OPPORTUNITIES FOR BLACK BEAR CORRIDORS THROUGH SOUTHERN GEORGIA

By

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(Under the Direction of Rosanna G. Rivero)

ABSTRACT

Loss of natural areas due to urban development is occurring at a rapid rate across the United States. Large predatory species tend to suffer most from the resulting habitat fragmentation because of their wide-ranging nature, naturally lower population sizes, and tendency for human-conflict. In an attempt to help save the state's threatened species, the state of Florida has planned a wildlife corridor that will extend to the Okefenokee National Wildlife Refuge in southern Georgia. It is essential that Georgia begin planning a corridor extension through the state to account for growing wildlife populations and to mitigate human-wildlife conflicts. Early identification of high-value natural lands and ideal wildlife road crossing locations will help public and private entities work together to protect Georgia's native wildlife. A preliminary identification of southern Georgia wildlife corridors is performed, using the Linkage Mapper and Circuitscape Geographic Information System (GIS) toolkits.

INDEX WORDS: environmental planning, wildlife corridor, American black bear, *Ursus americanus*, Linkage Mapper, Circuitscape, geospatial information systems (GIS), wildlife crossings

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DEDICATION

This thesis is dedicated to my husband, Justin. Our mutual love of nature heartens my commitment to the great outdoors. You convince me that I am more capable than I give myself credit and remind me to stay in touch with my “inner child.” Without your keys to Warnell, I never could have finished this project.

To my parents: my interest in Environmental Planning began while lying in our driveway, orchestrating the daily lives of ants. You instilled my creativity and scientific insight; you taught me to value my perceptiveness.

To my brother: you taught me *patience* and, above all, you taught me that small acts of kindness really do make people’s days. You are the coolest person I know.

And to all of the animals in my life: you have taught me the value of being a quiet observer.

AKNOWLEDGEMENTS

I would like to give endless thanks to my committee members: Rosanna Rivero, Jack Crowley, Jeff Hepinstall-Cymerman, and Jason Lee. In particular, I would like to thank Jeff and Jason, who unwittingly became involved in this project and were, nevertheless, whole-heartedly willing to help.

Special thanks go to Greg Nelms, Mike Chamberlain, and Michael Hooker for sharing their bear-knowledge and for steering my research in the right direction. Thanks, as well, to Rachel Strom at the Southern Georgia Regional Commission for her help in finding GIS data for the project.

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CHAPTER 1

INTRODUCTION & LITERATURE REVIEW

Purpose

Urban development across the United States is expanding as human population continues to rise. Projections from the 2010 US Census anticipate a national population growth of approximately 24% by the year 2040 (WCCPS, 2013). Meanwhile, 50 million acres of forestland in the United States are expected to disappear by the year 2050 as a result of urbanization (Alig, Stewart, Wear, Stein, & Nowak, 2010). The state of Georgia is predicted to experience a population growth and average forest loss even greater than the national average. The population of Georgia is projected to increase by 40% by the year 2040 (WCCPS, 2013). Approximately 7,754 square kilometers of forestland within the state are expected to disappear by the year 2050 (Nowak & Walton, 2005). These numbers are particularly troubling because Georgia is currently home to 62 species that are federally listed as threatened or endangered (USFWS, 2013). Furthermore, US Fish and Wildlife identifies habitat loss as the greatest threat to wildlife in Georgia (USFWS, 2012). The dramatic land cover changes and increases in impervious surfaces due to development across the state are illustrated in Figures 1.2a and 1.2b. It is of utmost importance to put systems in place now that will mitigate future urban impacts on native species.

The American black bear (*Ursus americanus*, hereafter, 'black bear') is the largest terrestrial species in the southeast. It is estimated that black bears occupy only seven percent of their historical habitat in the Southeastern Coastal Plain (Wooding, Cox, & Pelton, 1994). The Louisiana black bear sub-species (*U.a. luteolus*) is federally listed as threatened, while the

Florida sub-species (*U.a. floridanus*) has been proposed as threatened but currently remains unlisted. These population reductions are primarily a result of historical and continuing conflict with humans (Treves & Karanth, 2003; Johnson & Klemens, 2005).

Black bears in Georgia are fragmented into Northern, Central, and Southern populations (Figure 1.1). Studies are beginning to find that these divided populations have a lack of genetic exchange between one another (Cook, 2007). This is due to increasing fragmentation and habitat destruction (Pelton et al., 1999). Black bear populations have remained viable because of their wide-ranging nature. Unfortunately, the continued expansion and intensity of human-altered landscapes are proving to be formidable barriers (Pelton et al., 1999; Wooding et al., 1994).

Roads and Black Bears

Today, roadways and urban expansion are primary causes of death and reduced breeding success for many wildlife species in the United States (US DOT, 2011). The state of Georgia has $8,642 million in funding towards state route widening, bypasses, and the development of additional connections to major highways over the next four years (GDOT, 2013). This expansion is driven by the rapid population increase (more than twice the national average from 2000 to 2010) and increased industry that demands greater road capacity for increased freight and commuters (GDOT, 2013). Studies have found a strong correlation between road densities and population declines in large carnivores (Johnson & Klemens, 2005). A national report on annual wildlife-vehicular collisions estimated that the number of reported collisions is approximately 300,000 per year (Huijser, 2007). This number most likely reflects only a portion of overall vehicle-wildlife collisions due to a lack of reporting (Forman et al., 2003; Huijser, 2007).

Georgia roadways currently occupy 122,917 linear miles of the state's 58,056 square miles of existing land (US DOT, 2010; Figure 1.3). The state's overall lack of alternative transportation infrastructure catalyzes residents' reliance on personal motor vehicles (CDC, 2011). This vehicular dependence results in traffic congestion and drives the Georgia Department of Transportation (GDOT), politicians, and planners to increase roadway development.

In the face of this continual rise in demand for *new* highways, the Federal Highway Administration (FHWA) is also working extensively to repair and provide funding for existing infrastructure. According to the 2012 National Bridge Inventory, almost twenty-five percent of highway bridges in the US are structurally deficient or functionally obsolete (US FHWA, 2012). The alarming state of vehicular transportation infrastructure, coupled with the increasing demand for road creation and widening, is indicative of the large amount of road construction to come.

Highway construction and improvement projects are crucial opportunities to incorporate structures that allow wildlife to safely cross roadways (Figure 1.4). While wildlife crossings can be a costly endeavor, the structures can offer an immeasurable benefit to wildlife and humans (US DOT, 2011; US FHWA, 2008). The average property damage due to a vehicular-wildlife collision is approximately $1,577 (Forman et al., 2003). A long-term study evaluating the effectiveness of wildlife crossing structures in Banff National Park, Canada, estimated that the rate of large mammal vehicular mortality on the Trans-Canada Highway (TCH) had reduced by 80% since the initial installations (Clevenger, 2007). The 24 wildlife crossings, interspersed above and beneath the highway, were incorporated during the highway's expansion during the 1990s. The structures were originally designed for large terrestrial species and consist of a variety of over and under-pass structures. During a decade-long study, Clevenger (2007) revealed the crossings' successful utilization by wildlife, reporting, "10 species of large mammals [had] used Banff's 24 crossings more than 84,000 times" (p. 15).

Designs that retrofit existing structures and topography have proven effective and can minimize implementation costs (US DOT, 2011). Florida has implemented wildlife-crossing structures along many of their major roadways. In the southwestern region of the state, a network of 26 crossings utilizes existing overpasses, abandoned underpasses, and enhanced culvert structures (Land & Lotz, 1996). The structures cross multiple sections of two major highways adjacent to Fakahatchee Strand State Preserve, Florida Panther National Wildlife Refuge, and Big Cypress National Preserve. Although the crossings were initially designed for the Florida panther and Florida black bear, studies have documented a variety of species taking advantage of them (FFWCC, 2012; Foster & Humphrey, 1995; Land & Lotz, 1996).

Even when utilizing pre-existing crossing opportunities, design must remain an important consideration. Certain species do exhibit preference towards crossing structure elements such as size, available cover, and opportunities for feeding (Mata, 2003; Land & Lotz, 1996; US DOT, 2011). An observational study along the Rias Baixas motorway in northwestern Spain found that larger body size positively correlated with animals' crossing-structure-width preference (Mata, 2003). This is an important factor to consider when designing crossings for larger species like the black bear that may refuse smaller structures.

Another significant factor determining crossing structure use is "experience." This is particularly apparent with large mammal species. Studies in both Canada and Florida have shown a significant increase in crossing structure usage by black bear and large ungulates over time (Land & Lotz, 1996; Clevenger, 2007). This could be due to road avoidance, a pronounced behavior in large predators (Weaver, Paquet, & Ruggiero, 1996). Road crossings should be implemented as early as possible to encourage adjustment as soon as possible. It is also important that long-term monitoring or repeated studies are performed to appropriately assess wildlife usage of installed crossings (US DOT, 2011).

Roadways are an essential landscape component to consider when connecting wildlife populations. The potential threat that wildlife-vehicle conflicts pose denotes the need to implement safe crossing mechanisms and alternative routes that avoid highways. Possible planning devices for the mitigation of highway effects on wildlife movements will be discussed in the Results and Discussion chapters.

Urban Development and Black Bears

Urban development introduces problems of habitat connectivity and population isolation at a larger scale than roadways. Urban areas contain high road densities and the surrounding roadways frequently have additional physical barriers including high traffic concentrations, guardrails, fencing, and sound walls. These features can completely restrict wildlife crossings over extended sections of urban roads. Noise and air pollution further deter species from approaching urban areas. According to the University of Georgia (UGA) Natural Resources Spatial Analysis Lab's (NARSAL) analysis of Georgia's land cover changes, urban development has increased by twenty percent since 1974 (*Land cover trends*; Figure 1.2a). With high population growth projected for the future, it is reasonable to assume that these urban development trends will continue.

Additionally, the increased presence of humans raises the potential for direct conflict, particularly for larger wildlife species that can provoke fearful and violent reactions. Studies have found evidence linking predatory species' avoidance of urban landscapes to human-caused deaths (Hilty et al., 2006). In southern Georgia, black bear are hunted as a desired game species or as a pest. Black bear will frequently empty or destroy feeding stations set up to attract other game species, creating conflict with local hunters (Greg Nelms, personal communication, March 24, 2014).

Black bear have a greater frequency of human conflict than many other North American predators because of their gregarious nature. As opportunistic foragers, black bears readily adapt to urban environments that offer food in trashcans, vegetable gardens, and other accessible locations. Black bears habituated to garbage bins and other artificial food sources are a rising source of conflict. Termed “nuisance bears,” these individuals will repeatedly return to urban environments in spite of relocation efforts by the Department of Natural Resources and other black bear protection programs (FFWCC, 2012; M. Chamberlain, personal communication, January 28, 2014). One study in Nevada found that black bears captured in urban areas returned within 18 days despite relocation points more than 75 kilometers away and on the other side of desert mountain ranges (Beckmann & Lackey, 2004). In a Florida Fish and Wildlife Conservation Commission (2012) report of black bears euthanized between 2007 and 2011, “68% were associated with seeking out unsecured garbage or other human-provided food sources” (p. 12). Nuisance bears are a particular problem in Georgia. In a survey of agencies’ black bear management techniques, Georgia had the second-highest number of complaints-per-person in the continental United States (Spencer, Beausoleil, & Martorello, 2007). In the same study, agencies identified garbage or food attraction as the most common source of conflict.

Direct attacks on humans by large predatory species in the US are rare. However, a study assessed bear attack records in North America from 1900 to 2009 and noted the increasing rate of attacks appeared to reflect human population increases (Herrero, 2011). A rising frequency of human-black bear interactions may cause an increase in violent conflicts. This indicates the added importance of minimizing interactions between the large predators and urban residents.

In addition to creating conflict and barriers for wildlife, urban expansion directly destroys existing habitats. Areas clear-cut for residential complexes or commercial districts remove important ecosystem components. Young trees, trimmed plantings, and minimal plant diversity are characteristic of landscaping around new development. Urban plantings, overall, tend to be exotic or hybrid species that have lower quality or less available food and habitat structure for wildlife. Urban roadside vegetation tends to be invasive exotic grasses, like Bermudagrass (*Cynodon dactylon*), that disrupt nearby native plant communities (Forman et al., 2003). Adjacent water systems and vegetation are also affected by the increase in rainwater runoff due to cement, metal, and other impervious surfaces that inhibit absorption within urban areas. The loss of natural habitat and the insertion of impervious surfaces and unnatural plant communities result in degradation of the urban site and surrounding areas.

The large scale of habitat division and destruction involved in urban expansion requires cohesive planning to guide future development and maintain productive natural ecosystems. “Wildlife corridor” has a range of definitions (Collinge, 2009). For the purpose of this paper, the term will be defined as swaths of interconnected greenspaces, usually running between two significant conservation areas or wildlife populations, with the objective of increasing connectivity for one or more species. Note that the corridor itself may not entirely consist of valuable habitat. Instead, the objective of the corridor is to encourage successful wildlife movement between two or more locations.

