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Joseph Maddox Guthrie, Student

Dr. John J. Cox, Major Professor

Dr. David B. Wagner, Director of Graduate Studies

ABSTRACT OF THESIS

MODELING MOVEMENT BEHAVIOR AND ROAD CROSSING IN THE BLACK BEAR OF SOUTH CENTRAL FLORIDA

We evaluated the influence of a landscape dominated by agriculture and an extensive road network on fine-scale movements of black bears (*Ursus americanus*) in south-central Florida. The objectives of this study were to (1) define landscape functionality including corridor use by the directionality and speed of bear movements, (2) to develop a model reflecting selected habitat characteristics during movements, (3) to identify habitat characteristics selected by bears at road-crossing locations, and (3) to develop and evaluate a predictive model for road-crossing locations based on habitat characteristics. We assessed models using GPS data from 20 adult black bears (9 F, 11 M), including 382 unique road-crossing events by 16 individuals. Directionality of bear movements were influenced by the density of cover and proximity to human infrastructure, and movement speed was influenced by density of cover and proximity to paved roads. We used the Brownian bridge movement model to assess road-crossing behavior. Landscape-level factors like density of cover and density of roads appeared more influential than roadside factors, vegetative or otherwise. Model validation procedures suggested strong predictive ability for the selected road-crossing model. These findings will allow managers to prioritize and implement sound strategies to promote connectivity and reduce road collisions.

KEYWORDS: Black Bear, Brownian Bridge, Movement, Road Crossing, Florida

Joseph Maddox Guthrie

February 14, 2012

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THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture
at the University of Kentucky

By

Joseph Maddox Guthrie

Lexington, Kentucky

Co-Directors: Dr. John J. Cox, Adjunct Assistant Professor of Conservation Biology
and Dr. Songlin Fei, Assistant Professor of Forestry

Lexington, Kentucky

2012

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For Mom and Dad

The only gift is a portion of thyself – R. W. Emerson

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TABLE OF CONTENTS

Acknowledgments.....	iii
List of Tables	vii
List of Figures	viii
Chapter One: Introduction	1
Large Carnivore Ecology.....	1
North American Black Bear.....	2
Florida Black Bear	3
Chapter Two: Black Bear Movement in a Fragmented Landscape	10
Introduction.....	10
Study Area	16
Methods.....	22
GPS Data.....	23
Mapping Changes in Black Bear Movement Across the Landscape	25
Modeling the Relationship Between Movement Characteristics and Landscape	30
Results.....	33
Movement Behavior and Corridor Identification	34
Movement Behavior Modeling	37
Discussion	38
Chapter Three: Characterization of Black Bear Road Crossings in South-Central Florida.....	62
Introduction.....	62
Study Area	66
Methods.....	72
GPS Telemetry.....	73
Brownian Bridge Movement Model	76
Modeling Habitat Characteristics Associated with Highway Crossings ..	80
Results.....	84
Discussion	86
Management Implications.....	92
Literature Cited	106
Vita.....	121

LIST OF TABLES

Table 2.1, Summary of GPS data used to assess movement characteristics and landscape function for 15 black bears in Highlands/Glades counties, Florida, 2004-2009.....	45
Table 2.2, Combination scheme for classifying grid cells with measures of directionality and movement speed for black bear in south-central Florida.....	46
Table 2.3, Reclassification scheme of landcover map used to analyze movement rates and road crossing for the black bear of south-central Florida, 2004-2009..	47
Table 2.4, Description of 32 models evaluated for angular deviation and speed of movement of south central Florida black bears, with AICC values, Δ AICC and Akaike model weights (w).	49
Table 2.5, Summary results of linear regression modeling the effect of landscape structure on the angular deviation of black bear movements in south-central Florida	50
Table 2.6, Summary results of linear regression modeling the effect of landscape structure on the speed of black bear movements in south central Florida.	51
Table 3.1, Model training data used to analyze characteristics of road crossing locations in the Highlands/Glades black bear.	95
Table 3.2, Predictor variables used to analyze spatial and temporal patterns of road crossing for the black bear in Highlands/Glades counties, Florida, 2004-2009.	96
Table 3.3, Model selection results (number of parameters (K), Akaike Information Criterion adjusted for small sample bias (AICC), and AICC weights (wi)) used to evaluate habitat variable selected by black bears at 382 road crossing locations in Highlands and Glades Counties, Florida, 2004-2009.	97
Table 3.4, Parameter estimates and standard errors for the top 2 models and model averaged parameter estimates for selection of crossing locations by black bears along roads in Highlands and Glades Counties, Florida, 2004-2009.	98
Table 3.5, Summary results of model averaging for characteristics of road crossing in the Highlands/Glades black bear, based on GPS data collected 2004-2009.	99

LIST OF FIGURES

Figure 1.1, Aerial photo of the south-central Florida landscape.....	9
Figure 2.1, Examples of animal movement in (A) primary habitat with high amounts of movement, high angular deviation and little fragmentation, (B) a linkage zone with potential fragmentation, but movement similar to primary habitat, (C) a highly functional corridor with fragmentation but high amounts of directional (low angular deviation) movement, (D) a minimally functional corridor with high fragmentation and little movement.....	52
Figure 2.2, A minimum convex polygon (MCP) of the extent of black bear telemetry locations for the Highlands/Glades population of south-central Florida, shown in relation to major roads, county boundaries and large water bodies.	53
Figure 2.3, Private and public lands where trapping efforts were conducted for the Highlands/Glades black bear, 2004-2009.. Error! Bookmark not defined.	
Figure 2.4, Procedure for calculating and classifying the directionality of bear movements, developed using ArcGIS 9.3 Model Builder.	55
Figure 2.5, Black bear GPS locations distributed throughout Highlands and Glades Counties of Florida, USA, 2004-2009.	56
Figure 2.6, Merged 50% core area and 95% home range kernels derived from one hour GPS data of black bears in Highlands and Glades Counties, Florida, USA, 2004-2009.....	57
Figure 2.7, Angular deviation of black bear movements in the Highlands/Glades study area of south-central Florida, USA..	58
Figure 2.8, Movement speed of black bear in the Highlands/Glades study area of south-central Florida, USA..	59
Figure 2.9, Combined movement characteristics of angular deviation and movement speed for the black bear in the HGC study area.....	60
Figure 2.10, Estimated bear movement paths depicting primary habitat and corridor use in four areas of the HGC study area. Examples 1-3 represent highly functional corridors.....	61
Figure 3.1, Roadkill data for the Highlands/Glades black bear population, 1972–2009.....	100
Figure 3.2, A two-step approach to identify habitat characteristics of road crossings by black bears in south-central Florida.....	101
Figure 3.3, Road crossing movement paths of GPS-collared black bears in Highlands and Glades Counties, Florida, 2004-2009.....	102
Figure 3.4, GPS collared females based on the Hendrie/Smoak ranch complex (~6,000 ha) in southern Highlands County, Florida	103
Figure 3.5, Predicted road crossing areas for black bears in Highlands and Glades Counties, Florida, 2004-2009.	104
Figure 3.6, Rank correlation between model testing data (58 independent road crossing locations) and black bear road crossing probabilities predicted by logistic regression	105

CHAPTER ONE

INTRODUCTION

Large Carnivore Ecology

Large carnivores and their prey have been hunted for food and extirpated by humans since the late Pleistocene. The extirpation of many large carnivores and the current abundance of relatively small mammal species is the result of over-harvest, the introduction of exotic species, and habitat fragmentation (Berger et al. 2001). The first game laws in the United States were designed to protect game species such as the white-tailed deer (*Odocoileus virginianus*) from over-harvest, while large predators such as the gray wolf (*Canis lupus*) and the brown bear (*Ursus arctos*) were subjected to eradication efforts by government agents, contributing to extirpation throughout much of their historic range.

The 20th century witnessed a shift in the responsibility of the wildlife professional from predator controller to predator manager as enlightenments such as Leopold's (1949) vision of the wolf as an essential "cog" emerged and ecology became the standard. Restoration efforts have now replaced eradication efforts as conservation professionals and the public have come to appreciate the existence of large predators and the large natural areas they inhabit.

Studies of large carnivores consistently support the notion that the conservation of these species is a landscape-level issue, because the spatial requirements of large, wide-ranging animals such as the puma (*Felis concolor*) and the black bear (*Ursus americanus*) are large (Maehr 1997). Though the proposed solutions to shrinking habitat issues have generated debate (Harris and Gallagher 1989, Simberloff et al. 1992) all potential solutions to large carnivore conservation issues are land-extensive.

Large predators are often solitary or exist at low population densities, require large home ranges, and are generally wary of humans. Large carnivores are typically more sensitive to habitat perturbations than are smaller mesopredators like the striped skunk (*Mephitis mephitis*) or the raccoon (*Procyon lotor*). Research has shown that the larger bodied predators are often the first to abandon patches after habitat fragmentation or isolation (Crooks 2002).

North American Black Bear

Though it is less carnivorous than either of its North American related species, the black bear is today the largest remaining terrestrial carnivore over most of the continent. The black bear evolved in North America 2.5 million years ago, from ancestors that crossed the Bering Land Bridge (Craighead 2000). While the more predatory short-faced bears (*Arctodus simus*), dire wolves (*Canis dirus*) and saber-toothed cats (*Smilodon* spp.) were equipped to prey on large animals, the black bear found an ecological niche for a large, terrestrial, tree-climbing omnivore.

Differences in form and behavior between the black bear and the closely-related brown bear are the result of evolutionary processes (Herrero 1972) similar to those that led the black bear to avoid competition with the mega-carnivores of the Pleistocene. The brown bear evolved on the open plains, with adaptations for digging, with a larger body size and an aggressive temperament. The black bear remained a forest-dweller, and was likely excluded from areas populated by the brown bear (Herrero 1972). Through time, as the brown bear was eliminated from most of its historic North American range, the black bear has become widespread in those vacated areas, wherever sufficient forest cover allows (Pelton 1998). Historic patterns of forest cover and differences in behavior kept these relatives separate.

Today the black bear is the most widespread ursid in North America, and the only one of the family existing in the eastern United States in historic times (Pelton 1998). Similar to the brown bear, European colonization of the continent drove the black bear from accessible terrain, relegating populations to mountains, northern forests and lowland or coastal swamps. Though hunting and persecution by humans contributed to the retraction of the bear's range, habitat loss was and is the greatest threat to long-term survival of several subspecies. The loss of habitat in the eastern United States has, in many cases, relegated black bear populations to large tracts of public land (Maehr et al. 2001).

Florida Black Bear

Few states had more habitat loss than Florida, where the existence of the black bear is threatened by habitat fragmentation due to expanding agriculture and urbanization (Hellgren and Maehr 1992). The Florida black bear (*Ursus americanus floridanus*) – once common throughout the entire state including the Florida keys – is now restricted to approximately 27% of its former range (Maehr et al. 2001), and exists in seven separate populations (USFWS 1998, Dixon et al. 2007). Estimates of the bear population prior to European settlement suggest that as many as 11,500 may have once roamed Florida (FGFFC 1993, FFWCC 2010), with the lowest estimates at ~300 from 1950-1970 (McDaniel 1974, Brady and Maehr 1985).

The black bear's tolerance for a range of anthropogenic disturbances and threats is reflected in its wide continental distribution. Despite persecution related to apiary and livestock depredations, poaching, and unregulated hunting (DeVane 1978), Florida's larger populations are considered to be expanding now, as reflected by the recent decision to remove the black bear from the state's threatened species list. Its previous status as a

threatened species was due to shrinking habitat issues, human population increase, and the relative isolation of its seven populations. Based on hair snare surveys of the state's primary bear range, the Florida Fish and Wildlife Conservation Commission (FFWCC) estimates the current bear population is between 2000 – 3500 individuals (FFWCC 2010). Bear hunting ended in 1971 (with the exception of Apalachicola National Forest and Baker and Columbia counties, where hunting was permitted until 1994, when an experimental moratorium was imposed), leaving highway collisions as the most common form of human-related mortality (Simek et al. 2005). Populations with the reproductive characteristics of the five largest Florida bear populations can sustain up to 23% annual mortality (Bunnell and Tait 1980), but rates this high would be catastrophic for the two smallest populations in the state: Highlands/Glades County (hereafter referred to as HGC) and Chassahowitzka.

The discrepancy between the relatively stable bear populations of Florida and these two small populations present a challenge to management. The HGC population's historic connection (Maehr et al. 1988) to the Big Cypress region is functionally severed, leaving the population isolated from others in the state. It is believed this is the result of land use change and habitat fragmentation, which has left remnants of bear habitat (See Figure 1.1), scattered in the landscape and divided by roads. The lack of sufficient habitat has been noted by other authors (Hector 2003). The bear population likely numbers 75-100 individuals (FFWCC 2010). Genetic variation of the HGC population is among the lowest reported (expected heterozygosity = 0.384) for any bear population (Dixon et al. 2007), despite the likelihood that isolation has been in effect for less than 100 years.

Functional corridors provide habitat for foraging or searching for a mate and serve as conduits for natal dispersal and seasonal migration (Harris and Scheck 1991, Noss 1993, Rosenberg and Noon 1997, Hess and Fischer 2001). Several authors have suggested declining viability in the HGC bear is due to the loss of functional connectivity to other Florida subpopulations (Maehr et al. 2001, Dixon et al. 2007). Habitat restoration to improve functional connectivity has recently been adopted as a strategy under Florida's bear management plan (FFWCC 2010). Habitat conservation efforts in HGC are faced with many challenges because the landscape is privately-owned, whereas the rest of Florida's populations are centered on public land. The predominance of agriculture in the landscape renders the remaining forest patches of little value to wide-ranging forest obligates, and increases the chances for encounters between bears and humans and their vehicles.

Despite the challenges inherent in its landscape, the HGC black bear persists. Several of the remaining bear-inhabited areas are under conservation easements. Large tracts of suitable habitat appear to be uninhabited or isolated, and repatriation efforts may be feasible, but only if connectivity is enhanced. Prior to 2004 no peer-reviewed data on the status of the HGC black bear existed. Maehr et al. (2004) utilized a natural history observation catalogue from Archbold Biological Station (ABS; Venus, FL) to address long-term trends in bear sightings, road kill and acorn fruiting. This paper succinctly focused the direction of research efforts by the University of Kentucky for the first few years with the following passage:

“Although nothing is known about its demography or population trend, the black bear has persisted in Highlands County and the surrounding region despite widespread and

increasing development and agricultural activity. An obvious symptom of this human influence is highway mortality. Although road kill statistics have been suggested as a population monitoring tool on the assumption that road kills vary proportionally with population size in a given area, the effects of increasing human populations, habitat loss, and traffic volume have not been adequately considered as contributing factors in the relation between bear collisions and population status. Mortality rates and observations of family groups in Highlands County support the notion that the black bear continues to persist and reproduce in the region; however, habitat loss and fragmentation may have led to increased observability in areas of upland food production, and increased vulnerability to vehicular collision. Indeed, Wooding and Brady (1987) predicted that highway mortality would become a more important management issue as habitat becomes increasingly patchy. Regardless, the persistence of the black bear in this region belies the forest fragmentation that is so characteristic of Highlands County, and that is the result of natural and anthropogenic influences. Similarly denatured and non-forested habitats in Florida are devoid of the species. Perhaps the patterns of forest distribution, food productivity, and human development are such that the south-central Florida black bear can survive despite living in areas that are below the minimum preserve size threshold of 10,000 ha suggested by Hellgren and Maehr (1992). Although development continues to intensify, most patches of forest in the study area are still primarily surrounded by agricultural uses that may remain permeable to bear movements.”

Ulrey (2008) utilized GPS and VHF telemetry data collected in the initial phase of the research to describe home ranges, habitat use, and food habits. As GPS data and the number of sampled individuals has grown, analysis of population distribution and

movements have been enabled, allowing insights into the behavior of a small population of wide-ranging carnivores seemingly at the edge of its tolerance. Although extensive data have been collected and analyzed for the purposes of estimating black bear habitat suitability, movement ecology and relationships to roads and trails, few studies have dealt with a population of solitary large carnivores in a similarly denatured landscape.

Information on the distribution and spacing of primary habitat, seasonal patterns of movement, dispersals, and road crossing locations are important for the agencies tasked with managing Florida's wildlife. Additionally, the nature of working landscapes allows for expanded roads and development, which could further imperil the black bear and a host of sensitive endemic species associated with the Lake Wales Ridge.

Since the 1980s multiple agencies and organizations have worked to identify and conserve habitat and critical linkages throughout Florida (Harris 1984, Noss and Harris 1986, Noss 1987b, Harris and Gallagher 1989, Harris and Adkins 1991, Harris and Scheck 1991, Cox et al. 1994, Hctor et al. 2000). The south-central Florida landscape could serve as an important "stepping stone" of undeveloped land, with the potential to provide a corridor for animals moving north and south. Recently the region has been mentioned for its potential for expanded development and additional roads, such as the Heartland Expressway (Barnett 2006). Data on species likely to be affected by such large-scale projects are an important step in mitigating for conservation.

For the black bear, the long-term need is for functional connectivity between populations, particularly between the two southern-most populations. While the HGC black bear is in need of genetic variation from its nearest neighbor, the black bear of the Big Cypress region could eventually be forced north by climate change, as sea level rise

begins to affect the coastal areas of the south Florida peninsula. These issues would also affect the core range of the federally listed Florida panther (*Puma concolor coryi*), another famously wide-ranging, solitary carnivore.

The overall goal of this research is to fill a gap in the science that supports black bear management in Florida and the southeastern United States. As suggested by Maehr et al. (2004), the persistence of the HGC black bear defies what is known about habitat and space requirements for the black bear. The research I present here will hopefully add to the body of research on the American black bear and its habitat preferences, particularly with regard to human-dominated landscapes. Evidence from previous genetic trials suggest that the HGC population is at risk of losing further genetic variability unless functional connections are established between this and other subpopulations in Florida (Dixon et al. 2007).

Before intra-population connections can be facilitated, it is necessary to develop an understanding of the landscape from the perspective of the species of interest, and the location of important habitat bottlenecks that may act as filters to movement. Specifically, wildlife managers and policy makers need to know where important linkages exist that allow bears to move in the landscape. Secondly, it is well-documented that roads and their associated development impede movement for many species. I propose to use GPS data to classify movement characteristics throughout the HGC study area, placing emphasis on the identification of primary habitat zones, linkage zones, and bear movement corridors. I will relate the various movement classes to habitat and human variables in the landscape through modeling. My second objective is to characterize road crossings for the population, using GPS data to analyze patterns of

habitat selection and timing. Road crossing data will be used to develop and evaluate a predictive map, which can be used in landscape conservation planning and mitigation. This approach should inform land management and policy decisions that ultimately support the long-term survival of the black bear.



Figure 1.1. Aerial photograph of the south-central Florida landscape. This area is characterized by high habitat interspersion and small patch sizes. Human development, intensive agriculture, and the disruption of historic water flow patterns have all contributed to habitat loss and the isolation of the HGC black bear. (Photo courtesy of Carlton Ward Photography)

CHAPTER TWO

BLACK BEAR MOVEMENT IN A FRAGMENTED LANDSCAPE

Introduction

Habitat conservation and maintenance of habitat connectivity within and among animal populations are of increasing concern for wildlife managers, particularly those charged with maintaining viability of small populations in areas fragmented or degraded by human development (Soule and Orians 2001). While large, contiguous tracts of high quality habitat are the biological ideal for maintaining genetic and demographic connectivity, such landscapes that can facilitate large-scale migrations and the wide-ranging annual movements of some carnivores is an increasingly rare phenomenon in North America outside of remote mountainous areas and subarctic Canada (Berger 2004). In light of the threats facing wildlife populations worldwide, it has become increasingly important to identify remaining areas of high quality habitat and the species-specific corridors that connect them.

Large carnivores in particular are susceptible to the effects of habitat fragmentation because of low population densities, wide-ranging movements, and the potential for conflicts with humans (Noss et al. 1996, Crooks 2002). Many populations of large carnivores currently exist within fragmented habitats, encompassing areas too small to support long-term population viability (Woodroffe and Ginsberg 1998). Additionally, the long distance movements of large carnivores suggest they are more likely to use corridors for movements than species with limited dispersal capabilities (Lidicker and Koenig 1996, Harrison and Voller 1998).

Landscape ecologists have moved beyond earlier debates about the merits of managing landscapes for corridors and connectivity (Noss 1987a, Simberloff and Cox 1987). Corridors have been shown to increase movement of organisms among habitat patches (Haas 1995, Haddad 1999, Haddad et al. 2003), increase population potential (Hale et al. 2001), provide additional habitat (Perault and Lomolino 2000), and facilitate plant and animal interactions (Tewksbury et al 2002). Corridors may also enhance survival of individuals (Coffman et al. 2001), gene flow (Harris and Gallagher 1989), and population viability (Fahrig and Merriam 1985, Beier 1993). Recent studies of functional connectivity through genetic analyses confirm that corridors facilitate population viability in wide-ranging species (Coulon et al. 2004, Dixon et al. 2006, Costello et al. 2008; 2009, Cushman and Lewis 2010, Noyce and Garshelis 2011). Others have refined methods for identifying corridors (Graves et al. 2007, Horne et al. 2007).

Landscape functionality varies from primary habitat, or that which provides most of a species needs (food, water and shelter), to lower quality habitat, which is suitable for travel but little else, to non-habitat, which is not used due to lack of resources and safety (Graves et al. 2007, Horne et al. 2007). In primary habitat, movement paths are most likely to be dense (because animals spend the majority of their time there), slow (due to stopping to eat or rest) and tortuous (due to searching for food and resting areas). In linkage zones a potential barrier exists, such as a road or a fence line, but movements do not reflect interruption or fragmentation. In areas with greater fragmentation, additional hazards, or fewer resources we might expect to see movements become constrained, linear, and faster. I define corridors according to the definition put forth by Graves et al.(2007). This definition asserts that when animal behavior is restricted to travel rather

than spending time searching for food or other resources, the area is called a corridor. Corridors are typically defined according to its vegetative composition. Corridors have been defined as areas with the same characteristics as high quality habitat, but possessing certain characteristics (Haddad et al. 2003). These characteristics include vegetation that provides better food or cover than the surrounding habitat matrix, an arrangement of patches that are longer than they are wide, and often, alignment to an internal entity like a river, which may form a natural travel route (Forman 1995). Animals using highly functional corridors should exhibit frequent, highly directional, rapid movements; conversely, animals in less functional corridors would typically display more infrequent, long, rapid movements (Figure 2.1). As obstacles such as roads intersect corridors, or as corridors narrow, we expect risk to increase and the probability of use to decrease, until these areas are no longer conduits for movement. This is how Graves et al. (2007) define non-habitat.

Some previous attempts to identify corridors have relied on analyses of habitat characteristics representing food and shelter at point locations used by animals, usually in comparison to unused or available locations (Manly 2002, Mueller et al. 2004). However, few studies have tested whether putative corridors are functionally used as corridors by animals (Sutcliffe and Thomas 1996, Aars and Ims 1999).

Graves et al. (2007) recognized a knowledge gap between theoretical characteristics of corridors and the characteristics of animal movement within corridors. Graves et al. (2007) used the assumption that animals move more quickly within a corridor than in the surrounding matrix or primary habitat (Forman 1995), and described a new method for distinguishing patterns of landscape use based on movement

characteristics. In this analysis, I proposed similar methods, allowing movement characteristics to determine landscape functionality for a subpopulation of black bear in south-central Florida.

The black bear of Highlands and Glades counties (hereafter HGC) in south-central Florida inhabits a fragmented landscape, which is dominated by agriculture and a network of roads. Historical anecdotes (DeVane 1978), natural history observation records from Archbold Biological Station in Venus, Florida (Maehr et al. 2004) and results from recent genetic surveys (USFWS 1998, Dixon et al. 2007) indicate that a once-abundant population has become isolated from the state's other populations and is now susceptible to inbreeding depression. Based on these previous studies, the current bear management plan of the Florida Fish and Wildlife Conservation Commission (FFWCC) calls for establishing functional connectivity to facilitate gene flow between the HGC population and others within the state (FGFFC 1993, FFWCC 2010). To accomplish this goal, managers need a basic understanding of the current distribution of the population, its core areas and corridors that facilitate dispersal. To our knowledge, no other bear population exists in a landscape where habitat fragmentation is as extensive as in Highlands County (Ulrey 2008). Ulrey (2008) described patterns of habitat selection for the population and identified areas where adult females are active and resident, and found that male home ranges typically overlap those of multiple females (Rogers 1987, Hellgren et al. 2005, Noyce and Garshelis 2011). However, the existence, geographic location and scale of movement pathways remain uncertain for the HGC black bear.

