizations manage key conservation areas in Tyrrell County. Other significant natural heritage areas have been identified for protection that would provide connections between these areas and preserve their ecological integrity. Connecting corridors must have sufficient width to maintain interior habitat qualities that would enhance use by threatened area-sensitive species (Noss 1983; see also Noss and Cooperider 1994, and Soulé 1991). Understanding natural history requirements of species being considered is essential in design of functional corridors (Burbrink et al. 1998). Design of these landscape connections; however, are thwarted by the presence of roads within and surrounding habitat islands.

Studies of reserve network design recognize road density as a critical indicator for evaluating system integrity (Noss 1995). Roads, as a barrier to animal movement, are considered one of the six major determinants of functional connectivity (Noss and Cooperider 1994). The use of highway crossing structures at intersections with greenway linkages (habitat corridors) offers a method to reduce transportation-related, wildlife mortality and restore connectivity to the landscape. Recommended designs (as presented in this case) illustrate the use of wildlife crossings to permeate transport facilities (Noss 1995).

Management Considerations

Recreational activities, trails and public access

Access provides opportunities for recreational activities within wildlands, yet negative ecological consequences often result. Campgrounds located in or near carnivore habitat areas are an intrusion into otherwise native habitat that attract coyotes, foxes, etc. in search of food, often resulting in human-wildlife conflicts (Creachbaum et al. 1998). Trail systems used for ecotourism, recreation, and research can also change ecological systems (e.g., increased erosion, light penetration, and disturbance from humans and domestic predators). Human traffic caused activity shifts or avoidance by sensitive species near trails, and increased numbers of unaffected or habituated species (Griffiths and van Schaik 1993).

Trails need to be routed away from wildlife crossing sites whenever possible to minimize negative impacts of human presence on use of crossings by wildlife. Several studies have found that human presence reduces use and effectiveness of underpasses (Smith 2003a, Clevenger and Waltho 2000), McClellan and Shackleton 1988). Also presence of domestic predators was a deterrent to use of crossings by wildlife (Smith 2003b). Relevance of this is relevant to domestic dogs and cats in adjacent rural residential areas.

Sensitive and forest-interior species benefit by the low density of roads within the core area of the Palmetto-Peartree Preserve and Alligator River Game Lands Areas. We recommend that access roads be kept at their current density and that designated recreational trails use existing roads and firebreaks. This policy would provide opportunities for recreation and hunting opportunities for the public, but minimize access to remote road-less areas reserved for wildlife.

Environmental education

Public-private partnerships are needed to educate the public and local government officials about the value of nature and the protection of natural systems. NGOs can play a significant role as liaisons between resource agencies, the public and local government politicians and planners. The value of these conservation areas to local economic development and quality of life should be emphasized.

Kiosks or information plaques should be placed at trailheads and key locations that presents information on the value of wildlife and measures that should be taken while visiting the conservation areas that protects habitat and species for enjoyment by future visitors. Information that educates the public on the importance of wildlife crossings in habitat management and conservation of wildlife populations should be emphasized.

Threatened and endangered species in the area should be publicized at all public units to protect people and these species. These resources could be utilized by local schools and non-government organizations (NGOs) to promote environmental protection and study of ecological systems. This project touched on different aspects of the road and different managed habitat areas on wildlife populations; more research on effects of management techniques and basic wildlife biology of species affected by the highway is suggested.

Resource management activities

In managed pine habitats, areas surrounding the entrances to wildlife crossings need to be protected from clearcutting and other drastic management practices. This is necessary to maintain their function and to protect the significant investment in the construction of the proposed structures. The timing and staging of prescribed burns, hydraulic-ax thinning of understory, tree thinning and logging needs to be managed so that continuous corridors between the wildlife crossing structures and mature forest areas is maintained.

Standard management activities such as these are necessary to recycle nutrients, and maintain or restore high quality habitat, but may result in the temporary displacement of resident species in these areas. This displacement is attributable to the loss of cover and food and presence of humans. We suggest that future management activities be staged to limit the number of simultaneous actions in any one or adjacent management units. This will guarantee that an adjacent management unit (of similar resources) with sufficient cover and food is available for resident species to move to.

LITERATURE REVIEW

Roads are known as a major cause of habitat loss and fragmentation (Trombulak and Frissell 2000, Forman et al. 2003, Geneletti 2006, Watts et al. 2007), posing a threat to connectivity (Noss and Cooperrider 1994, Trombulak and Frissell 2000) and to core natural areas critical to the maintenance of biodiversity (Jantz and Goetz 2008). Roadways act as a barrier to many species (Forman and Alexander 1998, Jantz and Goetz 2008) reducing access to suitable habitat (Eigenbrod 2007), and decreasing the quality and quantity of available habitat (Glista et al. 2009). They increase animal mortality due to animal-vehicle collisions (Trombulak and Frissell 2000) and lead to avoidance behavior in many species (Forman and Alexander 1998), including large mammals such as black bear (Brody and Pelton 1989), bobcat (Lovallo and Anderson 1996), and birds (Forman and Alexander 1998, Laurance 2004, Francis et al. 2009). As traffic levels increase, roadways become less permeable to animals (Alexander et al. 2005). Overall, the documented negative impacts of roads on population abundance and diversity of species outweigh the positive documented impacts by at least five times (Fahrig and Rytwinski 2009).

Mitigation of these impacts is achieved through the modification of motorist behavior through signage and warnings or the modification of animal behavior through fencing or crossings (Glista et al. 2009). The effectiveness of wildlife crossings is dependent upon location, design, adjacent suitable habitat, and the use of fencing or walls adjacent to the passageways (Glista et al. 2009).

Structure Placement

A number of studies have discussed methods for determining appropriate locations for crossing structures. For example, GIS-based habitat models for species of interest, data on roadkill locations, radio telemetry, remote camera photos, known migratory paths of animals, and animal signs (such as tracks, scent markings or rubs) can be used to identify sites for highway crossing structures (Singer and Doherty 1985, Foster and Humphrey 1995, Scheick and Jones 1999, Clevenger et al. 2002/2003, Henke et al. 2002, Lyren and Crooks 2002, Smith 2003a, Smith and Voigt 2005, Alexander 2008, Brown et al. 2006, Ford et al. 2009). Additionally, newer technology, such as video recorders with photo beam triggers, proved reliable in gathering data on wildlife movement that can be used to determine location and design (Dodd et al. 2007).

Successful use of wildlife crossings is dependent on many factors; location and design attributes that address the needs of target species enhance their effectiveness. Decisions on placement and design of crossing structures can benefit from data on unsuccessful crossing locations (i.e., roadkills), but whenever possible should be combined with studies on successful road crossing locations (i.e., from radio-tracking or tracking stations) and a broader look at the landscape context of the proposed crossing, including the adjacent topography, vegetation, and land use (Smith 2003a). The presence of suitable and preferable habitat is an important consideration of structure placement that can enhance animal usage (Ng et al. 2004). Concentrations of roadkills may represent areas where many individuals are also crossing successfully, or alternately, may represent only unsuccessful crossings (for example, where there is a break in a fence). Roadkills are typically spatially aggregated, and often occur closer to vegetation cover and farther from wildlife crossings than stretches of highway with few roadkills (Clevenger et al. 2003).

Appropriate structure placement is critical to increasing permeability of roadways and decreasing landscape fragmentation. In Colorado, two major transportation corridors (I-25 and US-85) were studied to identify species interacting with the highways and understand habitat connectivity needs for the area (Henke et al. 2002). This study looked at surrounding public lands and documented movement through existing structures and across the highway. Using remotely sensed data to identify lynx habitat and model probable lynx dispersal routes across US-85, the optimal sites for locating crossing structures were identified. Another study used cluster analysis on available home range data to calculate the necessary crossing structure spacing for several species. For example, their data suggests that placing deer crossings 1.6 km apart in road-kill hotspot areas would have a positive effect on deer movement and driver safety (Bissonette and Adair 2008). Identifying migration pathways, species “ecological neighborhoods” and “interaction zones” is important to successful structure placement. For example, Klar et al. (2009) recommended placing crossing structures every 1.5-2.5 km, along with fencing, for wildcat passage, as this spacing corresponds to the size of their average home range.

Understanding life history and behavior of different species is an important factor in determining optimal structure location. For instance in Portugal, red foxes were observed avoiding areas with high levels of human disturbance (Grilo et al. 2009). Coyotes also avoided human interaction and use of crossings near urban areas (Ng et al. 2004). Structures that were high, wide and short in length were preferred by grizzly bears, wolves, elk and deer due to preference for open space; while more constricted structures were preferred by cougars and black bears (Clevenger and Waltho 2005). Small prey species such as voles and mice would benefit from smaller more frequently spaced structures with dense overhead vegetation due to their low mobility, small home ranges and wariness of predators (McDonald and St Clair 2004). Identifying how animals view and interact with the landscape is a key factor to successful design and placement of structures.

Animals and Roadways

Culverts and other structures not designed for wildlife movement may nevertheless be used by wildlife, especially when suitable habitat for the species in question exists on either side of the highway (Smith 2003b, Ng et al. 2004). Several crossing types may then be utilized including underpasses, overpasses, and culverts, with different groups of species responding best to each design type (Glista et al. 2009). Animals also respond differently to the openness, adjacent vegetation, light, substrate, noise levels, and presence of humans near the crossings (Glista et al. 2009, Clevenger and Waltho 2005). However, poorly designed crossings, such as small or flooded culverts, are not used by some animals (Beier 1993, Smith and Voigt 2005). For example, in southern California bobcats and coyotes preferred to cross roads rather than use culverts; however, culvert use increased early in the night, during heavy traffic, and if they contained less water (Tigas et al. 2002). In Texas, use of culverts by bobcats was positively related to the openness ratio (width x height/length) of the culvert and the amount of vegetation adjacent to the culvert. Fences erected to funnel wildlife toward culverts did not increase overall use of culverts, but may have increased use of the high-quality culverts (Cain et al. 2003).

On U.S. Highway 441 across Payne's Prairie in Alachua County, Florida, a year-long study of wildlife mortality was conducted prior to the construction by FDOT of a barrier wall and underpass system (ecopassage). This study (Barichovich and Dodd 2002), which documented significant mortality, especially for amphibians and reptiles, was followed by a post-construction survey (Smith and Dodd 2003), which showed a significant positive effect of the barrier wall and culvert. For example, whereas 2,411 roadkills were recorded in the 12 months prior to construction, only 158 animals were killed in the 12 months after construction (excluding hylid treefrogs) (Dodd et al. 2004). Foster and Humphrey (1995) found Florida panthers, bobcats, deer, raccoons, bears, and alligators, in addition to other species (e.g., wading birds and humans) using underpasses below I-75 in South Florida that were constructed to mitigate impacts of the highway on panthers. Studies elsewhere have shown that small to medium-sized mammals and many species of amphibians and reptiles use concrete culverts and drainage tunnels (Hunt et al. 1987, Brehm 1989, Dexel 1989, Norden 1990, Smith 2003b, Ng et al. 2004). Animals were found to quickly adapt to using crossing structures as a primary means of passage from one side of the road to the other (Bond and Jones 2008).

Smith (2003b) conducted a 2-year monitoring study for FDOT to determine the capacity of existing highway drainage-structure designs to function as wildlife passages. Fifty-five different organisms were identified from 47,955 records at 290 field sites. Twenty structural, environmental, and ecological factors affecting use or avoidance of highway-crossing structures by six faunal groups (birds, carnivores, herpetofauna, meso-mammals, small mammals, and ungulates) were evaluated through logistic regression analysis. Significance of factors differed by faunal group. The results were presented as wildlife-use thresholds by various structural and biological parameters. An advantage of developing this type of design standard is the identification of the optimal structure (for any particular context) that possesses dual-functionality, as drainage conveyances and as wildlife movement passages.

There has been some concern that wildlife crossing structures adversely affect prey populations by directing them to an area that can be exploited by predators. Clevenger and Ford (2010) studied this prey-trap hypothesis using ungulate-carnivore interaction data, both pre- and post-construction, from 28 crossing structures in Banff National Park, Alberta, Canada. These data encompassed over 32,000 site visits over 13 years. They found no evidence that predators were utilizing the structures as prey traps.

Structure Design

Preferred structure dimensions and attributes vary for different species; but structures can be configured to serve a broad range of wildlife. In one study, underpasses with dimensions of 2.5 m wide x 2.4 m high x 48 m long were utilized by a wide size range of species (Bond and Jones 2008). Clevenger and Huijser (2011) recommended a minimum of 5 m (16.5 ft) wide x 2.5 m (8.2 ft) high and an optimal size opening of > 7 m (23 ft) wide x > 3.5 m (11.5 ft) high for multi-species use underpasses. In a 5-yr monitoring study in central Florida, Smith and Noss (2011) recorded frequent and consistent use by many species (e.g., white-tail deer, black bear, bobcat, coyote, small mammals, reptiles and amphibians) of a 24 ft wide x 8 ft high wildlife crossing on a two-lane highway with more than 20,000 AADTs. These same structures have been successfully used in south Florida by Florida panther as well. The inclusion of ledges, rocks, vegetation, natural drainage, and other interior features can increase the variety of animals that utilize the structure (Alexander 2008).

Ungulates

Ungulates tend to prefer passages with high openness ratios. In a California study looking at tunnel, culvert and underpass use, mule deer use was more consistent at bridge spans and underpasses that had large cross-sectional areas (Ng et al. 2004). Although, and uncharacteristically, mule deer were also documented using a 1.5 m wide x 2.1 m high x 30 m long culvert with an openness of 0.11. This size was typically thought to be too small for an ungulate to voluntarily pass through (Krawchuk et al. 2005). Key deer utilized a box-type underpass of 8 m wide x 3 m high x 14 m long, equipped with directional fencing; this pairing had a 94% effectiveness rate of keeping deer off the road (Braden et al. 2008). In a Virginia study of white tailed deer, the smallest underpass deemed useful for deer passage was 3 m wide x 3.7 m high x 57.6 m long with an openness ratio of 0.19; but bridge type underpasses examined had the highest deer crossing rates, likely because of the absence of vertical walls and a more open appearance (Donaldson 2007). White-tailed deer in North Carolina frequently used three underpasses with openness ratios ranging from 2.48 – 4.03 (McCollister and Van Manen 2010). Red deer and roe deer in Spain were detected utilizing wildlife underpass structures within a specific range of dimensions (14-20 m width, 5-8 m height, 30-32.5 m length), but not larger or smaller structures, with the exception of red deer use of overpasses (Mata et al. 2008). A comparison of elk usage of two crossings in Arizona, found that they preferred the crossing of shorter length and larger openness ratio (Dodd et al. 2007). A summary of recommendations yielded the following as the minimal dimensions needed for deer crossing: round culverts 10 ft diameter, concrete box culvert 20 ft w x 10 ft h, multi-plate steel arch 20 ft w x 10 ft h, open-span bridge 20 ft w x 10 ft h, overpass 75 ft w and 8 ft h page wire fence. Open-span bridges and overpasses were noted as the more optimal crossing types (Ruediger and DiGiorgio 2007). Also see other recommendations for general multi-species underpass structures above under the heading, *Structure Design*.

Bears

Clevenger and Waltho (2005) found that black bears in Banff National Park, Alberta, Canada preferred smaller structures as passages. In British Columbia black bears were documented using a 7 m wide x 5 m high x 40 m long structure with an openness ratio of 0.88, but demonstrated higher use of a structure that was 1.5 m wide x 2.1 m high x 30 m long with an openness ratio of 0.11 (Krawchuk et al. 2005). Although, in North Carolina black bears used underpasses with openness ratios of 2.48 – 4.03, but successful use of these structures was thought to be related to placement and habitat connectivity, as opposed to preference for certain structural dimensions (McCollister and Van Manen 2010). A document summarizing several studies suggested that passages for black bears have the following minimum dimensions for effectiveness: round culverts- 10 ft diameter, concrete box culvert- 20 ft w x 10 ft h, multi-plate steel arch- 20 ft w x 10 ft h, open span bridge- 50 ft w x 12 ft h, overpass- 75 ft w and 8 ft h fencing. Open span bridges and overpasses were recommended as optimal structures (Ruediger and DiGiorgio 2007). Also see other recommendations for general multi-species underpass structures above under the heading, *Structure Design*.

The correlation between crossing location and surrounding habitat is an important element. In Colorado black bear roadkills were highest in areas that contained high quality oak-shrub habitat (Baruch-Mordo et al 2008). Home range assessment of black bears yielded a recommended distance between crossing locations of around 3 mi (Bissonette and Adair 2008).

Felids

Felids in Banff National Park tended to prefer more confined space. Mean crossing structure lengths used by lynx was 98.91 m; for cougars mean crossing length was 158.99 m, whereas mean length of crossings used by wolves was 176.21 m (Alexander 2008). These lengths varied with the width of the Trans-Canada Highway. Bobcats in Texas frequently used culverts that were 1.85 m x 1.85 m (Cain et al. 2003). Although in Spain, Mata et al. (2005) found higher utilization of over and under passes than of smaller culvert structures (open span under passes: 4-9 m width, 4-6 m height, 34-66 m length; under passes: 20 m width, 5-7 m height, 30-36 length; overpasses: 7-8 m width, 58-62 m length). Ruediger and DiGiorgio (2007) synthesized several studies and found that minimum dimensions of effective passages for lynx included: round culverts- 10 ft diameter, concrete box culvert- 20 ft w x 10 ft h, multi-plate steel arch- 20 ft w x 10 ft h, open span bridge- 20 ft w x 10 ft h and overpass- 75 ft w and 4 ft h fencing. For bobcats the following minimum dimensions were tabulated: round culverts- 48 in diameter and concrete box culvert- 48 in w x 48 in h. In reference to the additional structure types they note that larger structures will be adequate for these animals also. Also see alternate recommendations for general multi-species underpass structures above under the heading, *Structure Design*.