A variety of corridor models are being recognized as successful techniques in protecting and restoring wildlife populations (Gilbert, Gonzalez, & Evans-Freke, 1998; Tewksbury et al., 2002). One example, the Osceola-Ocala Corridor in Northern Florida, was designed and implemented in an effort to reconnect two Florida black bear (*U. a. floridanus*) populations in the area. A study examining the once isolated populations found promising breeding potential between the two following the implementation of the corridor (Dixon, 2006). Black bears have the potential to greatly benefit from wildlife corridors because they tend to be wide-ranging species with low overall populations (WHCWG, 2010; Dixon, 2006; FGFFC, 1994). While many agree that large predators have a high probability of benefitting greatly from wildlife corridors, not many studies have evaluated the success of established corridors in connecting dispersed populations (Dixon, 2006).

The concept of reconnecting isolated wildlife populations stems from the theory of island biogeography and from the concept of "metapopulation." R.A. MacArthur and E.O. Wilson introduced the idea of "island biogeography" in their 1967 book, *The Theory of Island Biogeography*. They proposed that diversity, population size, and extinction rates were dependent upon an island's proximity to the mainland, size, and topography (Figure 1.5). For instance, a large island located close to the mainland with significant variations in topography should host larger populations of a diversity of species. Proximity facilitates island access to many different species and encourages colonization. Topographic diversity suggests a variety of soil types, microclimates, thereby creating a variety of habitats that suit a greater number of species. Larger island size generally supports larger populations because it minimizes conflict over food sources, home ranges, and other resources. These higher colonization and lower death rates result in a reduced extinction rate on larger islands close to the mainland. While MacArthur and Wilson's theory applies to islands separated by water, others began to apply their concept of island biogeography to patches of habitat isolated by surrounding altered landscapes.

After *The Theory of Island Biogeography* was published, criticism arose regarding MacArthur and Wilson's neglect to account for species' adaptability and the inherent bias in their model. Hilty, Lidicker and Merenlender (2006) point out the theory's preference towards species with "good vagility […] those that can fly, swim long distances, or float easily in water or air currents" (p. 52). Furthermore, island biogeography only addresses locations separated by water. Landlocked populations looking to emigrate must cross a variety of barriers that can vary in difficulty. Dense urban development may be nearly impossible to navigate due to roadways, humans, and the built environment. An agricultural landscape may appear easier but can also contain barriers such as fencing or pesticides.

Richard Levins (1969) coined the term "metapopulation" to address population dynamics in a more comprehensive manner. Levins developed a mathematical model that Hastings and Harrison (1994) defined as representing "a 'population of populations' existing in a balance between extinction and recolonization" (p. 168). Unlike MacArthur and Wilson's island biogeography theory, Levin's metapopulation model addressed the dispersal and extinction patterns of a single species across its entire population range. Susan Harrison (1991) expanded upon the metapopulation concept, introducing four main categories of metapopulations and describing the typical composition, movements, and extinction rates for each (Figure 1.6). It is clear from these models that population compositions can vary greatly but they all rely on species' ability to disperse from one population concentration to another.

Black bear are well adapted to traverse a variety of land cover types. In central and southern Georgia, the species prefers forested areas, but can be found in open field and pastures (Cook, 2007). Some of the main predictors of black bear movements are available forest, food, and protective cover in the form of vegetation, drainage ditches, and other landscape characteristics that reduce their exposure (Cook, 2007; Rudis & Tansey, 1995; Sandell, 1989; Doan-Crider, 2003). Black bear's predisposition for large home ranges and occupation of a variety of habitats makes the species a great candidate for wildlife corridors. The diverse habitat suitability of black bear allows for the protection of a variety of habitats that can potentially benefit other species. Furthermore, black bear's ability to travel great distances suggests they will take advantage of a corridor network's full extent.

The state of Florida, along with federal and non-profit support, is working to implement a wildlife habitat protection plan that spans from the southern Everglades to the Okefenokee National Wildlife Refuge (ONWR) in southern Georgia (FL DEP, 2014; Figure 1.7). The Okefenokee Swamp is the most notable network of swamp and marshland in the region. It is approximately 700 square miles and includes areas of open water, forested swamps, bottomland bogs, and even upland forests (NARSAL, 2012). The ONWR spans 402,000 acres of the Okefenokee Swamp (approximately 92%) and is one of the only substantial areas of contiguous protected native Southern Coastal Plain habitats (USFWS, *Okefenokee*).

The Florida corridor will allow species, including black bear and Florida panther (*Puma concolor coryi*), to pass north and southward with minimal conflict with highways and urban areas. This project is receiving state, federal, and non-profit funding and established components are proving successful in encouraging black bear movement (Land & Lotz, 1996; Dixon, 2006). It is essential that Georgia account for this eventual influx of black bear into the Okefenokee region by developing a comprehensive plan for habitat connectivity within the state.

Role of Planning: Tools and Objectives

Planners are notoriously involved in the urban and transportation expansion boom that began with World War II (Johnson & Klemens, 2005). In reflection of the shifting public focus to environmental protection and ecological awareness, many planning professionals have begun to experiment with mechanisms that enhance and restore the natural world. “Sustainability” trends, such as alternative transportation, live-work-play communities, and green infrastructure are urban-based examples of this transitioning culture. Still, the fundamental conflict between human desire and the essential requirements of certain species and ecosystems remains a prominent issue.

Johnson and Klemens (2005) eloquently characterize this conundrum:

> It is ironic that the resulting [urban] sprawl has at its root so many people’s desire to move closer to nature and away from the confines of the urban quagmire; in the process of this movement, however, the very essence of what is natural is being erased or eroded. (p. 199)

Ecologists, biologists, wildlife managers, and other scientific professionals continue to be at the forefront of conservation and environmental protection initiatives. Unfortunately, the scientific process is inherently reactionary; the recognition of deleterious trends can come after it is too late to change their course.

At the same time, the planners and public officials that guide human land use patterns are frequently disconnected with the concepts and methods involved in successful habitat and species protection. This disconnect emphasizes the importance of enhancing communication between the scientific community and planners. It also indicates the need for accessible models for identifying and protecting important conservation areas.

Human development is the leading issue for black bear habitat conservation and population persistence in Georgia (US FWS, 2012). It is essential that the planners and public officials orchestrating the human activities detrimental to black bear habitat (urban and transportation development) take preemptive measures to protect important natural areas. If implemented correctly, protected natural spaces can benefit humans by reducing pollution, creating opportunities for hunting and outdoor recreation, and even increasing adjacent property values (Hilty et al., 2006). Harmonization of human benefits and black bear ecological requirements will ensure the persistence of black bears in Georgia.

Corridor plans have used a variety of criteria to identify focal species for their projects. Some use “keystone species,” species that create or significantly affect certain landscapes (Hilty et al., 2006). Others have focused on threatened or endangered species because they require immediate attention. Black bear are valuable as an “umbrella species” for a southern Georgia corridor. “Umbrella” refers to an individual or group of species whose habitat requirements or connectivity needs are representative of many other species’ needs (Hilty et al., 2006). By managing for the needs of the umbrella species, many other species are protected as well. A number of corridor projects have successfully designed plans using black bear in this way (WHCWG, 2010; FL DEP, 2014; FFWCC, 2012; Cox et al., 1994).

Conclusion

In order to maintain viable black bear populations and minimize conflict with humans, habitat connectivity must be addressed at a regional scale. The development and implementation of a wildlife corridor network through Georgia will promote the species by maintaining access to the variety of habitats they require and help divert potential nuisance bears away from urban areas. Black bear will be encouraged to remain within the corridor by the connected suitable habitats and implementation of road crossing mechanisms. This will be particularly important in southern Georgia as the black bear population enlarges and disperses due to current growth rates and increased connectivity with Florida populations. Without a protected network of natural spaces, it is likely that black bear populations will weaken due to human conflict and reduced genetic diversity, denning sites, escape cover, and food (Moritz, 2002; Dixon et al., 2006). A wildlife corridor will assist black bear by maintaining access to the variety of habitats they require and encouraging the dispersal of individuals away from the areas where they were born. In this way, connectivity within Georgia will help expand the genetic diversity of the currently fragmented black bear populations.

Wildlife corridors designed for black bear will promote other native wildlife as well. The variety of forested, wetland, and early succession habitats that black bears prefer support numerous game and non-game species in southern Georgia. While many are not as wide-ranging as black bear, the corridors will protect existing habitat and provide linkages at a local scale as well.

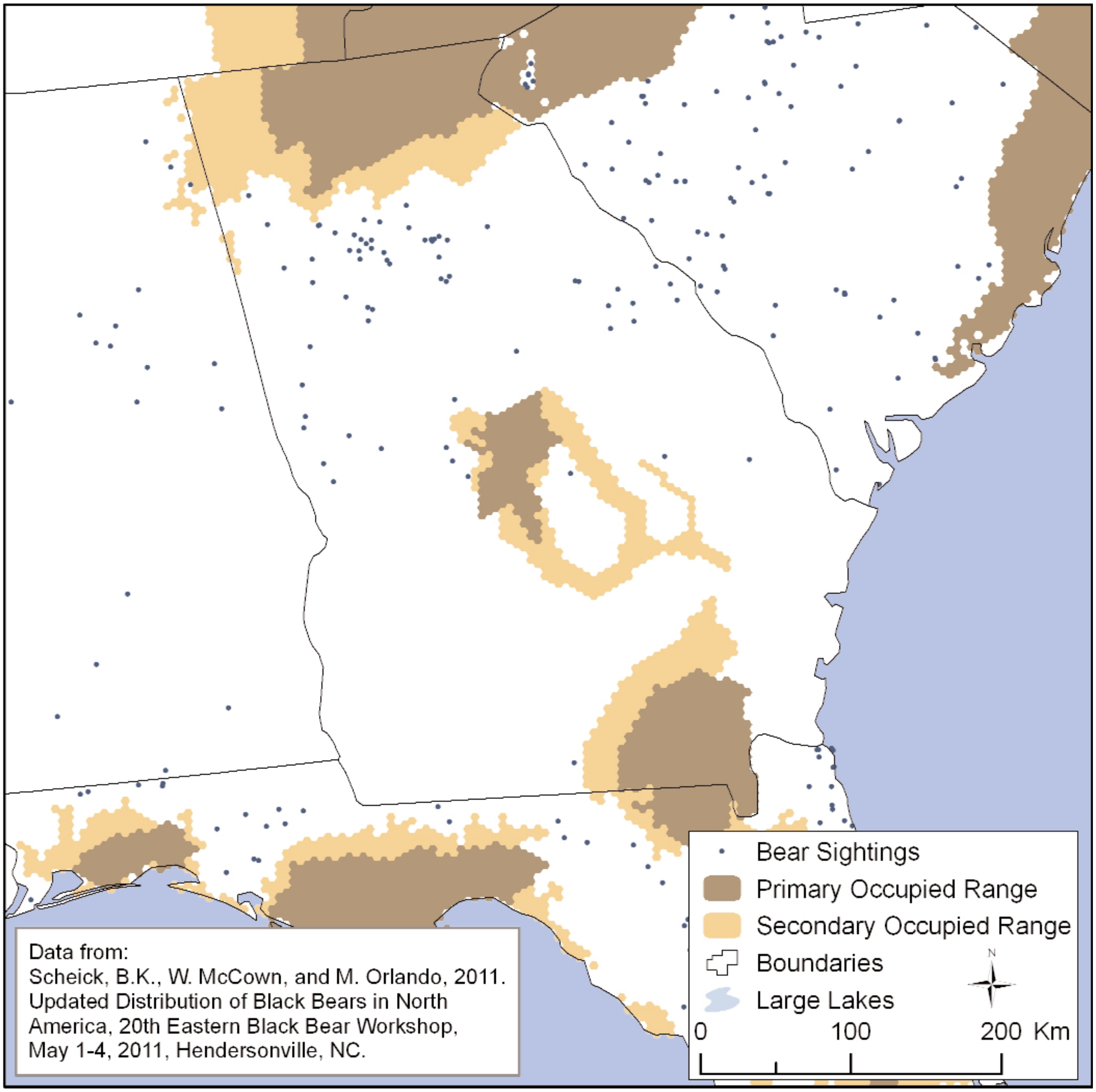


Figure 1.1: Distribution of black bear in Georgia (GA DNR, 2013)