GPS collars allow researchers to track animals across large landscapes at fine temporal and spatial scales, thus enabling better insight into specific animal behaviors

(Weimerskirch et al. 2007), intraspecific interactions (Courbin et al. 2009), responses to movement barriers (Dussault et al. 2007, Sawyer et al. 2009a, Lewis et al. 2011) and the use of corridors (Graves et al. 2007, Chetkiewicz and Boyce 2009, Sawyer et al. 2009b). In the HGC study area, I collected GPS data on a sample of black bears and analyzed the characteristics of movement. My approach was to use directionality and movement speed parameters extracted from GPS data to identify landscape features that enable bear movement and describe the landscape in a highly fragmented region.

The process of identifying corridors can be complex. Multiple papers have utilized the least-cost path method (Meegan and Maehr 2002, Schadt et al. 2002, Larkin et al. 2004, Kautz et al. 2006, Penrod et al. 2006). Least-cost path analysis is based on how the movement path of an animal may be affected by characteristics of the landscape, such as land cover, human density, roads, or slope (Singleton et al. 2002, Penrod et al. 2006) and models the relative “cost” for an animal to move between two areas. In theory, least-cost paths contain the most suitable habitat and the fewest movement barriers, and are the best route for a dispersing animal (Larkin et al. 2004). However, the method relies on the ability of researchers to correctly identify and rank resource selection in the species of interest, and then extrapolate those results to the landscape. The method I proposed removes this step, and eliminates uncertainty as to whether the least-cost path is the path preferred by dispersing animals. The Graves et al.(2007) approach eliminates the assumption that researchers can identify all the factors to which animals respond, and replaces the intermediate step of modeling resource selection when corridor identification is the only objective (Graves et al. 2007, Horne et al. 2007). Additionally, it removes

from the process the use of remotely sensed habitat data, eliminating the possibility that researchers or land managers might misidentify important habitats.

The methods described below focus on the contrast between movements within primary habitat and movements outside primary habitat areas. This is a new approach that could simplify traditional methods of identifying corridors. In addition these findings may help inform policy makers and development planners on where human land use is least impactful on black bear movement, and help design mitigation or restoration projects that could improve habitat connections or offset additional habitat loss.

Study Area

The study area, defined as where bear trapping and telemetry locations occurred, was comprised of a ~6500 km² mosaic of public and private lands centered in Highlands and Glades Counties of south-central Florida (27°12'N 81°20'W), although movements of bears incorporated portions of Lee, Charlotte and Polk Counties (Figure 2.2). The climate was humid sub-tropical, with an average July high temperature of 34°C. Annual precipitation in the study area averaged 136 cm, most of which falls between the months of May and October in afternoon thunderstorms. Winter was mild and typically dry, with an average January low of 8°C (ABS 2010).

The study area was contained within the southern reaches of the Florida Peninsula Ecoregion. This area of Florida demonstrates considerable tropical affinities, with pronounced wet and dry seasons, high annual rainfall, very rare winter freezes, flat topography and thick muck or peat soils in places. The Lake Wales Ridge (LWR) is the major geomorphological feature of the landscape, stretching approximately 186 km from Lake County to southern Highlands County (Weekley et al. 2008). The ridge is a relict of an ancient shoreline and beach dune system, probably dating to the Pleistocene epoch

(White 1970, Webb 1990). Level to gently sloping xeric uplands and shallow sinkhole lakes characterize the topography.

The LWR is marked by hundreds of shallow freshwater lakes, the result of dissolution by acidic waters of deeply-laid layers of limestone, creating a karst subsurface. The majority of the region's sinkhole lakes are small (< 60 ha) and shallow (< 5 m)(Kenner 1964). Two lakes, Lake Okeechobee (1890 km^2) and Lake Istokpoga (113 km^2), have surface areas greater than 100 km^2 . More than half of Florida's lakes occur in the sandy central ridge system. The Caloosahatchee River forms the southern boundary of Glades County, considered a transitional zone between the Lake Wales Ridge "highlands" and the Big Cypress region to the south. Fisheating Creek originates in the swamps and marshes of the region, flowing east to Lake Okeechobee. Several conservation easements were associated with Fisheating Creek, including mature cypress forests, hardwood hammocks and shrub swamps.

Primary land uses in the study area included agriculture, such as citrus groves, cattle ranching, sod farms, horticultural nurseries, pine and eucalyptus plantations. The largest patches of forest existed to the south in Glades and Charlotte Counties, the largest of which was in the Babcock Preserve/Webb Wildlife Management Area, a former private ranch consisting of roughly 12,000 ha of forest. Other forested properties were under the ownership of the Lykes Brothers, a Tampa-based agricultural conglomerate. Lykes Brothers properties included a 16,833 ha Fisheating Creek/Lykes conservation easement in southern Highlands and Glades County. Forested land in Highlands County was considerably less than its neighboring counties to the south. Aside from Highlands Hammock State Park (~ 3800 ha) near Sebring, most forested land was under private

ownership. Among the largest forested properties was the Hendrie Ranch (~2800 ha) in Venus, of which roughly 1400 ha was comprised of various forest associations.

Forest patches were often isolated by several kilometers of improved pasture or citrus groves. Conservation lands constituted ~14% (754 km²) of Highlands and Glades counties. Most research occurred on private lands that included several active cattle ranches with conservation easements as well as Archbold Biological Station, a private, long-term research station near Lake Placid, Florida (Figure 2.3). In addition several state and federal wildlife management areas and state parks were incorporated into research efforts, most notably the Lake Wales Ridge Wildlife and Environmental Areas (LWRWEA) network in Highlands County. Human activities on properties where research occurred included sod farming, prescribed burning, recreational vehicle riding, and hunting. The practice of hunting white-tail deer (*Odocoileus virginiana*) and feral hogs (*Sus scrofa*) over gravity-fed or timed release corn game feeders was common on these ranches and other smaller private lands within the study area. When active, game feeders were frequented by black bears (Ulrey 2008) and several other species.

The distinctive ecotype of the LWR was known generally as scrub, which has been described as “a xeromorphic shrub community dominated by a layer of evergreen, or nearly evergreen oaks, Florida rosemary (*Ceratolia ericoides*), or both, with or without a pine overstory, occupying well-drained, infertile, sandy soils” (Myers and Ewel 1990, p. 155). Scrub may appear over either the white and yellow sands common to the LWR, and typical plant communities were sand pine scrub, oak scrub, rosemary scrub, and scrubby flatwoods. Common pine species included slash pine (*Pinus ellioti*) and sand pine (*Pinus clausa*). Scrub hickory (*Carya floridana*), sand live oak (*Quercus geminata*),

scrub oak (*Quercus inopina*), Chapman's oak (*Quercus chapmanii*), and rusty lyonia (*Lyonia ferruginea*) are common scrub hardwoods. Saw palmetto (*Serenoa repens*) was abundant throughout the study area and was a feature of the understory of most forest types in the region, including the scrub, where it was joined by sabal palm (*Sabal etonia*).

Scrub may take on a variety of structures, even over similar soil types. Long unburned stands of sand pine scrub can develop an impenetrable shrub layer below tall, even-aged sand pines. In contrast, the sand pine/rosemary scrub familiar to ABS and other properties in the HGC region was characterized by sparsely grown, uneven-aged sand pines and an open shrub layer of rosemary and scrub oak.

At the margins of the ridge are a mix of soils and ecosystems associated with drainage patterns from the ridge. The predominant soil types along the margins are composed of marine and estuarine terrace deposits of alluvial sand and shell marl deposited during the Pleistocene and Recent epochs. These soils are typically level, poorly drained sands, with dark sandy subsoil layers, or a clay hardpan. They are most frequently associated with pine flatwoods, though wet and dry prairies are also common. Cutthroat seep, a distinctive feature of the edge of the LWR, is an increasingly rare community still present in places. The attrition of this feature is perhaps in part due to fire suppression, as succession is known to convert the mesic slash pine flatwoods favored by cutthroat grass (*Panicum abscissum*) to hardwood swamps (often referred to as "bayheads") and hardwood hammock (Myers and Ewel 1990). Additionally, these habitats are commonly converted for use as pasture, vegetables, and forest products. Near the southern terminus of the ridge a layer of level, poorly drained peat lies to the

southeast. Ecosystems there are typically hydric, with bayhead and marshes the dominant ecotypes (Brown et al. 1990).

Bay swamps, or “bayheads,” are a distinctive habitat type for the study area, characterized by an association of broadleaf, evergreen tree species growing on organic, strongly acidic soils in depressions in central and south Florida (Wade et al. 1980, Abrahamson et al. 1984, Stone et al. 2002). Bay swamps are dominated by broad-leaved trees with the common name bay, including red bay (*Persia borbonia*), loblolly-bay (*Gordonia lasianthus*), and sweet bay (*Magnolia virginiana*). Bay swamp species of lesser presence include red maple (*Acer rubrum*), swamp tupelo (*Nyssa biflora*), and slash pine. Historical hunting accounts (DeVane 1978) and aerial photography from the 1940s suggest bay swamps were historically more extensive, particularly east of the LWR. Much of the lowland area east of the ridge has been converted to agriculture, primarily ornamental caladium farming, cattle pasture, and sod.

Much of the HGC study area has been degraded by conversion to residential and agricultural development, especially along the LWR. Weekley et al. (2008) reported that 78% of the xeric uplands found on the ridge have been converted to development. In the study area the dry upland soils are often used for citrus groves and home sites. Approximately 85% of yellow sand habitats (oak-hickory scrub, sandhill) have been converted to other uses, while 47% of white sand habitat has been converted. Of the ridge counties, Highlands and Polk Counties are the least developed, with roughly 45% of white sand habitat lost, combined, and 80% of yellow sand habitat lost, combined. Only 31% of the LWR edge in Highlands County remains relatively intact (Weekley et al. 2008).

The LWR supported a great diversity of plant and animal species. Archbold Biological Station has recorded the occurrence of 27 fish species, 21 amphibian species, 44 mammal species, 48 reptile species, 208 bird species, and 593 plant species (ABS 2010). The LWRWEA supported twenty-one listed plant species, many of which were endemic to the ridge (USFWS 1999, Turner et al. 2006a,b). At least fifteen listed vertebrate species, such as Florida scrub jay (*Aphelocoma coerulescens*), Florida mouse (*Peromyscus floridanus*), Florida panther, and sand skink (*Neoseps reynoldsi*) have been documented on the ridge; however, only 11% of the LWR was considered protected conservation lands.

Approximately 1010 km of paved roads occurred within the area of the HGC used by radio-collared black bears (Figure 2.2), of which 757 km were classified as some form of rural road, and 253 km were classified as urban road. Rural roads varied from minor “collector” roads to major 4-lane “arterial” highways. Average annual daily traffic (ADT) data were available through the Florida Department of Transportation. Roads with <1000 ADT amounted to ~ 617 km within the area utilized by collared black bears. Roads with 1000-5000 ADT amounted to ~ 151 km, and roads with >5000 ADT amounted to ~ 241 km.

The study area was bisected by over 60 km of U.S. Highway 27, a 4-lane highway running north and south for the length of the Florida peninsula. Other major roads in the study area included State Road 70, a 2-lane bi-coastal highway. The intersection of these two major traffic arteries divided the study area into 4 quadrants. There were a number of secondary state and county roads connecting the towns of Sebring and Lake Placid (Figure 2.2), and an extensive network of gravel or shell roads used primarily by citrus

grove operators to access their crops. Highlands and Glades Counties fit the traditional model of a working agricultural landscape, in that traffic was relatively low (<1000 ADT) on most roads, except on highways connecting towns and through streets in the vicinity of towns (>10,000 ADT).

The estimated human population of Highlands County in 2010 was 98,786, an increase of 13% from 2000. Glades County's human population was estimated to be 12,884 as of 2010, an increase of 21% since 2000. Statewide, the estimated population increase since 2000 was 13.2% (U.S. Census Bureau 2010).

Methods

Bears were captured between 11 May 2004 and 2 November 2009 using Aldrich spring-activated foot snares (Johnson and Pelton 1980), culvert traps, and free-range darting. Capture locations included private ranches, Archbold Biological Station, and a number of state or federally managed conservation properties scattered throughout Highlands County.

Bears were immobilized using Telazol® (Fort Dodge Animal Health, Fort Dodge, IA) administered at 4.4 mg/kg estimated body weight (Kreeger 1996) via pole-mounted syringe, cartridge-fired or air-fired projector (Pneu-Dart, Inc., Williamsport, PA). Once immobilized, artificial tears were applied to the eyes to prevent drying. Bears' heads were shrouded with a towel to reduce visual and auditory stimuli. Temperature, respiration and pulse were measured and recorded. When body temperatures exceeded 101°F (38° C) ice was applied externally to lower body temperature and prevent overheating. All trap-related injuries were treated and recorded. Pre-existing scars or identifying marks were recorded. Each animal was given uniquely-numbered eartags, lip tattoos, and a passive integrated transponder (PIT) tag (Biomark, Inc., Boise, ID) injected

subcutaneously between the shoulder blades. A veterinary tooth elevator was used to extract a first upper premolar tooth from all bears determined to be one year or older (Willey 1974). Extracted teeth were dissected and aged using cementum annuli counts (Matson's Laboratory, LLC, Milltown, MT). Approximately 5-10 guard hairs with intact root bulbs were collected from each bear for later genetic analysis and archiving. Body measurements were recorded using flexible measuring tape and included: head length and width, total length, chest girth, neck girth, and foot pad length and width. Weights were measured with a canvas tarpaulin and a drop scale. Weights were estimated when sufficient personnel were not present to assist with weighing. Capture and handling procedures occurred under FFWCC permit #WXO3549, and in accordance with University of Kentucky Institutional Care and Use Committee (IACUC) Protocol #626A2003.

GPS Data

Adult bears field-aged at ≥ 2 years of age were fitted with one of the following models of GPS radiocollars: Lotek 3300, Lotek Wildcell (Lotek Wireless, Inc., Newmarket, Ontario, Canada), Telonics GEN III SST, and Telonics GEN III SOB (Telonics, Inc., Mesa, AZ, USA). All models were equipped with GPS receivers and vhf beacons, the latter facilitated locating animals via aerial or ground telemetry and alerted telemetry technicians to potential mortalities or collar drop-offs via a 4-hour inactivity switch. Collar models differed in how data were retrieved. Lotek 3300 and Telonics GEN III SOB were "store-on-board" units, which had to be physically retrieved in order to download data. Lotek Wildcell and Telonics GEN III SST had store on board capability as well as remote download capabilities. The Telonics GEN III SST had a UHF modem called "spread spectrum," enabling field personnel to download data once

within a certain range of the unit, using a UHF receiver. Lotek Wildcell units were equipped with a Global System for Mobile Communication (GSM) modem enabling remote retrieval of data via mobile telephone technology. Fix intervals for GPS collars varied (15 min, 20 min, 30 min, 1 hr, 2 hrs, and 4 hrs) according to available programming times as determined by collar model and to optimize battery life for different research objectives. GPS collars from both manufacturers were equipped with electronic breakaway units, designed to release the collar from the animal at pre-programmed time and date. Project personnel modified breakaway systems prior to deployment by inserting a leather spacer between the collar belt and the electronic breakaway units, as a back-up breakaway should the electronic units malfunction.

GPS data were collected from collared adult black bears from 12 May 2004 to 31 December 2009. GPS data collected at fix intervals >1 hr were withheld from the analyses discussed hereafter. I used data from collars programmed to take fixes at ≤ 1 hr resolution. A subset of GPS collars were programmed to collect locations at duty cycles of 0.25 hr, 0.33 hr and 0.5 hr. Hourly data were extracted from these data for inclusion in hourly movement analyses. I chose 1 hr GPS data because of its ability to detect differences in movement characteristics between the small patches of habitat or matrix types typical of the south-central Florida landscape. In addition, 1 hr data collection ensured that monitoring was continuous throughout the 24 hour cycle. The majority of available GPS data excluded were collected at 4 hr cycles on adult females. However, enough 1 hr data were collected for both sexes that I was comfortable making comparisons.

Duration of continuous GPS data collection ranged from 1-18 months (Table 2.1). Radio-collars programmed for shorter duty cycles had shorter battery life. Multiple collars ($n = 8$; 21%) failed from being damaged while deployed, either by the animal or by water leaking into the battery capsule. Data were screened to remove fixes associated with collar initialization and testing procedures, capture and collar recovery locations, and 2D fixes with PDOP values > 6 (Lewis et al. 2007). Data collected between 1 January and 31 April were excluded from analysis, to limit the influence of denning locations. I removed all non-consecutive fixes from the data, so that analysis of directionality and movement rates were based only on known locations and were the closest possible representation of where animals traveled. Unless otherwise noted, all spatial analyses were conducted in ArcGIS 9.3 or 10.0 (ESRI 2010).

Mapping changes in black bear movement across the landscape

As battery life in GPS collars has improved, collars have been programmed to collect locations at more frequent intervals. The full Highlands/Glades black bear dataset included bear locations collected at 0.25, 0.33, 0.5, 1, 2, and 4 hr intervals. To permit inclusion of as many bears as possible at the finest appropriate spatial scale, movement analyses were restricted to 1 hr GPS data and resulted in the use of 15 individual bears (9 males, 6 females).

Once GPS location data were screened and projected in a GIS, Hawth's Tools (Beyer 2004) was used to convert temporally consecutive bear locations into movement paths. I estimated movement paths as straight lines between consecutive locations. All subsequent functions in the analysis were calculated or performed using rasters. Raster-based GIS is a way of storing geographic information in a matrix that is divided into a

grid of equally sized cells. Grid cells are typically square. Each cell represents an area on the Earth's surface, such as 1m^2 , or 100m^2 , or any other convenient multiple. In GIS, attribute information is stored with each cell. Each cell is assigned a value that corresponds to what it contains on the ground. Cell size is defined by the user and corresponds to the length of one side of one grid cell. The cell size determines the grid's resolution, or the finest level of detail that can be depicted in the data layer. Choosing an appropriate cell size is an important issue that involves consideration of the features being analyzed, the geographic extent of the area of consideration, and the extent of any existing input data already in raster format. In the analyses reported below, the area of consideration, or "neighborhood," was adjusted according to cell size setting.

The use of "neighborhoods" in ArcGIS facilitated the calculations reported below. "Neighborhood" is a toolset found in the Spatial Analyst extension of ArcGIS, and is used to create output values for each grid cell based on the location value and values identified in a specified neighborhood, or the cells surrounding each cell. To calculate mean movement speeds for each cell, for example, I used a search radius neighborhood function, which performs various calculations based on what is within a specified distance from point or linear features such as movement paths. The search radius defines the area used to calculate the parameter. For instance, a 500 m cell size with a 250 m search radius assigns 500 x 500 m raster cells a number based on the characteristics of paths within a circle of radius 250 m around the cell center.

I calculated movement path density, mean movement speed and angular deviation of bear movement at 4 different scales: (1) 100m cell with a 250m search radius, (2) 500m cell with a 250m search radius, (3) 500m cell with a 1000m search radius, and (4)

1000m cell with a 3000m search radius. To calculate movement path density I used a line density function (Spatial Analyst) that focused analyses on areas that were most heavily used, such as primary habitat and highly functional corridors. The line density raster was used as the extent for all subsequent inputs and raster calculations, to ensure that cells in all layers were perfectly aligned.

To calculate mean bear movement speeds I performed a neighborhood Line Statistics analysis on the path length within each cell. The Line Statistics function calculates a statistic on the attributes of a line (in this case, path length) based on a circular neighborhood around the line. The resulting statistic was the mean length of all paths within the neighborhood. Because all data were collected at or filtered to the same 1 hr interval, the length of each line represented the average hourly movement rate. Mean movement rates were calculated for each cell under each of the cell size/search radius combinations.

The angular deviation of the direction of travel is analogous to a linear standard deviation, and I used this metric to describe directionality of movement. To examine directionality, I determined the length (p) and axial bearing (a) for each movement path in each cell, using Hawth's Tools. Once these data were included in the attributes table, two new fields, one for *sine* and one for *cosine*, were added to the attributes table. I calculated these metrics for the path axial bearing, with the resulting figure a number between -1 and 1. Next the movement path shapefile was incorporated into Model Builder in GIS. The following equation was performed in Model Builder:

$$r = \sqrt{\left(\frac{\frac{\sum_{i=1}^n p_i \cos(a)_i}{k}}{\frac{\sum_{i=1}^n p_i}{k}}\right)^2 + \left(\frac{\frac{\sum_{i=1}^n p_i \sin(a)_i}{k}}{\frac{\sum_{i=1}^n p_i}{k}}\right)^2}$$

Where p_i is the length of path i , n is the number of paths inside the search radius, a_i is the axial bearing of path i , and k is the area of the circle with radius equal to the search radius.

$\frac{\sum_{i=1}^n p_i}{k}$ is calculated using the line density tool with no weighting

$\frac{\sum_{i=1}^n p_i \cos(a)_i}{k}$ is calculated using the line density tool, weighting by $\cos(a)$

$\frac{\sum_{i=1}^n p_i \sin(a)_i}{k}$ is calculated using the line density tool, weighting by $\sin(a)$

The first equation was simplified by canceling out area.

$$r = \sqrt{\left(\frac{\sum_{i=1}^n p_i \cos(a)_i}{\sum_{i=1}^n p_i}\right)^2 + \left(\frac{\sum_{i=1}^n p_i \sin(a)_i}{\sum_{i=1}^n p_i}\right)^2}$$

In the first step, I calculated the line density three times for each cell size and search radius combination: once with *sine* as the population field, once with *cosine* as the population field, and once with no population field. I then divided the *sine* line density by the “no population field” line density, then divided the *cosine* line density by the no population field line density. The two resulting rasters were then squared, and the resulting raster output represented the X and Y mean angle, respectively. These two rasters were added together using Raster Math, and finally the square root was calculated, producing a raster that depicted the mean directional movement vector (r). This was projected in a GIS. In Raster Calculator, the angular deviation (S ; the angular equivalent to standard deviation) was derived by the equation:

$$S = (180/\pi) * \sqrt{2 * (1 - [\text{mean angle}])}$$

This calculation was exported as a GRID file. In Zonal Statistics (Spatial Analyst Tools) I used the “zonal statistics as table” tool to calculate the range, mean, and standard deviation of the raster, within a specified zone (see Figure 2.4).

Fixed kernel polygons were used to estimate bear home ranges. For each bear a 50% fixed kernel polygon was developed and treated as the “core” for each home range. All 50% core areas were merged to create a composite core area for included bears. Kernel home ranges were used rather than minimum convex polygons because the latter overestimates the area considered to be sampled (Kenward et al. 2001, Kernohan et al. 2001). The population-wide core area polygon was used as the specified zone in Zonal Statistics, allowing comparisons between the different classes of landscape movement. I used the standard deviation of core area angular deviation as a guide to delineate and categorize different types of movement as follows (Table 2.2):

- Slow, directional movement = (0.5 SD below mean movement speed to minimum) and (0.5 SD below mean angular deviation to minimum)
- Slow, moderately directional movement = (0.5 SD below mean movement speed to minimum) and (0.5 SD below mean angular deviation to 0.5 SD above mean angular deviation)
- Slow, non-directional movement = (0.5 below mean movement speed to minimum) and (0.5 SD above mean angular deviation to maximum)
- Moderate speed, directional movement = (0.5 SD below mean movement speed to 0.5 SD above mean) and (0.5 SD below mean angular deviation to minimum)

- Core area-normal movements = (0.5 SD below mean movement speed to 0.5 above) and (0.5 SD below mean angular deviation to 0.5 SD above)
- Moderate speed, non-directional movement = (0.5 SD below mean movement speed to 0.5 SD above mean) and (0.5 SD above mean angular deviation to maximum)
- Fast, directional movement = (0.5 above mean movement speed to maximum) and (0.5 below mean angular deviation to minimum)
- Fast, moderately directional movement = (0.5 SD above mean movement speed to maximum) and (0.5 SD below mean angular deviation to 0.5 SD above mean angular deviation)
- Fast, non-directional movement = (0.5 SD above mean movement speed to maximum) and (0.5 SD above mean angular deviation to maximum)

Different movement types were considered indicators of the quality of the landscape from the perspective of the individual bear (Bélanger and Rodríguez 2002).

Both average movement speed and angular deviation were mapped in GIS, depicting the differences in movement behavior throughout the study area. Using raster math the two measures of movement behavior were combined to create a landscape movement map. Average movement speed values were classified as 10, 20, or 30 for slow, moderate and fast movement, respectively. Angular deviation values were reclassified as 1, 2, or 3 for directional, moderate and non-directional movements. This created 9 unique combinations and allowed the delineation of the landscape according to movement behavior.

Modeling the Relationship between Movement Characteristics and Landscape

ArcGIS 9.3 was used to display and develop GIS layers relevant to black bear movement behavior. To describe movement behavior in relation to various landscape features I used the same measures of movement that were used to identify corridor use. A multiple linear regression (maximum likelihood parameter estimates) was used to test hypotheses relating movement speeds and angular deviation as functions of landscape and road-related variables. I used a 100m cell size/250m search radius combination to derive the raster map on which this analysis was based. Larger scale combinations led to depictions of movement that did not reflect the complexity of the landscape.