Canids

In Spain, large canids preferred large span over and underpasses (open span under passes: 4-9 m width, 4-6 m height, 34-66 m length; under passes: 20 m width, 5-7 m height, 30-36 length; overpasses: 7-8 m width, 58-62 m length) (Mata et al 2005). Subsequently, Mata et al. (2008) recorded high crossing frequency for red fox at over and underpasses with similar dimensions. Gray wolves also preferred larger, more open structures (Clevenger and Waltho 2005). A summary of available recommendations yielded the following minimal required dimensions for crossing usage by gray wolves: concrete box culvert- 32ft w x 12ft h, multi-plate steel arch- 23 ft w x 12 ft h, open-span bridge- 50 ft w x 12 ft h, overpass- 150 ft w, and 8 ft page wire fencing. Round culverts were not recommended and open-span bridges and overpasses were more optimal than other options (Ruediger and DiGiorgio 2007). Also see other recommendations for general multi-species underpass structures above under the heading, *Structure Design*.

Landscape attributes can have an effect on how and where wolves interact with roads. Alexander (2008) examined the best crossing areas for gray wolves using GIS information and snow-tracking data and found that wolves were positively influenced by distance to ruggedness but negatively influenced by brightness, eastness, terrain ruggedness, and elevation. Likewise, wolves tend to utilize areas with less human disturbance and roads that are less traveled. These factors seem to shape wolf movement (Houle et al. 2010). Additionally, wolves exhibited preference for areas of high prey abundance, shallow slopes and low elevations (Shepherd and Whittington 2006).

Herpetofauna

Reptiles and amphibians tend to select smaller spaces. Different species require different crossing design attributes; so to accommodate as many species as possible, wide multi-purpose or species-specific structures are needed. Smith (2003b) developed performance standards for size and other characteristics based on monitoring of herpetofaunal use of 106 different culverts in north and central Florida. A study performed in Nevada on desert tortoises found they readily used underground concrete structures with 2.44 m w x 1.22 m h entrances and 70 m in length (Ruby et al. 2004). Reptiles and amphibians demonstrated higher utilization of culverts (diameter 1.8 m, length 36-80 m) and adapted culverts (2-3 m width, 2 m height, 35-50 m length) than more open structures (Mata et al. 2005). A study in New York found that turtles and frogs avoided using tunnels with a diameter of 0.3 m, but readily used larger tunnels measuring 0.5 m, 0.6 m, and 0.8 m, with no discrimination on length that ranged from 3.0 - 9.1 m (Woltz et al. 2008). Green frogs preferred gravel and soil within the tunnels as opposed to bare PVC and concrete (Woltz et al. 2008). In Payne's Prairie State Preserve, Florida, a wildlife crossing configuration (consisting of a 2.4 - 2.8 km long, 1.1 m high barrier wall [with a 15.2 cm overhanging lip] that includes 8 culverts placed intermittently within) was assessed for its effectiveness in keeping animals, especially herptiles, off the roadway (Dodd et al. 2004). The new configuration added 4 new pipe culverts to the 4 pre-existing box culverts. The 8 culverts consisted of 2- 2.4 x 2.4 x 44 m long partially submerged box culverts, 2- 1.8 x 1.8 x 44 m long dry box culverts, and 4- 0.9 m dia. x 44 m long cylindrical culverts. Comparison of pre- and post- construction data showed increased culvert use (especially amphibians) and decreased road mortality, particularly in snakes, turtles and alligators. A small section included a Type-A fence installed, instead of the barrier wall, which proved to be ineffective (Dodd et al. 2004).

Fencing

Fencing is another important component to the success of a crossing structure. Fencing acts as a physical barrier along the roadway as well as a guide to safe passages. It is particularly effective at keeping large vertebrates off roadways (Bond and Jones 1008). A simulation model was created that analyzed fences and population persistence (Jaeger and Fahrig 2004). It found that in high mortality areas fencing enhanced population persistence and in low mortality areas it decreased population persistence, but when paired with crossing structures enhanced population persistence in every situation.

Fencing dimensions and structural needs differ depending on the target species; although fences can be configured to address a wide range of species. Broad-application fencing typically includes multiple materials that together inhibit small and large animals from gaining roadway access. Installation of 2.6 km long and 2.4 m high fencing in combination with wildlife crossings was very effective at preventing key deer from accessing US 1 in Florida (Braden et al. 2008). An Australian study found that a fence 2.48 m high (buried 5cm into the ground with a sheet of industrial rubber affixed from the bottom to a height of 48 cm and 59 cm metal flashing on the upper portion of the rubber) was sufficient to keep animals off the roadway and guide them towards the wildlife crossing (Bond and Jones 2008). Turtles were adequately contained and guided by drift fences measuring 0.6 m high, 600-700 m long with the last 80-100 m curving back and buried 20 cm into the ground (Aresco 2005a). The most effective barrier fence tested for desert tortoises was 1cm^2 mesh hardware cloth 60-75 cm high, buried 15 cm into the ground; although a buried depth of 60 cm was better for long term use (Ruby et al. 1994). This material was sufficient to prevent tortoises from breeching the barrier, but allowed them to see through the fence, which encouraged more attempts to penetrate the mesh. Wire mesh and corrugated plastic combinations caused mortalities of certain snakes and lizards as they became trapped in the fence. Concrete barriers seemed to deter tortoises as they reacted to visual, vibration and noise stimuli from the highway (Ruby et al. 1994). Behavioral experiments revealed that barriers 0.6 to 0.9 m in height were sufficient to exclude frogs and turtles from the roadway and direct them to crossing structures (Woltz et al. 2008).

High-tensile electric fences have been studied as an option for excluding ungulates from roads. Elk, pronghorn and mule deer were not influenced by electrical current up to 4.5 J and were largely able to breech a 4-wire electric fence. This type of fencing was not an effective barrier for these particular ungulates (Karhu and Anderson 2006). Electric fencing was an effective barrier for moose, yet required frequent monitoring and maintenance (Leblond et al. 2007). Though visually more appealing, these types of fence do not serve as a barrier for a wide range of species, primarily targeting large mammals.

Although fencing is an effective means of funneling wildlife to crossings and away from the road surface, it is not without flaws. A study in North Carolina found greater numbers of mortalities in fenced than in unfenced areas (McCollister and Van Manen 2010). Yet, deer-vehicle collisions were lowest near the crossing and increased with distance from the crossing. This occurred as a result of animals breeching the fence or entering around the ends of the fence and becoming trapped within the enclosure. This was attributed to the incongruency between small home range size and spacing between wildlife crossings.

Alternative Strategies

Several other measures have been investigated and implemented for decreasing wildlife-vehicle interactions. A trial of differential speed signs that reduced speeds in known areas of animal activity found that driver speed reduction was not adequately achieved (Dique et al. 2003). Another driver cue, the Flashing Light Animal Sensing Host (FLASH), flashes a driver warning signal when an animal is present. As with the speed reduction signs above, only a small amount (6-7%) of drivers reduced speeds in response to the visual indicator (Gordon et al. 2004). In Wyoming a wildlife sensing system, for deer in particular, was assessed for effectiveness in a 1.36 mi project area (Dai et al. 2009). This system worked by sensing an animal on the road and triggering a flashing light in coordination with a sign to caution drivers. This system was somewhat more effective, although at times had an approximately 20% false negative rate (this occurs when an animal is on the road and the system fails to respond). The system also required extensive modification and maintenance to remain in good working order. Furthermore, this system cost at total of $1,000,000 to install, including contract administration and inspection costs (Dai et al. 2009). Many other configurations of these animal detection and warning systems have been produced. Huijser et al. (2009a, 2009b) provides a review of their performance and associated cost.

Color reflectors used to deter deer and other large mammals from the roadway when a vehicle was present have typically been found ineffective. In fact, one study found that deer-vehicle interactions were more likely with than without the devices present (D'Angelo et al. 2006, Ramp and Croft 2006, Putman 1997, Groot Bruinerink and Hazebroek 1996). A major limitation of reflectors lies in the fact that they are activated by car headlights. In most cases, headlights are employed only at night, so the reflectors would not be effective at dawn, daytime, or dusk if headlights were not employed. High volume roadways may lead to the reflectors being continuously activated and animal habituation may result (Putman et al. 2004).

Electrified mats were tested as a means of keeping deer off the road surface where unavoidable fence breaks exist (Seamans and Heldon 2008). They were effective as long as power to mats was consistently charged and individual animals did not learn to run through or jump over the mats. Additionally, they were most effective if used in conjunction with other wildlife management measures (e.g., fencing, wildlife crossings). In Florida, bridge grating was evaluated at planned gaps in the fencing for access roads. It was found that a 6.1 m x 6.1 m grate with 10.1 cm x 12.7 cm rectangular openings and a diagonal cross member was 99.5% effective for excluding key deer from the roadway, and would also be safe for pedestrian and bicyclists (Peterson et al. 2003). On a consistent basis, non-barrier means of mitigating wildlife-vehicle interactions have not been adequately effective.

Vegetation

Management of roadside vegetation is another means of deterring wildlife from frequenting roads. Rea (2003) found that cutting roadside brush early in the spring yields lower quality vegetation regrowth that is less preferable to moose, and perhaps other ungulates. A study of carnivore road fatalities recommended managing vegetation near curves to improve driver visibility of animals in higher risk areas of the road corridor (Grilo et al. 2009). Nielsen et al. (2003) suggested that reducing forest cover and shrubby areas near roads can reduce deer-vehicle collisions. Although, Forman (2004) states that this is counterintuitive as having trees and shrubs closer to the road causes a "visual friction" that cause drivers to slow their speed and drive more cautiously. He also argues that it increases habitat connectivity and if speed is decreased (to between 45-55 mph where animal-vehicle interaction sharply declines) in conjunction with fencing and guard rails roadway safety for wildlife and humans can be increased. Strategic vegetation planting can also be employed. Planting palatable vegetation within the desired animal movement area and unpalatable vegetation near the roadway can help deter animals from the roadside (Brudin III et al. 2003, Ehinger et al. 2006). The incorporation of vegetation at and in the structure as well as using vegetation congruent with the surrounding habitat along paths to crossings and at crossings can encourage use (Ehinger et al. 2006, Carr et al. 2003, Smith 2003a).

Cost Comparisons

In Nevada, a one mile stretch of mesh fencing was estimated to cost $15,079 including labor and materials (Ruby et al. 1994). Three underpasses installed in North Carolina cost $1,200,000 each. All three underpasses were 3m high and 35m long, and had widths ranging from 29 to 47 m (McCollister and Van Manen 2010). A cost analysis study for Montana DOT (Huijser et al.

2007) stated that box culverts measuring 2.7 w x 3.3 h would cost $128,932 ($1,834/yard). An elliptical culvert measuring 7.7 w x 4.4 h would cost $161,165-179,073 ($3,537/yard). An open span bridge underpass 14.2 w x 5.5 h would cost $36,024. An overpass 70 m long would cost approximately $24,103 per meter. In the Netherlands, the cost of seven wildlife overpasses ranged between $1,735,546 and $6,974,184. In Montana, a proposed overpass that would span a 2-lane road had a projected cost of $1,500,000 - $2,400,000. Two effective underpasses for black bears constructed in central Florida, 24 ft w x 8 ft h built in1994 and 50 ft w x 8 ft h built in 2004 cost $1.3 and $1.9 million respectively (Steve Tonjes, FDOT, personal communication). Nearly half of the cost for these two structures was construction, operation and removal of temporary traffic detours. Costs differ significantly by geographic region and by variability in site conditions making it difficult to derive direct comparisons.

Performance Monitoring and Evaluation

Despite many promising studies, knowledge of the effectiveness of various designs for wildlife-crossing structures is still limited (Transportation Research Board 2002), in part because studies of wildlife crossings must deal with a large number of potentially confounding variables, including differences in behavior and response to crossings among various species, variation in human activity in the vicinity of the crossing, density of crossing structures, and other factors (Clevenger and Waltho 2005, Smith 2003b). Species of vertebrates differ in their requirements and behavioral preferences for crossings, such that a given crossing will be permeable to some species but not to others, potentially causing changes in predator-prey relationships and other community- or ecosystem-level properties (Clevenger and Waltho 2000, Smith 2003b). The same can be said regarding the effectiveness of drift fences and barrier walls. Techniques to minimize wildlife mortality on highways (for example, fencing) may conflict with measures to reduce population fragmentation (Cain et al. 2003) or may be ineffective in preventing circumvention by certain species (for example, treefrogs; see Barichovich and Dodd 2002). In any case, it has become clear that maintaining connectivity across roads for multiple species requires a diversity of crossing structures of mixed designs and size classes (Clevenger and Waltho 2005).

Monitoring of crossings needs to be significantly upgraded in order to provide reliable guidance to transportation planners (Forman et al. 2003). Monitoring should encompass existing structures and structures in the design or construction phase, and should include structures designed as wildlife crossings as well as culverts, enhanced culverts and other pathways under or over highways that various species may use. Importantly, monitoring of crossing structures, roadkills, and successful crossings of highways must encompass multiple species (e.g., amphibians and reptiles as well as mammals), because different structures and landscape/habitat conditions promote movement of different taxa. In addition, crossing structures designed for wildlife should be multi-functional and also include consideration of hydrological connectivity and other ecological processes.

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APPENDIX A

SPATIAL DISTRIBUTION OF ROAD-KILLS

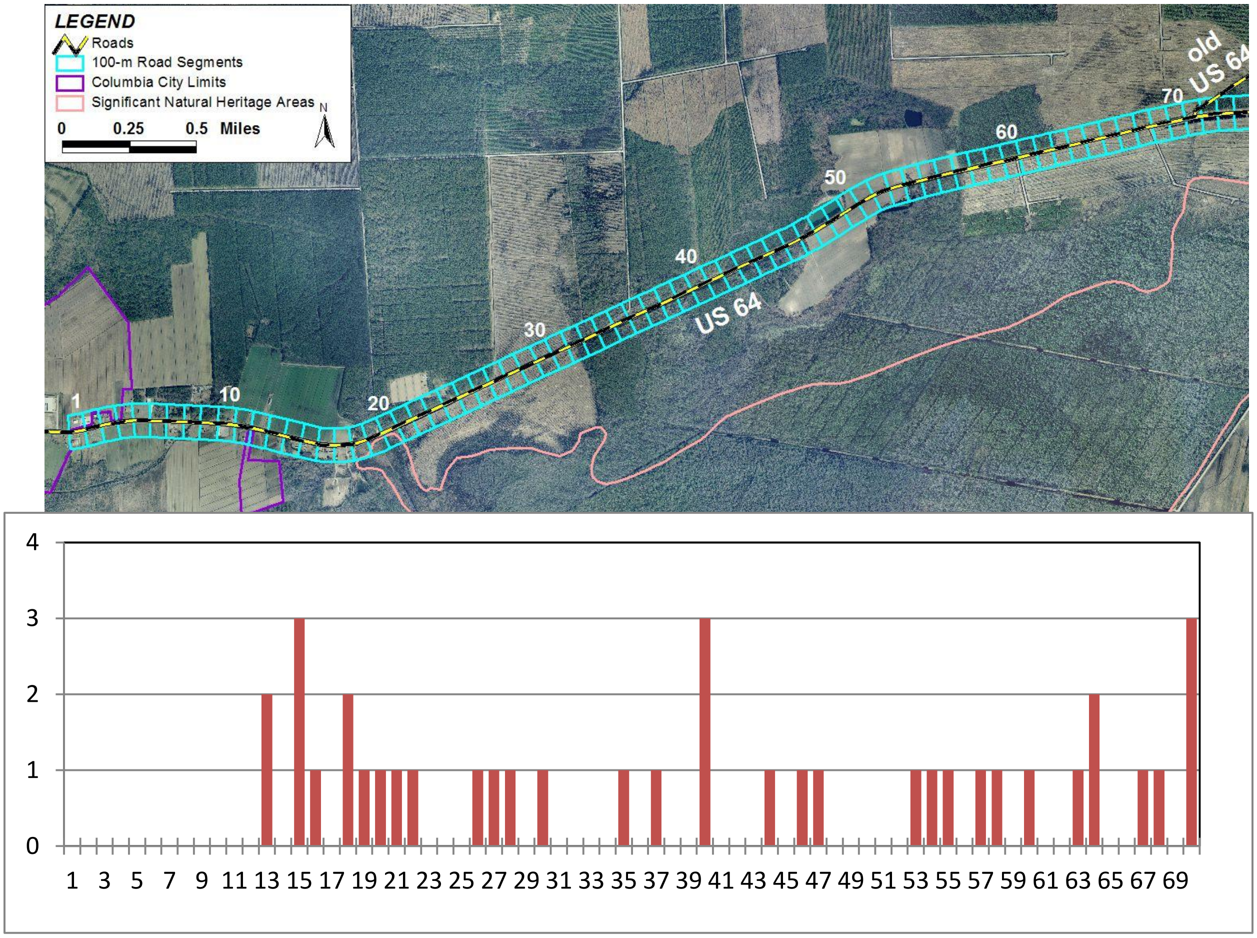


Figure A-1. Spatial distribution of road-killed mammals (west section).