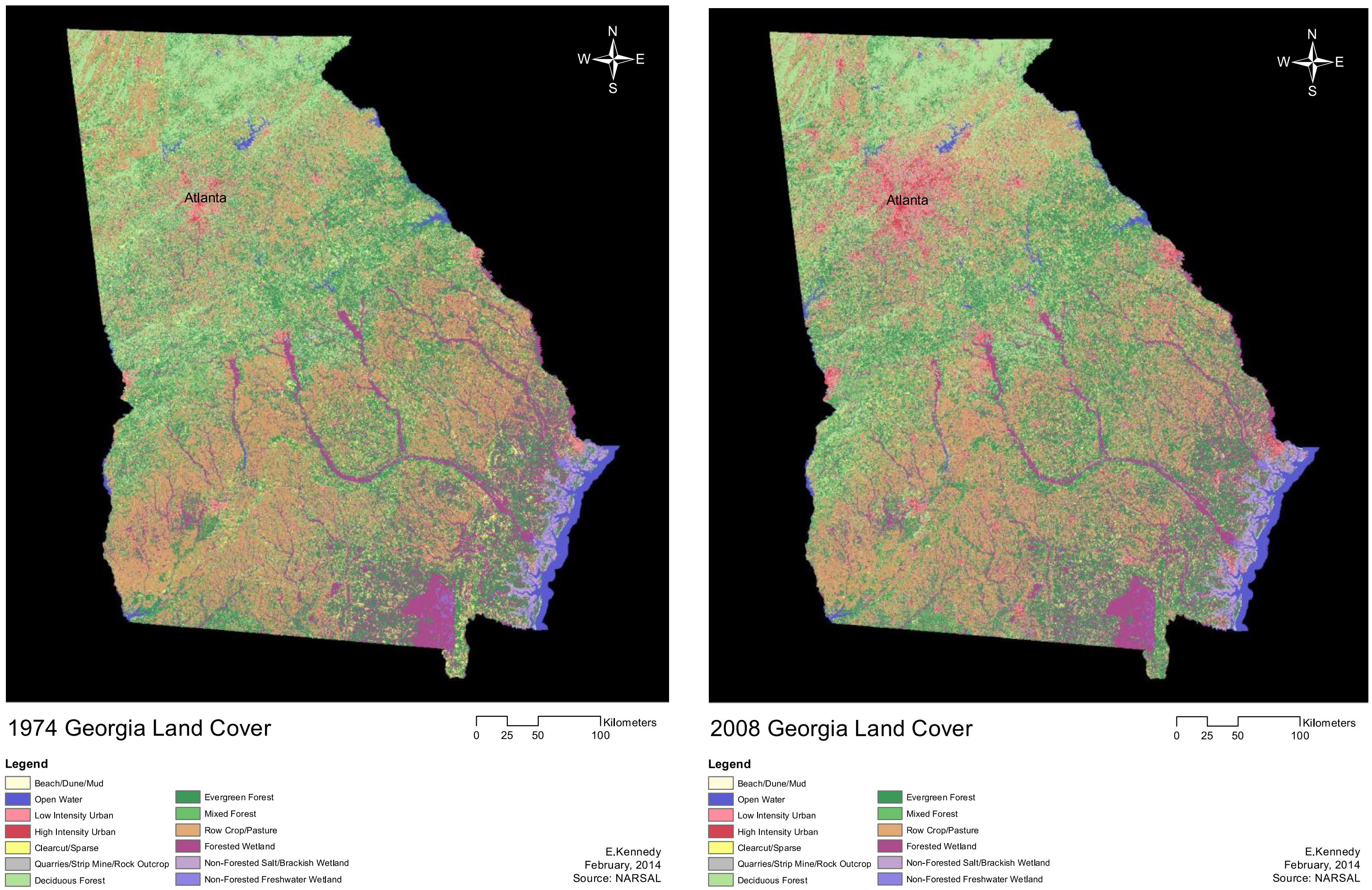


Figure 1.2a: Side-by-Side Comparison of Land Cover in Georgia, 1974 & 2008 (NARSAL, *Land cover trends*)

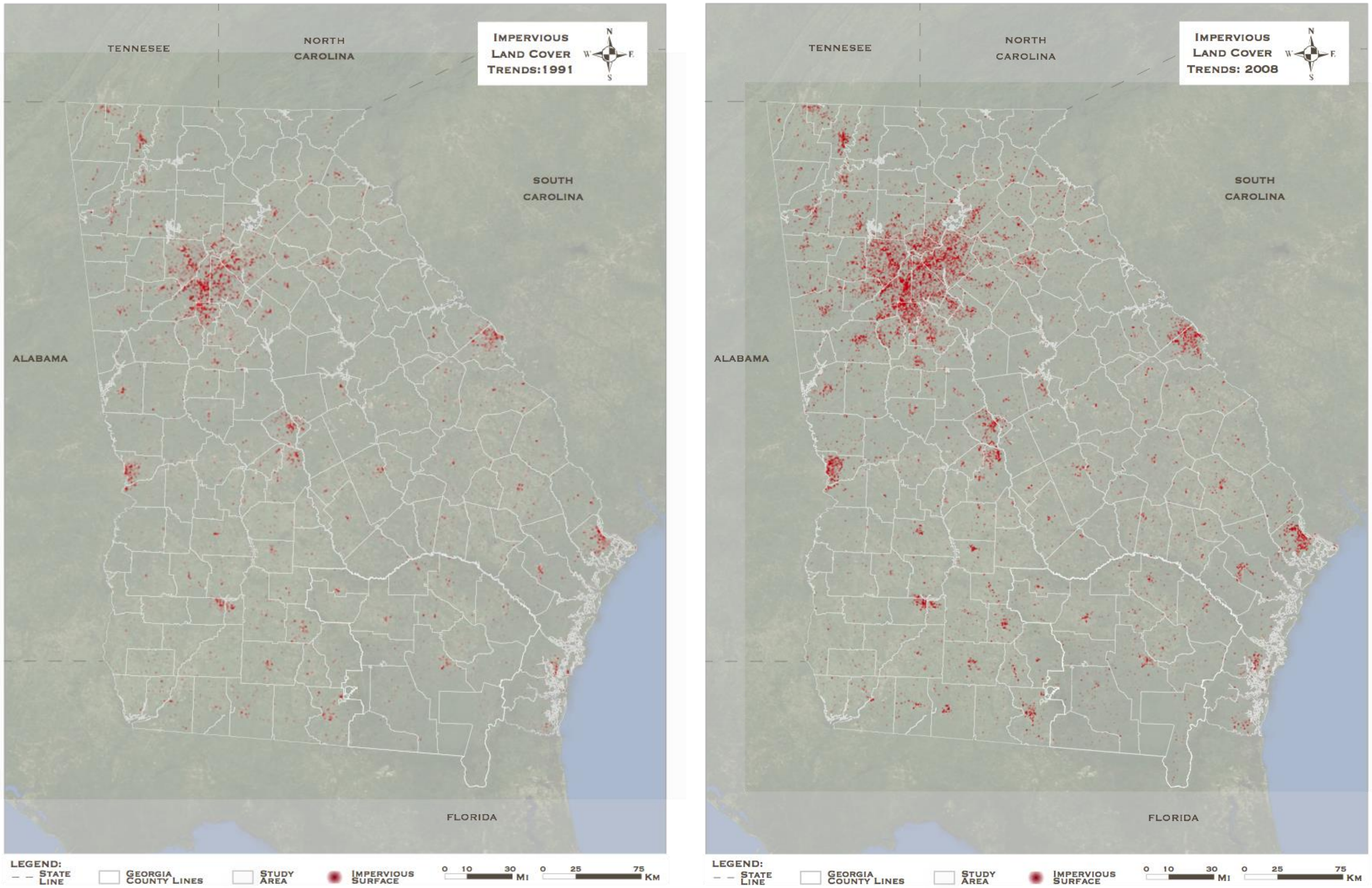


Figure 1.2b: Side-bySide Comparison of Impervious Surfaces in Georgia, 1991 & 2008 (NARSAL, *Land use trends*)

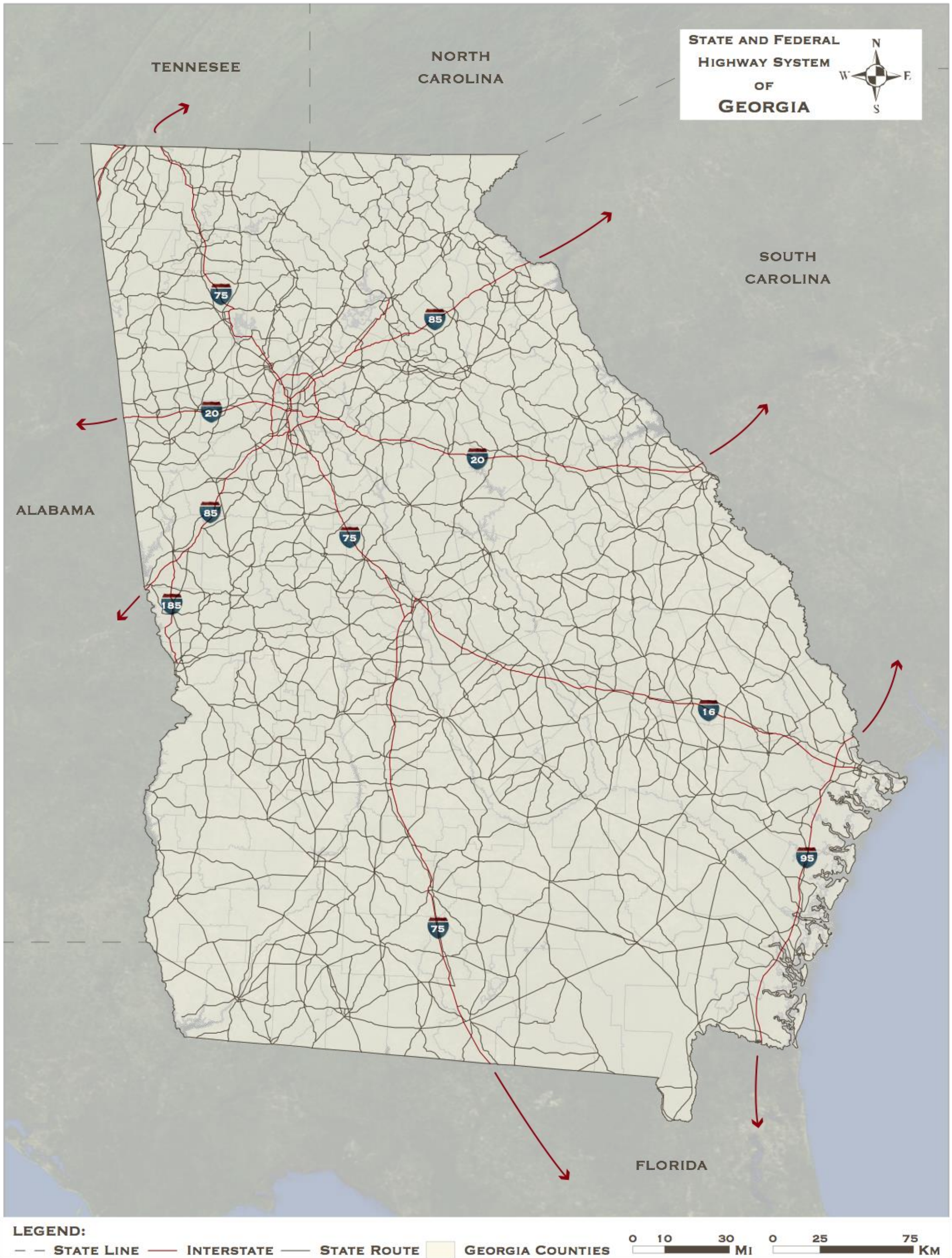


Figure 1.3: Georgia's Highway System (ESRI, USGS, GDOT)
Red arrows indicate the continuation of major interstates across state lines