Four explanatory variables (one categorical and three continuous) were used to characterize the landscape. 2004-2005 land use data from the South Florida Water Management District (SFWMD) and Southwest Florida Water Management District (SWFWMD) were used as the base for habitat classes and calculations of the density of forest (hereafter %forest), and percent cover (%cover) (McCoy 2005, Waller and Servheen 2005, Lewis et al. 2011). I reclassified land cover layers following Ulrey (2008). The continuous variable %cover was generated by reclassifying canopied habitat types, including citrus, and merging them into a single cover type layer. Cover-providing habitats were assigned values of 1, and non-cover types were assigned 0. To generate a grid layer of percent cover, this binary raster was exported as a “32 bit floating point” grid. This setting is the most appropriate for grids in which cell values contain decimal points, such as percentages. The final step in calculating the percent cover was to perform a neighborhood focal mean, with the appropriate search radius (3 cells x 3 cells, for instance) entered.

The variable distance to human infrastructure (Dist_human) was created by reclassifying residential and commercial human land use types and merging them into a single layer. Distances were calculated using the Euclidean distance function, which measures the shortest distance between two features. Euclidean distance was also used to measure proximity to roads (Dist_road).

For habitat type, landcover data were re-classified into forest, upland scrub, improved pasture, freshwater marsh, citrus and other tree crops, unimproved pasture, lakes and waterways, row crops, human development, extractive land, and open/recreational land (Table 2.3). Habitat was determined using a Focal Majority function in the Neighborhood toolset. The use of the focal majority calculator assigns the value of the majority habitat type in the specified neighborhood to each cell. This was the preferred method due to the high degree of habitat fragmentation, which causes small patches of habitat to appear in remotely sensed data layers. Using the majority function minimized the risk of misidentifying habitat type, and reduced the influence of small patches. Focal majority is a tool under the SPATIAL ANALYST extension for ArcMap 9.3. I used this tool to create a 10 m x10 m grid for habitat types. The variable “habitat” was classified as the dominant landcover type within a focal majority for a 150 m rectangular neighborhood.

Using the methods described above for calculating average movement speed and angular deviation, I developed individual movement models for each bear, with the two measures of movement behavior treated as response variables. Each individual movement model was based on raster functions. In order to incorporate the models into a regression model I converted grid cells into points located at the centroid of each cell.

The number of data points this produced ranged among individuals, so I drew a random sample of 500 locations for each. While restricting the analysis to 500 locations per individual may have removed some data, the need for higher resolution (i.e., more grid cells and associated locations) had to be balanced by the need for reasonable processing time in SAS. I subsampled 500 locations for each individual. These points retained the values for average movement speed and angular deviation. Location coordinates were added to the attributes, as well as unique animal identification data. All points were combined into a single layer, to expedite the process of extracting predictor variable data.

Akaike's Information Criterion (adjusted for small sample size; AIC_C) was used to determine the most parsimonious models to explain movement behavior in the landscape (Akaike 1973), using 32 candidate models, including 6 univariate models. I calculated AIC_C weights and performed model averaging to determine the best-fitting angular deviation and movement speed models. Models within 7 ΔAIC_C of the best fitting model were averaged to produce the final coefficient estimates and errors. The zero averaged method was used to average the best models. Through this approach a parameter estimate and error of zero is substituted into those models where the given parameter is absent, and the parameter estimate is obtained by averaging overall models in the top model set (Burnham and Anderson 2002, Lukacs et al. 2010, Nakagawa and Freckleton 2011).

Results

After screening, the analysis data set included 39,737 consecutive 1 hr locations (Figure 2.5) and 33,927 movement segments. Fifteen individual adult black bears (6 F, 9 M) were used to model movement characteristics (Table 2.1). Duration of GPS data

collection ranged from 37 days (595 locations) to 675 days (7655 locations) for the individuals sampled (Table 2.1).

Fifty percent core areas were identified on properties throughout both Highlands and Glades counties. Areas with concentrations of core areas were the Hendrie/Smoak complex, the Platt Branch WEA area south of CR 731, the XL/ABS complex and the Royce Ranch WEA (Figure 2.6).

Preliminary analysis of path density resulted in the use of a 100 m cell size and a 250 m search radius to depict landscape movement. This scale combination discriminated all centers of high location densities and displayed the best corridor continuity. Analysis with 500 m cell sizes and a 250 m search radius also discriminated all centers of high location density, but several corridors appeared to lack continuity. Larger cell size/search radius combinations consolidated isolated areas of high path density across the landscape, including areas where no bear movement had been documented. The 100m/250m (cell size/search radius) scale was appropriate for making comparisons and drawing inferences based on frequent GPS locations and small core areas.

Movement Behavior and Corridor Identification

Analysis of movement behavior highlighted areas of intense use and areas where dispersal occurs. Movement in population cores reflected intensive use by bears, displaying movements over 500m/hr and angular deviations above 60. Movements near 50% core zones showed similar characteristics (Figure 2.7), with most movements falling within 0.5 standard deviation of core area means. These movements were classified as moderate, relative to core area measures. Angular deviation within the 50% core area zones ranged from 0-80.9 ($\bar{x} = 66.75 \pm 14.97$). Highly directional movement was

identified between the Lake Placid Scrub Preserve and the Henscratch/Jacks Creek conservation properties, as well as between the Hendrie/Smoak ranch complex and Archbold Biological Station. Movement rates were variable across the landscape as well. Within 50% core areas movement rates ranged from 33.5-6991.8 ($\bar{x} = 1119.7 \pm 599.1$), with slower rates apparent in forested areas, and higher movement rates apparent between primary habitat areas and linkage zones (Figure 2.8).

Primary habitat was identified on the Hendrie/Smoak complex, a contiguous patch consisting of scrub, several forested upland habitats, and hardwood swamp associations. Patches of primary habitat were identified throughout the study area, though the only zone where potential barriers did not exist was Hendrie/Smoak. Analyses identified multiple areas that fit the criteria for linkage zones, highly functional corridors and minimally functional corridors. Figure 2.9 illustrates the movement characteristics discussed in the following paragraphs.

Three linkage zones were identified in Highlands County. These zones occurred: 1) between Archbold's main property and the outlying Red Hill Tract (divided by SR 8), 2) between the Clement Tract WEA and Royce Ranch WEA, and 3) across CR 619 from Holmes Ave WEA to private property to east. The Archbold/Red Hill linkage was 2.5 km in width, the entire length of which was bisected by SR 8. The landscape between Royce Ranch and the Clement Tract was divided by a 1 km section of railroad, which did not appear to interrupt bear movement (Figure 2.10, Map 1). The small linkage connecting Holmes Ave WEA to private property to the east was roughly 1.5 km in width, bisected by CR 619, a low volume rural road east of Lake Placid.

Four areas were identified as highly functional corridor zones (Figure 2.10). Three corridor systems facilitated movement between the scrub-dominated biological station and the surrounding properties.

1. XL/Blue Head Ranches to Archbold Biological Station Corridor 1-2 km in length: bears moving between Archbold and the XL and Blue Head properties traversed a matrix of improved pasture, wooded pasture, and a tree nursery.
2. Archbold to Jacks Creek corridor: bears moving to or from the biological station navigated a number of potential barriers in this roughly 21 km corridor. The most important barrier for dispersing bears was a crossing of SR 70 between SR 8 and Placid View Drive, a section of road roughly 3.5 km in length. Three smaller roads (Placid View Dr., Jefferson Ave., CR 621) and the Leisure Lakes subdivision posed additional hazards along the length of the corridor.
3. Platt Branch WEA to Archbold corridor ~ 6 km in length: movement through this corridor occurred across a series of small woodlots, crossing two low volume roads (SR 8 and CR 731).
4. Parkers Island corridor: movement through this corridor was mostly linear, though a small linkage zone existed east of Holmes Ave WEA (see above). This corridor was bounded by Highland Park Estates north of CR 621, and by SR 70 to the south. The town of Lake Placid limited westward bear movements, while a matrix of row crops and pastureland were to the east.

Five minimally functional corridors were identified.

1. Hendrie/Smoak to Parker's Island: bear movement through this corridor was rare, with only one collared animal moving between these areas (M10). These movements were characteristic of minimally functional corridors, displaying low angular deviation and high movement rates (Figure 2.10). Heavy forest fragmentation and the presence of SR 70 pose barriers.
2. Jacks Creek/Henscratch 27 to Clement/Royce: movement was impeded by US 27 and a smaller road, CR 17, as well as a residential neighborhood on the west side of the highway. East of the highway Josephine Creek facilitates movement toward the Clement/Royce complex. One collared animal has been documented utilizing this corridor to cross US 27.
3. Clement/Royce to Flamingo Villas megaparcels: movement between these two properties was impeded by US 98.
4. Holmes Ave to Royce Ranch: bears passing through this corridor navigated through Highlands Park Estates, a low density residential area. Some non-directional movements were apparent near forested habitat in the corridor.
5. Hendrie/Smoak to Platt Branch: movement across US 27 to the west occurs south of CR 731, facilitating movement further south and west into Fisheating Creek and Glades County. In addition this corridor may facilitate connectivity between the Archbold/XL/BlueHead complex via the Platt Creek to Archbold linkage.

Movement Behavior Modeling

The models within 7 Δ AIC of the best model (Table 2.4) were averaged to produce the final model for each measure of movement (Tables 2.5 and 2.6). Models for both angular deviation of movements and speed of movements demonstrated that %cover

in the landscape was the most important predictor variable, present in 100% of the best fitting models.

The top six models were averaged for angular deviation (Table 2.4). Angular deviation decreased as %cover decreased and as proximity to human infrastructure increased (Table 2.5). The negative relationship shows that bears become more directional in lower amounts of cover and closer to human activity. Ninety-five percent confidence intervals of the coefficient estimate calculated from model averaging did not overlap 0 (Table 2.5) for either %cover or distance to human infrastructure, meaning these behaviors do not vary significantly. The Cover-Human (CH) model received approximately 50% of the Akaike weight for angular deviation (Table 2.4). Distance to road was weakly predictive of the angular deviation of bear movements. Habitat type did not factor into angular deviation.

Five models were within 7 ΔAIC of the most parsimonious speed model (Table 2.4). %Cover was again the most important variable in predicting bear movement speed (Table 2.6). Distance to roads was equally influential in predicting movement speed (Table 2.6). This indicated that bears moved slower as cover decreased and as proximity to roads increased. As with angular deviation, 95% confidence intervals for both coefficient estimates did not overlap 0 (Table 2.6). Cover-Road (CR) received 50% of the model weight for explaining movement speed across the landscape (Table 2.4). The variable distance to human was a poor predictor of movement speed (relative variable importance = 0.14) (Table 2.6). Similarly, habitat type was found in only one model (HCR) within 7 ΔAIC_C of the top speed model (Table 2.4). Habitat type had minimal influence on either directionality or speed (Tables 2.5, 2.6).

Estimates of intra-class correlation (ICC) among individual bears were very low in the two best-fitting models (angular deviation – CH model = 0.037; speed – CR model = 0.06). Grid cells for an individual bear did not appear to be correlated.

Discussion

Animals living in fragmented or patchy environments must optimize movement behavior to avoid risky habitats, and reach high quality areas where resources and mates are available. Optimal movement path shape differs depending on the species reaction to habitat quality. My model suggested that when HGC bears move through areas where natural cover is reduced and human structures are present, movements are less sinuous, minimizing the time spent there. Similar behavior is reported in the fin whale (*Balaenoptera physalus*) and the *Eleodes* beetle (Crist et al. 1992, Mouillot and Viale 2001, Cant et al. 2005). In these cases animals adjusted movements to become more directional as they sense automobile traffic, residential areas, and habitat affected by agricultural operations. Movement paths for bears in this study were consistent with these findings, demonstrating straighter movements in proximity to residential or industrial areas. In contrast, movement paths in high-quality habitat are usually slower and more tortuous, which keeps the animal in the high-quality area (Goodwin and Fahrig 2002, Nolet and Mooij 2002, Fortin 2003, Cant et al. 2005). A strong positive relationship between angular deviation and forest cover density suggests that the same is true for the HGC black bear.

The outcomes of modeling angular deviation for the HGC black bear produced results that agree with a large volume of published data, though there have been few studies that specifically address these measurements of movement for the black bear (Hightower 2003). The relationship between the landscape and bear movement speed

suggests a phenomenon that has not been reported; that as cover density decreases and proximity to roads increases bears move slower. Negative coefficient estimates for %cover and distance to road, in addition to the strongly negative confidence intervals for these two variables, confirm the direction of the relationship. Speed alone should not be used as a movement indicator to suggest a portion of the landscape is less suitable, as species are capable of high movement rates in their primary habitat as well.

Bears in this study appeared to move cautiously in or near less favorable habitats. Road avoidance in the black bear is well-documented (Brody and Pelton 1989, Kasworm and Manley 1990, Brandenburg 1996, Fecske et al. 2002, Orlando 2003). Others have suggested that traveling bears, particularly adults, are cautious and evasive when moving through unfamiliar or risky areas, and by doing so avoid mortality better than bears that stay within their normal home ranges during hunting seasons (Noyce and Garshelis 2011). These findings support the hypothesis that the ecological generalist black bear, known to opportunistically move near forest edges to exploit food resources (Hellgren and Maehr 1992), evolved in landscapes where movement outside of habitat posed risk (Fahrig 2007). Moving outside of primary habitat likely exposed the smaller, less aggressive black bear to predation by brown bear and other carnivores (Herrero 1972). Species in such environments develop a strong “boundary response” (Fahrig 2007). For the black bear, moving outside of habitat (i.e. forest) often resulted in mortality, providing selective pressure against moving far from habitat.

Vehicle collisions are the most frequent cause of death in the HGC population. Maehr et al. (2004) reported the distribution of roadkills from 1972-2001, finding that the highest concentrations were found on high traffic volume roads. Bears generally avoid

busy roadways (Brody and Pelton 1989, Hellgren et al. 1991, Orlando 2003), but will attempt to cross, perhaps out of social or nutritional necessity. In the HGC bear population individuals rarely crossed the busiest highway, US 27, perhaps due to their behavioral adaptations to avoid danger. However, when they did cross US 27 they were often killed (11 documented on US 27 from 2004-2009). Bears that do not exhibit highway apprehension will not only suffer higher mortality (Mattson et al. 1987), but also fail to pass their tendencies on to offspring. Similar selective pressure may have occurred over time in the HGC population, resulting in a fearful bear population. Low annual nuisance complaints in the HGC (~10) population may reflect such a phenomenon (FFWCC 2010).

It has been reported elsewhere that adult females and juveniles occupy habitats in closer proximity to roads than adult males in non-habituated/non-food conditioned populations (Tietje and Ruff 1983, McLellan and Shackleton 1989). Further investigation should examine whether there is an avoidance zone around roads, and whether traffic volume causes avoidance zones to vary in size. Small sample sizes limited the ability to investigate differences in sex-age class of bears in a multivariate framework. Increasing the sample of individuals would provide the statistical power necessary to detect differences in the spatial relationship among sex-age groups to the various road classes.

Classification of the landscape through movement analysis shows that practically all bear-inhabited areas in Highlands County are functioning as a form of corridor. Much like the dimensions of the Greater Chassahowitzka Ecosystem in west-central Florida, the habitat for the black bear of the HGC population is distributed in elongated dimensions,

increasing the potential for edge effects to negatively affect remaining habitat (Orlando 2003). Though female bears in the HGC population inhabit relatively small home ranges within what is likely highly productive bear habitat (Ulrey 2008), much of the core habitat being used by females is fragmented by agriculture, roads, and human land uses.

Some researchers suggest that bears have an ability to assess environmental characteristics and to incorporate aspects of their own physiology and ecology into decisions relating to movement (Rogers 1987, Hellgren et al. 2005, Noyce and Garshelis 2011). Such parameters can change both within and between seasons, making the task of modeling or predicting this movement behavior as much an art as it is a science. Given the influence of learning and the ability of bears to be flexible to stochastic changes in available resources, the challenge to managers is to make use of what data are available to satisfy the basic necessities for the population. For the black bear this translates into conserving pathways of connectivity that link a landscape of diverse habitats and resources, allowing bears to travel long distances to find hotspots for breeding and food.

The method I describe should only be applied to populations in which the majority of individuals have been sampled. This approach may not identify all landscape connections even when a large proportion of a population is sampled. This method can only be used to assess areas where a population has been sampled or where sampled individuals travel during the course of the study.

Bears in areas not represented by our capture efforts due to limited accessibility, particularly in Glades County, or those that occupy less suitable areas where risk-taking may be rewarded (e.g. dumpster-diving at the urban-wild interface), may behave differently than individuals in this study. In Highlands County it is likely that bears have

been excluded from areas where they've not yet been documented, though determining this requires additional research, because radio-collaring efforts were not uniform throughout. It is important to note the potential for intraspecific competition to influence movement behavior during different seasons (Rogers 1987, Costello et al. 2008). Care was taken to use only data from adults. Movements of juvenile bears may reflect avoidance of more dominant adults (Rogers 1987). Additionally, dispersal from maternal home ranges is common in both sexes (Lee and Vaughan 2003) but was beyond the scope of this study.

The areas identified as corridors or habitat are scale dependent. I used GPS data collected at 1 hr intervals in a landscape typified by small patch size, narrow habitat bottlenecks, and a complex network of roads. It was important that the scale of analyses allowed the assessment of fine scale movements between habitats and matrix. I assessed several scale combinations and found that the smaller settings delineated more of the areas identified by the line density function, and depicted continuous movement through narrow bottlenecks more clearly. Graves et al. (2007) tested the effect of different GPS fix cycles, emphasizing the importance of matching cell size to appropriately fine scale data.

Despite some limitations, these methods are useful for identifying parts of the landscape bears use for movement. Because the current distribution of bear home ranges in HGC are generally north-south oriented, the barriers of greatest concern were east-west running roads. SR 70 south of Lake Placid and SR 98 north of Lake Placid were each high traffic volume, arterial highways. SR 70 was a movement barrier in the Archbold to Jacks Creek corridor west of Placid Lakes. Movement data suggested it was

primarily used by traveling males, though one GPS collared male, M08, was seen during a telemetry flight following what was presumably an adult female in August 2004 in the Jacks Creek Water Management Area. I suspect additional males collared with traditional VHF units at Royce/Clement have used the corridor to reach the XL/Archbold complex, where they were recaptured. Some sections of Archbold to Jacks Creek appear discontinuous, but this was due to several missed location fixes that were intentionally removed from the analysis. Aside from the connection this corridor provides for Jacks Creek, it is a potential linkage to habitat at Highlands Hammock State Park to the north (though this would require bears to cross SR 66). Improving the permeability of this corridor would likely improve connectivity on a regional scale, for multiple species.

East of the town of Lake Placid, bear movement was constrained by Highlands Park Estates on the outskirts of town, Lake Istokpoga, and extensive row crop operations south of the lake. The Clement/Royce property supported at least two adult females in their core ranges during the period of study. Holmes Ave WEA was bounded by two small roads, one of which, CR 619, has a history of bear roadkills (Maehr et al. 2004). Bear movement was non-directional and slow, suggesting that areas of primary habitat are present, even in the confined space. Movements south of Parker's Island, toward Hendrie/Smoak, were impeded by SR 70 and a ~10 km expanse of non-habitat. Habitat restoration appears necessary if this corridor is to become highly functional.

Habitat in Highlands County as a whole is fragmented, relative to population centers throughout the rest of Florida (Ulrey 2008, FFWCC 2010). Ongoing road development and land use change will reduce habitat identified as core range for several adult females. Reduced core habitat may limit resources (i.e. food, cover) and

compromise demographics and survival. This may result in the loss of core habitat, which could lead to the disappearance of the bear population long before the forest disappears (Kinnaird et al. 2003).

To ensure the long-term survival of the population current levels of connectivity should be preserved. There are several linkages that can be protected, and several that can be restored in order to facilitate bear dispersal. Currently uninhabited properties such as Highlands Hammock State Park and the Avon Park Air Force Bombing Range appear to have the habitat and space required for the placement of more bear core areas. Establishing functional linkages to these and other properties would be beneficial to the HGC population, providing additional land for dispersing bears and expanding the distribution northward, in the direction of the Ocala National Forest.

Maintaining or restoring demographic and genetic connectivity within the HGC population may require multiple strategies. Maintaining high densities of bears in remaining habitat may encourage dispersal and eventually could lead to the re-colonization of areas outside the known distribution of the HGC population. Preventing additional primary habitat loss and fragmentation is important. Expanding the habitat for the HGC population will require additional easements, the purchase of more conservation lands, fostering agreements with private landowners and reducing human activity in important movement corridors (Beier 1995, Dixon et al. 2006). Improving connectivity may also require mitigating the effects of highways by incorporating crossing structures to allow safe passage for bears.

Table 2.1. Summary of GPS data used to assess movement characteristics and landscape function for 15 black bears in Highlands/Glades counties, Florida, 2004-2009.

Bear ID	First day of monitoring	Last day of monitoring	Data duration (number of days)	Number of observed 1 hour steps	Mean step length (m)	Fix rate ^b (%)
M08	08/11/2004	11/20/2004	101	952	279.27	74
F08	10/07/2004	12/15/2004	69	1,175	263.32	80
M10	10/15/2005	03/31/2006	167	2,324	264.78	72
F11 ^a	12/16/2005	09/20/2008	675	7,566	236.29	80
M16	05/19/2006	06/24/2006	37	595	271.25	79
M19 ^a	10/12/2006	08/22/2007	289	3,999	296.30	75
M21	06/26/2007	04/11/2008	290	5,082	210.52	85
M09	07/22/2007	12/25/2007	156	2,231	286.74	74
M05	11/17/2007	06/10/2008	206	763	245.19	36
F03	05/24/2008	09/16/2008	115	1,647	283.06	79
F05 ^a	05/28/2008	02/02/2009	250	3,122	274.03	72
M22	06/03/2008	08/30/2008	80	1,030	274.60	63
F20	06/06/2008	08/18/2008	73	712	236.21	56
M29	06/11/2008	09/16/2008	98	1,367	273.94	73
F12	08/26/2008	01/12/2009	139	1,362	241.54	56

^a Data were collected from these individuals in separate monitoring bouts, i.e. collection of GPS data was not continuous between first and last days of monitoring. Gaps in monitoring were included in calculation of data duration.

^b Fix rate is the percentage of successful locations that the GPS unit managed to acquire.

Table 2.2. Combination scheme for classifying grid cells with measures of directionality and movement speed for black bear in south-central Florida. Directionality was determined by calculating the angular deviation of all movement paths within a cell. Movement speed was calculated by finding the average movement rate of paths with a cell. Values within each cell were compared to that found in 50% kernel core use areas, and classified according to the mean and SD found within those core areas.

	Speed →	0.5 SD below mean to minimum	0.5 SD below mean to 0.5 SD above mean	0.5 SD above mean to maximum
Directionality↓	Reclass	10	20	30
0.5 SD below mean to minimum	1	Slow, directional movement	Moderate speed, directional movement	Fast, directional movement
0.5 SD below mean to 0.5 SD above mean	2	Slow, moderately directional movement	Normal core area movement	Fast, moderately directional movement
0.5 SD above mean to maximum	3	Slow, non-directional movement	Moderate speed, non- directional movement	Fast, non-directional movement

Table 2.3. Reclassification scheme of landcover map used to analyze movement rates and road crossing for the black bear of south-central Florida, 2004-2009. Landcover data was reclassified from SWFWMD and SFWMD datasets.

Model variable	Habitat category	Habitat type	Area (km ²)	%	Original classification
Habitat	Forest/scrub	Forest	1310	24	Bay swamp, cabbage palm, coniferous plantations, cypress, forest regeneration. areas, hardwood-coniferous mixed, hydric pine flatwoods, live oak, longleaf pine-xeric, pine-mesic oak, pine flatwoods, streams and lake swamps, upland coniferous. forest, upland hardwood forest, wetland coniferous. forest, wetland forested mixed, wetland hardwood forest, woodland pasture
		Scrub	369	7	Upland shrub and brush, sand pine
	Citrus	Citrus	648	12	Citrus groves, tree crops
	Human development	Human development	218	4	Airports, commercial and services, communications, feeding operations, golf courses, industrial, institutional, marinas and fish camps, parks and zoos, recreational, residential-high density, residential-medium density, residential-low density, sewage treatment, utilities
	Improved pasture	Improved pasture	352	7	Improved pasture, herbaceous (dry prairie), mixed rangeland
	Open land	Crop and pastureland	1319	24	Crop and pasture

Table 2.3 (continued)

Model variable	Habitat category	Habitat type	Area (km ²)	%	Original classification
		Row crop	181	3	Row crop, nurseries and vineyards
		Open land	140	3	Open land (rural), extractive, disturbed land, barren land
	Freshwater marsh	Freshwater marsh	637	12	Emergent aquatic vegetation., freshwater marsh, wet prairie, intermittent ponds, shorelines
	Water	Water	214	4	Lakes, reservoirs, streams and waterways, mangrove swamps, bays and estuaries, tropical fish farms
	Other	Exotic species	8	<1	Melaleuca, Brazilian pepper, Australian pine, Lygodium

Table 2.4. Description of 32 models evaluated for angular deviation and speed of movement of south central Florida black bears, with AICC values, $\Delta AICC$ and Akaike model weights (w). Models within 7 $\Delta AICC$ were incorporated into model averaging to produce final models.