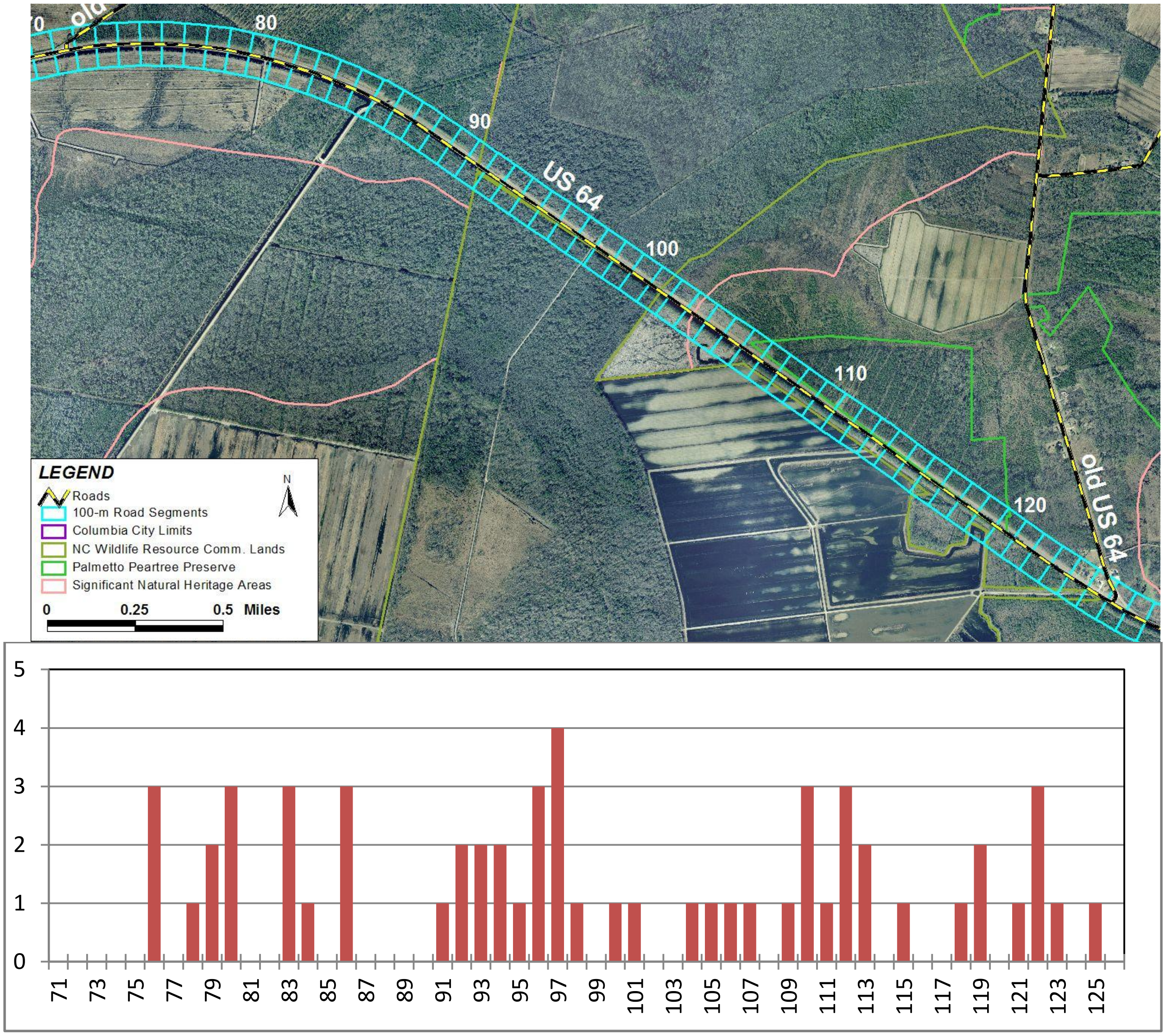


Figure A-2. Spatial distribution of road-killed mammals (center section).

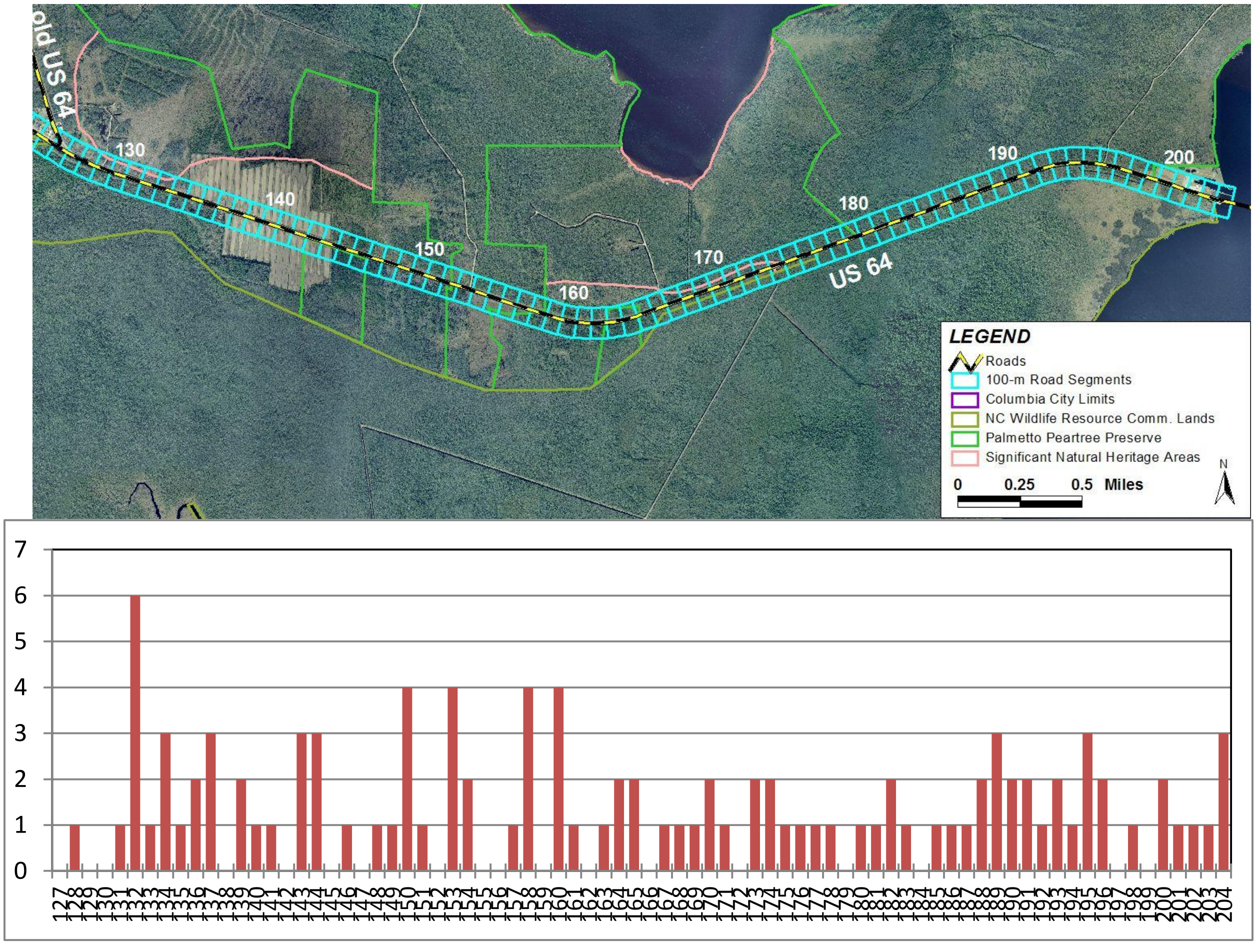


Figure A-3. Spatial distribution of road-killed mammals (east section).

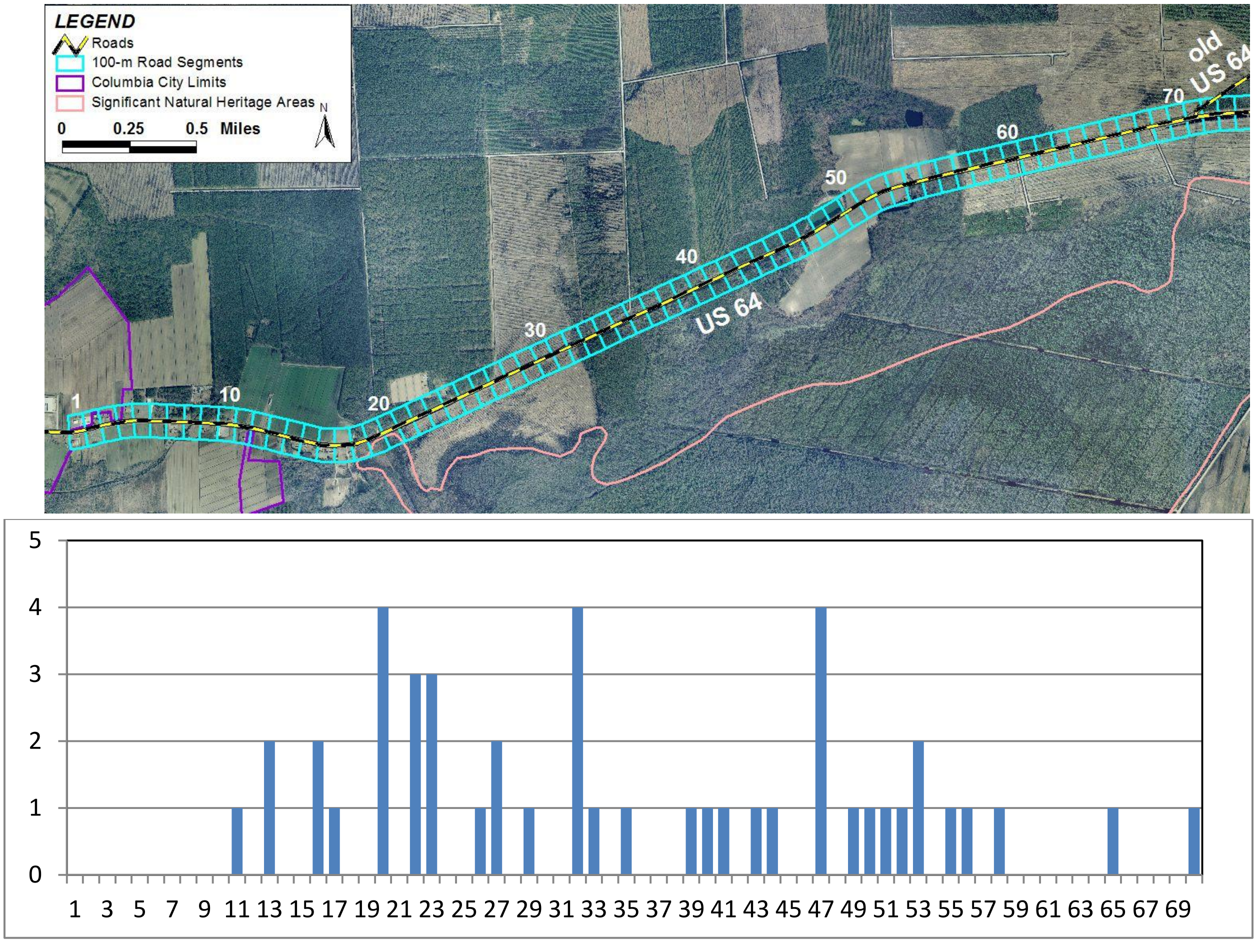


Figure A-4. Spatial distribution of road-killed birds (west section).

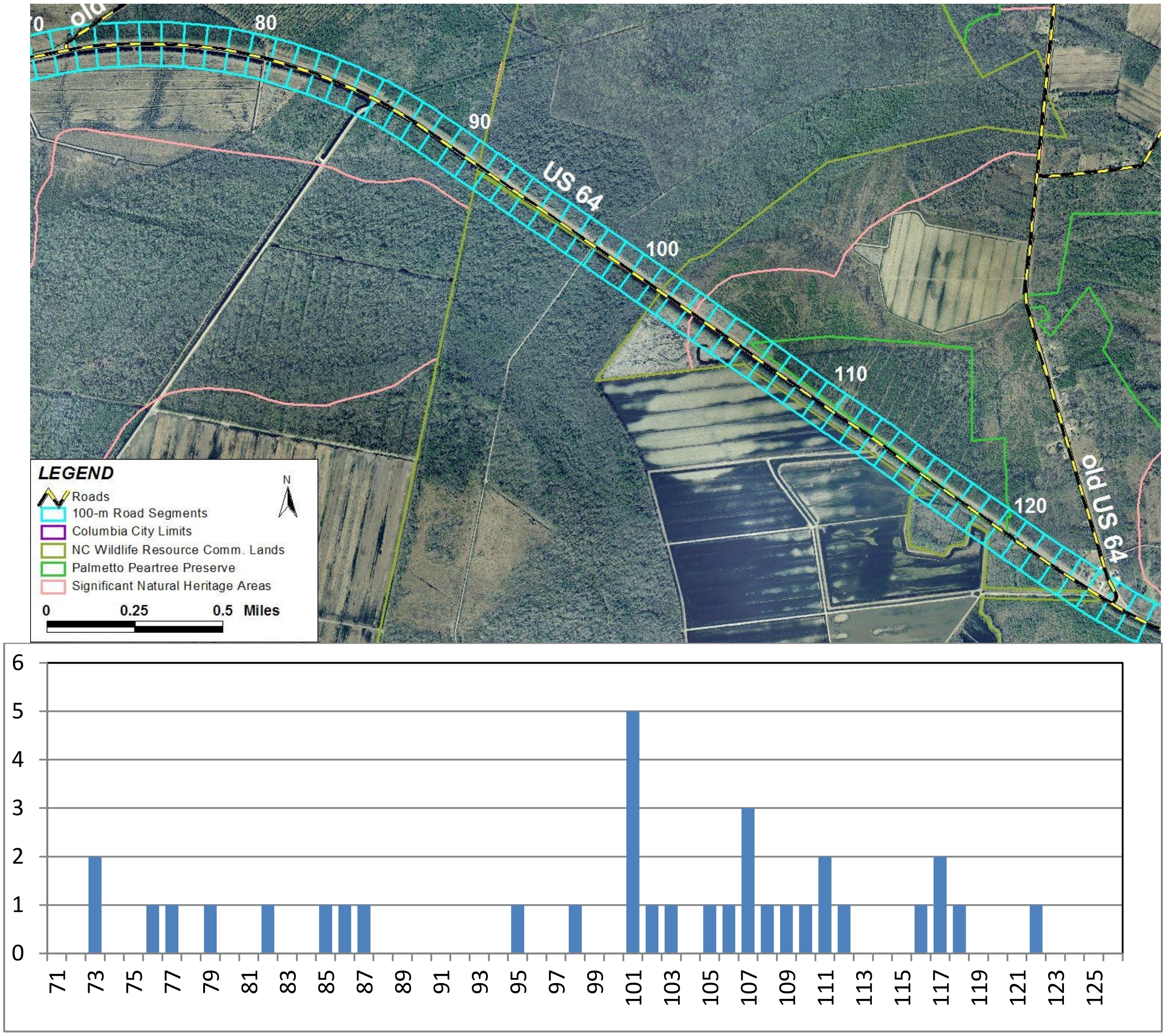


Figure A-5. Spatial distribution of road-killed birds (central section).