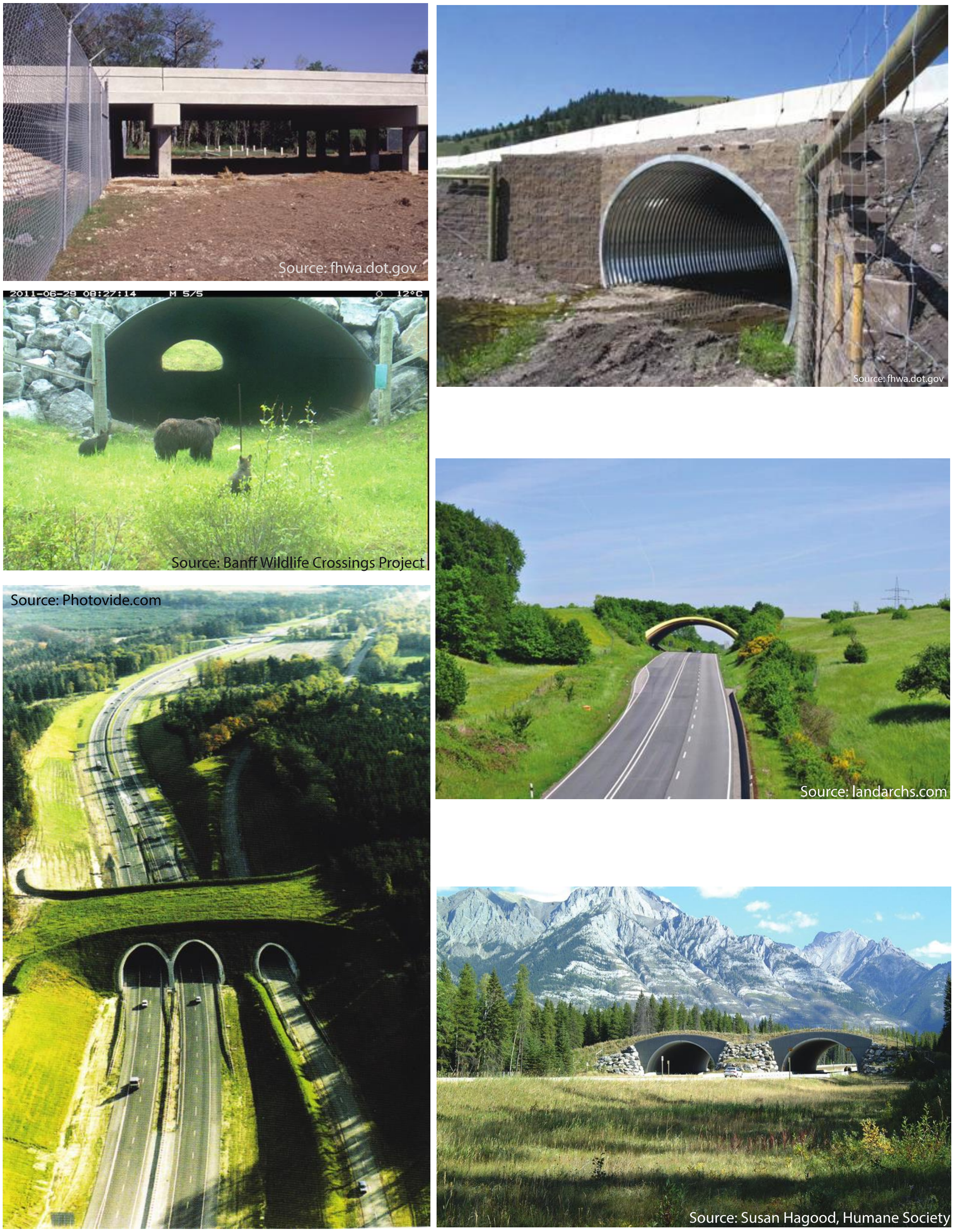
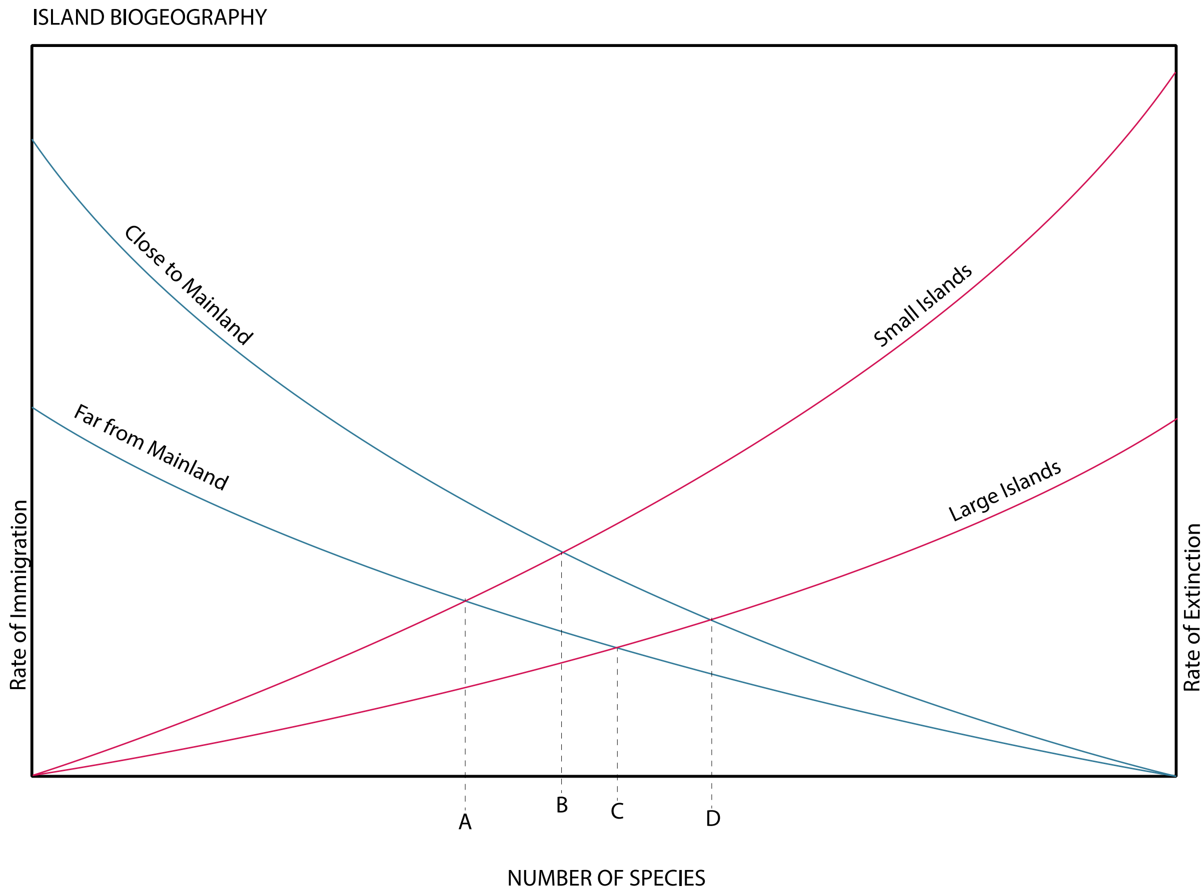


Figure 1.4: Examples of Wildlife Over and Under-pass Crossing Structures



The letters "A," "B," "C," and "D" indicate the predicted number of total species for each island scenario once populations reach equilibrium.

Figure 1.5: Island Biogeography (Adapted from MacArthur & Wilson, 1967)

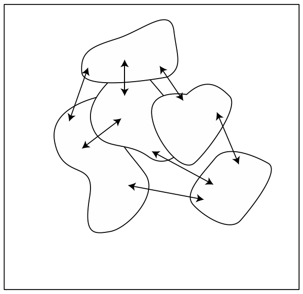
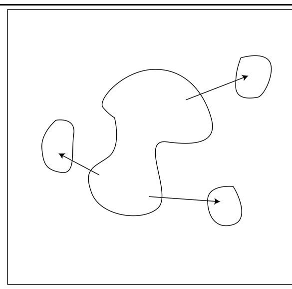
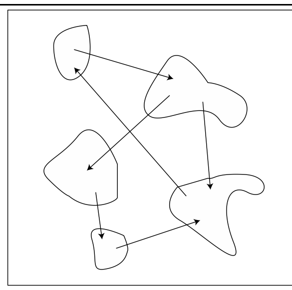
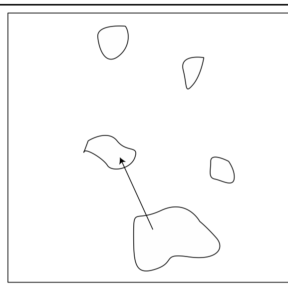
	*Patchy:* Local populations are well connected with frequent dispersals between them. If and when populations in a certain patch become extinct, the area is quickly recolonized. This is one of the most common patterns and is most resistant to overall extinction.
	*Core-satellite:* Highly similar to island biogeography theory and is also called "mainland-island." There is one large, extinction resistant population with a satellite population that is in a separate, smaller habitat patch. Dispersal is mostly unidirectional (main population to satellite location). When extinction of the smaller population does happen, decolonization occurs soon after. This makes the satellite populations relatively resistant to extinction as well.
	*Classic Levins:* A network of separated populations exists within a patchwork of habitats with dispersal, immigration, and extinction occurring within each one. Survival of the species with this population arrangement depends on the number of patches and the level of connectivity between them.
	*Nonequilibrium:* The arrangement of the populations is in patches similar to those in Classic Levins. However, the populations have little to no dispersal between one another. Also, there is no larger, secure population to recolonize patches that go extinct. This metapopulation configuration is at highest risk for complete extinction.

Figure 1.6: Metapopulation Figure representing and describing Harrison's (1991) Four Types of Metapopulations (Adapted from Hilty et al., 2006)

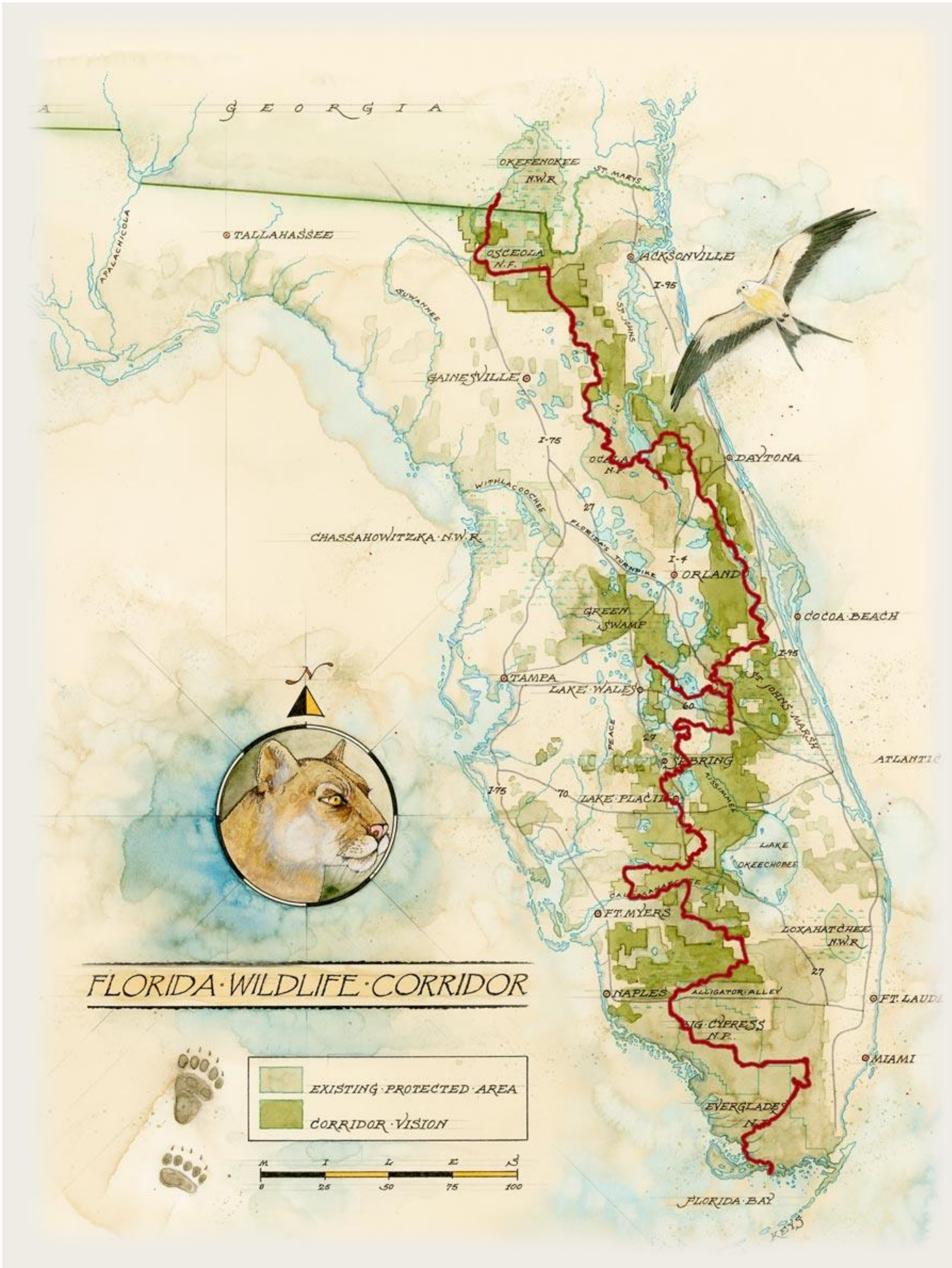


Figure 1.7: Florida Wildlife Corridor (Florida Wildlife Corridor, 2014)

CHAPTER 2

METHODS

Study Area Selection

The study area for this project runs from the border of Georgia and Florida, up to the Altamaha River (Figures 2.1a & 2.1b). The eastern and western edges include the counties adjacent to those containing Interstates 95 and 75, respectively. A list of the counties that comprise the study area can be found in Table 2.1. This area was chosen because it contains the Okefenokee National Wildlife Refuge (ONWR), which is home to the second-largest black bear population in Georgia. This population is of particular importance because the state of Florida is planning a network of conservation areas that will connect to ONWR. This has created the potential for population growth and increased genetic exchange within the area. It calls for the enhancement of black bear habitat connectivity within Georgia.