Model acronym	Model description	Angular Deviation			Speed		
		AIC _C	ΔAIC_C	w	AIC _C	ΔAIC_C	w
CH	Cover human	1266.3	0.0	0.50	2609.2	12.7	0.00
SCH	Sex cover human	1267.4	1.2	0.28	2610.0	13.5	0.00
CRH	Cover road human	1269.7	3.4	0.09	2600.1	3.6	0.08
SCRH	Sex cover road human	1270.8	4.6	0.05	2600.9	4.4	0.05
CR	Cover road	1271.9	5.7	0.03	2596.5	0.0	0.50
SCR	Sex cover road	1273.3	6.9	0.02	2597.3	0.80	0.33
C	Cover	1273.6	7.3	0.01	2609.6	13.1	0.00
SC	Sex cover	1274.9	8.6	0.01	2610.4	13.9	0.00
HaCH	Habitat cover human	1279.5	13.2	0.00	2615.8	19.3	0.00
SHaCH	Sex habitat cover human	1280.6	14.3	0.00	2616.6	20.1	0.00
HaCRH	Habitat cover road human	1283.1	16.8	0.00	2606.7	10.1	0.00
G	Global	1284.2	17.9	0.00	2607.4	10.9	0.00
HaCR	Habitat cover road	1285.5	19.2	0.00	2603.4	6.9	0.02
HC	Habitat cover	1286.7	20.4	0.00	2616.9	20.4	0.00
SHaCR	Sex habitat cover road	1286.8	20.5	0.00	2604.2	7.64	0.01
SHaC	Sex habitat cover	1287.9	21.7	0.00	2617.7	21.2	0.00
HaH	Habitat human	1293.4	27.1	0.00	2675.7	79.2	0.00
SHaH	Sex habitat human	1294.3	28.0	0.00	2676.7	80.2	0.00
HaRH	Habitat road human	1296.6	30.3	0.00	2667.2	70.7	0.00
SHaRH	Sex habitat road human	1297.6	31.3	0.00	2666.1	69.6	0.00
HaR	Habitat road	1298.8	32.5	0.00	2662.1	65.5	0.00
SHaR	Sex habitat road	1299.9	33.6	0.00	2663.0	66.5	0.00
Ha	Habitat	1300.5	34.2	0.00	2677.4	80.9	0.00
SHa	Sex habitat	1301.6	35.3	0.00	2678.4	81.9	0.00
H	Human	1305.0	38.7	0.00	2728.7	132.2	0.00
SH	Sex human	1305.8	39.6	0.00	2730.0	133.5	0.00
RH	Road human	1307.6	41.2	0.00	2713.1	120.6	0.00
SRH	Sex road human	1308.5	42.2	0.00	2718.4	121.9	0.00
R	Road	1309.3	43.0	0.00	2713.9	117.4	0.00
I	Intercept	1312.0	45.7	0.00	2730.1	133.6	0.00
SR	Sex road	1310.3	44.1	0.00	2715.2	118.6	0.00
S	Sex	1313.1	46.8	0.00	2731.4	134.9	0.00

Table 2.5. Summary results of linear regression modeling the effect of landscape structure on the angular deviation of black bear movements in south-central Florida. Six candidate models within 7 Δ AIC of the top model were averaged to produce coefficient estimates, s standard errors and 95% confidence intervals. Relative variable importance was calculated based on the Akaike weights of models in which the variable occurred.

Parameter	Estimate ^a	SE	Confidence interval	Relative importance
Intercept	1.125	0.002	(1.036, 1.214)	
Sex				
female	0.043	0.006	(-0.111, 0.198)	0.35
male ^b	...	...	...	...
%cover	-0.080	0.001	(-0.104, -0.057)	1.00
Dist_road ^c	-0.009	0.001	(-0.053, 0.035)	0.19
Dist_human ^d	-0.109	0.002	(-0.191, -0.026)	0.93

^a Effect sizes standardized by the mean and SD.

^b Male was treated as the reference category

^c Distance to roads

^d Distance to human infrastructure (other than roads)

Table 2.6. Summary results of linear regression modeling the effect of landscape structure on the speed of black bear movements in south central Florida. Five candidate models were within 7 Δ AIC of the top model and were averaged to produce final coefficient estimates, standard errors and confidence intervals. Relative variable importance is based on the Akaike weight of candidate models in which a given variable occurs.

Parameter	Estimate	SE	Confidence interval	Relative importance
Intercept ^a	2.76	0.004	(2.630, 2.886)	
Sex				
female	-0.061	0.011	(-0.271, 0.148)	0.39
male ^b	...	...	...	...
%Cover	-0.144	0.001	(-0.170, -0.119)	1.00
Dist_road ^c	-0.144	0.001	(-0.212, -0.076)	1.00
Dist_human ^d	0.006	0.001	(-0.043, 0.032)	0.14
Habitat				0.02
-forest	-0.083	0.083	(-0.030, 0.028)	
-scrub	-0.080	0.083	(-0.030, 0.027)	
-improved pasture	-0.092	0.084	(-0.032, 0.029)	
-open land	-0.022	0.083	(-0.021, 0.021)	
-citrus	-0.108	0.081	(-0.035, 0.032)	
-human	-0.25	0.230	(-0.088, 0.080)	
-fw marsh	-0.064	0.084	(-0.027, 0.025)	

^a Effect sizes standardized by the mean and SD.

^b Male was the reference category.

^c Distance to road

^d Distance to human infrastructure (other than roads)

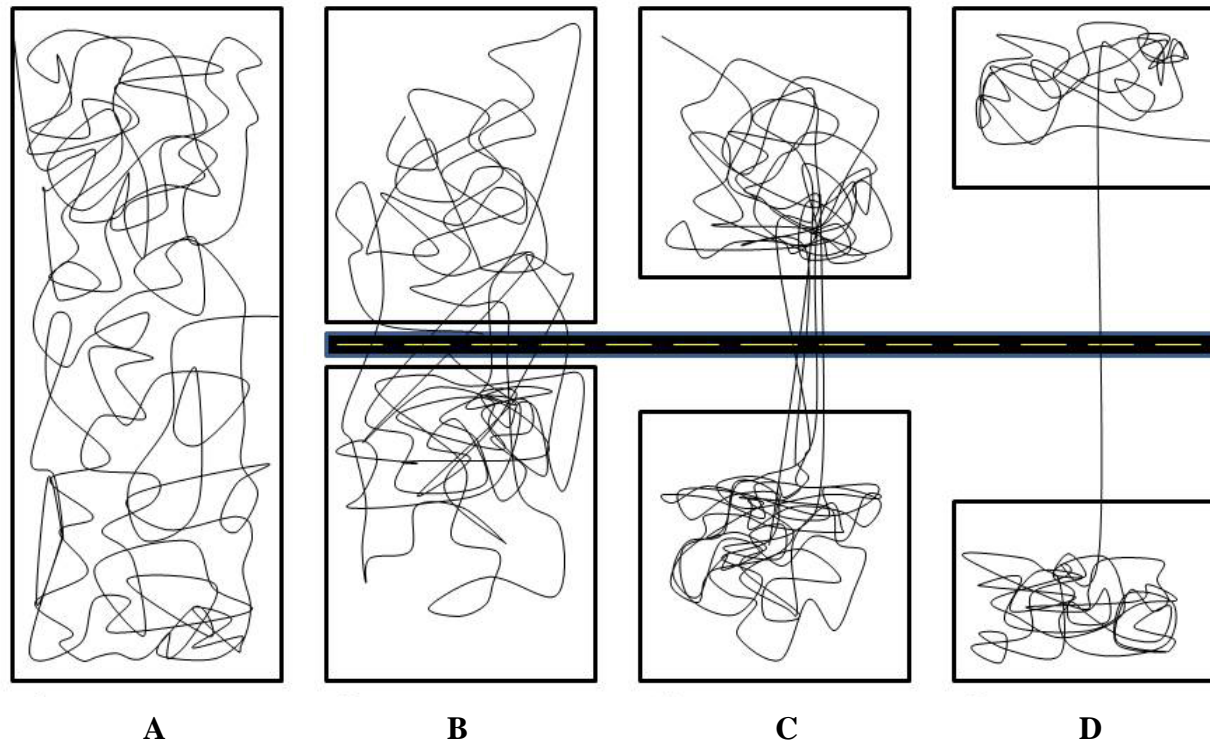


Figure 2.1. Examples of animal movement in (A) primary habitat with high amounts of movement, high angular deviation and little fragmentation, (B) a linkage zone with potential fragmentation, but movement similar to primary habitat, (C) a highly functional corridor with fragmentation but high amounts of directional (low angular deviation) movement, (D) a minimally functional corridor with high fragmentation and little movement. Reproduced from Graves et al. (2007).

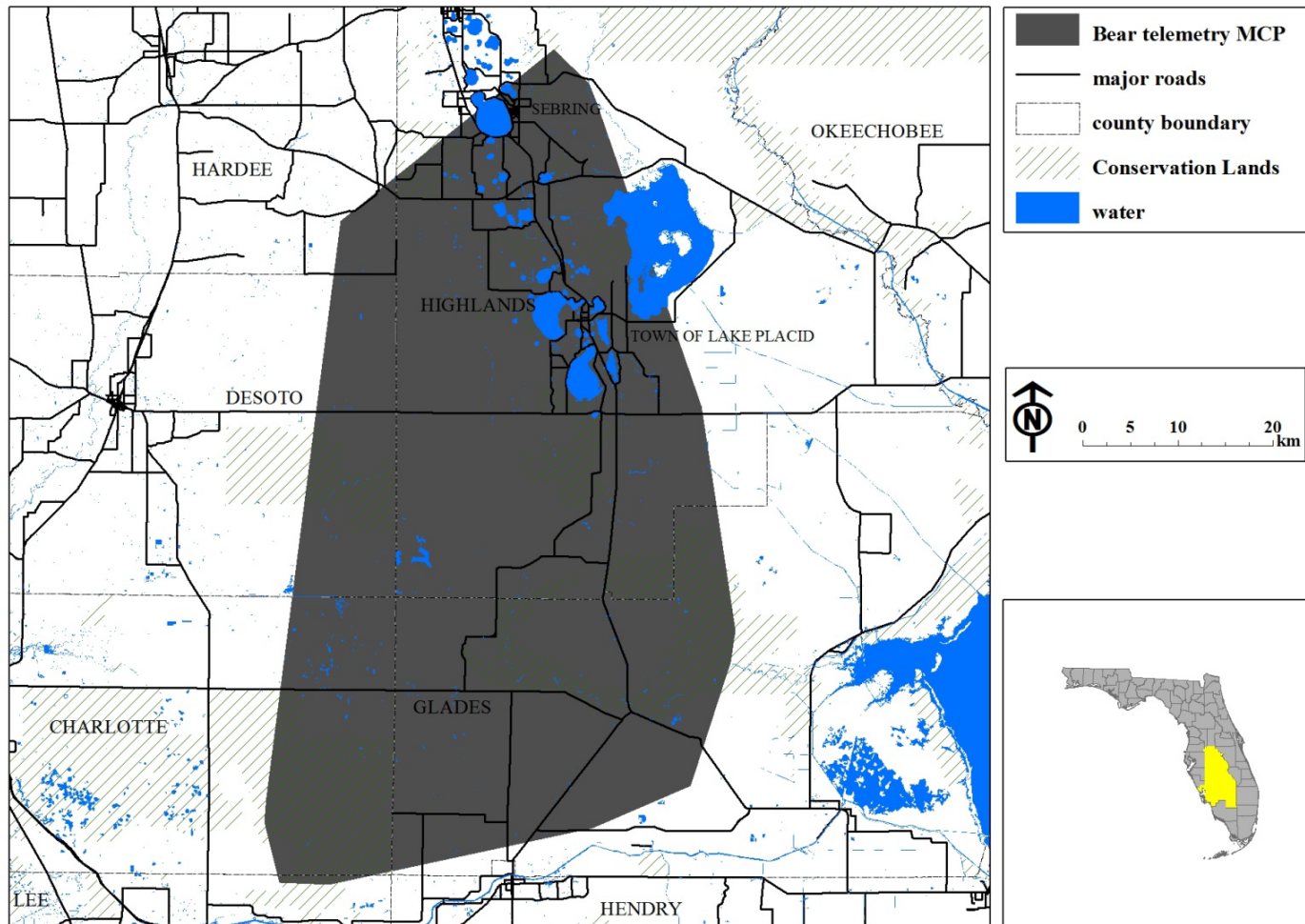


Figure 2.2. A minimum convex polygon (MCP) of the extent of black bear telemetry locations, 2004-2009 for the Highlands/Glades population of south-central Florida, shown in relation to major roads, county boundaries and large water bodies.

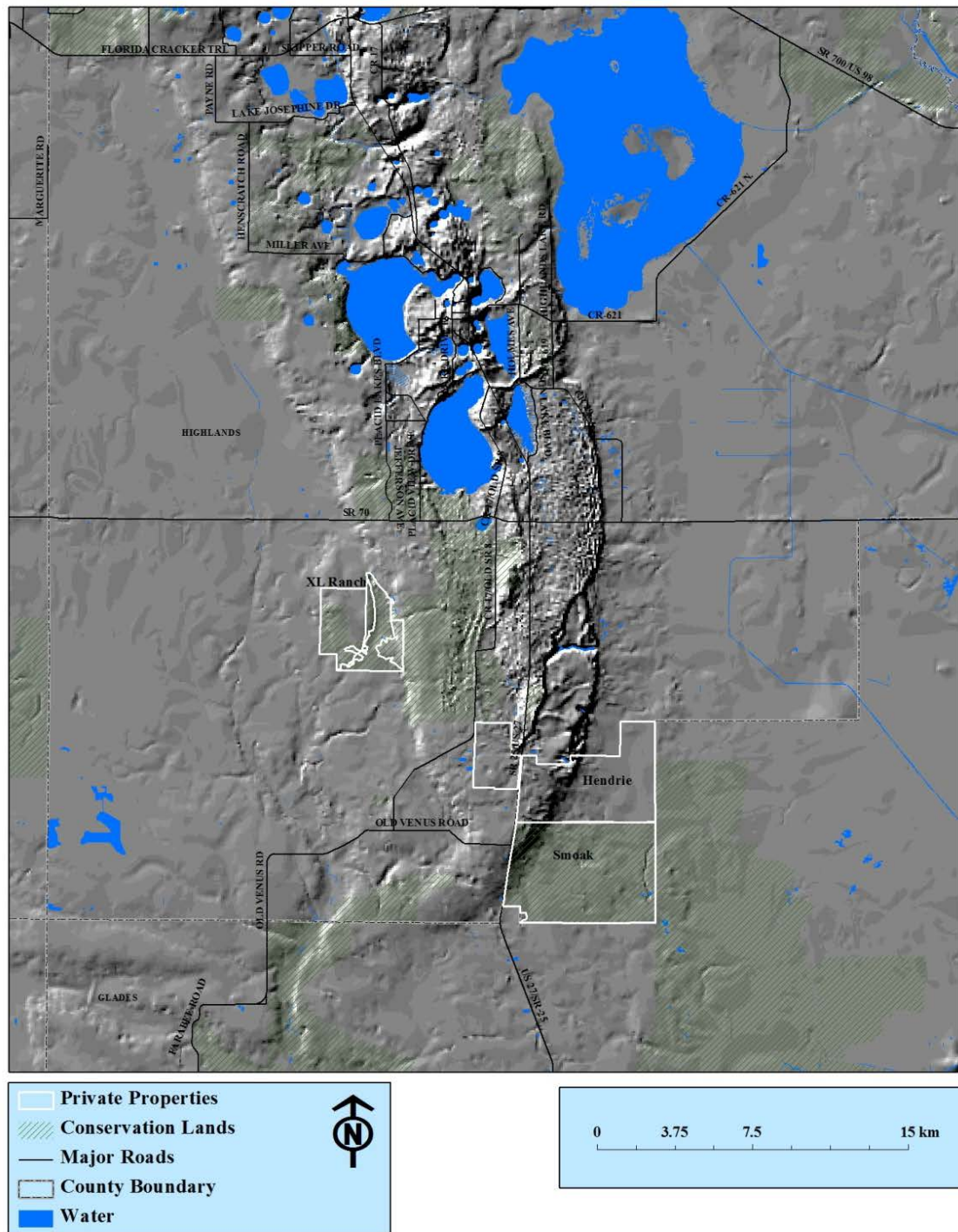


Figure 2.3. Private and public lands where trapping efforts were conducted for the Highlands/Glades black bear, 2004-2009. The shade relief background layer illustrates the topography of the southern Lake Wales Ridge in south-central Florida.

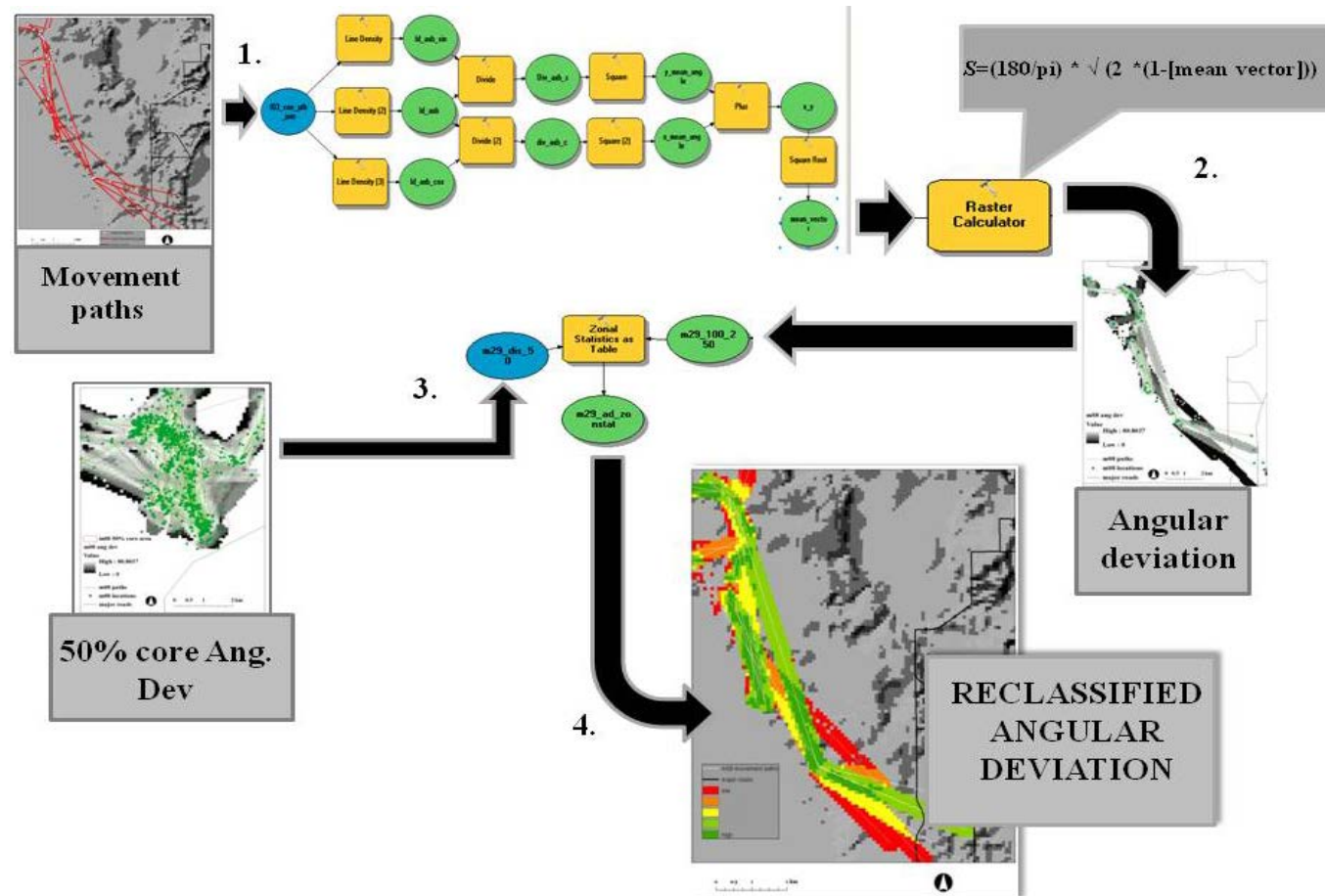


Figure 2.4. Procedure for calculating and classifying the directionality of bear movements, developed using ArcGIS 9.3 Model Builder. (1) Shape files of individual animal movements with path bearings in the attributes are input using specified cell size and search radius (2) mean vector grid converted into angular deviation grid (3) angular deviation within 50% core areas calculated (4) angular deviation grid re-classified to reflect directionality of movement in comparison to movements within core areas.

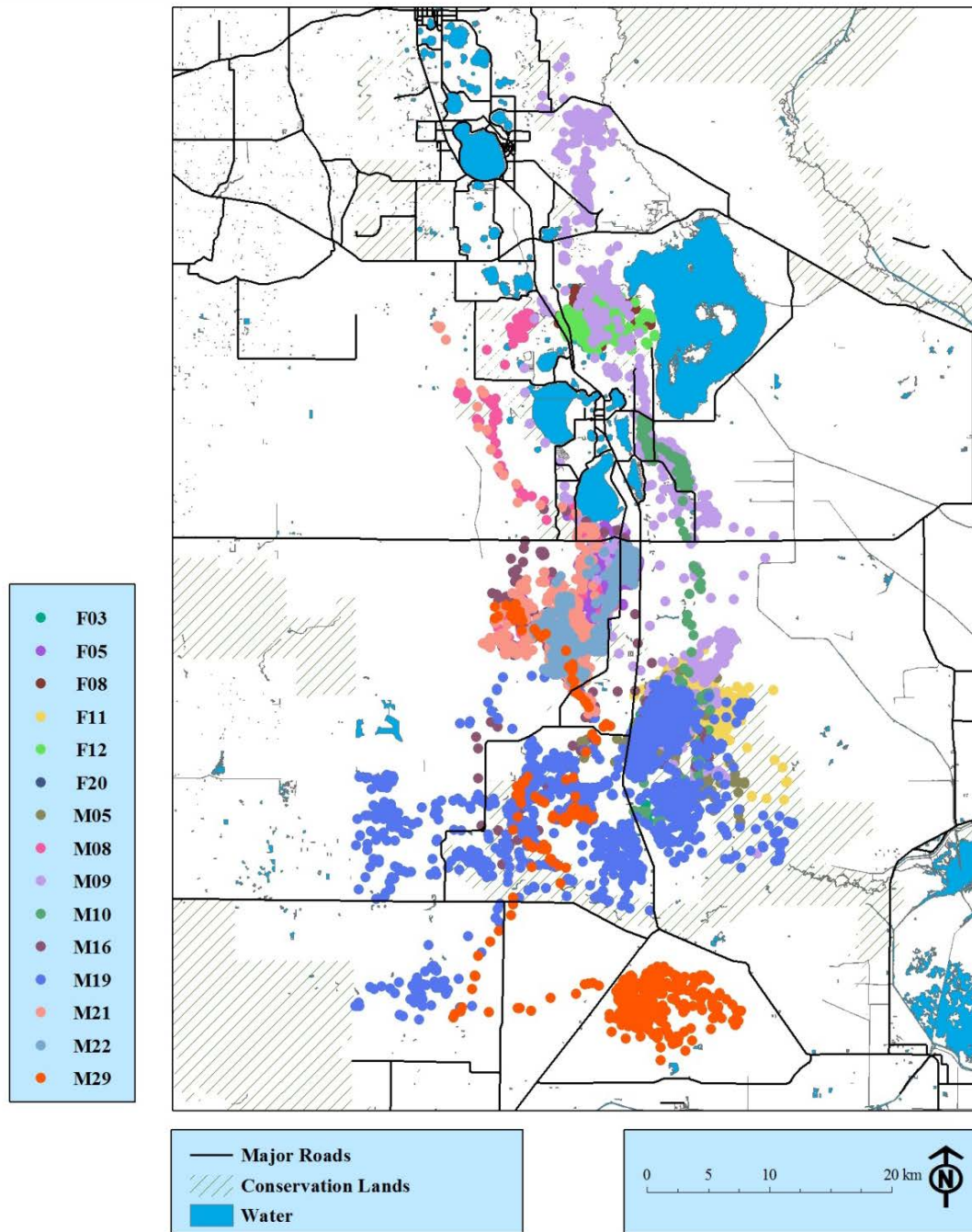


Figure 2.5. Black bear GPS locations distributed throughout Highlands and Glades Counties of Florida, USA, 2004-2009. GPS data were collected at fix intervals of 1 hr, 30 minutes, 20 minutes and 15 minutes. Data collected at < 1 hr were filtered to 1 hr.