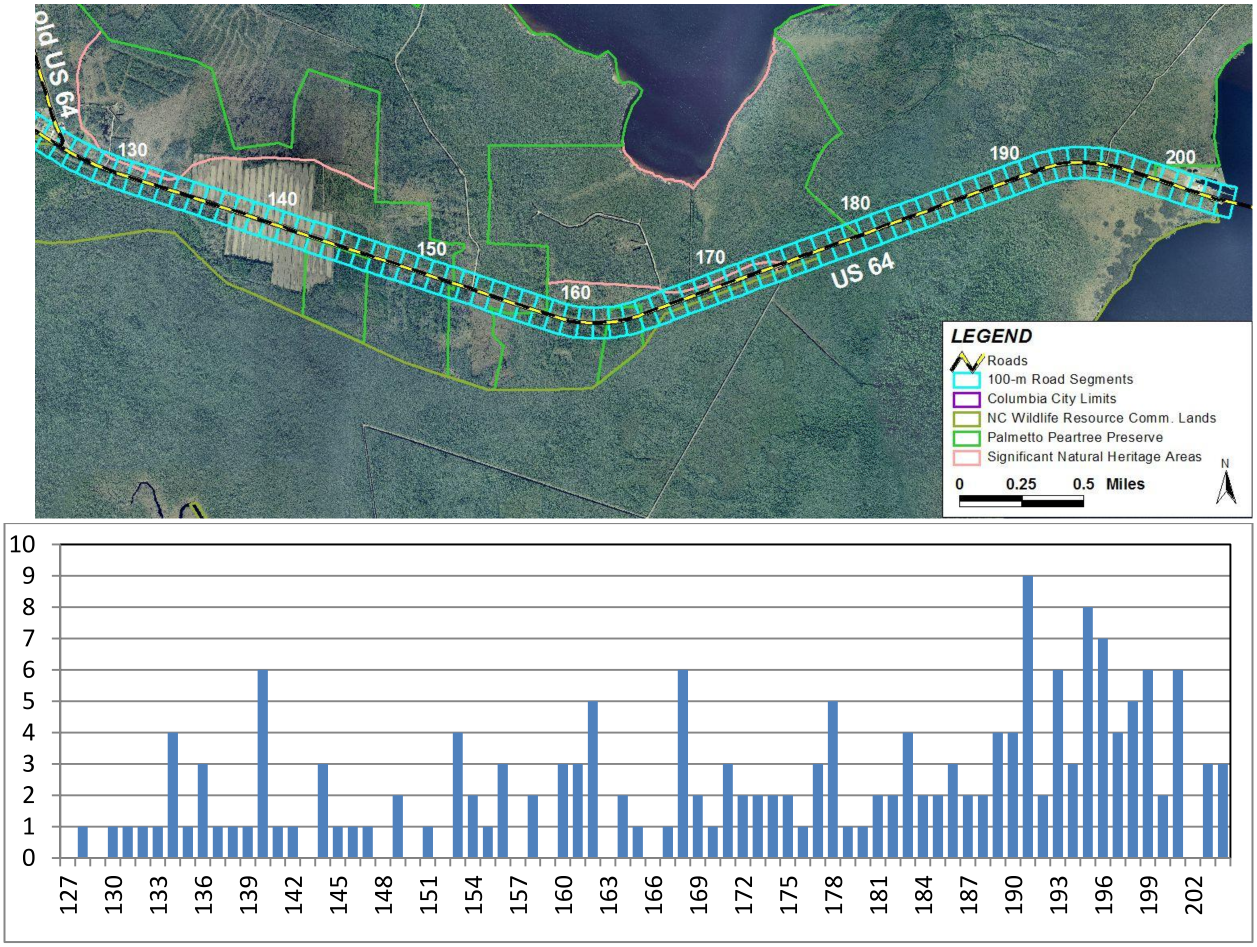
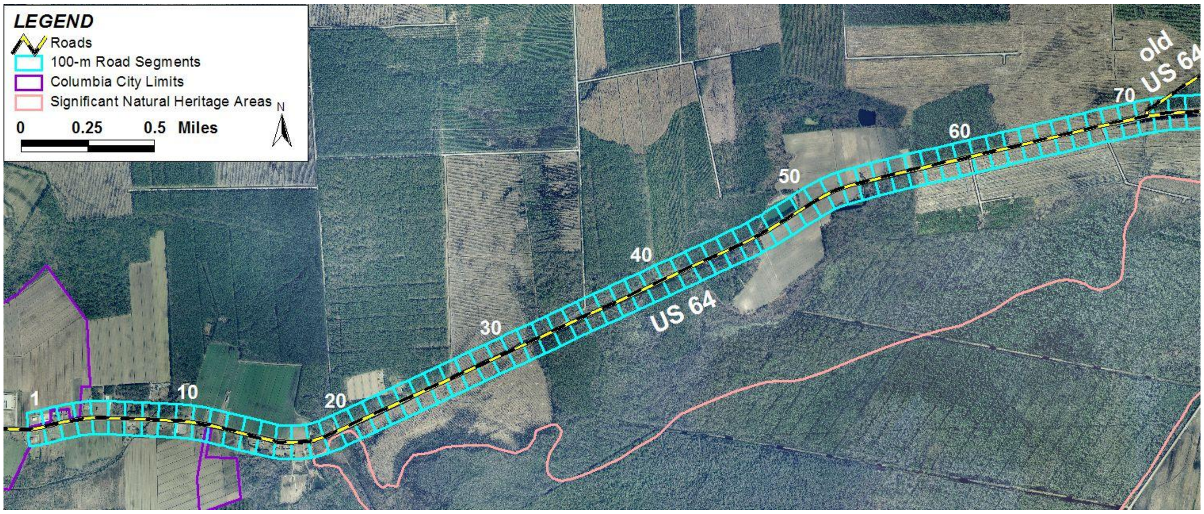


Figure A-6. Spatial distribution of road-killed birds (east section).



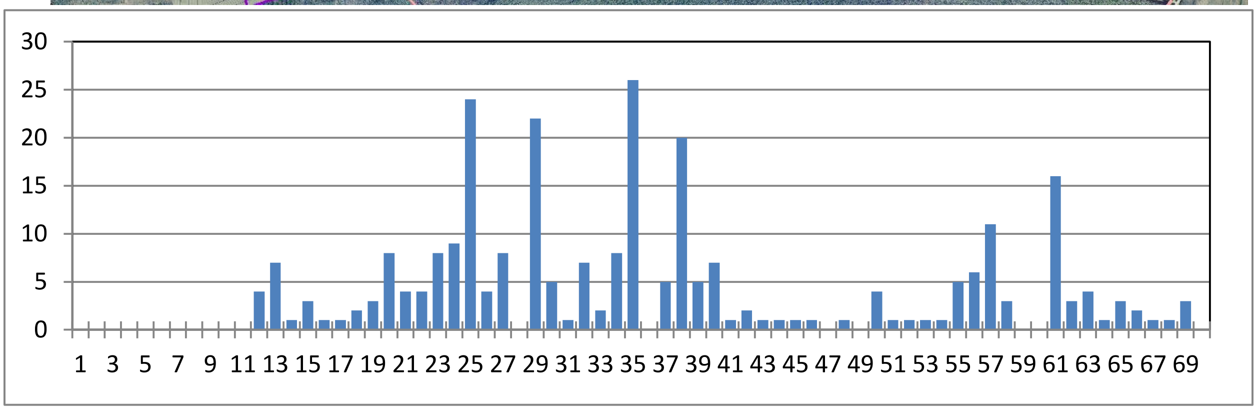
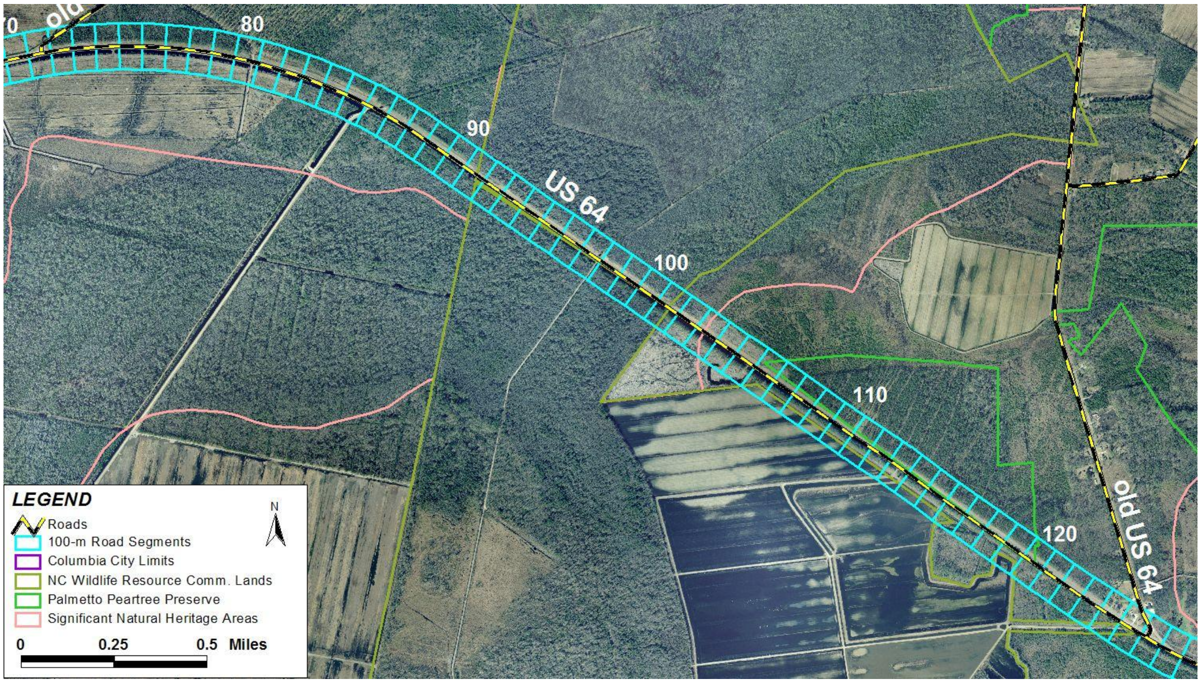


Figure A-7. Spatial distribution of road-killed frogs (west section).



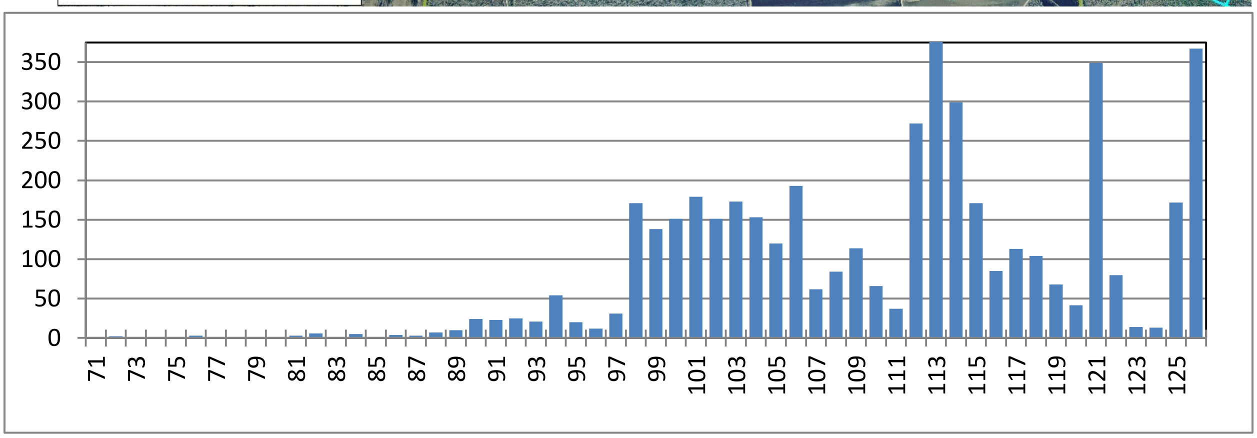
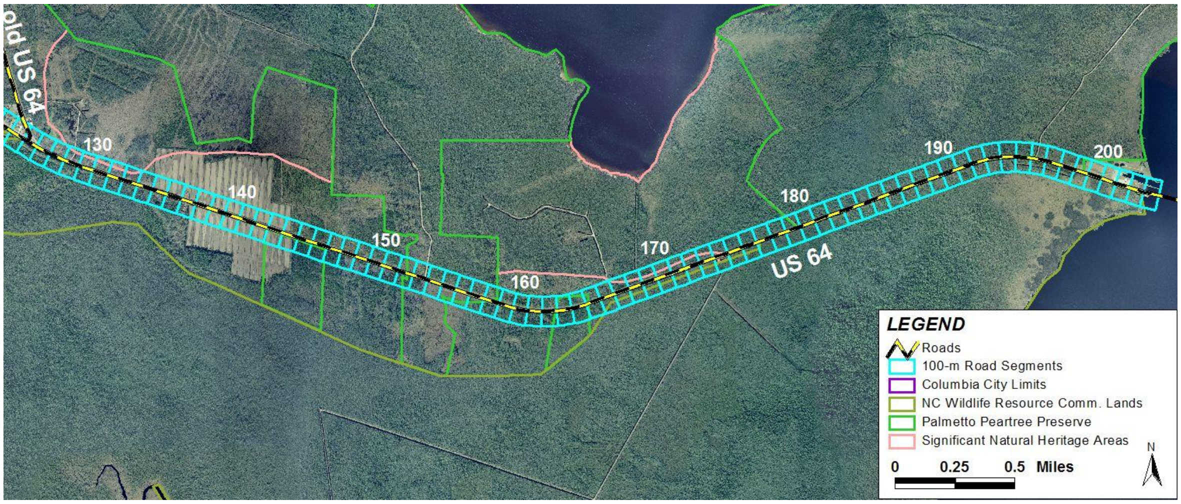


Figure A-8. Spatial distribution of road-killed frogs (central section).



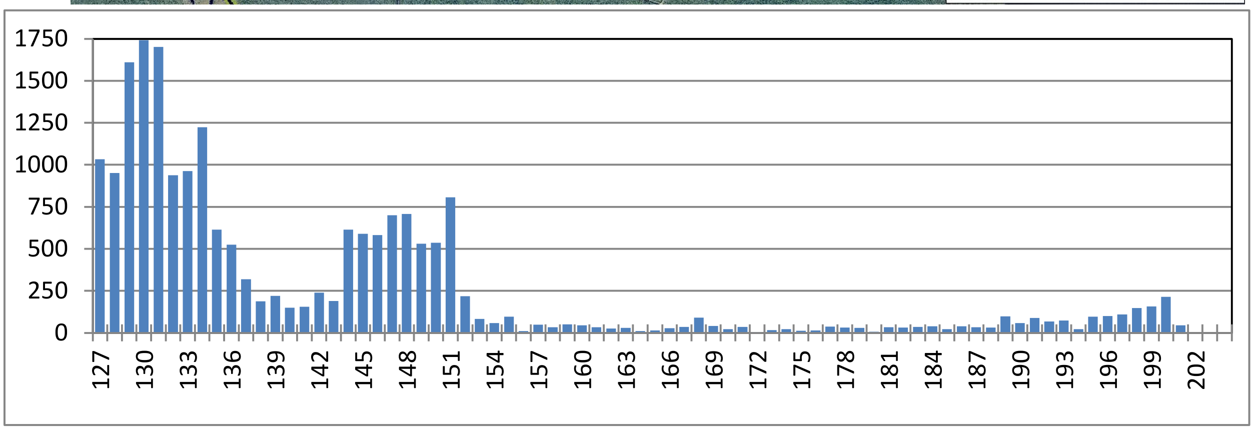


Figure A-9. Spatial distribution of road-killed frogs (east section).

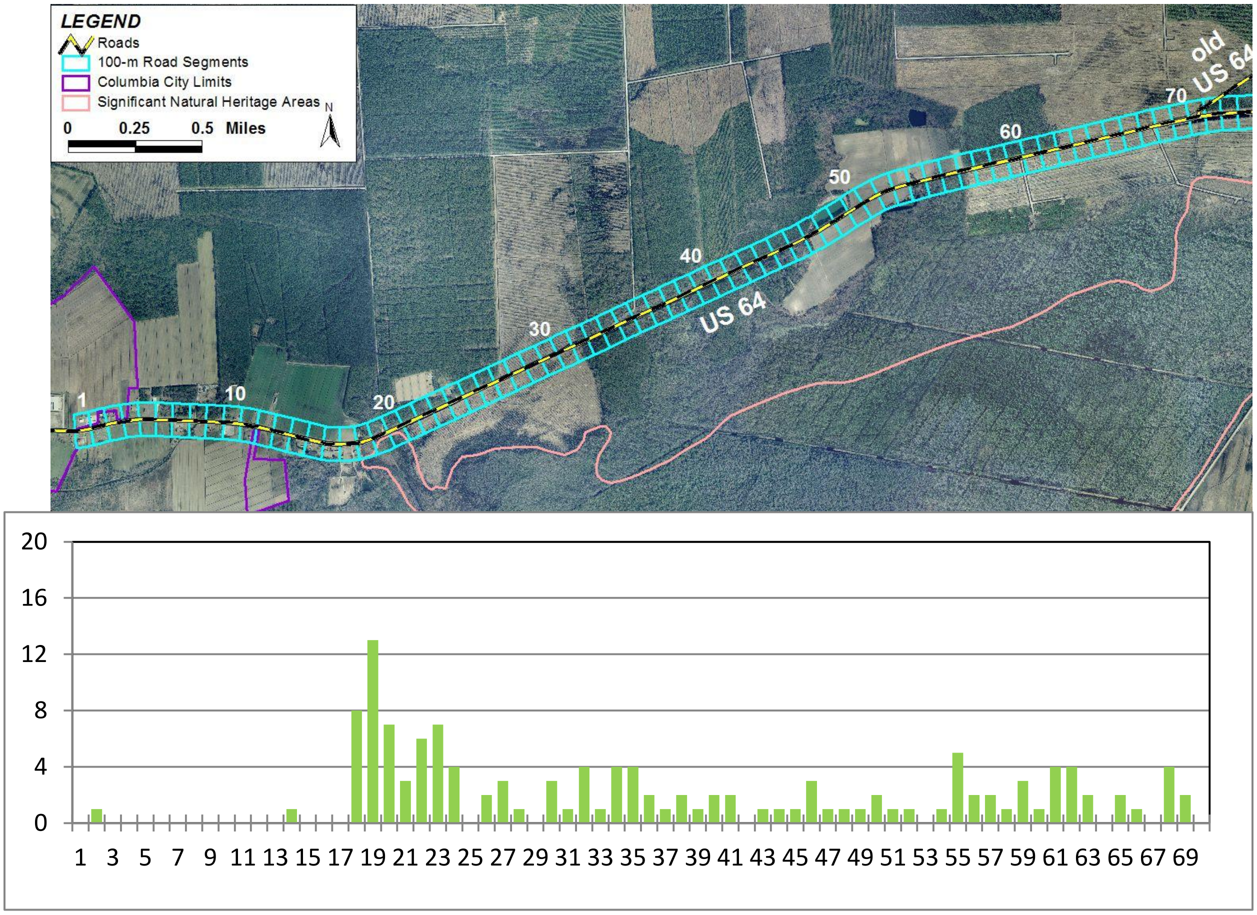


Figure A-10. Spatial distribution of road-killed snakes (west section).