Table 2.1: Study Area County Population Trends (US Census 2000 & 2010)

County Code:	County Name:	Population (2010 Census):	Population Growth (2000-2010):
001	Appling	18,236	4.69%
003	Atkinson	8,375	10.1%
005	Bacon	11,096	9.83%
017	Ben Hill	17,634	0.86%
025	Brantley	18,411	18.34%
049	Charlton	12,171	18.37%
065	Clinch	6,798	(-)1.16%
069	Coffee	42,356	13.21%
101	Echols	4,034	7.46%
155	Irwin	9,538	(-)3.96%
161	Jeff Davis	15,068	18.8%
173	Lanier	10,078	39.22%
229	Pierce	18,758	20.21%
299	Ware	36,312	2.25%

305	Wayne	30,099	13.3%
Study Area Total:		**258,964**	**11.1%**
State of Georgia Total:		**9,687,663**	**18.3%**

The human population within the region, according to the 2010 Census, is 258,964 people. The highest population concentrations occur within the largest cities in the study area: Waycross, Douglas, and Jesup (Figure 2.1). Due to the predominance of farming and commercial timber in the region, the human population within the study area currently comprises less than three percent of the total population of Georgia (US Census Bureau, 2010). In fact, Georgia has the largest area of forested land cover in the South as a result of its extensive timber industry (Harper, 2012). Unfortunately, these commercial monoculture forests, for the most part, do not contain the complex ecosystems of naturally occurring forests.

While the current lack of urban areas is promising for future conservation efforts, land cover change analyses have identified a decrease in agricultural areas, a decline in non-commercial forest cover, and an overall increase in human development over the last thirty-four years (Table 2.2; Figures 1.2a & 1.2b). The population growth figures in Table 2.1 indicate a population rise greater than 10% in more than half of the study area counties. These trends are highlighted by the highway expansion and improvement projects occurring throughout the area (GDOT, *Active projects*).

Table 2.2: NARSAL State of Georgia Land Cover Data (NARSAL, *Land cover trends*)

Land Cover Class	**1974**	**1985**	**1991**	**1998**	**2001**	**2005**	**2008**
Low Intensity Urban (Acres)	610,468	799,863	1,700,761	1,837,606	2,902,055	2,958,806	3,055,732
High Intensity Urban (Acres)	128,901	163,726	229,930	247,681	336,796	458,597	600,385

The study area does not include counties crossed by the two main interstates (I-75 and I-95) because research has demonstrated black bears' extreme avoidance of major roadways (Brody & Pelton, 1989). While it is impossible to avoid all significant roadways in southern Georgia, I-75 and I-95 represent the most impassible highway features in the region due to their large footprint, high traffic volumes, and high vehicular speeds.

The Altamaha River was selected as a northern boundary for the study area (Figure 2.1b). The river runs 137 miles from central Georgia, south of the city of Macon, eventually reaching the Atlantic coast, south of Savannah. Both sides of the Altamaha contain unique and valuable habitat for black bear and other native species in Georgia (GA DNR, 2005). Historically used to transport people, agricultural goods, and timber, the Altamaha is still affected by pollution and development (Altamaha River Partnership, *History*; Georgia Water Coalition, 2012). A recent increase in public awareness of the Altamaha's subjection to pollution, industry, and development has encouraged restoration and protection of the river and the land bordering it.

In 2005, the Georgia Department of Natural Resources (DNR) identified the Altamaha as a "high priority site" in the Georgia State Wildlife Action Plan. Since then, a significant portion of land along the river has been placed into conservation easements or purchased for permanent conservation by a variety of public and private entities (Figure 2.2). The Nature Conservancy recently contributed a significant addition to the protected shoreline, purchasing 6,277 acres that span almost nine miles of the Altamaha (Nature Conservancy, 2013). The extensive public, nonprofit, and private initiative to protect the Altamaha River and surrounding lands makes it an ideal preliminary target for black bear connectivity.

In addition, the Altamaha's linkage with the Ocmulgee River creates the opportunity for future corridor extensions to Georgia's central black bear population (Figure 2.6). This central population, located adjacent to the Ocmulgee River and south of Macon, is the smallest black bear population in Georgia. It is currently presumed to be genetically isolated from the southern and northern black bear communities (Cook, 2007).

Brief Introduction to Geographic Information Systems (GIS)

Esri, a current leader in geospatial software and data development, defines GIS as: "a geographic information system (GIS) [that] integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information" (n.d.). There is no definite origin for GIS; documented computer-based use began in the mid-1900s. GIS offers faster and more advanced data organization, interpretation, and geographic analysis than previously available in printed charts and maps. The ability to input data, attach it to a physical location, and manipulate it to illustrate current environments or project future conditions has been invaluable for researchers, scientists, planners, and countless others interested in landscape analysis and visualizing trends. Access to satellite imagery has further enhanced GIS, allowing for large-scale land cover analysis. Recently, use of this technology has been extended to the general public through programs such as Google Earth.

While a powerful tool, GIS relies on data defined and created by the user. It is important that input data and parameters are based on existing research. In identifying potential wildlife corridors, one must gain an understanding of the influential landscape factors and the behavioral tendencies of the focal species in order to properly develop a geospatial model that accurately maps black bear habitat needs. This project will utilize pre-existing geospatial data to analyze existing, redefined, and created land cover and land use data and map habitat requirements between existing protected areas.

Characterization of Black Bear Habitat in the Study Area

A variety of habitat types within the Southern Coastal Plain and Southeastern Plain support black bear in Georgia (GA DNR, 2005). It is difficult to pinpoint habitats of highest value for black bear because food availability shifts throughout the year and they are a highly flexible species (Maehr et al., 2001). Females with cubs tend to be most selective about their surrounding habitats. This is because they are anchored to smaller home ranges while raising their young and need a greater variety of habitat types within a close proximity (Powell, 1986).

Black bear will enter open areas, usually under cover of darkness, but generally prefer forested habitats with a mast-producing understory (FFWCC, 2012; Maehr et al., 2001; Cook, 2007). Forests with dense understories are preferred over those with minimal shorter vegetation (Maehr et al., 2001). Den sites are frequent in these tightly vegetated areas or in sections of forest with fallen trees. Low-growing trees and shrubs tend to produce the majority of fruits and insects in the region as well. In order to maintain a productive understory, forest canopies must be periodically thinned to allow sunlight to reach the vegetation below. Many of the high-value mast producers, such as persimmon (*Diospyros virginiana*), blueberries (*Vaccinium spp*.), and blackberries (*Rubus spp.*), require at least partial sunlight. Palmetto berries (*Serenoa repens*) and gallberries (*Ilex glabra*) are some of the most common forest-dwelling mast-producers taken by black bear in southern Georgia. In the past, systems were frequently exposed to fire and other mechanisms that prevented an overgrowth of large-canopied hardwoods. Today, controlled burning is being promoted as a management tool but the labor, cost, and conflict with adjacent urban areas hinders its optimal use.

Bottomland forests and swamps are another set of attractive habitats for black bear. As long as nearby upland areas are available for denning, these hydric systems can support a black bear population. This is clear in the case of Okefenokee Swamp, home to the majority of the second-largest black bear population in Georgia. In these bottomland forests, black bears feed mainly on available soft masts like black gum (*Nyssa sylvatica*) and dewberry (*Rubus trivialis*) (Cook, 2007).

Commercial pine stands are human-altered forests but are frequently utilized by black bear. Timber stands offer the species a route of travel generally devoid of humans, busy roadways, and other potential threats. However, mature commercial timber stands generally do not offer a significant amount of food for black bear because of their dense canopy cover. These areas also have the tendency to change drastically, due to harvesting, and clear-cuts are of relatively low use to black bear if the area is chemically treated.

It is plausible that black bears utilize timber stands because of a lack of available native forest. This is particularly apparent in Georgia, where approximately 98% of the state's forests are commercially harvested, to varying degrees (Harper, 2012). Some steps have been taken to encourage timber stand management techniques that promote multidimensional habitat throughout the growing and harvesting process. The Sustainable Forestry Initiative (SFI) provides guidelines, certifications, and helps to ensure a higher market price for participating companies' products. Unfortunately, the maintenance of wildlife habitats within a lucrative timber stand is high-cost and labor intensive. For this reason, the majority of commercial stands in southern Georgia remain a monoculture.

Clearings adjacent to forested habitat can be as important as the forested area, depending on the season. In early spring and summer these clearings provide sustenance in the form of insects, cold-weather forages such as clover (*Trifolium spp*.), and soft masts (Cook, 2007; M. Chamberlain, personal communication, January 28, 2014; M. Hooker, personal communication, January 7, 2014). These edge habitats also attract white-tailed deer whose young are readily taken by black bear (M. Chamberlain, personal communication, January 28, 2014). Early succession habitats are conducive to soft mast producers like blackberries (*Rubus spp.*) and pokeberries (*Phytolacca americana*), both high preference foods for the species (K. Miller, personal communication, October 30, 2013).

Agricultural lands also attract black bear during certain times of the year. Row-crops can provide a source of carbohydrate-rich foods in the fall, particularly peanuts and corn (M. Chamberlain, personal communication, January 28, 2014; M. Hooker, personal communication, January 7, 2014). Despite the caloric value of certain crops, they do not provide much cover for black bear for most of the growing season. Due to the extensive nature of row-crops and pastureland in southern Georgia, black bear in the area rely on drainage ditches, overgrown fencerows, and other thin strips of vegetation to navigate between forested patches (M. Chamberlain, personal communication, January 28, 2014; M. Hooker, personal communication, January 7, 2014). Other agricultural products, like pecans, peaches, and blueberries, are sources of black bear food and provide some consistent cover for travel.

Overall, it appears that black bear habitat-use is primarily dictated by the seasonal availability of foods and access to forest cover. Females tend to be more discretionary when raising cubs since they require reliable denning sites and sufficient food within their smaller home ranges. It appears that habitats of highest value are located away from major roadways or human development. These factors will be reflected in the geospatial model.

Geospatial Model and GIS Analyses for Corridor Identification

A number of studies have implemented GIS models to identify existing habitat and key areas to connect for black bear. Cox, et al. (1994) analyzed existing native wildlife populations, human development, native land cover, agricultural land, and other landscape characteristics to identify important regions for black bear, Florida panther, and other wildlife native to Florida. The SE GAP (2011) combined topographic data, land cover, species geographic ranges, and species-habitat associations to identify potential habitat for black bear and other native species in Georgia.

The GIS model used for this project is derived from the methodology implemented by the Washington Wildlife Habitat Connectivity Working Group's (WHCWG) for their Washington Connected Landscapes Project (2010). The Connected Landscapes Project took a collection of umbrella species into account, including black bear. Due to the limited breadth of this project, black bear is the only species considered. The model will use WHCWG's qualification and grading system for black bear in the GIS analyses. A complete modeling and analysis flow-chart is illustrated in Figure 2.5.

A "resistance" raster, created from overlaying roads, distances from roads, housing density, and land cover data, guides the identification of optimal pathways between conservation sites within the study area. Higher resistance values reflect an increased difficulty in black bear movement through an area. The Connected Landscapes Project incorporated land cover, housing density, roadways, forest structure, and topographical features to create their resistance raster (WHCWG, 2010). Similar projects have used roads, forests, urban areas, and elevation as significant landscape elements when characterizing landscape connectivity for black bear (Cushman, McKelvey, & Schwartz, 2009; Cushman, McKelvey, Hayden, & Schwartz, 2006). For this project, slope and elevation data are not included because there is less than a 500-foot elevation change across the entire study area. No reports were found that identify any significant topographical barriers for black bear in southern Georgia.

Forest structure is also not included in this analysis, due to a lack of available data. Housing density, road type and proximity, and land cover data were categorized and valued based on the methods identified in the *Washington Connected Landscapes Project* (WHCWG, 2010) and the *Closing the Gaps in Florida's Wildlife Habitat Conservation System* report (Cox et al., 1994). Resistance values and ranking methodologies from other black bear suitability analyses were examined (Cushman, Landguth, & Flather, 2012; Cushman, et al., 2006). However, the resistance values used could not be applied for this study because they fell significantly below Linkage Mapper's recommended maximum resistance values of at least 100 (McRae & Kavanagh, 2014).

Roads

Roadway analysis was simplified from the WHCWG's criteria due to the relatively low human population and highway traffic volume in the study area. Road data was obtained from GDOT for each county within the study area. State and federal highways were then extracted from the overall road network for analysis. Average annual daily traffic (AADT) values were recorded for each road segment based on 2012 Georgia Department of Transportation data to account for the greater crossing difficulty across roads with higher traffic volumes (WHCWG, 2010). Highway sections were then categorized, depending upon their AADT levels. "Low-traffic highways" are defined as having AADT values less than 400, "high-traffic highways" have greater than 5000, and "medium-traffic highways" fall in-between (US FHWA, 2009; Transportation Research Board [TRB], 2011). Local roads were not included in the road-level analysis because black bears in the area do not exhibit significant avoidance of such low-use roads (Brody & Pelton, 1989).

Roads were buffered 500 and 1,000 meters, respectively, to account for the varying highway avoidance distances of black bear according to traffic-levels (Brody & Pelton, 1989; WHCWG, 2010). Road centerlines were erased from 500-meter buffers, which were erased from 1,000-meter buffers, to avoid overlapping resistance values. Road centerline and distance data were converted to a raster and reclassified according to their traffic volumes and buffer distances (Figure 2.5).