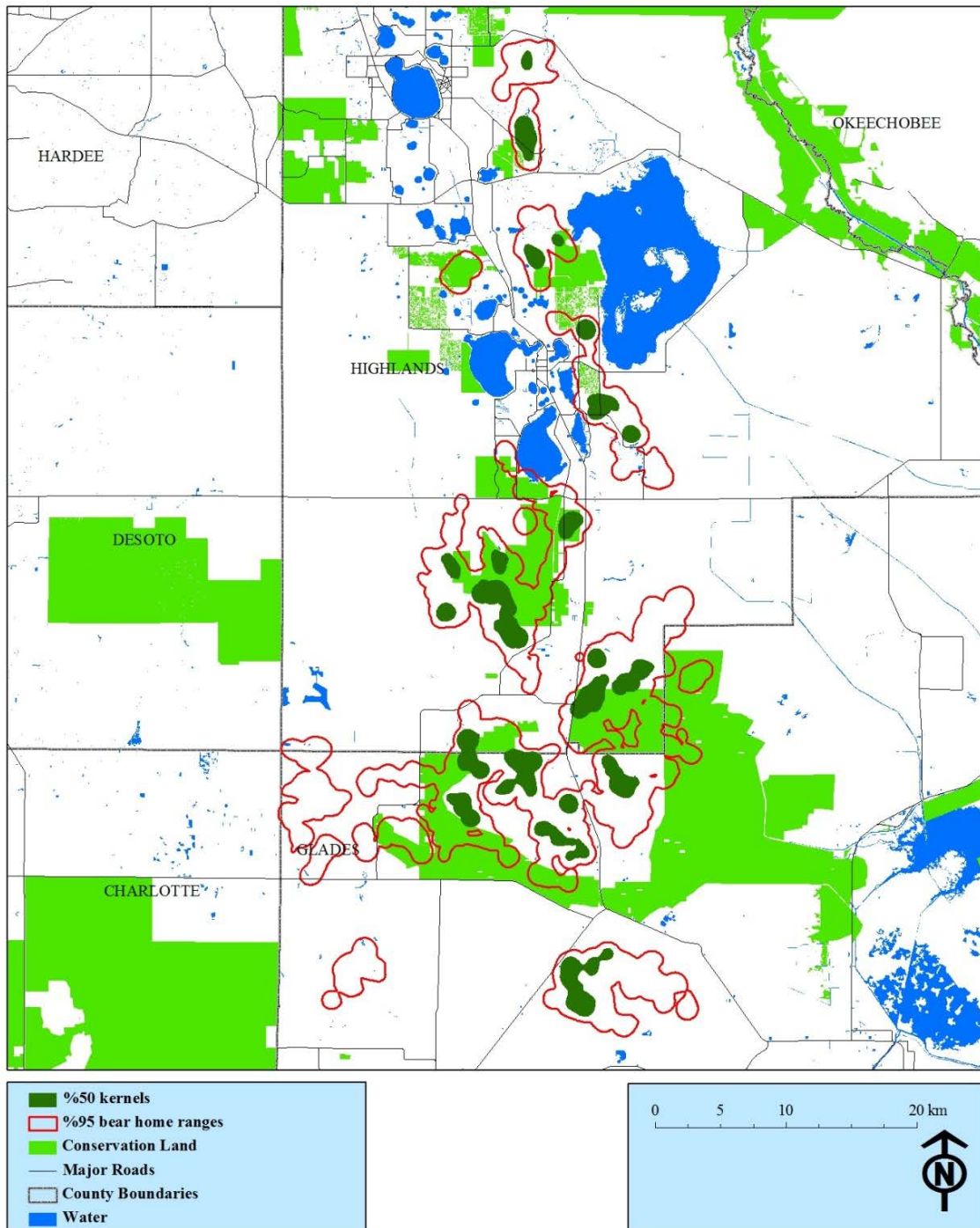


Figure 2.6. Merged 50% core area and 95% home range kernels derived from one hour GPS data of black bears in Highlands and Glades Counties, Florida, USA, 2004-2009.

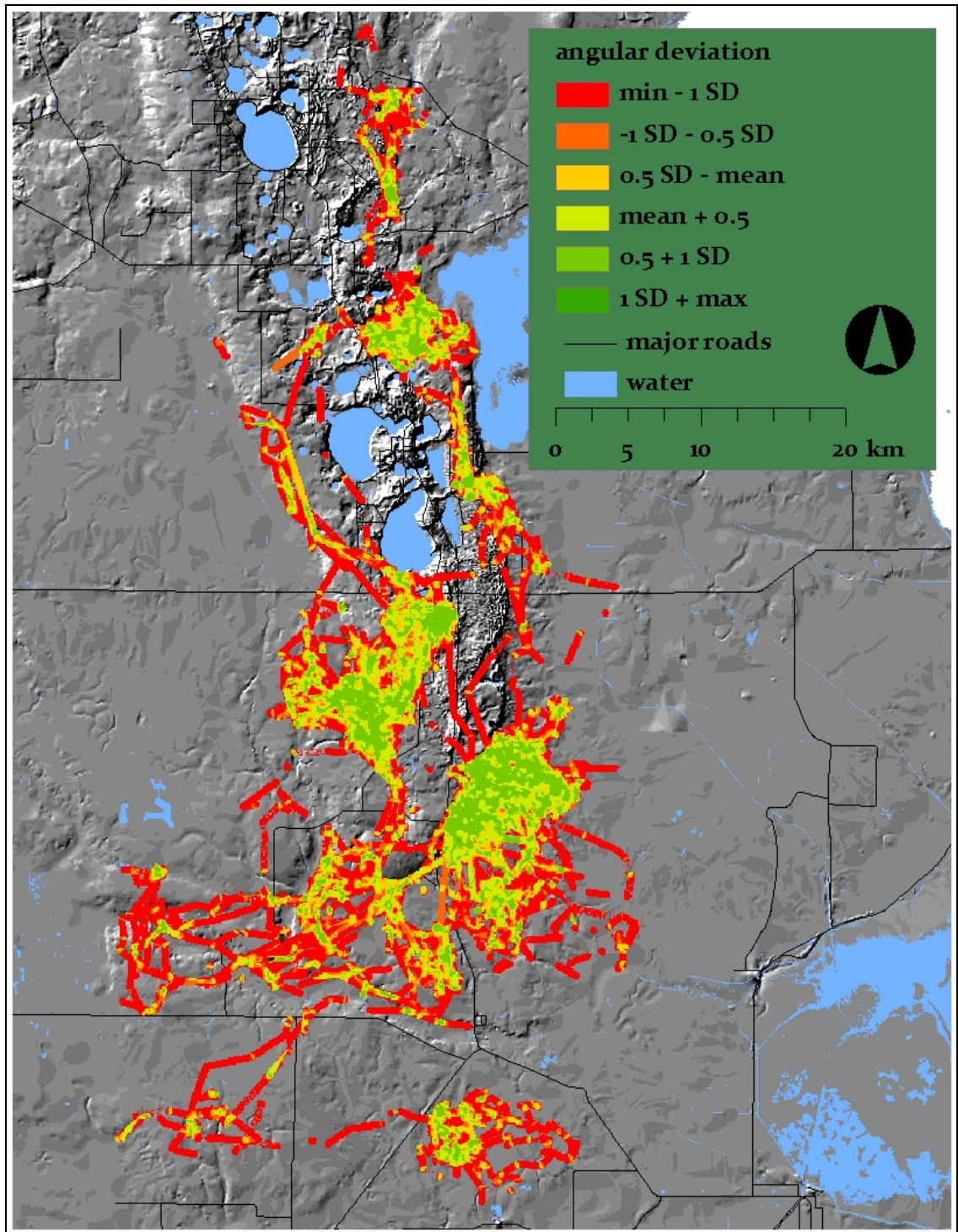


Figure 2.7. Angular deviation of black bear movements in the Highlands/Glades study area of south-central Florida, USA. Calculations were based on GPS locations collected at 1 hour fix intervals. Overall angular deviation was compared to that found in composite 50% kernel core areas, and classified according to the mean and standard deviation for angular deviation found within those core areas.

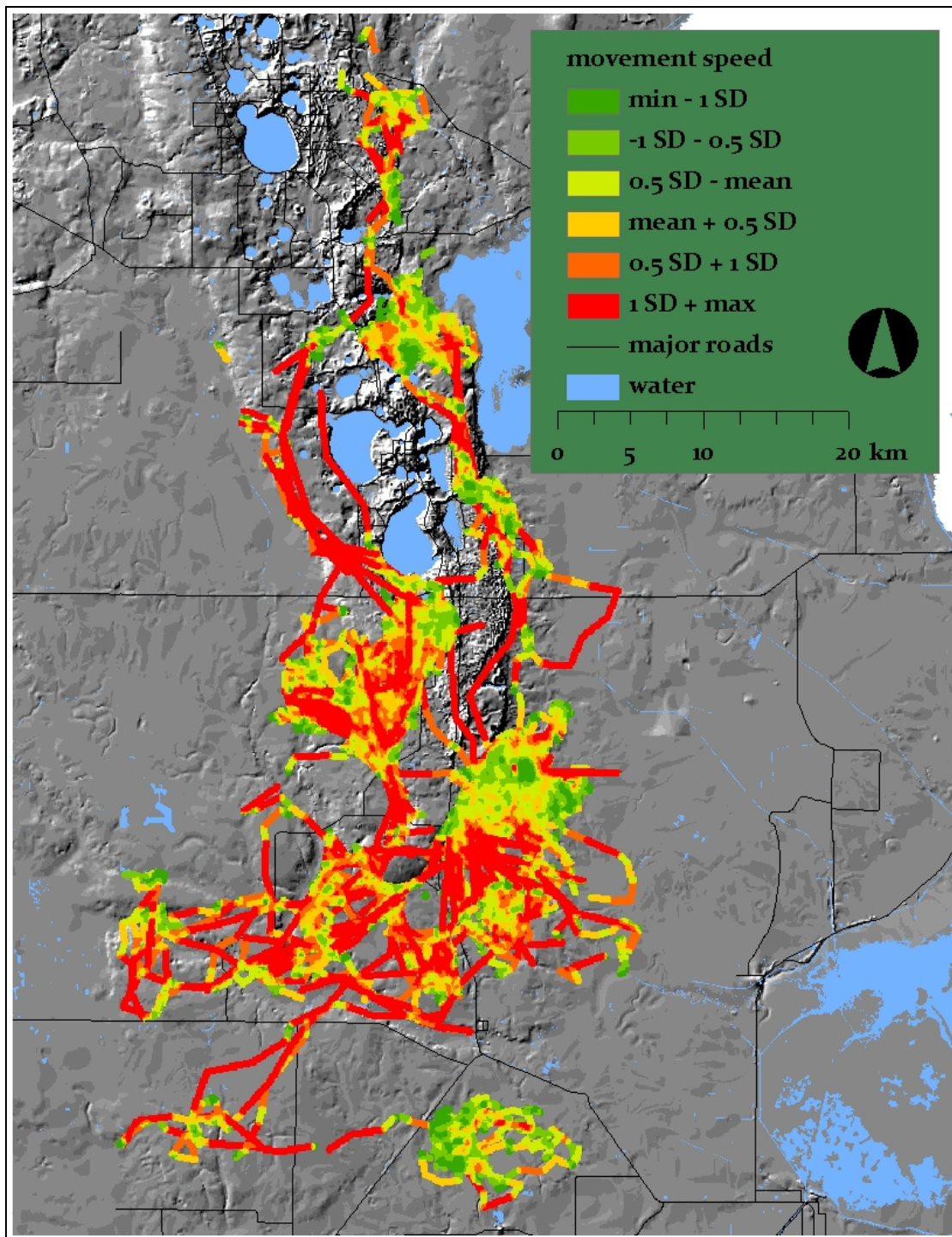


Figure 2.8. Movement speed of black bear in the Highlands/Glades study area of south-central Florida, USA. Calculations were based on GPS locations collected at 1 hour fix intervals. Overall speed was compared to that found in composite 50% kernel core areas, and classified according to the mean and standard deviation for speeds found within those core areas.

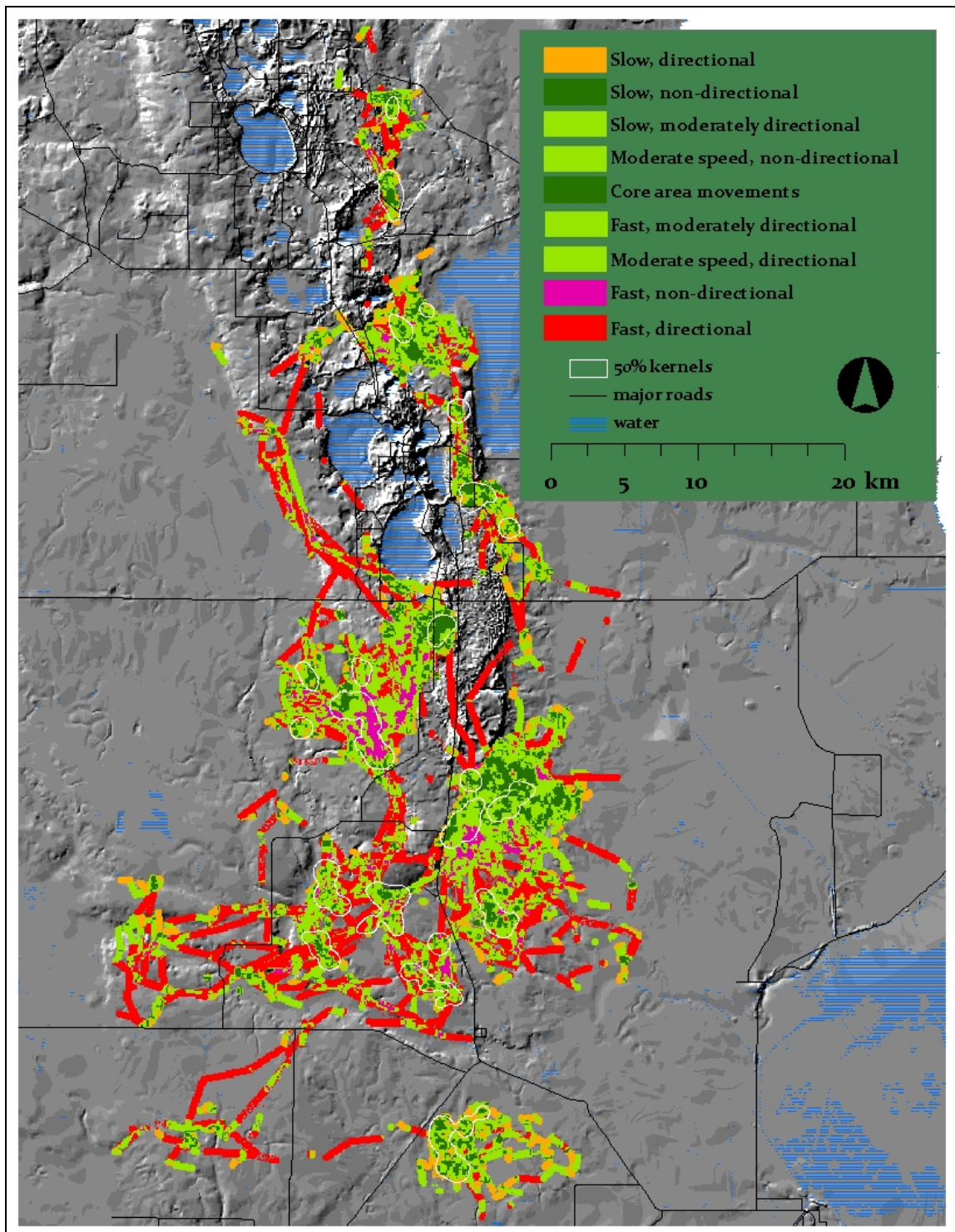


Figure 2.9. Combined movement characteristics of angular deviation and movement speed for the black bear in the HGC study area. Areas characterized as moderate were those that fell within 0.5 standard deviation of the 50% kernel core area mean for either measure.

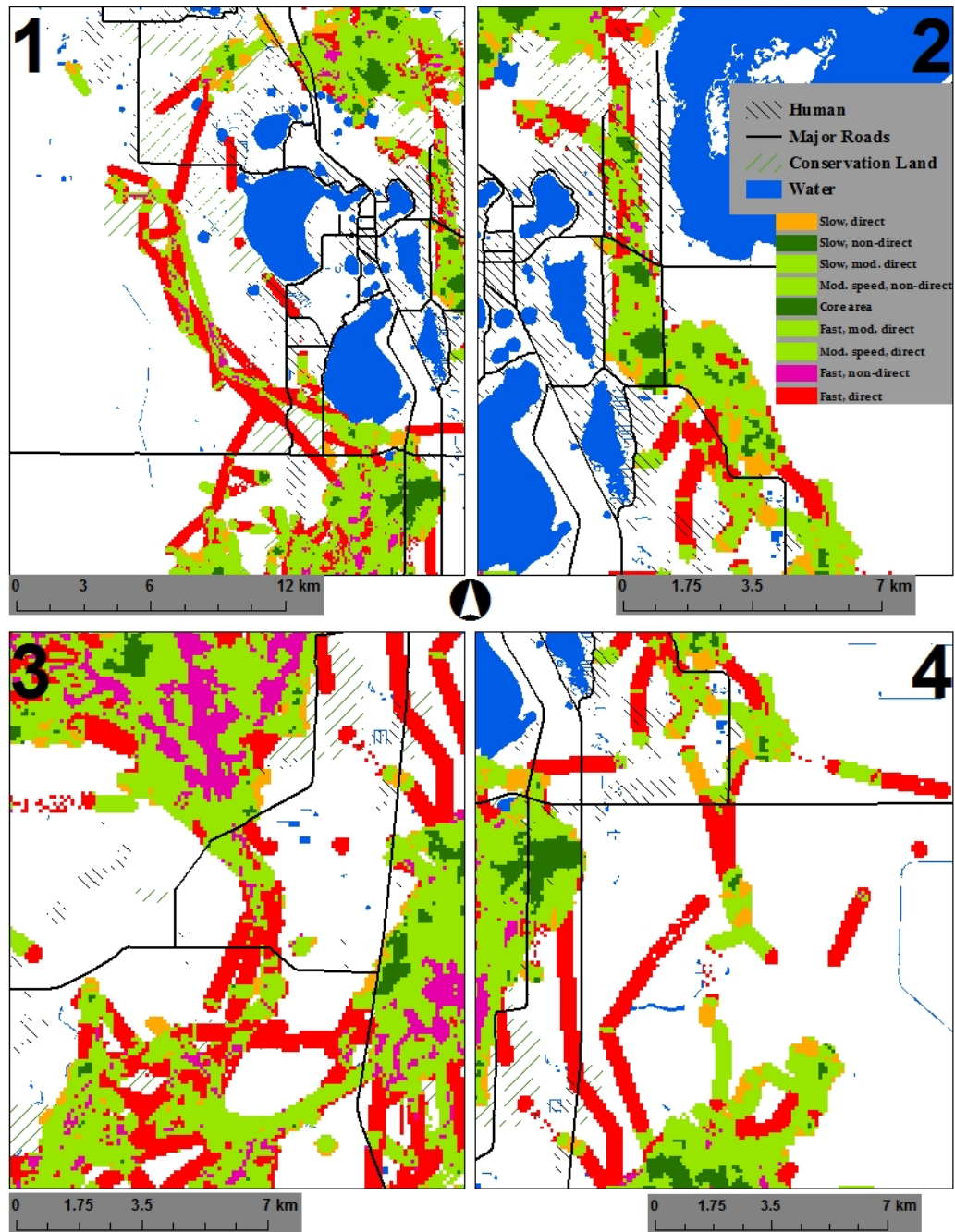


Figure 2.10. Estimated bear movement paths depicting primary habitat and corridor use in four areas of the HGC study area. Examples 1-3 represent highly functional corridors. (1) Archbold to Jacks Creek, with SR 70 barrier crossing between ABS and Lake Placid Scrub Preserve (2) Parker's Island corridor east of the town of Lake Placid, with CR 619 barrier running north-south on east side of Holmes Ave WEA, and Highlands Park Estates residential area to the north of CR 621 (3) Platt Branch WEA to ABS corridor, which crosses CR 731 and SR 8 (4) Parker's Island to Hendrie/Smoak, a minimally functional corridor bisected by SR 70 on the east side of US 27 and the Lake Wales Ridge.

CHAPTER THREE

CHARACTERIZATION OF BLACK BEAR ROAD CROSSINGS IN SOUTH-CENTRAL FLORIDA

Introduction

Habitat loss and fragmentation are the primary cause of biodiversity loss in most ecosystems globally (Millennium Ecosystem Assessment 2005). Large carnivores typically require large areas of habitat, are not well tolerated by humans, and are especially susceptible to habitat fragmentation (Hector et al. 2000, Gibeau et al. 2002, Whittington et al. 2005). The conservation threats inherent to isolated populations in fragmented landscapes can be partially mitigated by allowing individuals to move among viable patches and thereby maintain demographic and genetic linkages (Mills and Allendorf 1996, Dobson et al. 1999, Couvet 2002). Landscape linkages such as wildlife habitat corridors can allow movement and help maintain the connectivity of individuals among populations (Beier 1995, Beier and Noss 1998, Tewksbury et al. 2002, Levey et al. 2005, Dixon et al. 2006). However, even in landscapes managed to maintain connectivity among populations, animals frequently encounter movement barriers.

Roads are one of the most prominent causes of habitat fragmentation. The network of roads covering the planet is the largest human artifact on Earth, with 8 million km. occurring in North America alone (Forman 2003). The economic and social benefits of roads to humans are obvious, but it is also increasingly apparent that roads have directly or indirectly caused the loss of ecological processes, services, and components (Forman 2003). Increased mortality from vehicle collisions, alteration of behavior, encouragement of further human development, and increased access to and illegal harvest

of wildlife are other ways that roads negatively impact wild populations (Trombulak and Frissell 2000, Forman 2003, Glista 2008, McGregor et al. 2008). Gene flow of animals can be significantly reduced by roads (Epps et al. 2005, Riley et al. 2006).

Wildlife species move in response to food or other resources that shift geographically, leading some species to range widely. Wide-ranging species are likely to encounter many anthropogenic sources of disturbance as they move across landscapes. Behavior in response to roads has increasingly been the focus of research efforts and concern by wildlife managers (Gibeau et al. 2002, Chruszcz et al. 2003, Cleavenger et al. 2003, McCown et al. 2004, Reynolds-Hogland and Mitchell 2007, Eigenbrod et al. 2009). Depending on the distribution of habitats, resources, movement pathways, and various other disturbance factors in the landscape, the permeability of all roadways is a continuum. Even multi-lane, high speed roads are often not complete barriers for many species of wildlife (Serrouya 1999, Graves et al. 2006, Dodd et al. 2007, Dussault et al. 2007). However it is often the case that a species will select road crossing areas with favorable attributes that lowers movement and detection risks (McCoy 2005, Waller and Servheen 2005). While understanding the direct effects roads have on an animal species is important, to more fully understand this relationship it should be examined within the context of each unique landscape.

Understanding species-specific responses to roads is important for minimizing disturbance effects on animals and for maintaining connectivity among and viability of wildlife populations. The effects of road type, traffic volume and landscape context are important considerations for understanding the impacts of roads on wildlife. For example, telemetry studies on several species of carnivore, including black bear, suggest

that animals shift home ranges to avoid high road density areas (Thiel 1985, Van Dyke et al. 1986, Mech et al. 1988, Brody and Pelton 1989, Lovallo and Anderson 1996a).

Highways in particular create barriers to animal movement (Brody and Pelton 1989, Beringer et al. 1990). Black bears (*Ursus americanus*) are more likely to move across roads with less vehicle traffic (Brody and Pelton 1989), but they may use unpaved timber roads or fire lanes as travel routes (Hellgren et al. 1991). Other studies have shown that bears modify their movement patterns in response to habitat and human-related factors (McCoy 2005, Graves et al. 2007).

When black bears cross highways and other high traffic volume roads they select for specific habitat characteristics (McCoy 2005, Waller and Servheen 2005). Most research that has examined road effects on the black bear has occurred on public lands or managed forestry lands (Brody and Pelton 1989, Beringer et al. 1990, McCown et al. 2004, Lewis et al. 2011) where habitat is widely available at the road edge. Little is known about what landscape features are important to black bears crossing roads in more agricultural, urban, and other areas less suitable for bears where habitat patches are scattered and disjunct, and rarely found in close proximity to or on both sides of roads.