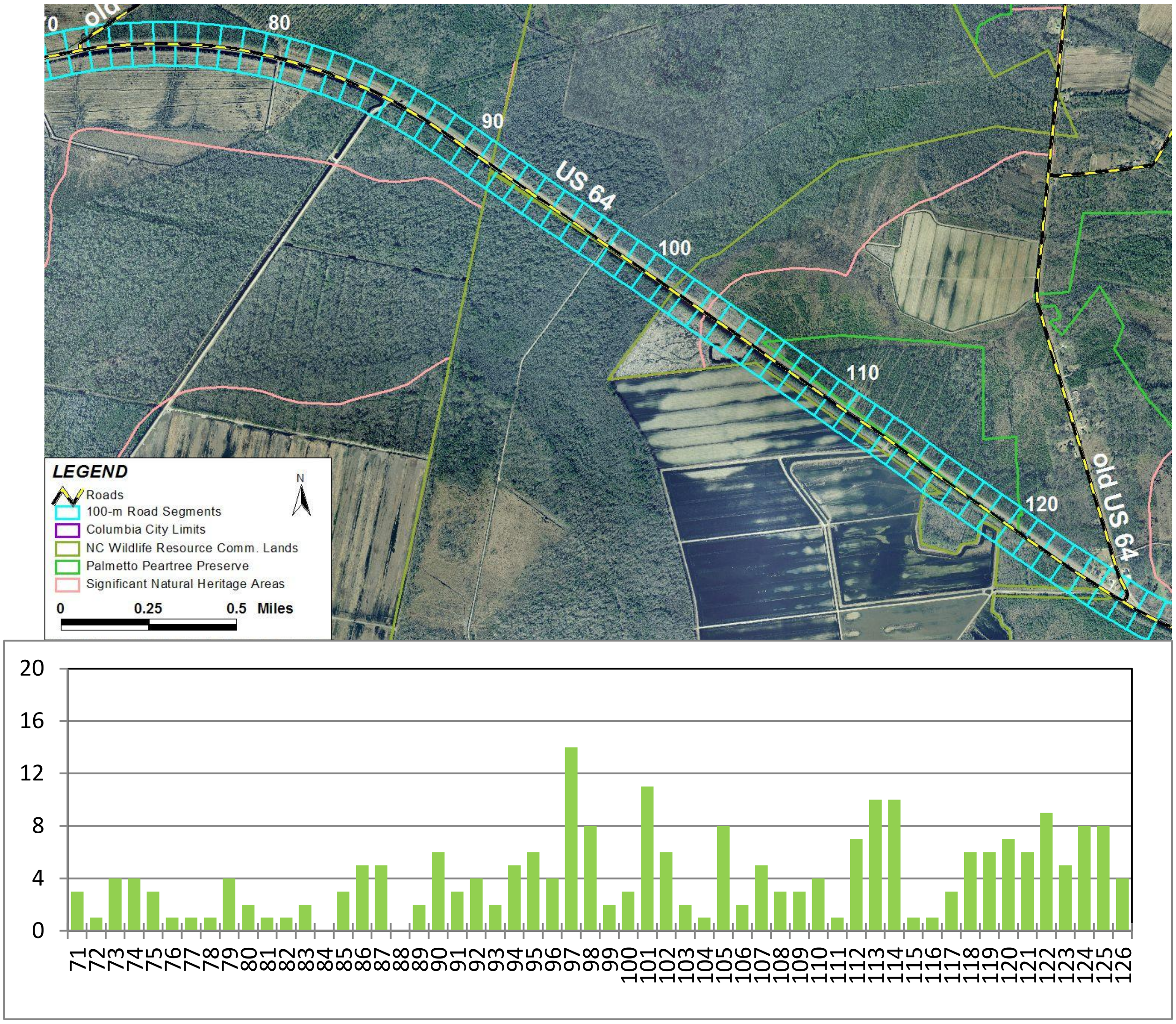


Figure A-11. Spatial distribution of road-killed snakes (central section).

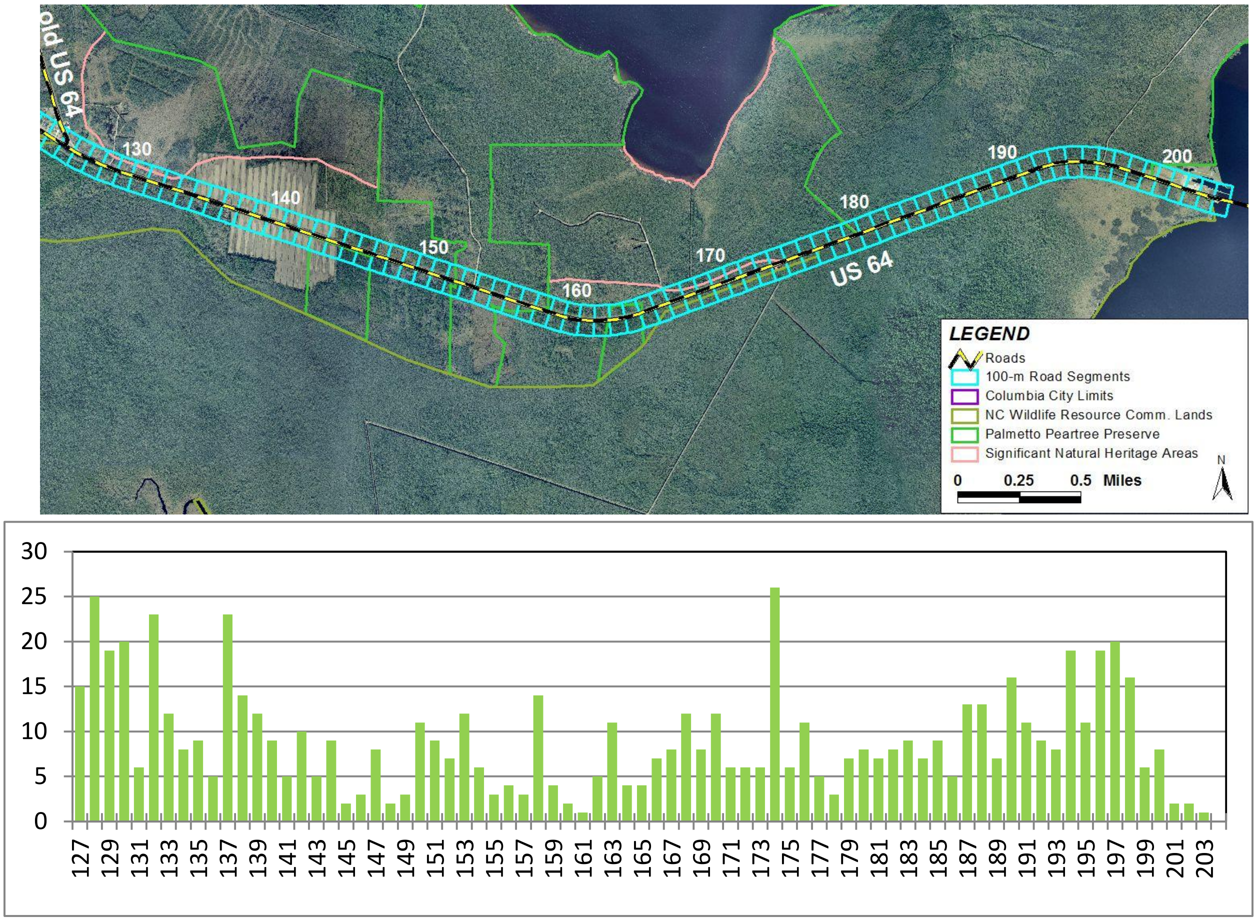


Figure A-12. Spatial distribution of road-killed snakes (east section).

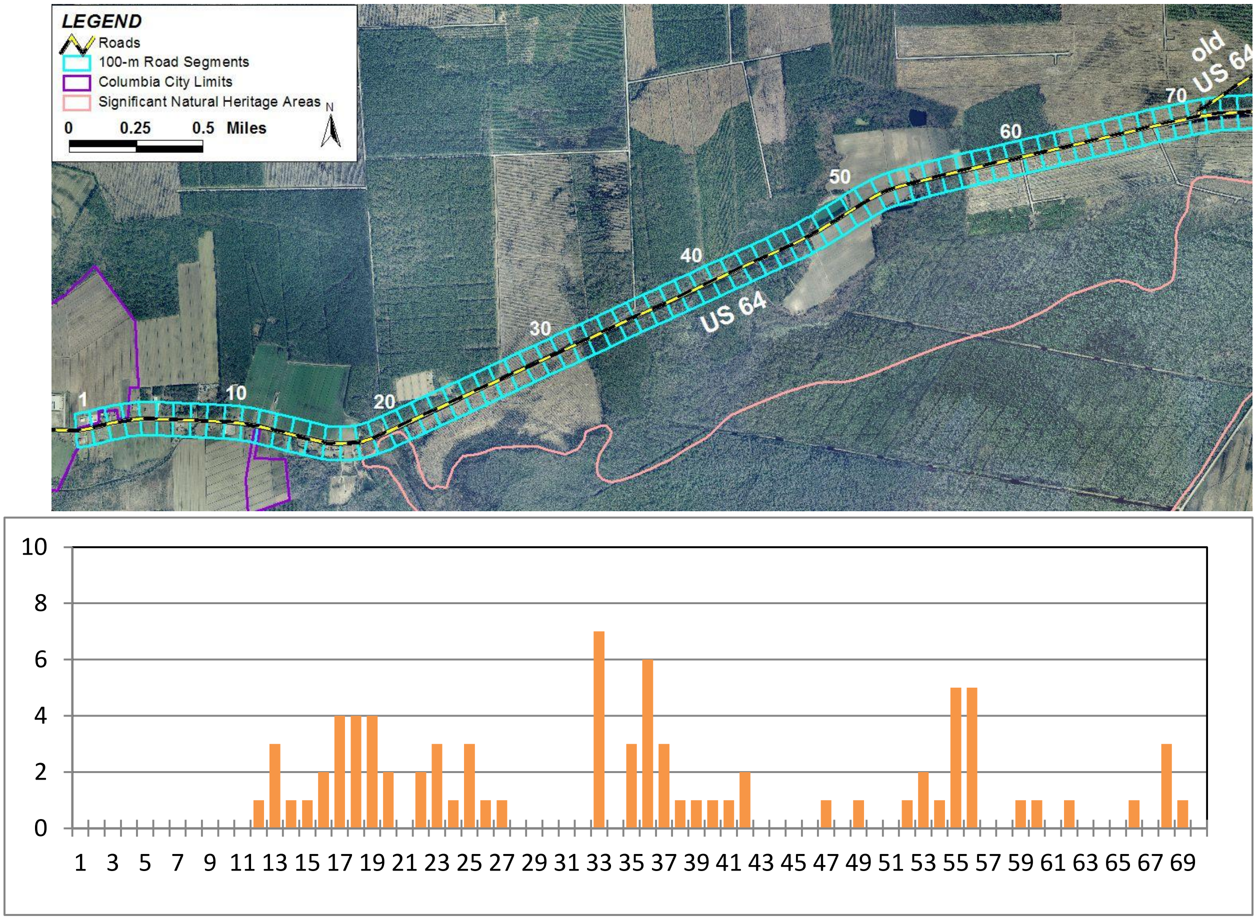
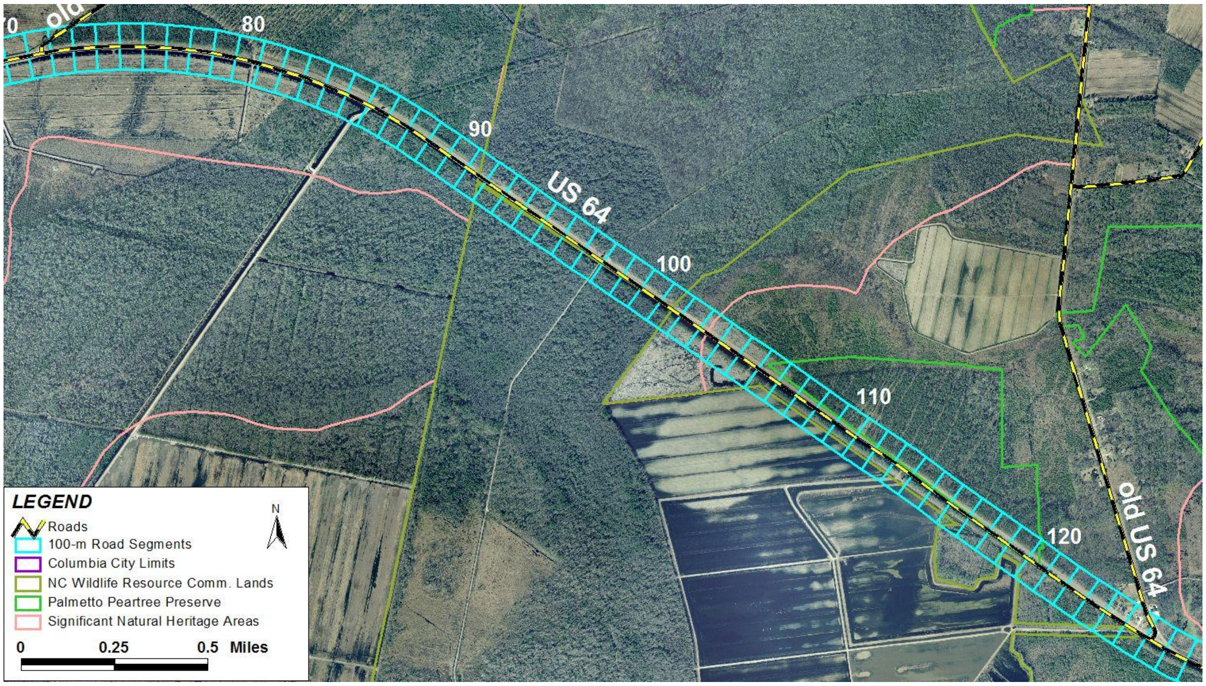


Figure A-13. Spatial distribution of road-killed turtles (west section).



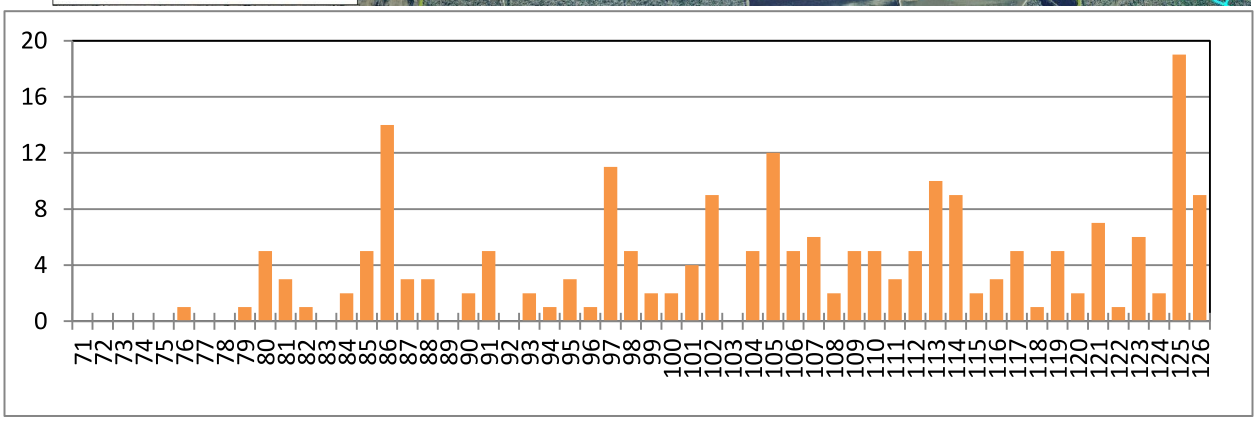


Figure A-14. Spatial distribution of road-killed turtles (central section).

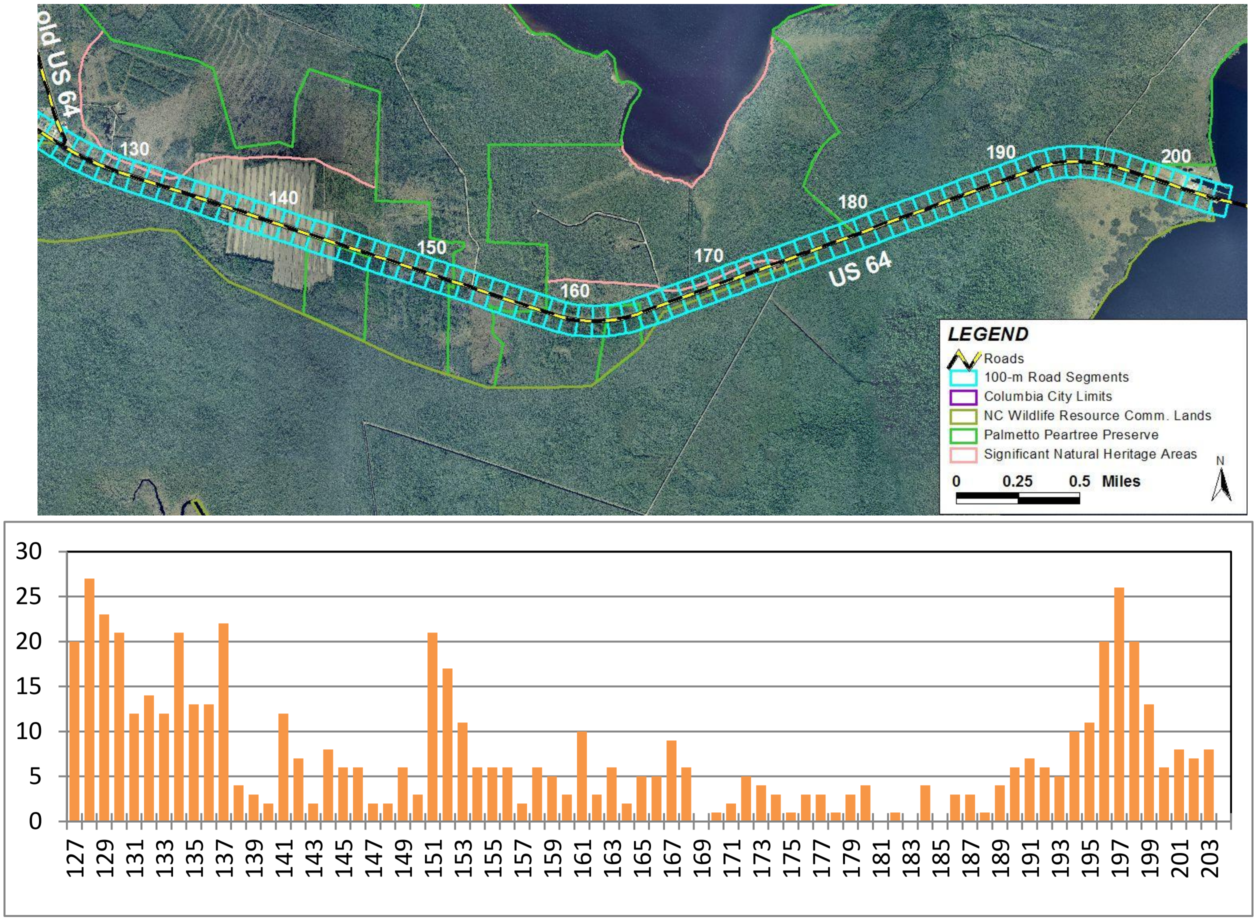


Figure A-15. Spatial distribution of road-killed turtles (east section).