A number of freight railways cross through the study area and are owned by three main entities: Norfolk Southern, CSX, and St. Mary's Railway West. There is a lack in literature clearly identifying the effects of railroads on wildlife. Some sources suggest adverse effects from associated noise and habitat loss during railway construction. Others identify wildlife use of railroad corridors for movement (Trewhella & Harris, 1990). Railroads are not identified as a significant threat in the black bear management plans of neighboring southeastern states (NCWRC, 2012; Ruth, 2011; FFWCC, 2012). Furthermore, the intermittent train schedule and overall low density of railways in the study area minimize any barrier effect the system may have on wildlife in the area. Existing railways were not included in the resistance raster due to the lack of data identifying railroads as a barrier or threat to wildlife in the area.

Housing Density

Housing density was calculated at housing units per acre. Housing unit and census block area data were taken from 2010 TIGER Census data. Housing densities were grouped into three categories: "low density" at less than ten units per acre, "medium density" between ten and eighty units per acre, and a "high housing density" of greater than eighty units per acre. A raster was created from the three density categories. Raster values were reclassified and given resistance scores “0,” “10,” and “100,” for the low, medium, and high-density areas, respectively (WHCWG, 2010; Figure 2.5).

Land Cover Data Collection and Organization

Land cover data was obtained from the Southeastern Gap Analysis Project (SE GAP) that is in cooperation with the Natural Resources Spatial Analysis Lab (NARSAL). This data was re-organized into categories and subcategories based on professional opinion, published studies, and the SE GAP Species Modeling Report for black bear (SE GAP, 2011). Categories reflect each habitat’s use by black bear in southern Georgia. Professional opinion and published studies were used to create and apply this ranking system. Preliminary attempts to separate valuable black bear habitat into two levels based on cover and food availability were abandoned due to lack of forest structure data and the seasonal ambiguity of the project. A complete table of the study area land covers names and categories can be seen in Figure 2.5.

High quality natural habitat for black bear was defined as containing cover and/or food for some portion of the year. Food and cover are important components that will help attract the black bears through the region and provide security during travel. These primarily consist of forested and wetland habitat types. Contiguous land covers within this category were then subdivided into areas greater than and less than 0.15 square kilometers. Those greater than 0.15 square kilometers represent existing areas of highest quality and reflect the important black bear habitat size identified in *Closing the Gaps in Florida’s Wildlife Habitat Conservation System* report (Cox et al., 1994).

For the purpose of this initial design, seasonal changes are not incorporated into the analysis. Cover remains moderately available throughout the year because of the relatively mild winters in the study area. Subsequent analysis will be needed to assess how much food is available to black bears within the corridor sections at specific times of the year. Despite seasonal changes, the corridors will be viable networks because they are intended to primarily serve as connective routes and do not need to fulfill permanent home range requirements.

Agricultural areas were divided into two categories: those within 300 meters of the greater than 0.15-kilometer high quality habitat and those beyond that distance. The 300-meter distance is derived from the model used in the SE GAP black bear analysis (2011). These areas were identified using Euclidean Distances from the above-described highest quality habitats. As with commercial timber stands, lack of reported conflict between farmers and black bear in the region offsets the need to completely restrict the species' use of these human-influenced areas (G. Nelms, personal communication, February 24, 2014).

Land covers associated with urban development are grouped into a single category since the corridor should avoid cities, roadways, and development when possible. This will help discourage the potential for injury, property damage, and attraction of scavenging bears. Published studies and repeated accounts by researchers of the serial tendencies of nuisance bears indicate the importance of establishing black bear corridors at a distance from urban environments.

Roadway and road-edge land cover data is included in the SE GAP "low, medium, and high-intensity developed" land cover categories. Since right-of-ways are not delineated from urban development in the land cover data, the overlapping highway layer, discussed above, will account for the additional barrier-effect that highways have on black bear.

All remaining land cover types were grouped into a single category representing areas of no particular threat or habitat value. Due to the generalist tendencies of black bear, there are few land cover types that they will completely avoid (Maehr et al., 2001; M. Chamberlain, personal communication, January 28, 2014; G. Nelms, personal communication, February 24, 2013). Individual black bears have been observed traveling distances of two to three kilometers across entirely open fields (M. Hooker, personal communication, February 5, 2014). For this reason, any non-urban land cover that offers little refuge or food can still make up a portion of the corridor. Until conservation lands are expanded and improved land management practices are brought into the area, attempts at restricting urban development on these patches may be necessary for protecting a cohesive network for the future.

Land cover data was reclassified based on the final eight categories. Resistance values for urban areas, water, agricultural lands, and habitat types are based on the values used for black bear in the Connected Landscapes Project (WHCWG, 2010, p. A-71). Open water is given a higher score as a reflection of the WHCWG project. Black bears are avid swimmers and are known to cross major waterways (G. Nelms, personal communication, February 24, 2014; M. Hooker, personal communication, January 7, 2014). However, open water can act as a barrier to less fit individuals and does not have habitat value by itself (Maehr et al., 2001). Because the black bear habitat in southern Georgia differs from those identified in the Connected Landscapes Project out of Washington State, black bear habitat values were correlated based on relative quality for the two black bear populations. These categories were then given resistance values accordingly (WHCWG, 2010).

The existing land cover in the study area can be seen in Figure 2.4. A full list of land cover types in the study area and their corresponding categories and resistance values can be found in Figure 2.5.

Conservation Lands

Existing conservation lands will represent the focal areas for the corridor to connect. Conservation lands are managed natural areas that will usually remain protected in perpetuity. ONWR is the largest conservation area in the study area and is the primary range of the southern Georgia black bear population and is the southernmost focal area (Figure 2.1b). Conservation areas along the Altamaha Corridor will make up the northernmost destination points. Protected areas in-between will serve to create a network of corridors within the study area that run between the target areas of ONWR and the Altamaha.

Geographic information for conservation lands in Georgia was obtained from the National Resources Spatial Analysis Laboratory (NARSAL, 2012). It contains owner, management, and land-use information for any land "assigned conservation measures that qualify their intent to manage lands for the preservation of biological diversity and other natural, recreational, and cultural uses" (NARSAL, 2012). This data was created in cooperation with Georgia DNR and the US Geological Survey. Areas specifically dedicated to conservation of wildlife and natural habitat were extracted from this layer to represent target areas for the corridor to connect. The Three Kings WMA was removed from the data because it is no longer a conservation easement. Flat Tub WMA was added to the existing data since it was created after 2012.

Only conservation lands with areas greater than 0.15 square kilometers were used in the final analysis. This reflects the same minimum habitat size requirement as defined in the land cover section. Smaller conservation lands are valued based upon their existing land cover attributes, described in the previous section.

Linkage Mapper

The Linkage Mapper ArcGIS Toolkit was developed to model optimal connective pathways between areas identified as particularly important for conservation (WHCWG, 2010; McRae & Kavanagh, 2012). Road, housing density, and land cover data rankings are added together to create a single "resistance" raster layer. Each raster pixel value represents the difficulty level a black bear has crossing through that section of land. Areas of lowest resistance values are indicative of desirable habitat with low human activity.

The significantly sized conservation lands, as described in the previous section, represent the core areas to connect across the resistance raster. Linkage Mapper is used to calculate the Euclidean distance, least-cost pathways, and cost-weighted distances between these Georgia conservation lands. The initial resistance raster values were subsequently doubled to create a second resistance raster. Linkage Mapper was run again with the second resistance raster as a sensitivity analysis, testing whether significant changes resulted from the shift in resistance values. A complete description of the tools and Python script utilized by Linkage Mapper can be found in the *Linkage Mapper User Guide* (2014), available at: https://code.google.com/p/linkagemapper/downloads/detail?name=LinkageMapper1_0_8.zip.

Pinchpoint Mapper (Circuitscape)

Circuitscape has been linked into the Linkage Mapper Toolkit extension "Pinchpoint Mapper" (McRae & Shah, 2009; McRae, 2012). This extension calls on Circuitscape to identify "pinch points" by assessing the least-cost corridors output from Linkage Mapper (McRae, 2013). "Pinch points" are locations along the Linkage Mapper-identified least-cost corridors that have higher resistance values. These areas were calculated using the pairwise mode in order to assess the connectivity between each conservation area in the study region. This mode determines constriction points between each conservation area along the corridor segments (McRae & Shah, 2013). These "pinch point" areas are indicative of landscape barriers, such as roads, that fall within the corridor.

The cost-weighted distance cutoff for this project, which determines the maximum corridor width, is set to 60 kilometers. This reflects the "limits of 'frequent' dispersal" identified in *Closing the Gaps in Florida's Wildlife Habitat Conservation System* (Cox et al., 1994) report's section on black bear (p. 51). There is no need to account for potential territorial conflicts within the corridor space in this measurement since local bears are reported to have a generally high tolerance for other individuals at a relatively close proximity (Powell, 1986; M. Chamberlain, personal communication, January 28, 2014). While 60 kilometers is less than corridor width values identified by other black bear corridor projects, this number has been applied to adjacent populations and should best represent the dispersal behaviors of the southern Georgia black bears in focus (WHCWG, 2010; Cox et al., 1994).

The Pinchpoint Mapper output data can then be analyzed with regards to barrier type and degree. Mitigation methods are suggested in the following chapter. A complete description of the tools and Python script utilized by Circuitscape can be found in the *Circuitscape User Guide* (2013), available at:

https://circuitscape.googlecode.com/files/Circuitscape_3.5.8_User_Guide_rev3.pdf.