Studies of the impact of roads on Florida bears have been focused on populations that inhabit high quality habitat that often occurs in contiguous blocks of public land (Orlando 2003, McCown et al. 2004). While these studies examine landscapes where bear habitat is consistently distributed within or around roads, the two smallest bear populations in Florida exist in close proximity to a network of roads, urban development, and agricultural areas (Orlando 2003, Maehr et al. 2004, Ulrey 2008). Roads have impacted these smaller bear populations primarily by inhibiting or restricting the

movement of individuals among viable habitat patches and between other bear populations within the state, and by direct killing via vehicular strikes (Orlando 2003, Larkin et al. 2004, Maehr et al. 2004).

Florida's second smallest black bear population, estimated at between 100-200 individuals, occurs in south-central Florida, in Highlands and Glades Counties (HGC). This population forms a critical link in a proposed statewide metapopulation of bears by serving as a potential bridge between the larger Big Cypress population to the south and bear populations to the north. There are many potential obstacles to bear movement in the south-central Florida landscape, including multiple major highways that bisect the bear population. Over the years roadkills confirm the continued existence of the population; however, if we assume that roadkill varies in proportion to population size it appears that the population is not growing, despite game laws and the addition of conservation land in recent years (Figure 3.1).

Understanding the rapidly changing landscape dynamics in increasingly urbanized areas and its effect on bears is an important, though complex, task. Where roads appear to impact long-term viability of animal populations, identifying habitat associated with road crossing areas can allow land managers and transportation planners to focus management activities in key areas to promote wildlife movement across roadways, or implement other measures such as underpasses so as to maintain connectivity among individuals within and among populations.

Resource selection by animals is an important determinant of fitness, and is a focus of many ecological studies (Franklin et al. 2000). For threatened and endangered species, understanding resource selection during risky movements is key to prioritizing

and planning conservation measures. GPS collars allow the collection of animal locations at frequent time intervals and evaluation of resource use and movement patterns at finer scales than most typical vhf datasets. In recent years resource selection functions (RSFs) have become a common approach for wildlife researchers examining species occurrence and habitat selection. When combined with a geographic information system (GIS), RSF models can be powerful tools in natural resource management, with applications for land management planning (Boyce et al. 2002, Hebblewhite and Merrill 2008) and population viability analysis (Boyce 1992, Boyce and Waller 2000). RSFs allow researchers the ability to make and test predictions based on actual data (Boyce et al. 2002). RSFs are frequently used to build predictive maps that can inform natural resource managers and policy decisions.

In this study I developed a RSF for black bear road crossings in the HGC study area using GPS data from collared individuals in this population. My study objectives were to develop a resource selection function to characterize bear movement patterns and identify important landscape features at highway crossings. I developed and evaluated a predictive model for bear road crossing locations in HGC. My findings should prove informative to wildlife managers and land planners seeking to reduce future impacts of roads on this threatened bear population.

Study Area

The study area, defined as where bear trapping and telemetry locations occurred, was comprised of a ~6500 km² mosaic of public and private lands centered in Highlands and Glades Counties of south-central Florida (27°12'N 81°20'W), although movements of bears incorporated portions of Lee, Charlotte and Polk Counties (Figure 2.2). The climate is humid sub-tropical, with an average July high temperature of 34°C. Annual

precipitation in the study area averages 136 cm, most of which falls between the months of May and October in afternoon thunderstorms. Winter is mild and typically dry, with an average January low of 8°C (ABS 2010).

The study area was contained within the southern reaches of the Florida Peninsula Ecoregion. This area of Florida demonstrates considerable tropical affinities, with pronounced wet and dry seasons, high annual rainfall, very rare winter freezes, flat topography and thick muck or peat soils in places. The Lake Wales Ridge (LWR) is the major geomorphological feature of the landscape, stretching approximately 186 km from Lake County to southern Highlands County (Weekley et al. 2008). The ridge is a relict of an ancient shoreline and beach dune system, probably dating to the Pleistocene epoch (White 1970, Webb 1990). Level to gently sloping xeric uplands and shallow sinkhole lakes characterize the topography.

The LWR is marked by hundreds of shallow freshwater lakes, the result of dissolution by acidic waters of deeply-laid layers of limestone, creating a karst subsurface. The majority of the region's sinkhole lakes are small (<60 ha) and shallow (<5 m)(Kenner 1964). Two lakes, Lake Okeechobee (1890 km²) and Lake Istokpoga (113 km²), have surface areas greater than 100 km². More than half of Florida's lakes occur in the sandy central ridge system. The Caloosahatchee River forms the southern boundary of Glades County, considered a transitional zone between the Lake Wales Ridge "highlands" and the Big Cypress region to the south. Fisheating Creek originates in the swamps and marshes of the region, flowing east to Lake Okeechobee. Several conservation easements are associated with Fisheating Creek, including mature cypress forests, hardwood hammocks and shrub swamps.

Primary land uses in the study area included agriculture, such as citrus groves, cattle ranching, sod farms, horticultural nurseries, pine and eucalyptus plantations. The largest patches of forest exist to the south in Glades and Charlotte Counties, the largest of which is in the Babcock Preserve/Webb Wildlife Management Area, a former private ranch consisting of roughly 12,000 ha of forest. Other forested properties are under the ownership of the Lykes Brothers, a Tampa-based agricultural conglomerate. Lykes Brothers properties include a 16,833 ha Fisheating Creek/Lykes conservation easement in southern Highlands and Glades County. Forested land in Highlands County is considerably less than its neighboring counties to the south. Aside from Highlands Hammock State Park (~3800 ha) near Sebring, most forested land is under private ownership. Among the largest forested properties is the Hendrie Ranch (~2800 ha) in Venus, of which roughly 1400 ha is comprised of various forest associations.

Forest patches were often isolated by several kilometers of improved pasture or citrus groves. Conservation lands constituted ~14% (754 km²) of Highlands and Glades counties. Most research occurred on private lands that included several active cattle ranches with conservation easements as well as Archbold Biological Station, a private, long-term research station near Lake Placid, Florida (Figure 2.3). In addition several state and federal wildlife management areas and state parks were incorporated into research efforts, most notably the Lake Wales Ridge Wildlife and Environmental Areas (LWRWEA) network in Highlands County. Human activities on properties where research occurred included sod farming, prescribed burning, recreational vehicle riding, and hunting. The practice of hunting white-tail deer (*Odocoileus virginiana*) and feral hogs (*Sus scrofa*) over gravity-fed or timed release corn game feeders was common on

these ranches and other smaller private lands within the study area. When active, game feeders were frequented by black bears (Ulrey 2008) and several other species.

The distinctive ecotype of the ridge is known generally as scrub, which has been described as “a xeromorphic shrub community dominated by a layer of evergreen, or nearly evergreen oaks, Florida rosemary (*Ceratolia ericoides*), or both, with or without a pine overstory, occupying well-drained, infertile, sandy soils” (Myers and Ewel 1990, p. 155). Scrub may appear over either the white and yellow sands common to the Ridge, and typical ecosystems are sand pine scrub, oak scrub, rosemary scrub, and scrubby flatwoods. Common pine species include slash pine (*Pinus ellioti*) and sand pine (*Pinus clausa*). Scrub hickory (*Carya floridana*), sand live oak (*Quercus geminata*), scrub oak (*Quercus inopina*), Chapman’s oak (*Quercus chapmanii*), and rusty lyonia (*Lyonia ferruginea*) are common scrub hardwoods. Saw palmetto (*Serenoa repens*) is abundant throughout the study area and is a feature of the understory of most forest types in the region, including the scrub, where it is joined by sabal palm (*Sabal etonia*).

Scrub may take on a variety of structures, even over similar soil types. Long unburned stands of sand pine scrub can develop an impenetrable shrub layer below tall even-aged sand pines. In contrast, the sand pine/rosemary scrub familiar to Archbold Biological Station and other properties in the HGC region is characterized by sparsely grown, uneven-aged sand pines and an open shrub layer of rosemary and scrub oak.

At the margins of the ridge are a mix of soils and ecosystems associated with drainage patterns from the ridge. The predominant soil types along the margins are composed of marine and estuarine terrace deposits of alluvial sand and shell marl deposited during the Pleistocene and Recent epochs. These soils are typically level,

poorly drained sands, with dark sandy subsoil layers, or a clay hardpan. They are most frequently associated with pine flatwoods, though wet and dry prairies are also common. Cutthroat seep, a distinctive feature of the edge of the LWR, is an increasingly rare ecosystem still present in places. The attrition of this feature is perhaps in part due to fire suppression, as succession is known to convert the mesic slash pine flatwoods favored by cutthroat grass (*Panicum abscissum*) to hardwood swamps (often referred to as “bayheads”) and hardwood hammock (Myers and Ewel 1990). These habitats are commonly converted for use as pasture, vegetables, and forest products. Near the southern terminus of the ridge a layer of level, poorly drained peat lies to the southeast. Ecosystems there are typically hydric, with bayhead and marshes the dominant ecotypes (Brown et al. 1990).

Bay swamps, or “bayheads,” are a distinctive habitat type for the study area, characterized by an association of broadleaf, evergreen tree species growing on organic, strongly acidic soils in depressions in central and south Florida (Wade et al. 1980, Abrahamson et al. 1984, Stone et al. 2002). Bay swamps are dominated by broad-leaved trees with the common name “bay,” including red bay (*Persia borbonia*), loblolly-bay (*Gordonia lasianthus*), and sweet bay (*Magnolia virginiana*). Bay swamp species of lesser presence include red maple (*Acer rubrum*), swamp tupelo (*Nyssa biflora*), and slash pine. Historical hunting accounts (DeVane 1978) and aerial photography from the 1940s suggest bay swamps were historically more extensive, particularly east of the LWR. Much of the lowland area east of the ridge has been converted to agriculture, primarily ornamental caladium farming, cattle pasture, and sod.

Much of the HGC study area has been degraded by conversion to residential and agricultural development, especially along the LWR. Weekley et al. (2008) reported that 78% of the xeric uplands found on the ridge have been developed. In the study area the dry upland soils are often used for citrus groves and home sites. Weekley et al. (2008) report that approximately 85% of yellow sand habitats (oak-hickory scrub, sandhill) have been converted to other uses, while 47% of white sand habitat has been converted. Of the ridge counties, Highlands and Polk Counties are the least developed, with roughly 45% of white sand habitat lost, combined, and 80% of yellow sand habitat lost, combined. Only 31% of the LWR edge in Highlands County remains relatively intact (Weekley et al. 2008).

The landscape supports a great diversity of plant and animal species. Archbold Biological Station has recorded the occurrence of 27 fish species, 21 amphibian species, 44 mammal species, 48 reptile species, 208 bird species, and 593 plant species (ABS 2010). The LWRWEA supports twenty-one listed plant species, many of which are endemic to the ridge (USFWS 1999, Turner et al. 2006a,b). At least fifteen listed vertebrate species, such as Florida scrub jay (*Aphelocoma coerulescens*), Florida mouse (*Peromyscus floridanus*), Florida panther, and sand skink (*Neoseps reynoldsi*) have been documented on the ridge; however, only 11% of the LWR is protected conservation lands (Weekley et al. 2008).

Approximately 1010 km of paved roads occurred within the area of the HGC utilized by radio-collared black bears (Figure 2.2), of which 757 km were classified as some form of rural road, and 253 km were classified as urban road. Rural roads varied from minor “collector” roads to major 4-lane “arterial” highways. Average annual daily

traffic (ADT) data were available through the Florida Department of Transportation.

Roads with <1000 ADT amounted to ~ 617 km within the area utilized by collared black bears. Roads with 1000-5000 ADT amounted to ~ 151 km, and roads with > 5000 ADT amounted to ~ 241 km.

The study area was bisected by over 60 km of U.S. Highway 27, a 4-lane highway running north and south for the length of the Florida peninsula. Other major roads in the study area included State Road 70, a 2-lane bi-coastal highway. The intersection of these two major traffic arteries divided the study area into 4 quadrants. There were a number of secondary state and county roads connecting the towns of Sebring and Lake Placid (Figure 2.2), and a network of gravel or shell roads used primarily by citrus grove operators to access their crops. Highlands and Glades Counties fit the traditional model of a working agricultural landscape, in that traffic was relatively low (< 1000 ADT) on most roads, except on highways connecting towns and through streets in the vicinity of towns (> 10,000 ADT).

The estimated human population of Highlands County in 2010 was 98,786, an increase of 13% from 2000. Glades County's human population was estimated to be 12,884 as of 2010, an increase of 21% since 2000. Statewide, the estimated population increase since 2000 was 13.2% (U.S. Census Bureau 2010).

Methods

Bears were captured between 11 May 2004 and 2 November 2009 using Aldrich spring-activated foot snares (Johnson and Pelton 1980), culvert traps, and free-range darting. Capture locations included private ranches, ABS, and a number of state or federally managed conservation properties scattered throughout Highlands County.

Bears were immobilized using Telazol® (Fort Dodge Animal Health, Fort Dodge, IA) administered at 4.4 mg/kg estimated body weight (Kreeger 1996) via pole-mounted syringe, cartridge-fired or air-fired projector (Pneu-Dart, Inc., Williamsport, PA). Once immobilized, artificial tears were applied to the eyes to prevent drying. Bears' heads were shrouded with a towel to reduce visual and auditory stimuli. Temperature, respiration and pulse were measured and recorded. When body temperatures exceeded 101°F (38° C) ice was applied externally to prevent overheating. All trap-related injuries were treated and recorded. Pre-existing scars or identifying marks were recorded. Each animal was given uniquely numbered ear tags, lip tattoos, and a passive integrated transponder (PIT) tag (Biomark, Inc., Boise, ID) injected subcutaneously between the shoulder blades. A veterinary tooth elevator was used to extract a first upper premolar tooth from all bears determined to be one year or older (Willey 1974). Extracted teeth were dissected and aged using cementum annuli counts (Matson's Laboratory, LLC, Milltown, MT). Approximately 5-10 guard hairs with intact root bulbs were collected from each bear for later genetic analysis and archiving. Body measurements were recorded using flexible measuring tape and included: head length and width, total length, chest girth, neck girth, and foot pad length and width. Weights were measured with a canvas tarpaulin and a drop scale. Weights were estimated when sufficient personnel were not present to assist with weighing. Capture and handling procedures occurred under FFWCC permit #WXO3549, and in accordance with University of Kentucky Institutional Care and Use Committee (IACUC) Protocol #626A2003.

GPS Telemetry

Adult bears field-aged at ≥ 2 years of age were fitted with one of the following models of GPS radiocollars: Lotek 3300, Lotek Wildcell (Lotek Wireless, Inc.,

Newmarket, Ontario, Canada), Telonics GEN III SST, and Telonics GEN III SOB (Telonics, Inc., Mesa, AZ, USA). All models were equipped with GPS receivers and vhf beacons, the latter facilitating the location of animals via aerial or ground telemetry and alerted telemetry technicians to potential mortalities or collar drop-offs via a 4-hr inactivity switch. Collar models differed in how data were retrieved. Lotek 3300 and Telonics GEN III SOB were “store-on-board” units, which had to be physically retrieved in order to download data. Lotek Wildcell and Telonics GEN III SST had store on board capability as well as remote download capabilities. The Telonics GEN III SST had a UHF modem called “spread spectrum,” enabling field personnel to download data once within a certain range of the unit, using a UHF receiver. Lotek Wildcell units were equipped with a Global System for Mobile Communication (GSM) modem enabling remote retrieval of data via mobile telephone technology. Fix intervals for GPS collars varied (15 min, 20 min, 30 min, 1 hr, 2 hrs, and 4 hrs) according to available programming times as determined by collar model and to optimize battery life for different research objectives. GPS collars from both manufacturers were equipped with electronic breakaway units, designed to release the collar from the animal at pre-programmed time and date. Project personnel modified breakaway systems prior to deployment by inserting a leather spacer between the collar belt and the electronic breakaway units, as a back-up breakaway should the electronic units malfunction.

GPS data were collected from collared adult black bears from 12 May 2004 to 31 December 2009. Duration of continuous GPS data collection ranged from 1 month up to 18 months (Table 3.1). Radio-collars programmed for shorter duty cycles had shorter battery life. Multiple collars ($n = 8$) failed from being damaged while deployed. Data

were screened to remove fixes associated with collar initialization and testing procedures, capture and collar recovery locations, and 2D fixes with PDOP > 6 (Lewis et al. 2007). Data collected between 1 January and 31 April were excluded from analysis, to limit the influence of denning locations. All non-consecutive fixes were removed from the data, so that analysis of movement directionality was based only on known locations and were the closest possible representation of where animals traveled. Data were classified into three seasons: winter, summer and fall. Season was assigned based on timing of the black bears' annual behavioral shifts of denning, breeding, and hyperphagia. I added diel period information to GPS data, to indicate dawn, diurnal, dusk, and nocturnal activity. Daily sunrise/sunset times for Lake Placid, FL were accessed from the U.S. Naval Observatory database (USNO 2010).

Once GPS location data were screened and projected in a GIS, Hawth's Tools (Beyer 2004) was used to convert temporally consecutive bear locations into movement paths. Previous research evaluating wildlife-highway crossings have assumed that crossing sites occurred at the intersection of a line connecting 2 animal locations and the highway (McCoy 2005, Waller and Servheen 2005, Dodd et al. 2007, Dussault et al. 2007). This method does not incorporate uncertainty about crossing location and becomes unreliable as the time interval between locations increases. I defined a highway crossing event as two successive bear locations occurring on opposite sides of the highway with co-occurrence of ≥ 1 additional sequential locations on the same side, because a single location in isolation could be the result of GPS location error.

GPS fix-rate bias (Nielson et al. 2009) was not a concern given that the locations of interest were not the recorded locations but an assumed location along the road. Ulrey

(2008) estimated a mean GPS error of 18 m for stationary GPS collars in bay-dominated habitats. All other habitat types had smaller GPS error, thus I used 18 m for the error term for all crossings analyzed. The Hawth's Tools (Beyer 2004) extension was used in a GIS to convert the major roads polyline to a points file, for use in estimating the probability of use at defined crossing points. The procedure for calculating these probabilities is explained further in the section below. Distance between all road points was set at 100 m. This distance provided high-resolution mapping, while maintaining acceptable processing time. Unless otherwise noted, all spatial analyses were conducted in ArcGIS 9.3 or 10.0 (ESRI 2010). All road-crossing adult bears with GPS data were considered for analysis.

Brownian Bridge Movement Model

Horne et al. (2007) demonstrated the usefulness of the Brownian bridge movement model (BBMM) for evaluating animal home ranges, estimating migration routes, and analyzing fine-scale resource use (also see Sawyer et al. 2009b). In each of these approaches, provided that movement data are collected at frequent intervals and with some measure of error, the BBMM provides a probabilistic estimate of a movement route by incorporating the location error and the uncertainty of the movement trajectory between locations. The estimate of the Brownian movement route produces a “utilization distribution” (UD) of the probability of use over the given area. The Animal Space Use program (Horne and Garton 2009) used to calculate Brownian bridges contains a feature that allows the estimation of the probability of use at user-specified points, such as points distributed along roads. The “used” points along roads can be selected from the UD generated by the program. This advancement allows the estimation of the relative probability of use by road crossing animals at multiple points along roads. The

relationship between points and multiple environmental variables can then be investigated in a GIS.

I modified the Brownian bridge approach of Lewis et al. (2011) to analyze road crossings by black bears. I used the program Animal Space Use (Horne and Garton 2009) to estimate a Brownian bridge probability distribution (PD) for each individual bear road crossing event detected by GPS tracking. The BBMM for road crossing locations required the input of: 1) the sequence of time-specific GPS locations associated with a road crossing, 2) the estimated error associated with the location data, 3) the road point file, i.e those locations along the road at which the probability of use is to be estimated, and 4) an estimate of the animal's mobility, referred to as the "Brownian motion variance" (BMV; Horne et al. 2007).

The BBMM was used to create a PD of use at the points derived from the major roads polyline. The distribution of any probability > 0 defined the area considered for each crossing event. The intersection of the PD with the highway represented the probability that an animal crossed at a given location along the highway (Figure 3.2). A specific location within the PD was selected and designated as the actual crossing or "used" location. I defined the availability of potential road crossing locations for each individual bear. Only bears that crossed roads were included in these analyses. Points on any major road segment (Fl. Dept. of Transportation 2009) within the 99% minimum convex polygon (MCP) for an individual that crossed roads during the study were considered available. Data collected from the same animal over multiple years were combined when calculating MCPs.

Using this approach meant that habitat selection during road crossing movements was considered at the home range level, or at the third order scale following Johnson's (1980) hierarchy of scales of selection. This was consistent with the McClean et al. (1998) recommendation that the study-area level of habitat availability should be based on the distribution of radio-collared animals. One hundred fifty random locations were generated for each individual home range to represent habitat availability. The number of available locations was based on subjective observations of how many points were able to reasonably represent bear home ranges of widely varying size. Available locations were allowed to overlap with used locations, in order to estimate a RSF that was proportional to the probability of use. This approach is consistent with the findings of Johnson et al. (2006), who argue that treating available resource units as units that may be either used or unused (as opposed to one or the other) is the correct way to estimate a true RSF. In addition to environmental variables, random seasons and diel periods were calculated for available points in proportion to the amount of time each animal was sampled during those periods

The two assumptions associated with the BBMM are that location errors correspond to a bivariate normal distribution and that movement between successive locations is random. The assumption of normality is appropriate for GPS telemetry, but the assumption of conditional random movement between successive locations may become less likely as time between locations increases. Given that the longest fix interval in location data used was 4 hrs, and Horne et al. (2007) applied the BBMM to data collected at 7 hr intervals, I considered the assumption of conditional random movement to be reasonable.

The BBMM is a continuous-time stochastic movement model, where the probability of being in an area is conditioned on the distance and elapsed time between successive locations, the location error, and the BMV. Assuming odd-numbered locations are independent observations from Brownian bridges connecting even-numbered locations, the BMV can be estimated by maximizing the likelihood of observing the odd locations (Horne et al. 2007). Because this research was only concerned with movement between two locations, I used the calculated average movement rate for each individual animal observed during road crossing events as the BMV input. If the bear had <15 crossings the calculated mean movement rate for road crossings of all bears of that sex was input.

I examined 5 environmental variables as potentially important predictors of road crossing locations, including road density (Brody and Pelton 1989, Chruszcz et al. 2003), road class (Brody and Pelton 1989, Chruszcz et al. 2003), percent forest (hereafter %forest), percent cover (%cover)(McCoy 2005, Waller and Servheen 2005, Lewis et al. 2011), and habitat type (Chruszcz et al. 2003). Average annual daily traffic (ADT) data from FDOT was used to divide all roads in the study area into low (< 1000), moderate (1000-5000) and high (> 5000) traffic classes. Road density was calculated for 2- and 4-lane paved roads in the study area by using the line density tool with a 1000 m search radius in a 30 m x 30 m grid. 2004-2005 land use data from the South Florida Water Management District (SFWMD) and Southwest Florida Water Management District (SWFWMD) were used as the base for habitat classes. Landcover data was reclassified into forest, upland scrub, improved pasture, freshwater marsh, citrus and other tree crops, unimproved pasture, lakes and waterways, row crops, human development, extractive

land, and open/recreational land (Table 2.3). A Neighborhood analysis was then carried out through a focal majority procedure in the SPATIAL ANALYST extension for ArcMap 9.3 to create a 10 m x10 m grid. The variable “habitat” was classified as the dominant landcover type within a focal majority for a 150 m rectangular neighborhood at the roadside for each point. Habitat was calculated using the NEIGHBORHOOD extension in ArcMap 9.3. Percent forest and %cover in the landscape were developed in 30 m x 30 m grids using SFWMD/SFWMD land cover data converted to raster format (Table 3.2). Appropriate habitats were assigned values of 1 or 0 for forest/cover types and non-forest/cover types, respectively. Grids were converted to 32 bit float pixel type, so that each pixel would be assigned a percent value. Next, a focal mean procedure was performed with various search radii. Forest and cover densities were calculated (using a rectangular search window) at 120 m (4x4), 210 m (7x7), 300 m (10x10), 510 m (17x17), 600 m (20x20), and 990 m (33x33). Values for percent cover, percent forest, road density, and habitat were extracted for all points in a GIS. Arcsine-root transformations were performed on percent cover and percent forest data. All extracted values of the habitat neighborhood procedure were checked for accuracy using 2008 color orthophotos.