APPENDIX B

LOCATIONS OF FOCAL SPECIES ROAD-KILLS

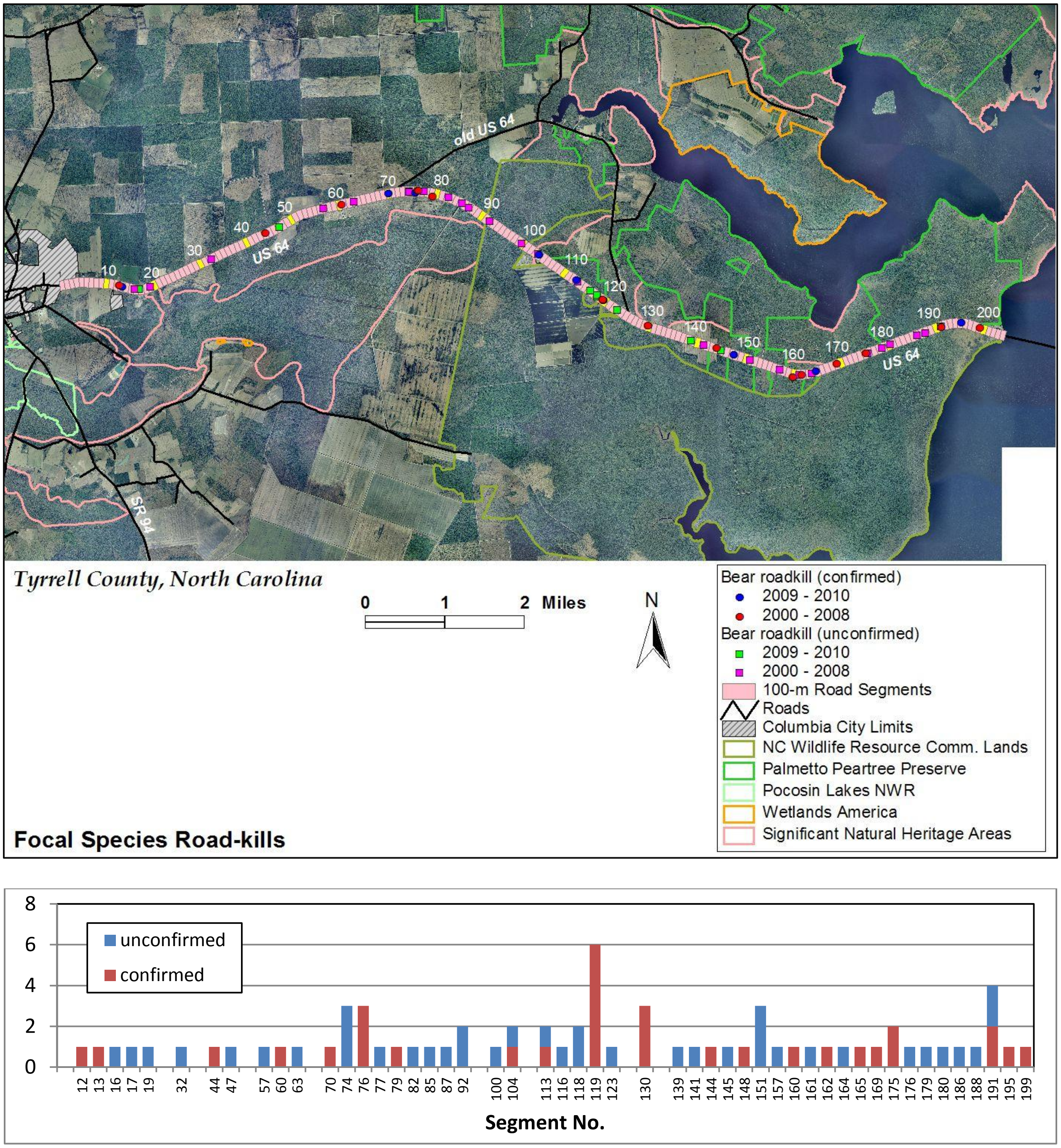


Figure B-1. Location of road-killed black bears on US 64, east of Columbia in Tyrrell County. Notes: the unconfirmed records are from NC vehicle accident reports, each location is an approximation based on mileage from nearest street or other landmark. Locations of confirmed records from 2000 to 2008 are lat//longs converted from Quad/Block/Square data and are only accurate to +/- 0.5 mi.

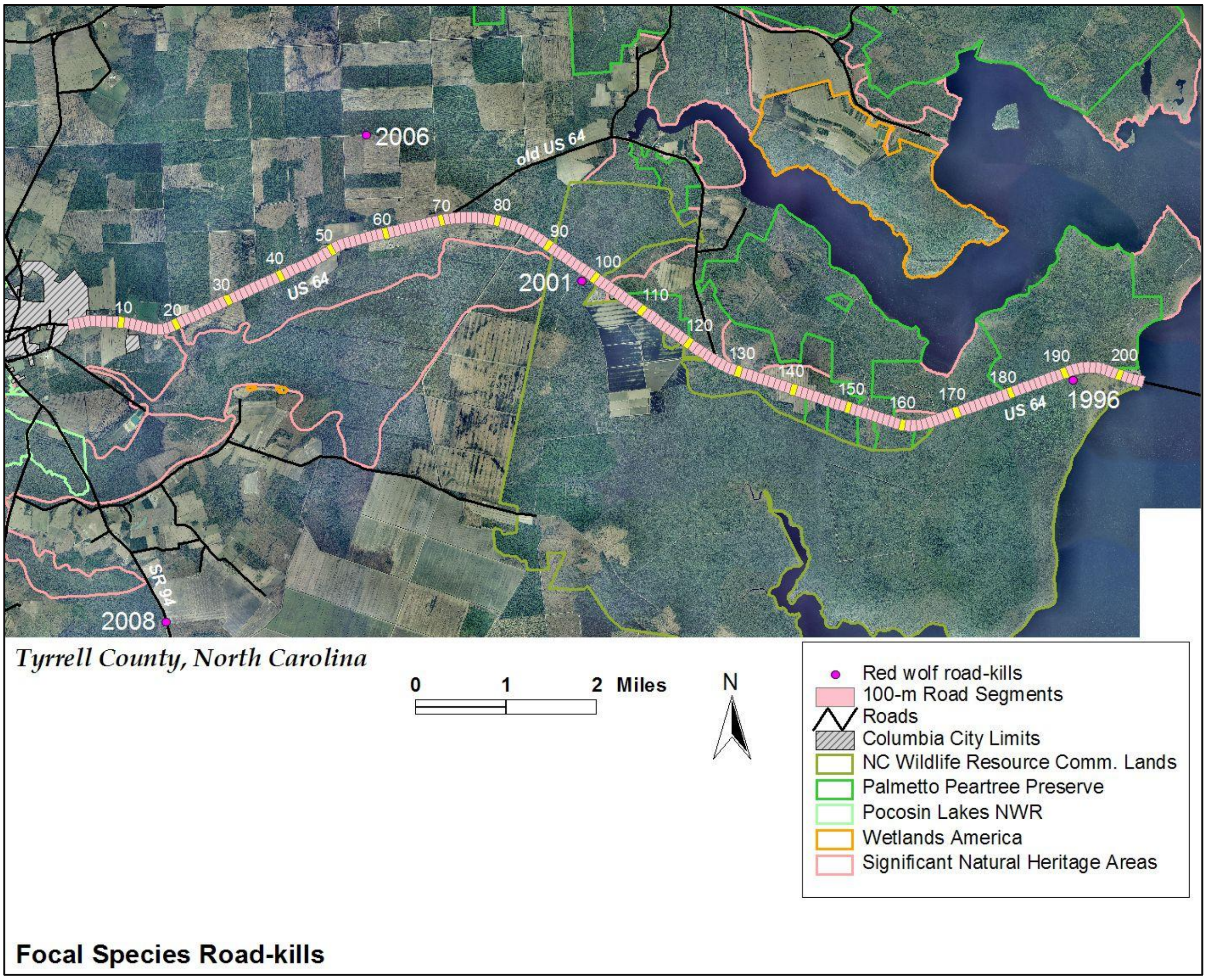


Figure B-2. Location of road-killed red wolves on US 64, east of Columbia in Tyrrell County.

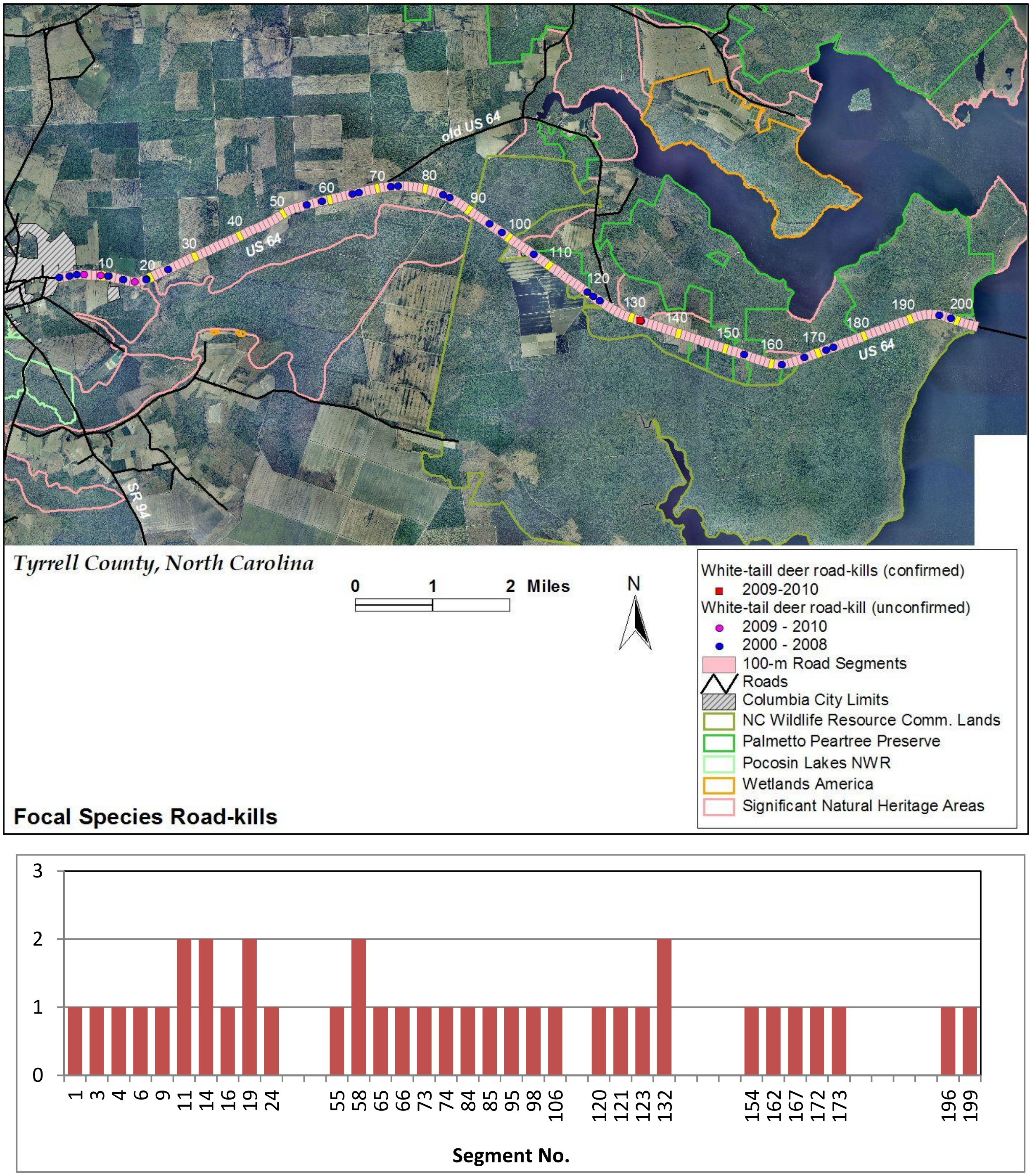


Figure B-3. Location of road-killed white-tail deer on US 64, east of Columbia in Tyrrell County. Note: the unconfirmed records are from NC vehicle accident reports, each location is an approximation based on mileage from nearest street or other landmark.

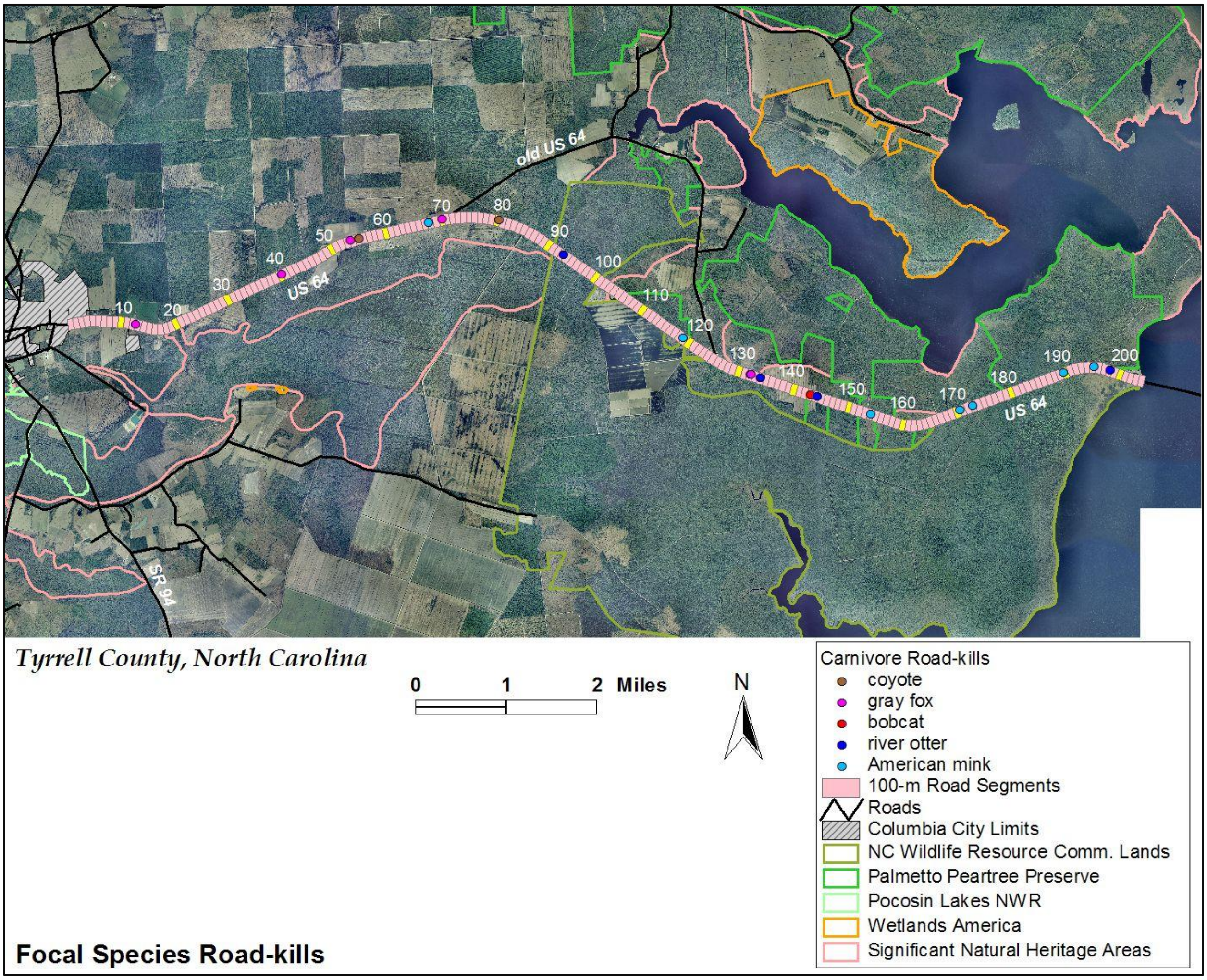


Figure B-4. Location of other road-killed carnivores of conservation interest on US 64, east of Columbia in Tyrrell County.