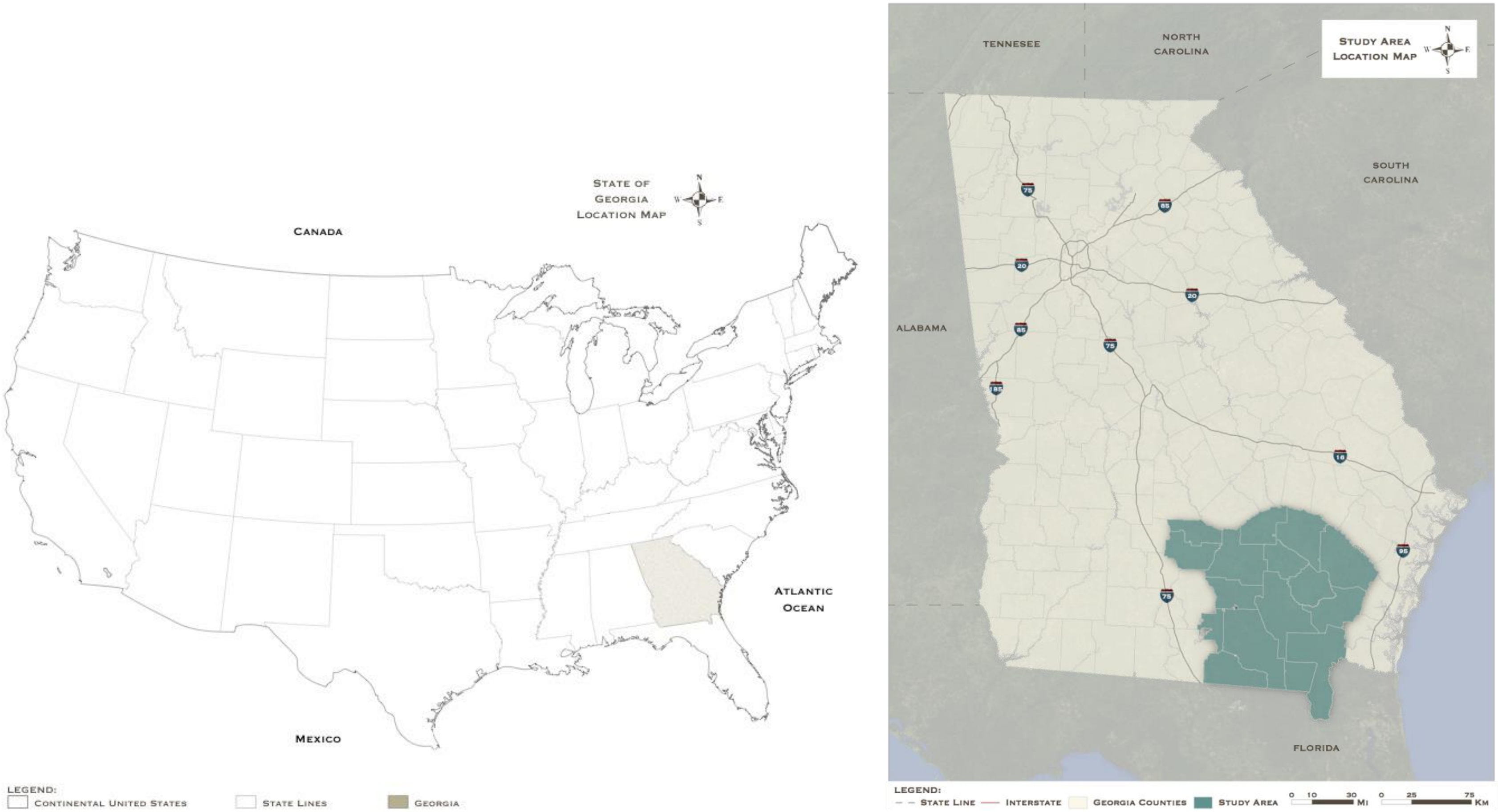


Figure 2.1a: Study Area Location: Georgia, USA

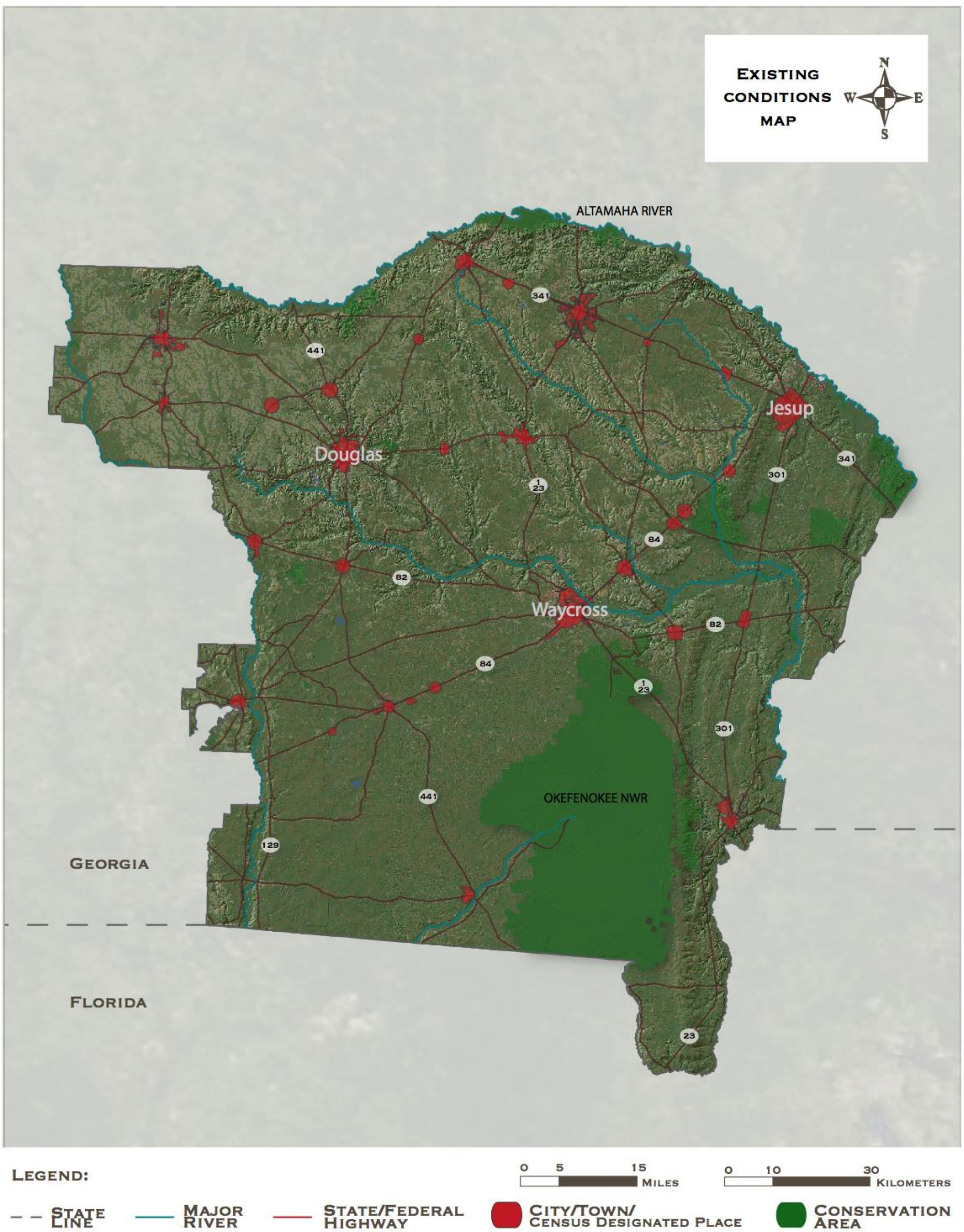


Figure 2.1b: Study Area Conservation Lands and Major Cities

Figure 2.2: Altamaha River Corridor

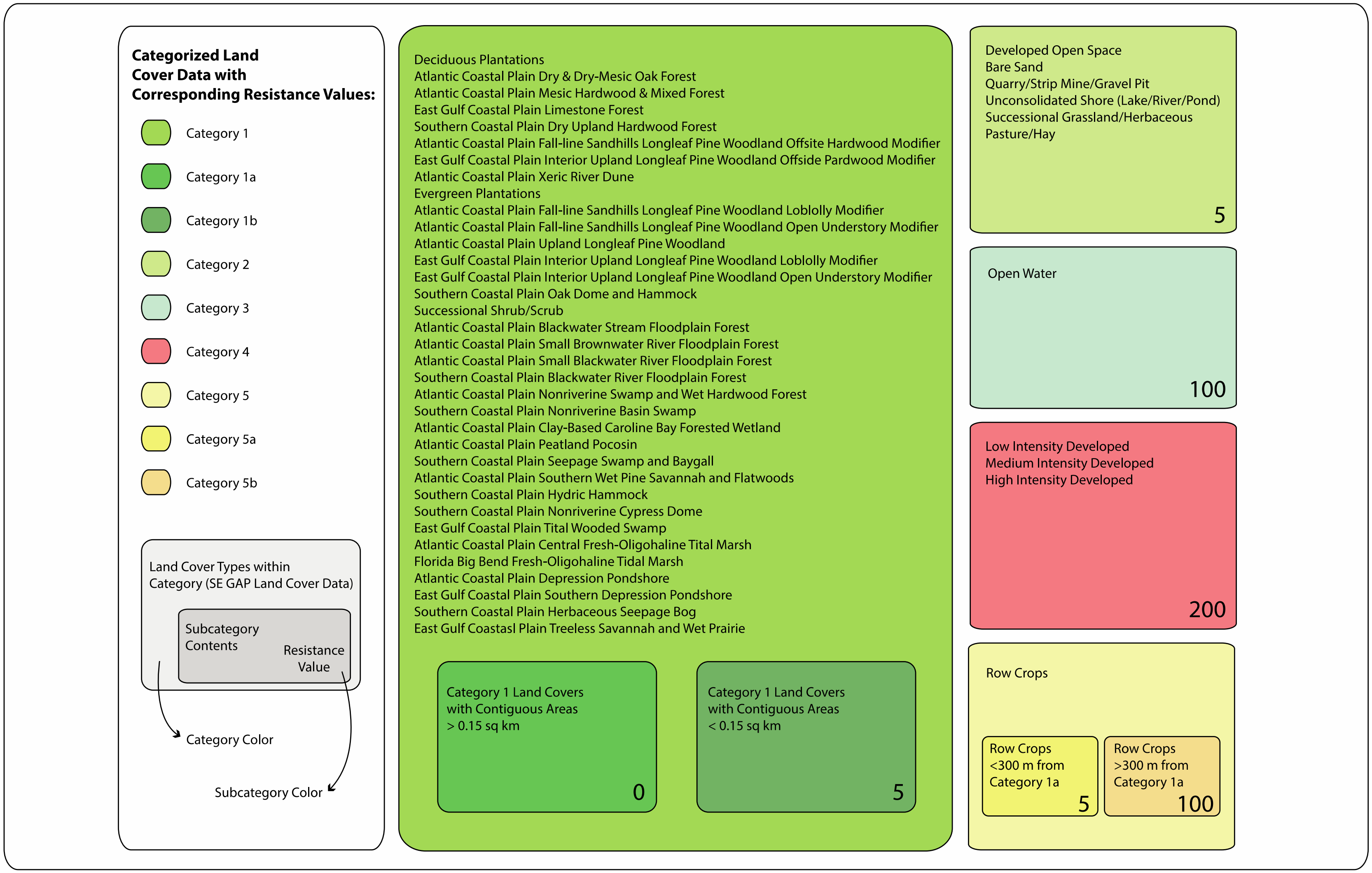


Figure 2.3: Land Cover Classifications

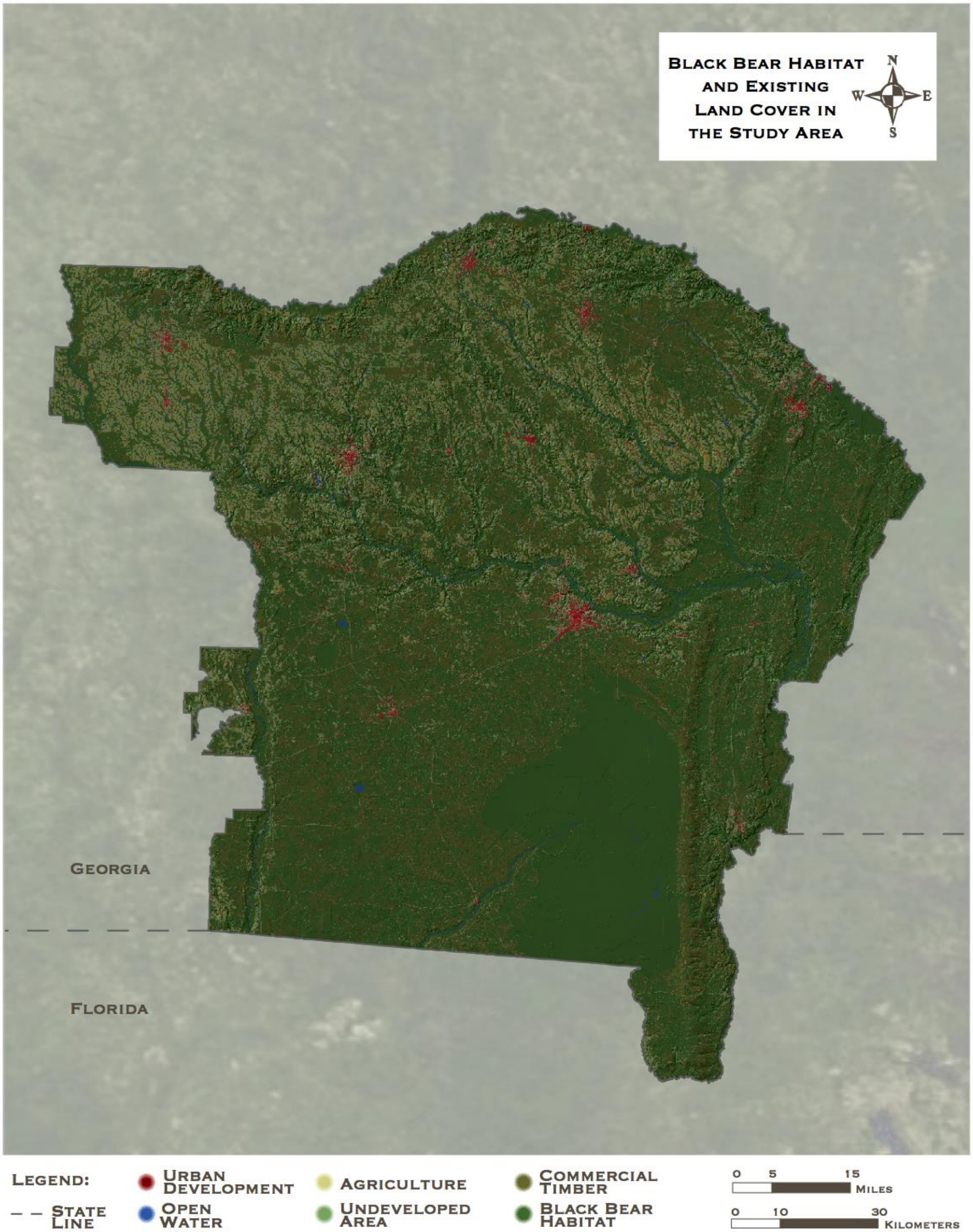


Figure 2.4: Existing Land Cover and Black Bear Habitat in the Study Area

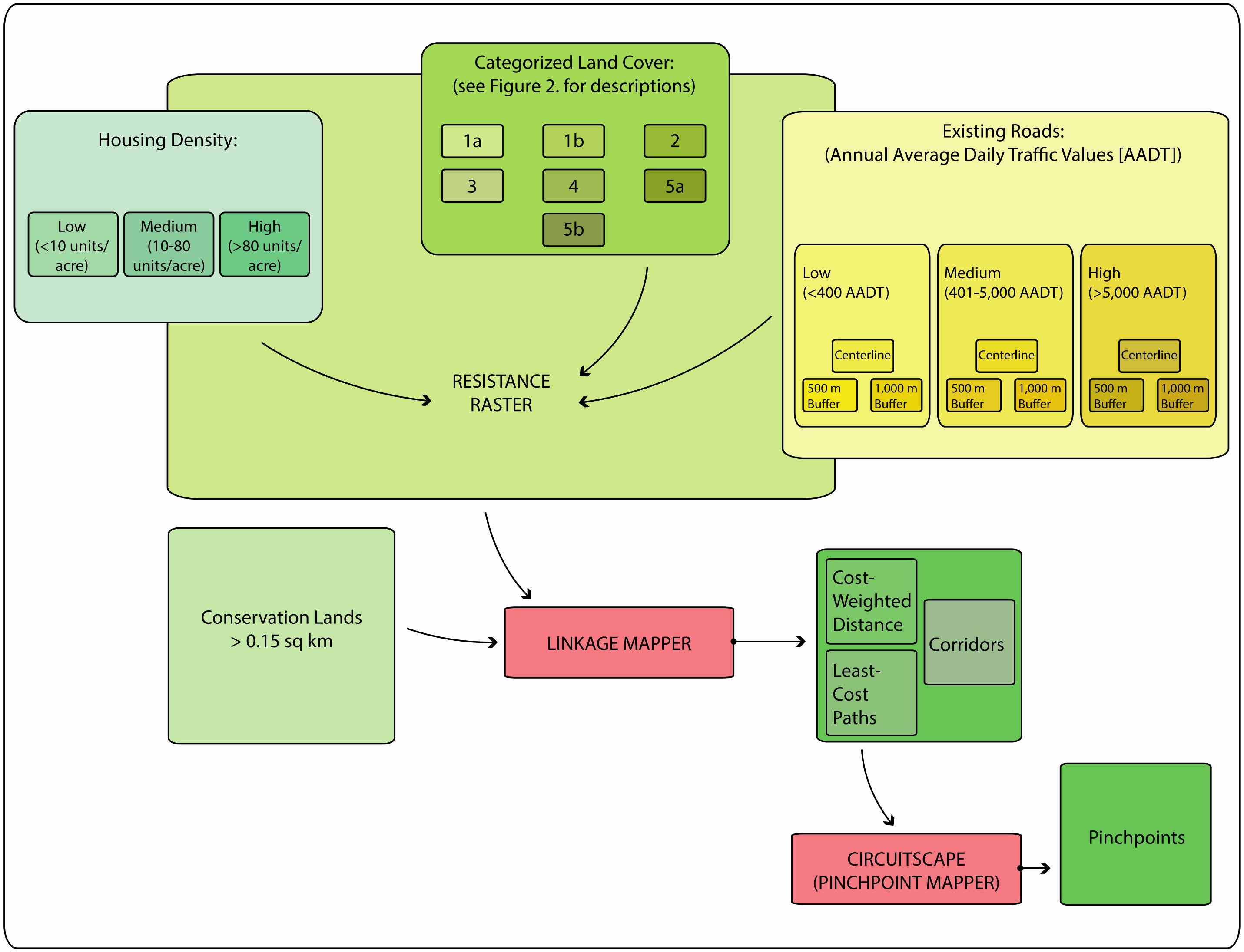


Figure 2.5: GIS Analysis Flow-chart

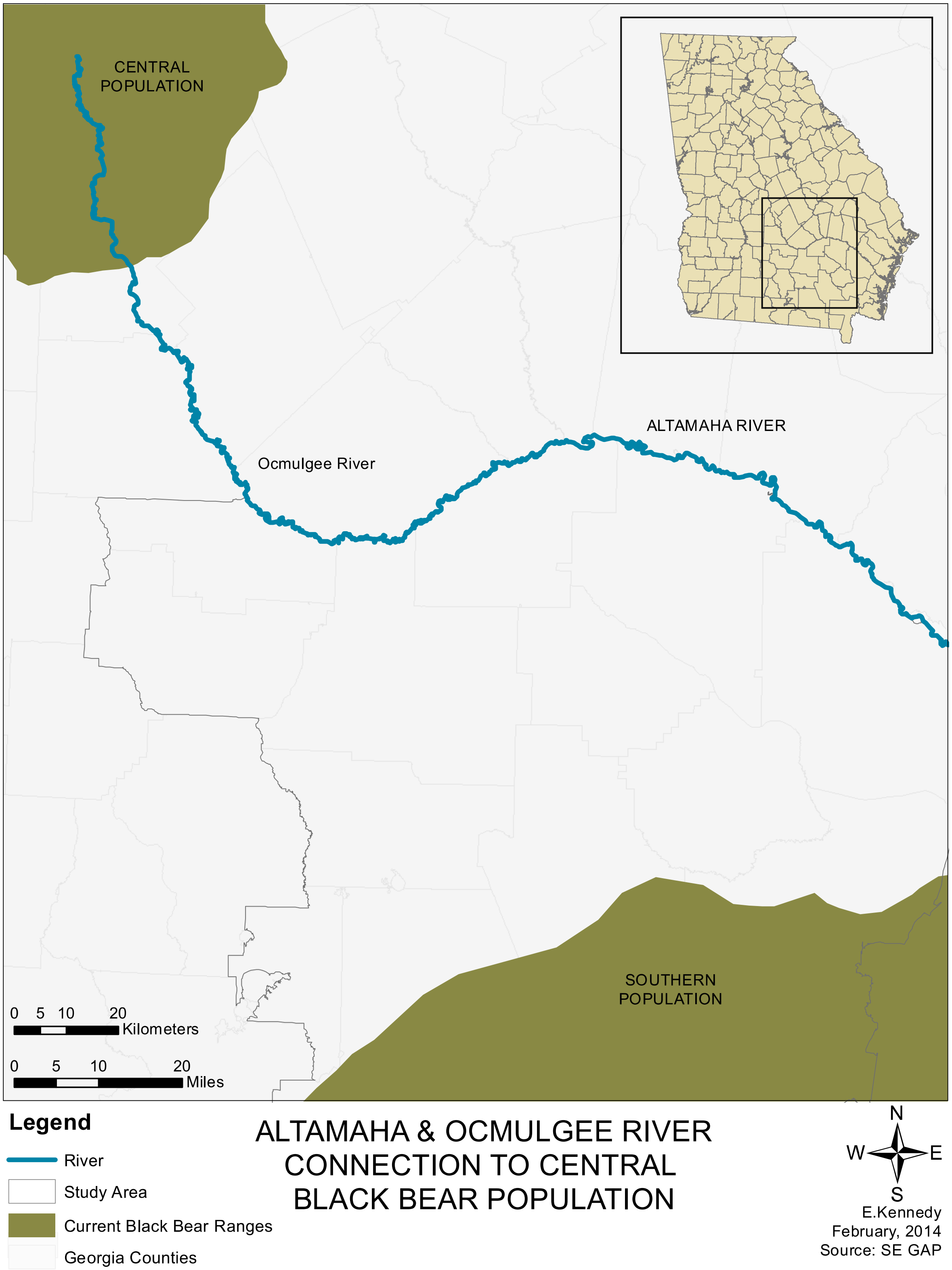


Figure 2.6: Altamaha River as a Potential Connection to the Central Bear Population

CHAPTER 3

RESULTS

Resistance Raster

The road, housing density, and land cover data were combined to create a composite resistance map ranging in values from zero to 1,350 (Figure 3.1). The pixel resolution for the resistance raster was a 30-meter cell size. The study area contains relatively good quality black bear habitat, overall. This is most likely reflecting the mix of agricultural land and commercial timber stands that make up most of the area. Forty-five conservation areas larger than 0.15 square kilometers were identified for connectivity within the study area (Figure 3.2).

Linkage Mapper

Euclidean distances, or straight paths, between conservation areas ranged from five to 77,775 meters. Cost-weighted distance values reflect the potential meanderings and directional changes necessary to avoid undesirable or high-conflict areas (i.e., high resistance values; Figure 3.3) and ranged from 30 to 703,293. The least-cost paths, which take into account the amount of resistance a black bear would endure along a path, ranged from 30 to 152,789 (Figure 3.2). Cost-weighted distance ratios between the least-cost paths and the Euclidean distance paths capture how far off a straight-route a black bear must go because of landscape barriers. A cost-weighted distance to Euclidean distance ratio of one is optimal (WHCWG, 2010, p. 46). The mean cost-weighted distance to Euclidean distance ratio was 13.96.

The Linkage Mapper corridor output indicates a variety of intertwining pathways that avoid larger urban areas, as expected (Figure 3.4a & 3.4b). A large percentage of the area north of ONWR falls within the 200-kilometer maximum corridors distance (value automatically selected by Linkage Mapper). This expanse of acceptable black bear habitat in the area most likely reflects the extensive agricultural and commercial timber stands in the area. It is also indicative of the relatively low traffic along the highways in the study area.

The "best" corridor options become particularly clear when the corridors are truncated to the 60 kilometer cut-off for average black bear distances, identified in the Circuitscape section of the previous chapter (Figure 3.4b). These paths clearly avoid Waycross and the other urban areas in the region. The dominance of human-altered of the landscape is reflected in the thinning of the corridors across the northern half of the study area.

When comparing the corridor output to the cost-weighted distance output, it is clear that the corridors running northeast between ONWR and the Altamaha have the lowest overall cost-weighted distances (Figures 3.2, 3.4a, & 3.4b). Areas of high cost-weighted distances stretch from Waycross, just north of ONWR, westward across the northern portion of the study area. While potential corridors do cross that area, their least-cost paths have higher values than those extending to the northeast.

The wide swath extending westward from Okefenokee NWR supports the SE GAP (2011) analysis identifying black bear habitat within that region (Figure 3.4b). Connectivity also appears along the majority of the Altamaha River. The gap along the northeastern section of the Altamaha may reflect the exclusion of the conservation lands that lie on the opposite bank, outside of the study area (Figure 2.2). Inclusion of these areas would most likely close fill in this gap of potential corridor space along the river.

The sparse corridors found along the southern Georgia border most likely reflect the exclusion of the Florida conservation areas to the south of the study area. The resistance raster values along the state border are not significantly higher than those reflected in the rest of the study area and should not have affected the cost-weighted paths more than other parts of the study area. Including conservation areas in Florida and in adjacent counties would likely increase the corridor density in this area.