Modeling Habitat Characteristics Associated with Highway Crossings

A RSF model is a form of habitat suitability index (HSI; USFWS 1981) but with statistical rigor. Some HSI models are created using expert opinion and other methods not tied to statistical estimation, whereas RSF models are estimated directly from data. A RSF is defined as any statistical model that is proportional to the probability of use by a species (Manly 2002). The units being selected by animals (often pixels of land) are treated as resources. Predictor variables associated with these resource units may be the resources themselves or covariates of the resources e.g. elevation, soil type, or human

disturbance. A RSF usually is derived from observations of (1) presence/absence (used vs. unused) or (2) presence/available (used vs. available) resource units. For both of these sampling designs the prevailing statistical model is a binomial generalized mixed model (GLM) in the form of a logistic regression.

Ideally, sufficient data would exist to estimate models for each individual bear that could be averaged across all individuals to construct a population model (Otis and White 1999, Johnson et al. 2000, Sawyer et al. 2009b). The rise of GPS technology in wildlife telemetry studies has aided the development of sophisticated RSF methodology. Deriving RSF models based on direct GPS locations for a given animal is typically not as constrained by the number of observations as are traditional vhf telemetry studies. However, modeling road crossing restricts data sets to only those GPS locations associated with a specific activity (road crossing), leaving sample sizes for some animals very small. In part because of unbalanced sampling design, several bears in this study had few documented road crossings, while other bears had large numbers of documented crossings. Estimates of resource selection for animals with few numbers of observations are likely to be imprecise, and unless weighted properly, could influence population-wide estimates and produce inaccurate models. Avoiding this scenario requires properly weighting individuals with few observations.

Gillies et al. (2006) demonstrated that the use of random intercepts accounts for unbalanced sampling and improves model fit when dealing with unbalanced samples. Without a random intercept for individuals with unbalanced data, sample size differences may influence model coefficients. I used logistic regression to compare habitat characteristics at used locations to available locations along HGC highways. Performing

this analysis required that the individual road crossing be treated as the sampling unit; in effect assuming that individual response to environmental variables was fixed (i.e. similar) throughout the population. I accepted the assumption of fixed effects, and accounted for the unbalanced sample by including a random intercept for the individual bear in all models. In effect, the random intercept weighted all animals according to their sample size. The inclusion of the random intercept in a fixed-effects model creates a mixed-effect model $g(x)$, the logit model, of the form:

$$g(x) = \ln \left[\frac{\pi(x)}{1 - \pi(x)} \right] = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n + Y_0,$$

where x_n are covariates with fixed regression coefficients β_n , β_0 is the mean intercept, and Y_0 is the random intercept for individual bear. Logistic regression was performed in SAS GLIMMIX (SAS SAS Institute 2004)

Habitat variables were assessed for multicollinearity using Pearson's correlation matrix, and $r < 0.6$ was considered to be uncorrelated. The most appropriate scale to use for %forest and %cover was determined by conducting univariate logistic regression analyses for each variable scale. The scale with the lowest Akaike Information Criteria (adjusted for low sample size (AIC_C) value (Akaike 1973, Burnham and Anderson 2002) was determined to be the best scale.

AIC_C was also used to select the model that best explained habitat variables associated with highway crossing locations for black bears. Eight *a priori* candidate models were constructed based on a variety of landscape, vegetative and human factors (Table 3.2). Parameter estimates were averaged across models that were within 4 AIC_C points of the best model (Burnham and Anderson 2002). The best model was

extrapolated to all major HGC roads and displayed in a GIS using the following relationship:

$$w(x) = \frac{\exp(\beta_0 + \beta_1 x_1 + \dots + \beta_n x_n)}{1 + \exp(\beta_0 + \beta_1 x_1 + \dots + \beta_n x_n)}$$

where $w(x)$ represents the resource selection function for predictor variables, x_n , with associated selection coefficients β_n (Manly 2002).

An important facet of any modeling is the testing of predictions against an independent data set (Wiens et al. 2008). Data used in modeling is referred to as “training data.” To validate the predictive ability of a model, researchers typically withhold a portion of data from the training data set. These withheld data are referred to as “testing data.” Models can be evaluated based on whether testing data are correlated with model predictions. I tested our predictive models with an independent data set comprised of road crossing data that were withheld from the model training data. I withheld data for four individual bears for use in the testing data.

Probabilities from the final model were divided into 6 equal interval bins from lowest to highest value, and the proportion of the study area in each bin was calculated. The RSF score for each testing point was extracted from the model and placed into the appropriate bin. The number of testing points that fell within each bin was recorded. The frequency of testing points within each bin was adjusted by dividing the number of points within each bin by the number of study area-available points within each bin (Boyce et al. 2002), so that each bin was assigned an availability-adjusted weight. The availability-adjusted weight of observations of RSF values from the testing data were compared to the median value for each RSF bin using a Spearman rank correlation. A strong predictive

model would demonstrate increasing numbers of locations within successive bins as the probabilities increase, and a significant, positive correlation (Boyce et al. 2002).

Results

Thirty-nine individual black bears (20 F, 19 M) were fitted with GPS collars between 2004 and 2009. Among those bears that appeared to cross major study area roads, 16 (7 F, 9 M) produced data of sufficient quality for this analysis and yielded 66,393 locations used to derive 382 individual road crossings (Table 3.1; Figure 3.3). Two individuals (1 F, 1 M) included in this analysis died during the study. The median number of major road crossings for females was 19, while the median for males was 12. U.S. 27 formed the boundary of home ranges for all adult females at the Hendrie/Smoak complex (Figure 3.4) in southern Highlands County.

A univariate logistic regression indicated the most appropriate scale for measuring %forest and %cover in the landscape was 1000 m. The top 2 models were within 4 ΔAIC_C and were averaged to produce the final model (Tables 3.3 and 3.4). Coefficient estimates for %cover were influenced by the inclusion of citrus as a form of cover (2.36 ± 1.03 for best model when citrus was included; 1.96 ± 0.26 for best model when citrus was excluded). Percent cover was the most powerful environmental predictor of road crossing (relative variable importance = 1.00). AIC_C calculations suggested that the best fitting model combined %cover including citrus, road density (relative variable importance: 0.76), and habitat type at the road edge (0.95). None of the habitat types of the road edge were significant predictors of road crossing. All classifications showed positive relationships, but the 95% confidence interval for each category overlapped 0 (Table 3.5). Final model coefficients were applied to road locations throughout the study area to derive a predictive map (Figure 3.5).

Season and diel periods were important determinants of road crossing likelihood. For all bears, the three seasons differed significantly ($p < 0.001$) when compared using the LS MEANS procedure in SAS. Odds ratios calculated for season categories suggest that bears were approximately twice as likely to cross roads during the summer as they were in the fall (0.86 ± 0.16 ; $p < 0.001$). Roads were crossed least during winter. Nocturnal periods in both summer and fall were the preferred crossing time, while daytime crossings were rare. Bears were roughly 8 times as likely to cross at night as they were by day (95% C.I. 4.68 – 15.50). Nocturnal and dusk diel periods were the only periods that were not significantly different ($p = 0.99$).

To evaluate the predictive ability of the final averaged model from the BBMM I used 58 independent highway crossings (testing data) from 4 bears: 50 crossing events from three males (M33 = 29 crossings, M34 = 4 crossings, M14 = 17 crossings) and 8 crossing events from one female (F29). The Spearman rank correlation demonstrated a significant positive relationship ($r_s = 0.94$, $0.025 > p > 0.01$; Figure 3.6) indicating that the model had good fit and predictive ability (Boyce et al. 2002). The percent of validation locations adjusted for availability that occurred within the highest to lowest probability bins were 22%, 30%, 18%, 15%, 10% and 5%.

In a separate modeling iteration, citrus groves were held separate from cover, analyzed only as a habitat type at crossing locations. Under this approach the coefficient estimate for citrus increased to 1.76 ± 0.64 ($p < 0.01$), suggesting that its presence at the road crossing location had strong predictive power. Results of this approach were applied to a predictive map, which was then tested using the same model validation data and procedures described earlier. The Spearman's rank correlation showed a strong

negative correlation between testing locations and high road crossing probability bin weights ($r = -0.759$), evidence that the approach wherein citrus was withheld from consideration as a cover type was insufficient for predicting road crossing locations.

The calculation of two varieties of cover, that including citrus and that without it, allowed the detection of a pattern of cover use by bears. When %cover was calculated without citrus, 149/382 road crossings (39%) occurred in < 50% cover, of which 65 (44%) were attributed to females. When cover included citrus, only 74/382 (19%) road crossings occurred in < 50% cover; of those, only 1 crossing was by a female.

Discussion

The use of roads as home range boundaries strongly suggested that roads, particularly high trafficked ones such as US 27 and SR 70, were movement barriers in this small population. US 27 had 4-8 lanes of traffic and an ADT of 6100-37500 (Fl. Dept. of Transportation 2009) throughout its length in the study area. SR 70 ranged from 4200-5100 ADT, and SR 66/98 ranged from 3600-8100 throughout the study area. Bears have been repeatedly killed by vehicle collisions on these roads. However, this analysis demonstrated that bears were capable of crossing even these busy roads where sufficient cover was available in the landscape. Though road-crossing analysis was restricted to a subset of animals, at least 60% (39 of 65) of all bears observed during this study crossed major roads. Among those animals analyzed, conditions of the landscape seemed to be more important than the conditions at the immediate road edge. Specifically, bears were most likely to cross the road where the landscape offered the most concealment, and where road densities were low. Preferences for habitat type at the crossing location were not apparent.

In south-central Florida, the road network associated with extensive human development presents a challenge to highly mobile species such as the black bear. The response to roads varied among the bear-inhabited core areas I studied. It was apparent that any female not based in either the Hendrie/Smoak or XL/BlueHead complex was able to tolerate the presence of paved roads within their home range. In the case of the adult females centered on Hendrie/Smoak, the only major road in the area (US 27) served as the western boundary of all home ranges and was not crossed, even during extra-territorial forays (Figure 3.4). This relationship is consistent with other studies that have analyzed the impact of high traffic volume roads on bears (Manville 1983, Brody and Pelton 1989, Kaczensky et al. 2003), though it is possible that the diversity of habitats at Smoak/Hendrie enabled females to avoid crossing roads. Elsewhere, as near the ABS/XL Ranch complex, adult female home ranges overlapped US 27, SR 70 and numerous lower volume rural roads (Ulrey 2008). Site fidelity for frequent road crossings was apparent for this subset of females. The majority of the analyzed road crossings among females occurred in the fall, during the period of hyperphagia in anticipation of denning. In Florida the black bear shifts from eating soft mast food items into hard mast near the end of August. In south-central Florida this is when bears shift to feeding in the food-rich scrub, such as is found at Archbold Biological Station (Maehr et al. 2004). Annual shifts to the scrub are an important ecological event for this population, similar to mast-driven treks documented by many others (Amstrup and Beecham 1976, Garshelis and Pelton 1980, Rogers 1987, Larivière et al. 1994, Noyce and Garshelis 2011). The availability of scrub oak acorns, sabal palm berries and scrub hickory likely plays a crucial role in propelling females toward their reproductive and survival thresholds for winter, while for

males it may increase their chances of mating the following spring (Kovach and Powell 2003, Costello et al. 2009, Noyce and Garshelis 2011). Further road development on or near these habitats will impact the ability of bears in the study area to access such seasonally important food hotspots, unless road projects specifically mitigate for road crossing locations. The protection of scrubby habitat is a conservation objective that would benefit many species in south-central Florida (Deyrup 1989, Lohrer and Swain 2000, Weekley et al. 2008).

Ulrey (2008) found that citrus was neither selected nor avoided as a habitat type for HGC bears. Investigating the function of citrus was important, given its widespread distribution in the landscape. Modeling predicted that road crossings were most likely to occur in areas with higher cover density, including citrus, in the landscape. I defined landscape cover as any habitat that offered visual concealment, included forested habitats, scrub habitats, and tree nurseries such as citrus groves and pine plantations.

Uneven sampling and the lack of duration in most male GPS data sets precluded statistical comparisons by sex. However, the reduction by half of used crossings by both sexes in open habitats is evidence that both sexes preferred to cross where the landscape offered concealment, such as is found in mature groves. The conclusion that males make larger-scale movements and were less likely to select particular sections of road was consistent with other studies (Nielsen et al. 2002, Graham et al. 2010).

Black bears chose to cross roads based mostly on vegetative characteristics of the landscape around the road, although road density was a significant variable of the best fitting models (Table 3.4). I used a 1000 m search window to quantify landscape cover. Given the patchy nature of bear habitat, it was likely that the 1000m scale had the most

support because most bears crossed roads that existed within their home range, and home ranges were typically comprised of the largest available forested patches (Ulrey 2008).

The significance of citrus as a barrier or conduit for bear movement has yet to be fully resolved; it appeared to be a relatively unimportant conduit for fast movement, based on analyses reported previously (see Chapter 2). Before Ulrey (2008) first documented the occurrence of citrus seeds in scat analysis, Maehr et al. (2001) had suggested it was one of the rare fruits not eaten by the Florida black bear. Our observations suggested an ecological relationship may exist between the black bear and the citrus groves of Highlands County. Ulrey (2008) reported a juvenile female who appeared to remain entirely within a citrus grove for up to 6 weeks during one summer. In a different summer, over the course of 40 days, adult female F05 visited an orange grove on the edge of the Red Hill tract every night, often remaining there until 0500 before returning to the scrub. F08 and F12, a mother-daughter pair, occasionally used the orange groves that bracketed the Clement tract north of Lake Placid. It is notable that in each of these cases, the groves were bordered by US 27, which may have caused cautious females to spend time searching within the stretch of highway bordered by concealing habitat (the grove) for a suitable crossing location; however, I found no crossings associated with these forays.

The presence of apiaries associated with citrus groves have been the source of conflict in the past for Highlands County bears, leading to depredation and poaching (DeVane 1978), though this nuisance activity was not reported during the course of our studies. However, multiple grove operators have reported bears destroying young citrus trees and eating oranges (Ulrey 2008). The likelihood of these conflicts and

manipulations by humans makes citrus groves hazardous places for the bear.

Nevertheless, it appears that citrus groves provide concealment for bears and can at least provide a movement corridor between more food-rich habitats as opposed to row crops that bears tend to avoid (Ulrey 2008). The bear-citrus grove relationship may be unique in this small population, although it appears to be an issue of concern primarily for Highlands County, as citrus is far less common in Glades County. Other counties in the region have extensive citrus operations, but appear to be uninhabited by the black bear (FFWCC 2010).

Vegetative and human characteristics at the road edge unexpectedly lacked influence on road crossing. The lack of model significance of forested habitats at the road edge may be caused by the constrained nature of movement pathways in general for this population. All available forested pathways are also potentially used paths, so detecting differences at the third order scale may be difficult. The inclusion of citrus in cover density calculations prevented it from being significant as a road edge habitat for road crossing. Similar anthropogenic habitats, such as pastureland, cropland and barren land were classified as one habitat type, and were also insignificant as predictors of road crossing.

Road density had a negative relationship with road crossing, as has been reported by previous investigations of road networks (Brody and Pelton 1989, Beringer et al. 1990, Lovallo and Anderson 1996b, Serrouya 1999). I did not make comparisons among roads with different traffic volume due to low sample size of bears.

Results did not indicate that bears avoided human infrastructure along the road, as has been found in similar studies (Lewis et al. 2011). McCoy (2005) also found that

black bears did not avoid human development when crossing roads, though half of the animals in that study were known to be food-conditioned or habituated to humans.

Nuisance behavior associated with food conditioning or habituation is rarely reported for this population (< 10 annual complaints)(FFWCC 2010). One male (M09) tracked during the Highlands/Glades project exhibited behavior that would suggest habituation during three weeks in fall 2007. Analysis of movement behavior demonstrated that proximity to human development caused bears to exhibit more linear movement (Chapter 2). I speculate that the inability to detect significant differences may have to do with the third order scale used for comparisons, because bear home ranges are likely to be positioned away from human development.

Notable temporal patterns emerged from comparing seasons and diel patterns of road crossing. Road crossings were most likely to occur nocturnally for both sexes in both summer and fall. The daily timing of road crossings suggested that bears active at dawn and dusk may be waiting until darkness to cross roads, perhaps to benefit from additional concealment or in order to avoid high traffic volumes (Kaczensky et al. 2003, McCoy 2005, Waller and Servheen 2005). Seventy-four percent of road crossings by male bears occurred in the summer, the majority (63/120, 52.5%) in the nocturnal diel period. Females also crossed roads at night, though in contrast to males, more road crossings were recorded in the fall. These patterns have been observed elsewhere. Dispersal and mate searching characterized the summer months for the male black bear, leading to periods of sustained activity (Amstrup and Beecham 1976, Garshelis and Pelton 1980), elevated movement rates (Garshelis et al. 1983), and long distance (≥ 80 km) forays outside of home ranges (Maehr et al. 1988, Stratman et al. 2001, Lee and

Vaughan 2003), which increased the likelihood of road crossing, at least for HGC bears. For the female black bear, peaks in activity are reported to coincide with peak mast availability and hyperphagia (Amstrup and Beecham 1976, Garshelis and Pelton 1980, Larivière et al. 1994). Though activity rates were not analyzed, fall movement rates among females were slightly more consistent throughout 24 hours, in contrast with summer movement rates, which demonstrated crepuscular patterns (J. Guthrie, unpublished data).

The tendency toward night-time road crossing likely reflected a strategy to avoid humans (Ayres et al. 1986, Beckmann and Berger 2003). The proximity of roads to remaining high-value habitats such as scrub attracts bears into areas where they are likely to encounter anthropogenic sources of disturbance. Noyce and Garshelis (2011) suggested that bears are capable of adjusting their movement habits, practicing more caution, when moving through unfamiliar habitats during movements outside of home ranges. This behavioral flexibility may benefit males in the HGC population, who must navigate wide areas of non-habitat and a network of roads in order to mate.

The BBMM is a conservative method for assessing a complex landscape and a secretive, wide ranging species. The use of a randomly selected “used” location incorporated all locations within the probability distribution, rather than only considering points where the probability of crossing was highest (Lewis et al. 2011). The random approach to used point selection may have introduced some imprecise used locations. However, a clear pattern of road crossing where cover is most available was apparent.

Management Implications

Understanding how wildlife cross roads is an important facet of road management, and may lead to mitigation efforts that encourage wildlife movement and

connectivity, which maintains viable wildlife populations. In addition, a better understanding of the road crossing habits of animals can improve highway safety by reducing wildlife-vehicle collisions (Huijser et al. 2007). Each year in the U.S. there are over 1 million deer-vehicle collisions that result in hundreds of human fatalities, 26,000 human injuries, and \$8 billion in damage and associated costs (Conover et al. 1995, Huijser et al. 2007). The cost is much higher when considering the other wildlife species that are commonly struck by motorists. Nearly all animals struck by vehicles are killed, resulting in both ecological and economic loss.

I focused on whether the black bear physically crossed roads and utilized empirical data to predict and validate high probability road crossing areas in the HGC population of south-central Florida. Efforts to mitigate for road crossing could be incorporated into strategies that improve habitat connectivity in general for the study area. These strategies would include conservation easements, purchasing additional conservation land, and reducing human activity (Beier 1995, Duke et al. 2001, Dixon et al. 2006). Connectivity may be improved by retrofitting highways to allow safe passage for bears (Foster and Humphrey 1995, Larkin et al. 2004). I identified several zones where mitigation may be appropriate, and recommend focusing these efforts on US 27 and SR 70, the two highways where roadkills were most common.

I advise caution when interpreting these results due to the unique nature of the landscape under study, and caution against making conclusions regarding the relationship between the black bear and citrus groves. It is not clear the extent to which bears use this form of agriculture. Additional data collection could address how to categorize the

ecological function of citrus for the black bear. I cannot yet say whether it is a habitat, a conduit, a filter, a barrier, a source, or a sink.

The generalist habits of the black bear give these data applicability to other species likely to encounter roads in the region. These data can be incorporated into landscape planning strategies to help maintain critical habitat connectivity for species living in a human-dominated landscape, where the network of roads exacerbates the effects of land use change and habitat fragmentation. The depiction of likely crossing areas might aid wildlife and landscape managers in prioritizing management actions near likely crossing zones, which should be beneficial to animal conservation as well as the safety of motorists (Lewis et al. 2011).

Table 3.1. Model training data used to analyze characteristics of road crossing locations in the Highlands/Glades black bear.

Bear ID	Data duration	Fix interval	Locations	Road crossings
M08	8/11/2004 – 11/20/2004	1 h	1821	8
F05	9/12/2004 – 4/28/2005	4 h	910	4
F07	10/1/2004 – 11/1/2005	4 h	615	7
F08	10/6/2004 – 12/15/2004	1 h	1369	3
F14	9/6/2005 – 11/17/2005	4 h	313	18
M10	10/15/2005 – 3/31/2006	1 h	2912	2
M10	4/09/2006 – 10/8/2006	4 h	721	2
M16	5/19/2006 – 6/24/2006	1 h	716	15
F08	6/6/2006 – 9/21/2007	4 h	2000	4
M19	10/13/2006 – 4/15/2007	1 h	3275	1
F19	10/17/2006 – 2/11/2007	4 h	605	34
M19	5/12/2007 – 8/22/2007	0.33 h	6568	25
M21	6/27/2007 – 4/11/2008	1 h	5899	14
M09	7/21/2007 – 12/25/2007	1 h	2796	71
F25	11/16/2007 – 6/20/2008	2 h	2117	59
M05	11/17/2007 – 6/10/2008	1 h	1794	4
F05	5/27/2008 – 8/18/2008	0.25 h	6683	40
M22	6/3/2008 – 8/20/2008	0.25 h	5987	12
M29	6/11/2008 – 9/11/2008	0.25 h	6834	8
F05	8/20/2008 – 2/03/2009	0.50 h	7650	37
F12	8/26/2008 – 1/12/2009	0.50 h	4808	14
Total			66,393	382

Table 3.2. Predictor variables used to analyze spatial and temporal patterns of road crossing for the black bear in Highlands/Glades counties, Florida, 2004-2009.

Variable group	Variable	Data source	Description
Temporal	Season	Author	Winter, summer and fall; seasons based on timing of annual behavioral shifts of denning, breeding, and hyperphagia, respectively
	Diel	U.S. Naval Observatory	Daily sunrise/sunset times for Lake Placid, FL; days were classified into 4 diel periods: dawn, diurnal, dusk, and nocturnal; period one hour prior to and post sunrise and sunset were used to define dawn and dusk activity
Landscape	%cover	SWFWMD ^a , SFWMD ^b	A moving window calculation of the percentage of cover-providing habitats in the landscape, including forest, scrub and citrus; calculated with 30m x 30m cell size and search radii of 120m, 210m, 300m, 510m, 600m, and 990m
	%forest	SWFWMD, SFWMD	A moving window calculation of the percentage of forested habitats in the landscape (not including scrub habitats or citrus); calculated with 30m x 30m cell size and search radii of 120m, 210m, 300m, 510m, and 990m
	Road density	FDOT ^c	A moving window calculation of the km/km ² of major roads in the study area; calculated with 30m x 30m cell size and search radii of 990m
Vegetation	Habitat	SWFWMD, SFWMD	Dominant habitat type at the road edge for major roads; re-classified from land cover/land use vector data, converted into 10m x 10m cells, adjusted using focal majority calculation with 150m search window; habitats include forest, scrub, improved pasture, unimproved pasture/cropland, citrus, human development and freshwater marsh

^a: Southwest Florida Water Management District

^b: South Florida Water Management District

^c: Florida Department of Transportation

Table 3.3. Model selection results (number of parameters (K), Akaike Information Criterion adjusted for small sample bias (AICC), and AICC weights (wi) used to evaluate habitat variable selected by black bears at 382 road crossing locations in Highlands and Glades Counties, Florida, 2004-2009.

Model #	Model ^a	K	AIC _C	ΔAIC _C	w _i
1	Season diel %cover rdden hab	14	1,667.69	0.00	0.72
3	Season diel %cover hab	13	1,669.94	2.25	0.23
2	Season diel %cover rdden	9	1,673.21	5.52	0.05
5	Season diel %forest rdden hab	14	1,690.46	22.77	0.00
4	Season diel rdden hab	13	1,721.47	53.78	0.00
7	Diel %cover rdden hab	12	1,753.97	86.28	0.00
6	Season %cover rdden hab	11	1,801.04	133.40	0.00
8	Null	2	2,015.86	348.20	0.00

^a Variables used in modeling included: season=season of crossing, diel=time of day of crossing, %cover=percent cover and citrus in the landscape (1000m search radius), %forest = percent forest in the landscape (1000m search radius), rdden=road density on the landscape (1000m search radius), hab=habitat type: forest/scrub, improved pasture, open/unimproved, citrus, human development, and freshwater marsh; habitats subjected to focal majority function with 150m search window.

Table 3.4. Parameter estimates and standard errors for the top 2 models and model averaged parameter estimates for selection of crossing locations by black bears along roads in Highlands and Glades Counties, Florida, 2004-2009.