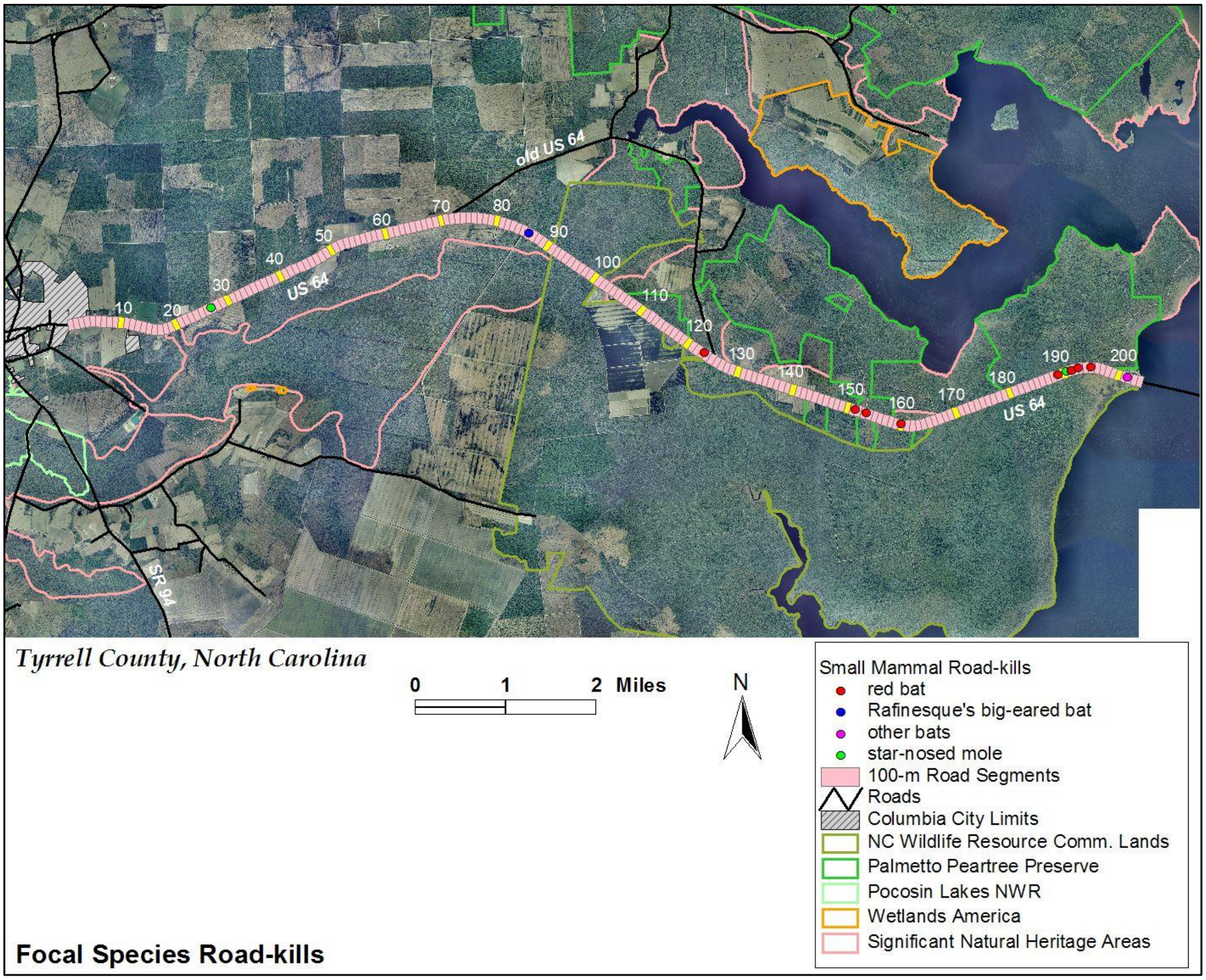


Figure B-5. Location of road-killed small mammals of conservation interest on US 64, east of Columbia in Tyrrell County.

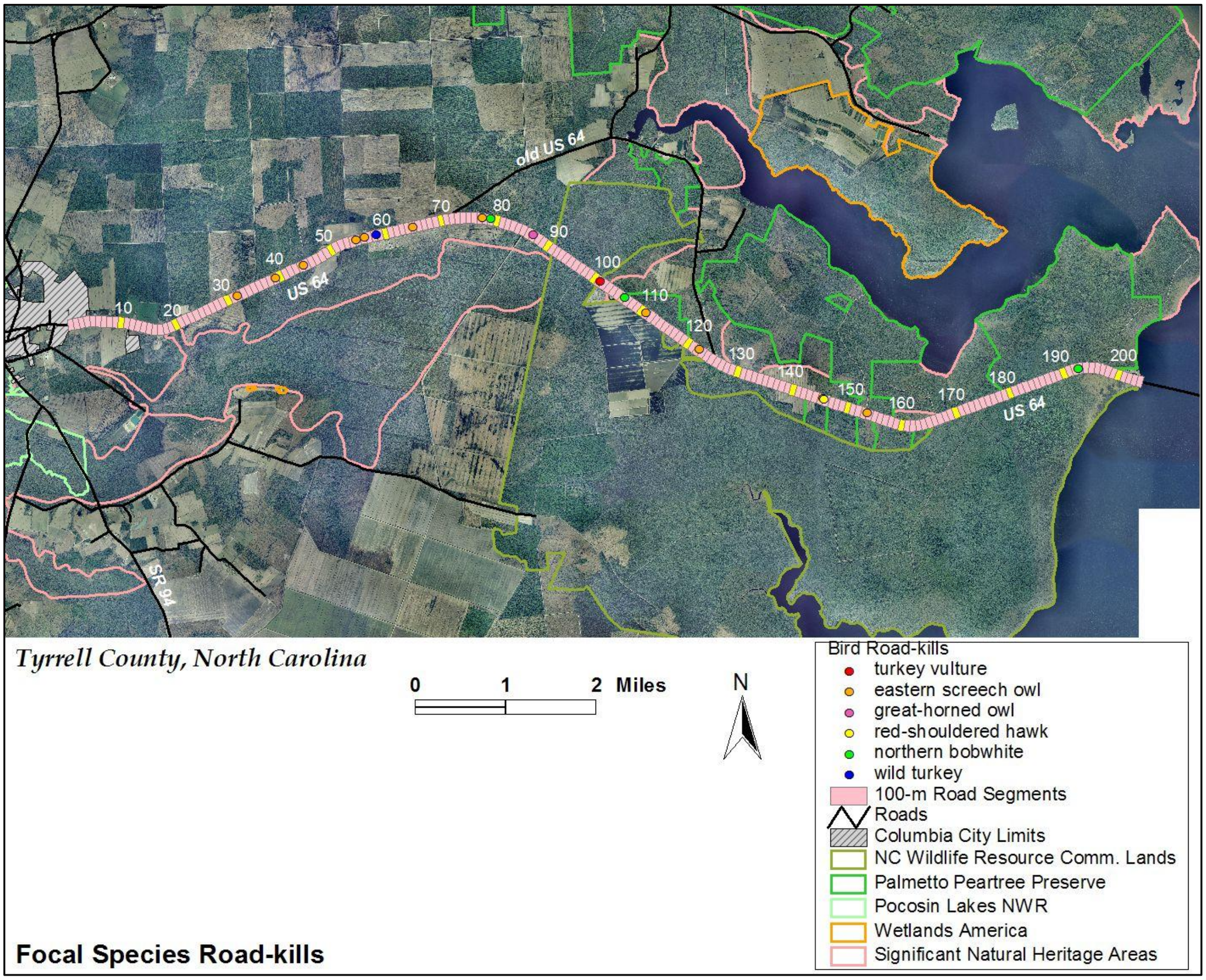


Figure B-6. Location of road-killed birds of prey and game birds on US 64, east of Columbia in Tyrrell County.

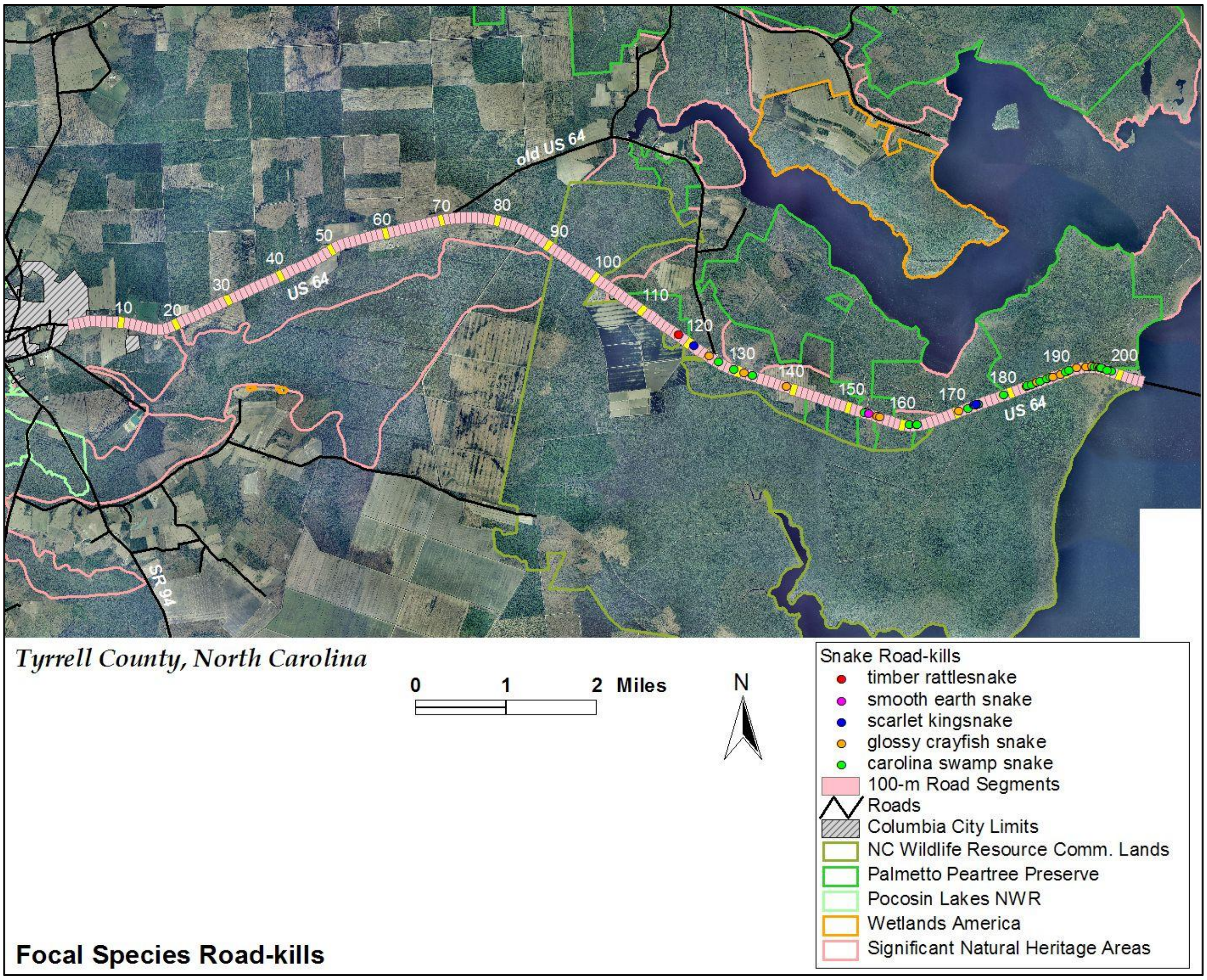


Figure B-7. Location of road-killed snakes of conservation interest on US 64, east of Columbia in Tyrrell County. Note: the smooth earth snake is an unconfirmed record.

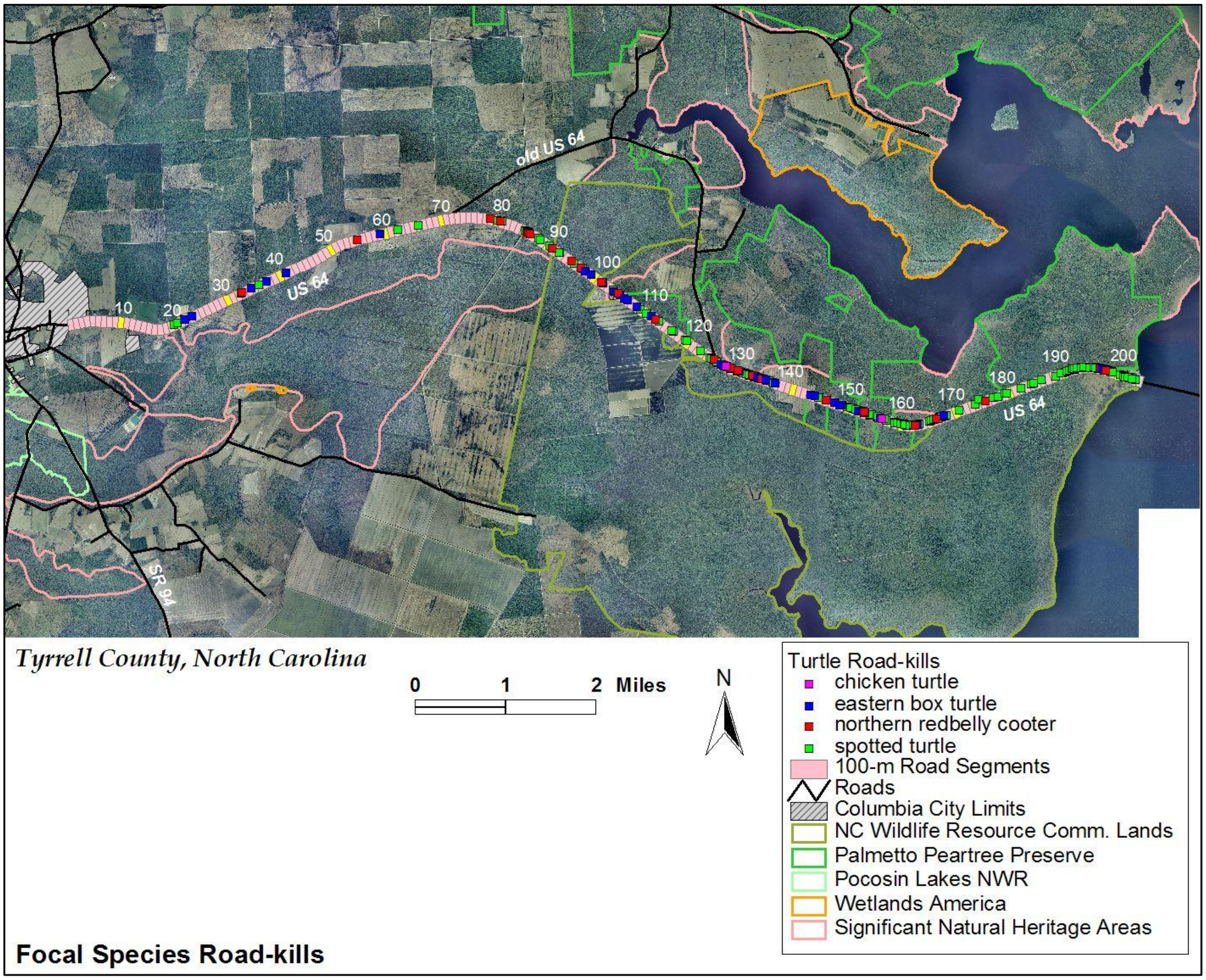


Figure B-8. Location of road-killed turtles of conservation interest on US 64, east of Columbia in Tyrrell County. Note: the chicken turtles are unconfirmed records.