Model#	w _i	% cover	Road density	Forest / scrub	Improved pasture	Open / unimproved	Citrus	Human	Fwm ^a
1	0.72	2.36(0.33)	-0.66(0.32)	1.03(0.63)	0.21(0.81)	1.11(0.64)	0.46(0.65)	0.77(0.67)	0(0)
3	0.23	2.43(0.33)	-	0.99(0.63)	0.10(0.81)	1.12(0.64)	0.40(0.65)	0.64(0.67)	0(0)
Averaged	-	2.38(0.11)	-0.49(0.16)	1.02(0.40)	0.18(0.66)	1.11(0.41)	0.45(0.42)	0.74(0.45)	0(0)

^a Freshwater marsh; treated as the habitat reference category.

Table 3.5. Summary results of model averaging for characteristics of road crossing in the Highlands/Glades black bear, based on GPS data collected 2004-2009.

Parameter ^a	Estimate	SE	Confidence interval	Relative importance
Intercept	-4.72	0.616	(-6.262, -3.186)	
Season ^b				1.00
winter	-1.452	0.278	(-1.997, -0.906)	
summer	0.818	0.161	(0.502, 1.135)	
fall	....	....	....
Diel ^b				1.00
dawn	-0.671	0.206	(-1.076, -0.266)	
diurnal	-2.169	0.244	(-2.647, -1.692)	
dusk	....	....	....
nocturnal	-0.025	0.153	(-0.325, 0.275)	
%Cover	2.382	0.108	(1.737, 3.025)	1.00
Road density	-0.494	0.156	(-1.269, 0.281)	0.76
Habitat				0.95
forest/scrub	1.02	0.400	(-0.219, 2.254)	
improved pasture	0.181	0.661	(-1.413, 1.773)	
open land	1.114	0.408	(-0.138, 2.365)	
citrus	0.447	0.422	(-0.827, 1.720)	
human	0.737	0.454	(-0.584, 2.056)	
fw marsh	....	....	....

^a Intercept, %Cover, Road density are continuous data. Season, diel and habitat are categorical data.

^b Season and diel estimates are from the top overall AIC_C model.

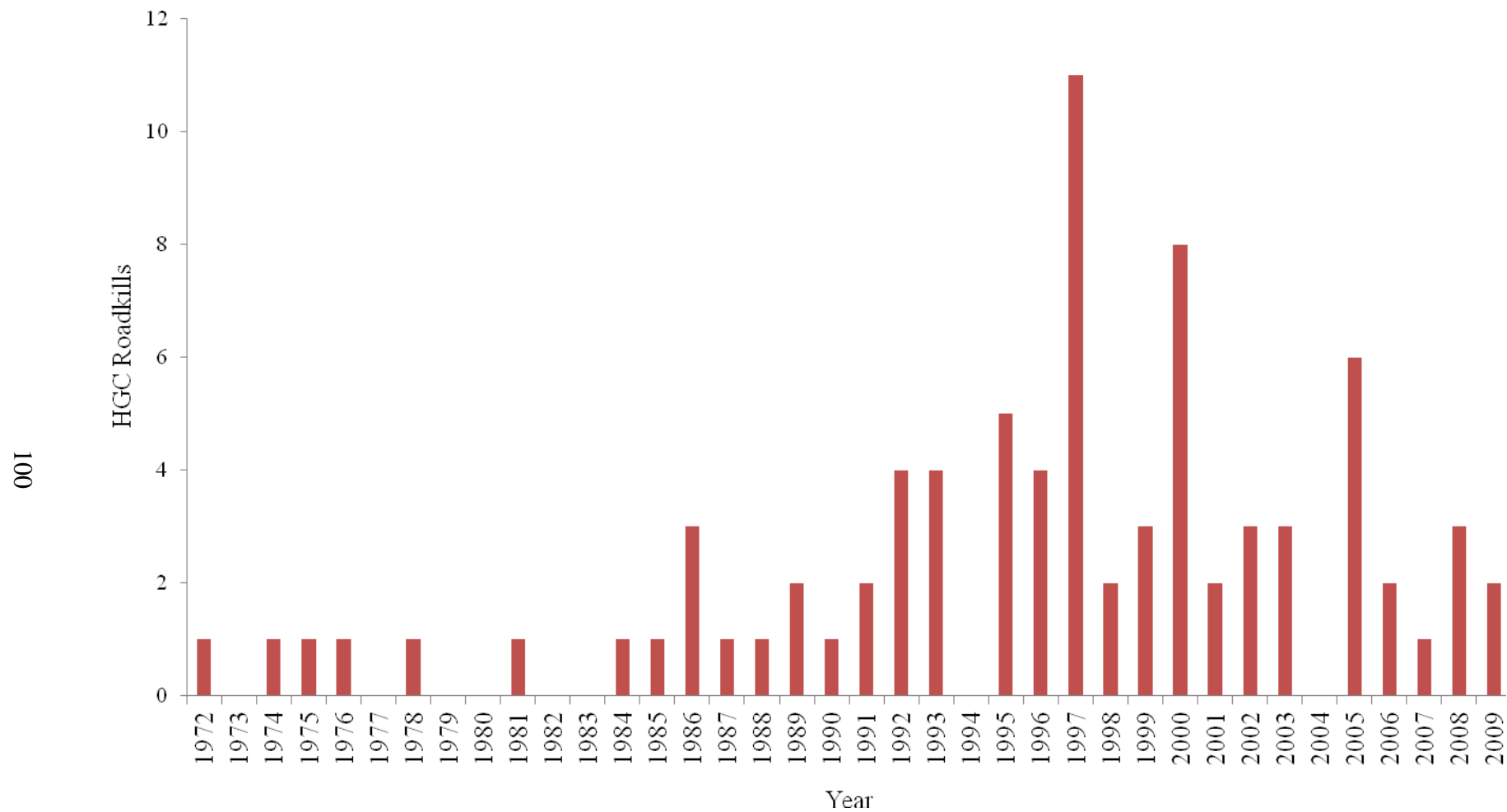


Figure 3.1. Roadkill data for the Highlands/Glades black bear population, 1972–2009.

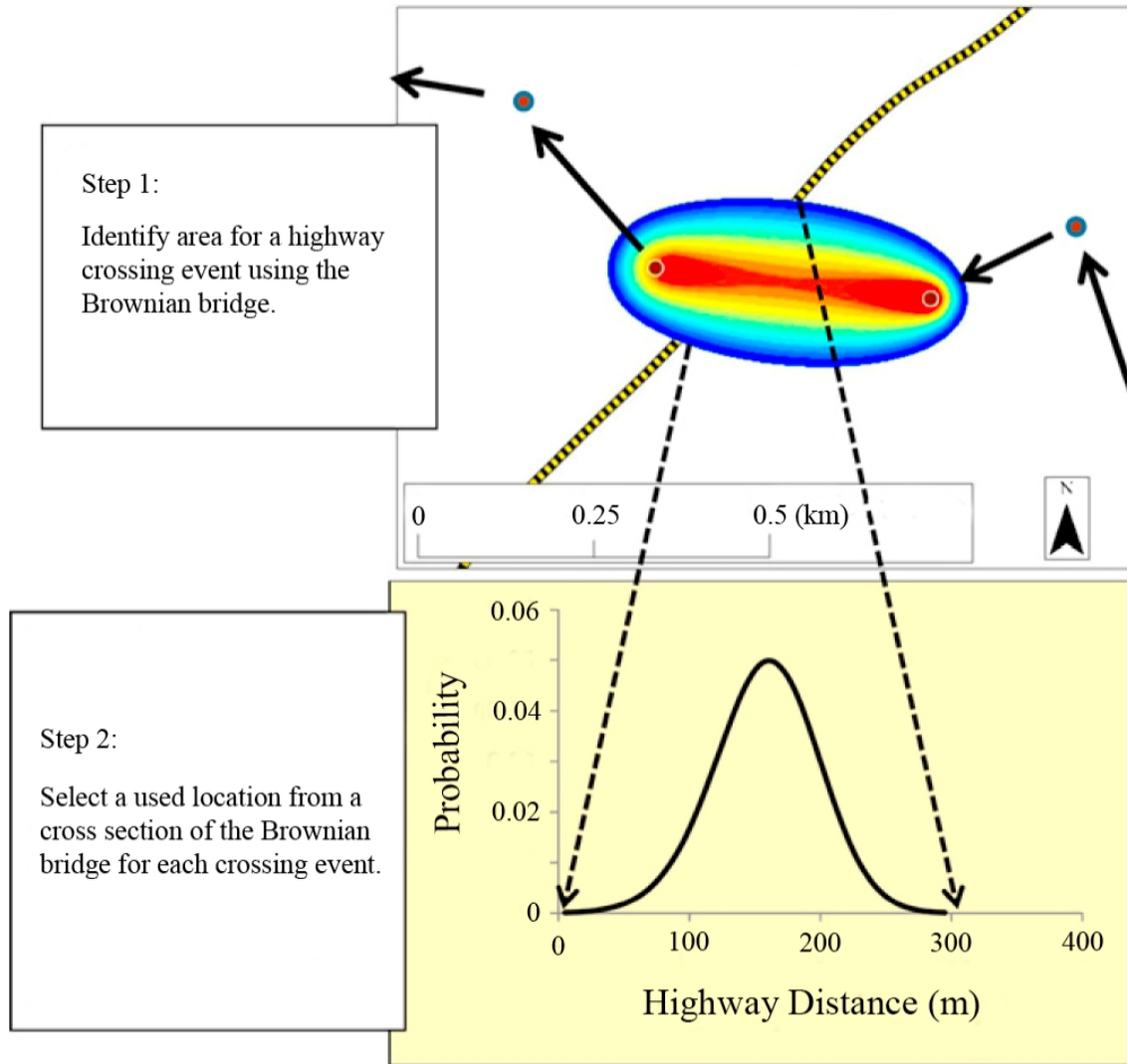


Figure 3.2. A two-step approach to identify habitat characteristics of road crossings by black bears in south-central Florida. First, a Brownian bridge movement model was constructed to create a probability distribution between locations flanking a highway crossing (arrows and dots represent movement lines and locations, respectively, for a highway crossing). Second, a “used” crossing location was randomly chosen from the cross section of the Brownian bridge and habitat characteristics associated with it were then compared to “available” locations using a logistic regression. Figure reproduced from (Lewis et al. 2011).

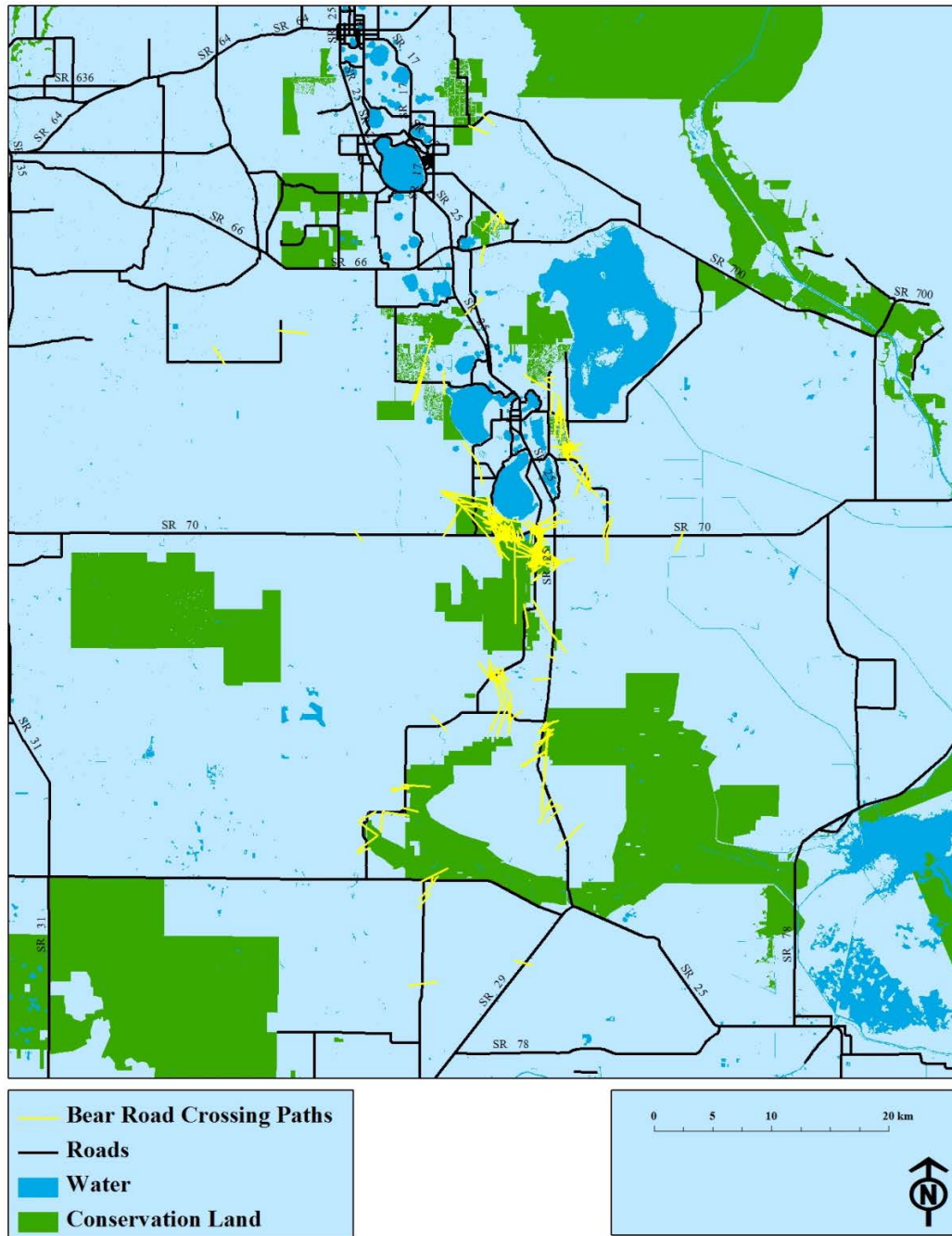


Figure 3.3. Road crossing movement paths of GPS-collared black bears in Highlands and Glades Counties, Florida, 2004-2009.

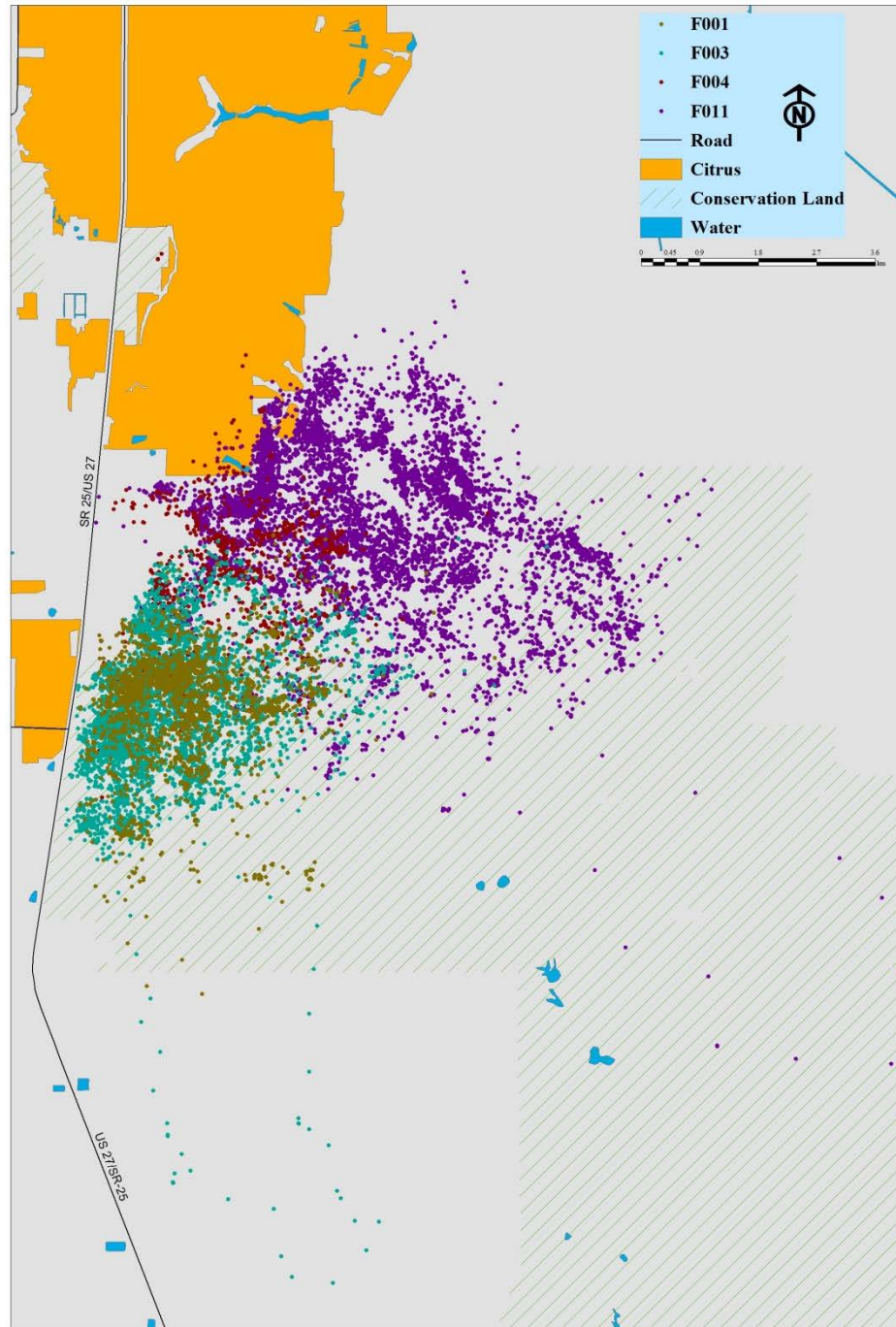


Figure 3.4. GPS collared females based on the Hendrie/Smoak ranch complex (~6,000 ha) in southern Highlands County, Florida. US Highway 27 formed the western boundary of multiple female home ranges, and occasional forays did not include highway crossings.

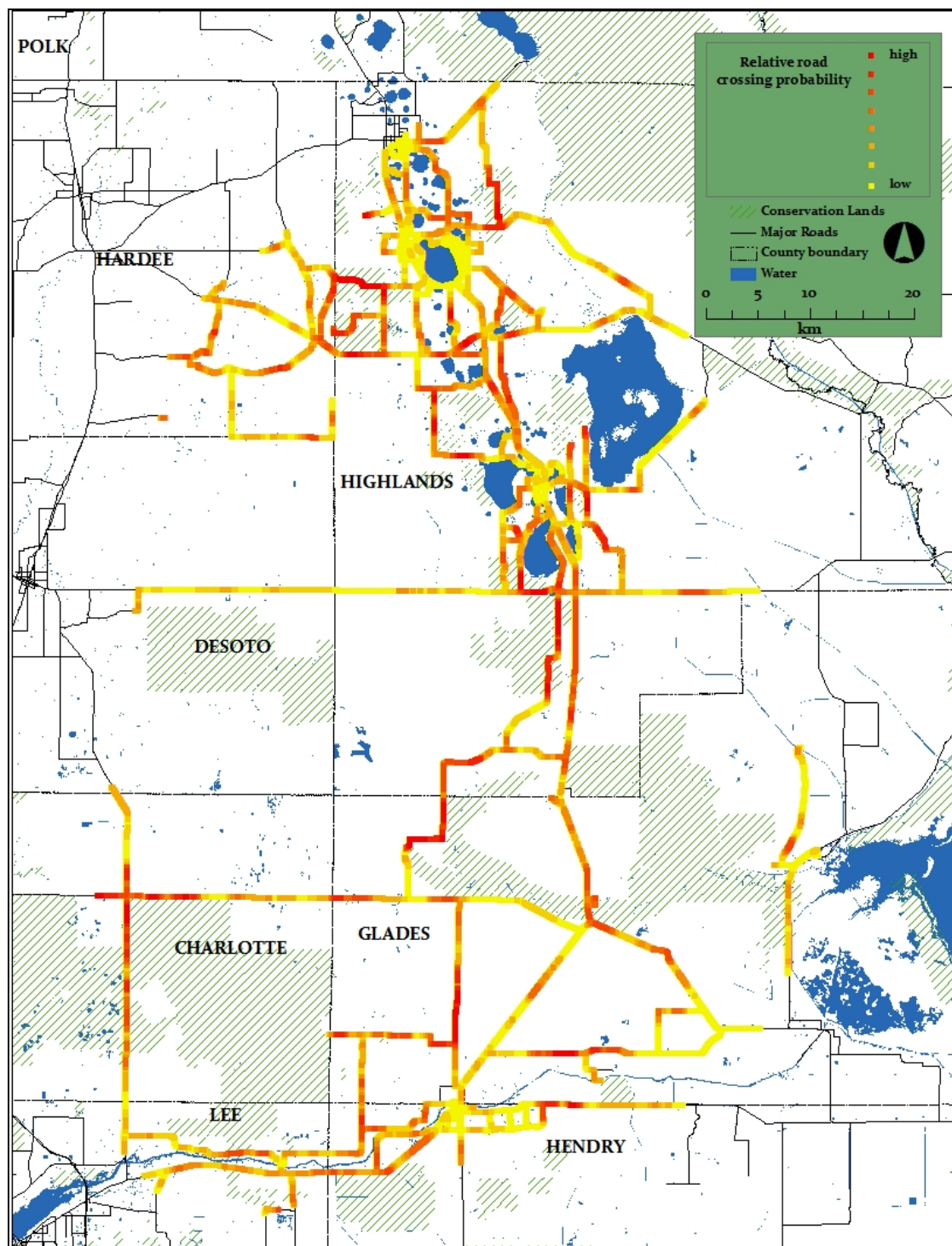


Figure 3.5. Predicted road crossing areas for black bears in Highlands and Glades Counties, Florida, 2004-2009.

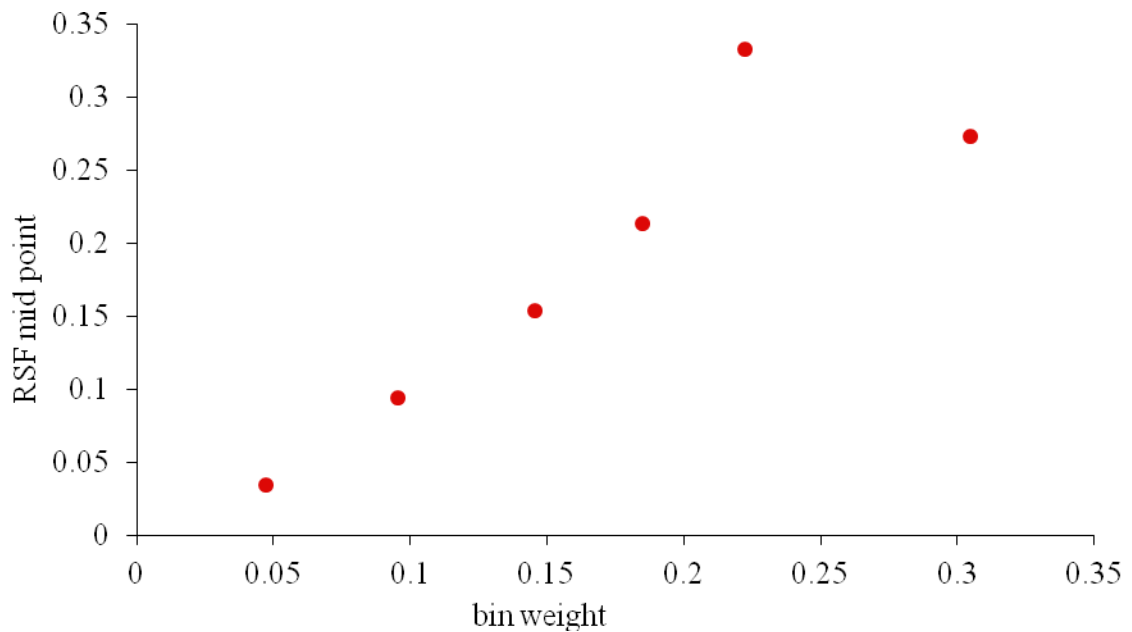


Figure 3.6. Rank correlation between model testing data (58 independent road crossing locations) and black bear road crossing probabilities predicted by logistic regression. Predicted probability map was divided into 6 quartile bins from low to high (y axis). Testing data were distributed among 6 probability bins, which were weighted according to their proportion of testing locations (x axis). Spearman's rank correlation test was used to calculate correlation between bin weights of testing data and mid points of 6 quartiles.

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Publications and Presentations

Guthrie, J.M., W.A. Ulrey, and J.J. Cox. Modeling road-crossing and movement behavior for the south-central Florida black bear. 2011. The Wildlife Society Annual Conference. Waikaloa, HI.

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