APPENDIX C

LIVE SIGHTINGS OF FOCAL SPECIES OF CONSERVATION INTEREST

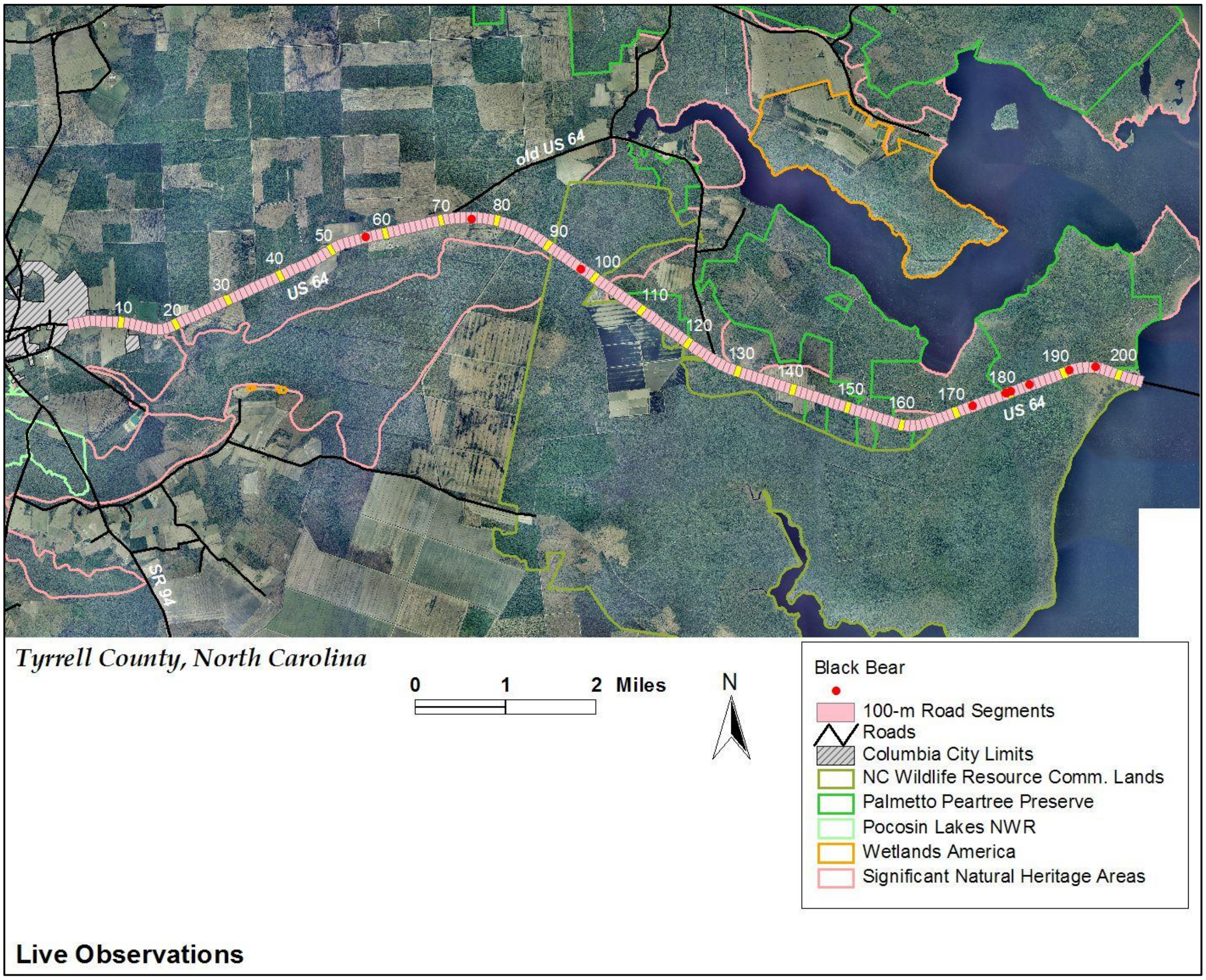


Figure C-1. Live sightings of black bears along US 64, Tyrrell County, NC.

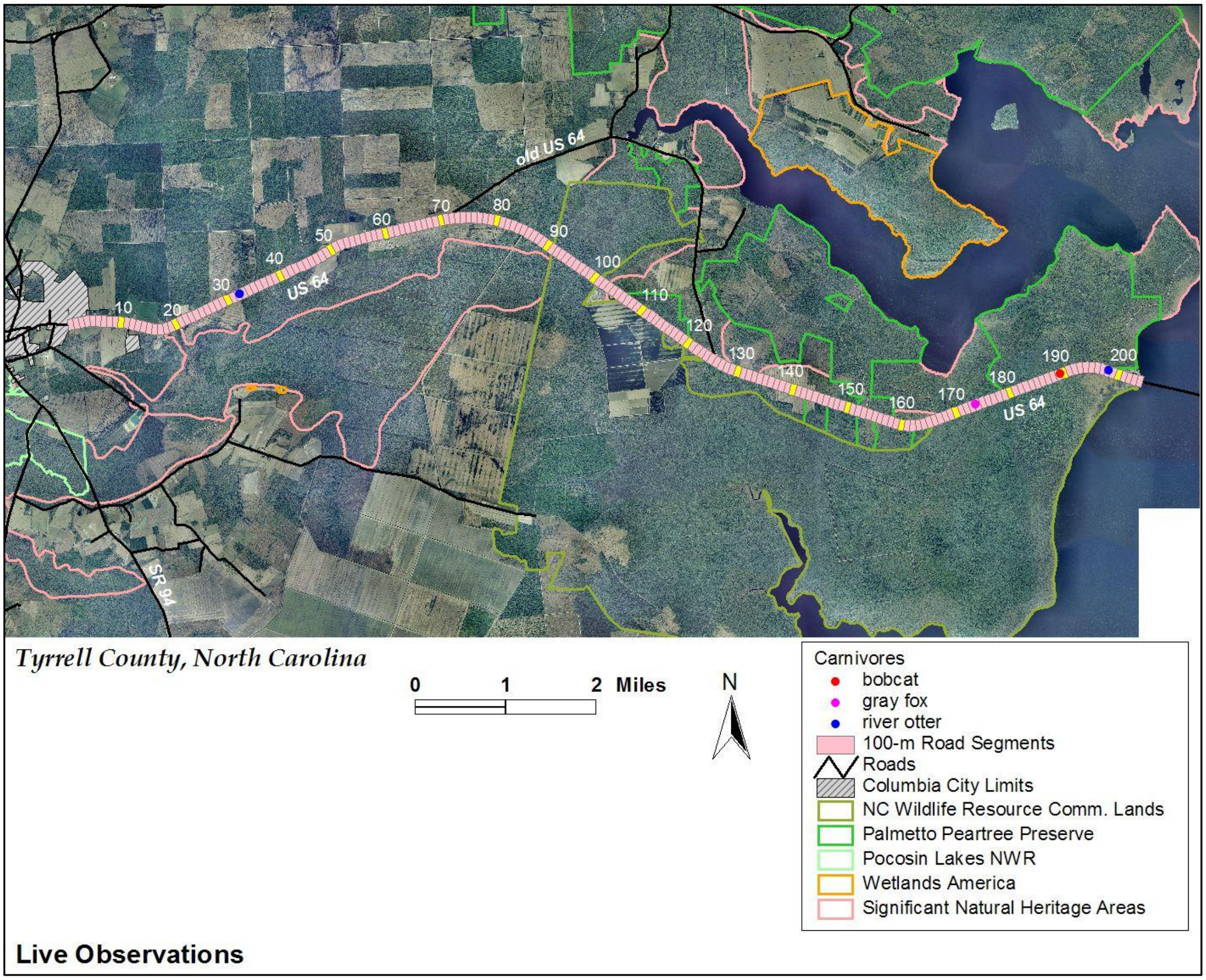


Figure C-2. Live sightings of other carnivores of conservation interest along US 64, Tyrrell County, NC.

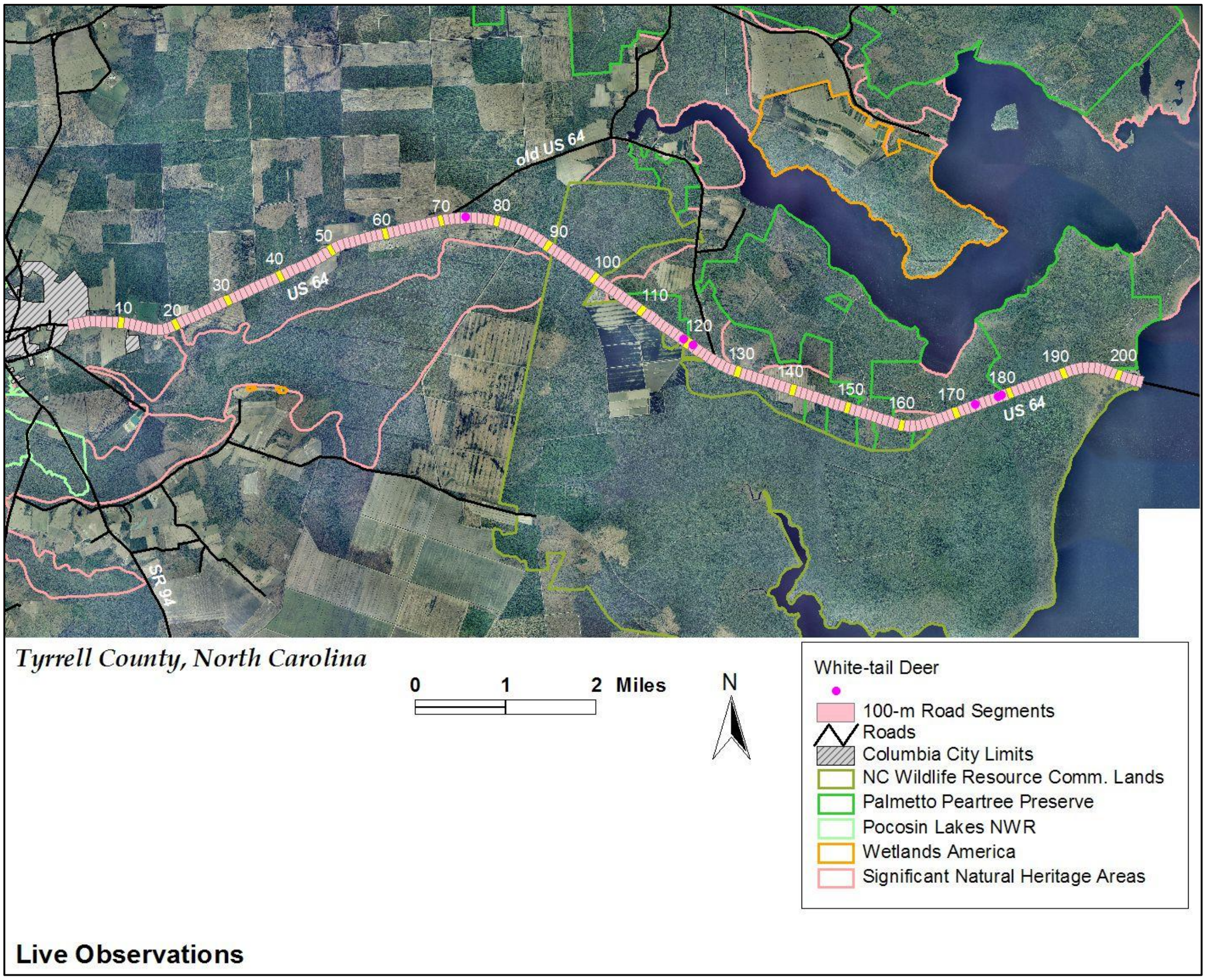


Figure C-3. Live sightings of white-tail deer along US 64, Tyrrell County, NC.

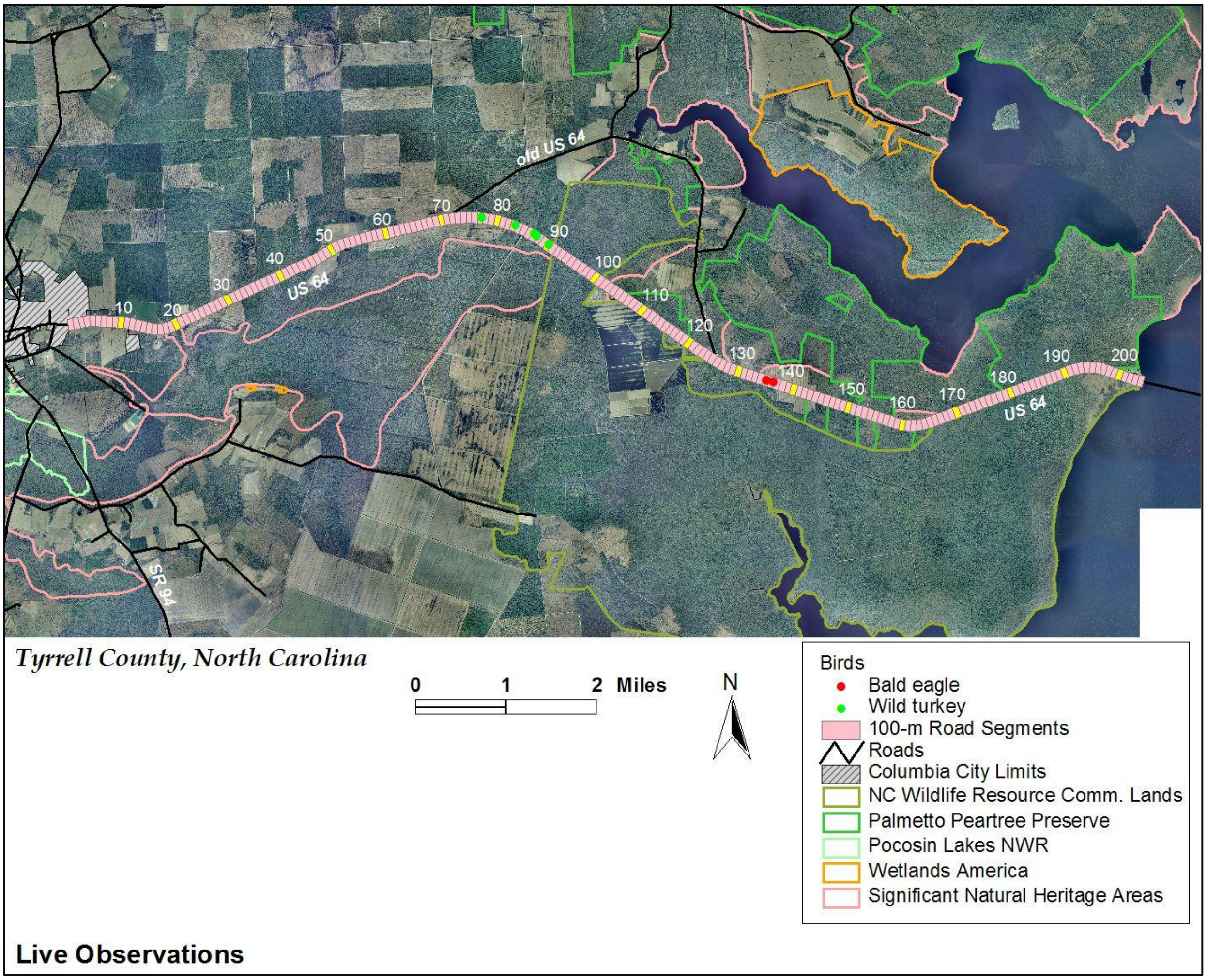


Figure C-4. Live sightings of birds of conservation interest along US 64, Tyrrell County, NC.

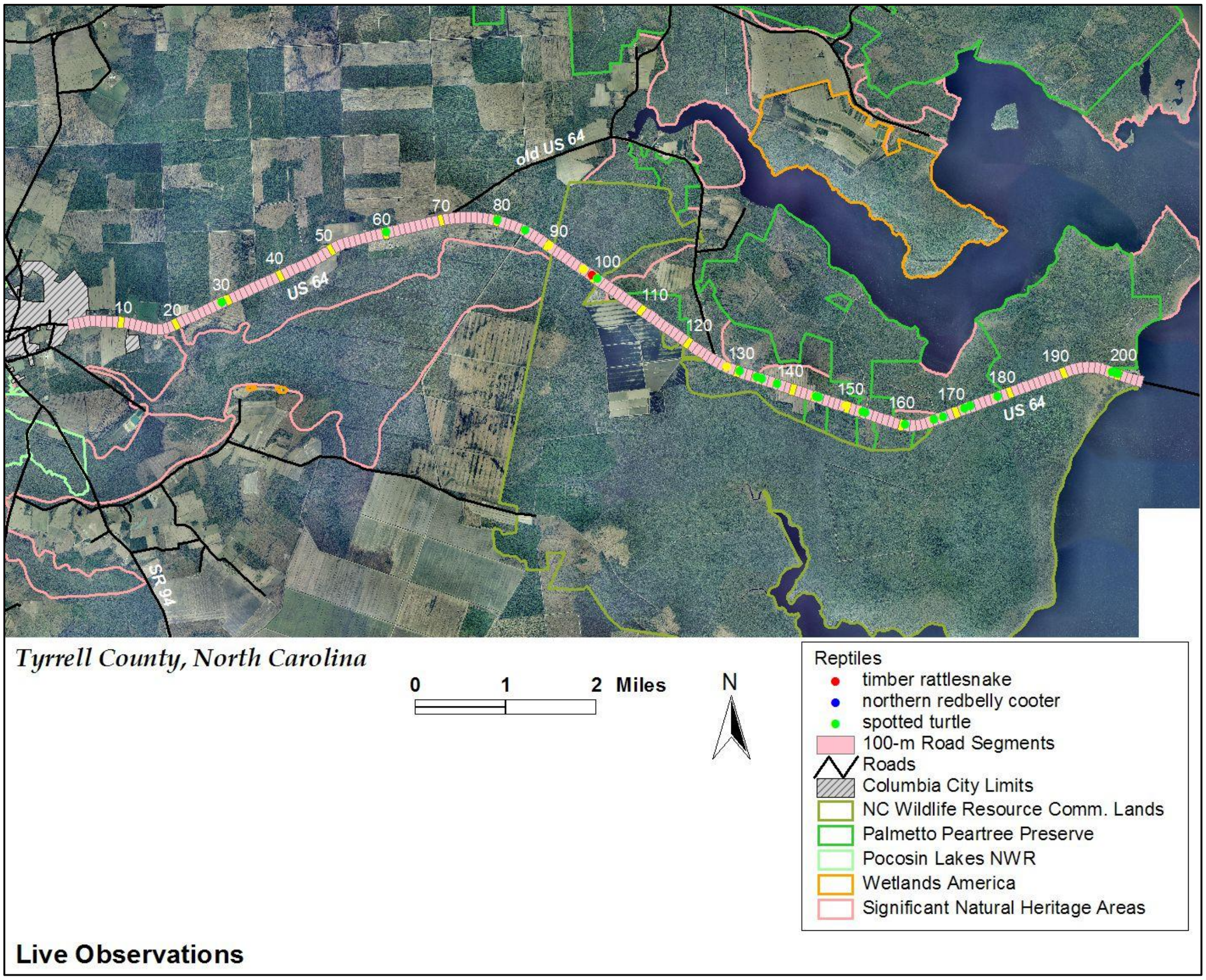


Figure C-5. Live sightings of reptiles of conservation interest along US 64, Tyrrell County, NC.