There were no significant changes in the least-cost path, cost-weighted distance to Euclidean distance ratio, or corridor outputs in the sensitivity analysis.

Pinchpoint Mapper (CircuitScape)

Pinchpoint Mapper illustrates a connectivity map in the study area, reduced according to the 60-kilometer cut-off described in the previous chapter. The output highlights points of highest difficulty along each path (Figure 3.5). There is still a dense network in the northern portion of the study area despite this reduction in travel-distance limit.

The most direct route to the Altamaha River Corridor appears to curve southeast of Waycross, the largest city in the study area (Figure 3.7). It contains the densest collection of least-cost paths as well. This potential corridor passes through the Little Satilla WMA, the second-largest conservation area in the study area. Road intersections are unavoidable; this corridor crosses eight highways, which appear to correlate with the pinch points identified along the connections. Pre-existing bridges along highway-conflict areas offer an opportunity to mitigate at least some roadway conflict in a relatively inexpensive manner (Figure 3.6).

Another viable corridor winds west of Waycross and passes through smaller conservation areas until reaching the confluence of the Altamaha and Ocmulgee Rivers (Figure 3.8). Despite this corridor's greater overall length compared to the one discussed above, it takes a more direct route towards the central Georgia black bear population that resides to the Northwest of the study area (Figure 2.6). This path also has greater opportunity for meandering segments that touch more conservation lands and other areas of existing habitat. This would allow for inclusion of neighboring areas with unique habitat opportunities.

This linear corridor does contain more pinch points than the first corridor (Figure 3.8). Most of these fall around the cities of Waycross and Douglas. There is room to avoid Douglas to the East. Unfortunately, this would require multiple crossings of Route 441, one of the largest roadways in the region. Waycross is another relatively unavoidable barrier, located at the north end of ONWR. Fencing or other barriers may be necessary around these urban spaces to deter black bears from entering the area. There are existing bridges in close proximity of the majority of the highway-cased pinch points (Figure 3.6). However, mitigation would likely be more costly than that required within the first corridor option.

The corridor with the most direct route to the Ocmulgee and towards the central black bear population stretches up along the northwestern section of the study area (Figure 3.9). This corridor meets areas of resistance between ONWR and Waycross (Figure 3.9 and 3.8). Unlike the corridor previously discussed, it circumvents the city of Douglas. More than ten highways cross this potential corridor, with Route 441 having the highest traffic and representing the greatest road barrier along the corridor. Fortunately, there are a number of existing bridges, particularly in the section parallel to Douglas that could be retrofitted with wildlife crossing structures.

Summary

Results revealed a variety of corridor sections that can connect ONWR to conservation areas along the Altamaha River. Some paths may be skewed due to the exclusion of conservation areas outside of the study area in adjacent counties or states. Viable corridors through the middle of the study area seem to follow the larger rivers in the area (Figures 3.8 & 3.9). Waycross, Douglas, and Route 441 represent the greatest sources of conflict along the potential corridors. The most direct connection between ONWR to the Altamaha River runs east from Okefenokee and follows northwest along the river (Figure 3.7). Longer routes have the potential to connect between more conservation areas. Corridors that reach the western end of the Altamaha along the northern study area boundary reach more directly to the black bear population in central Georgia.

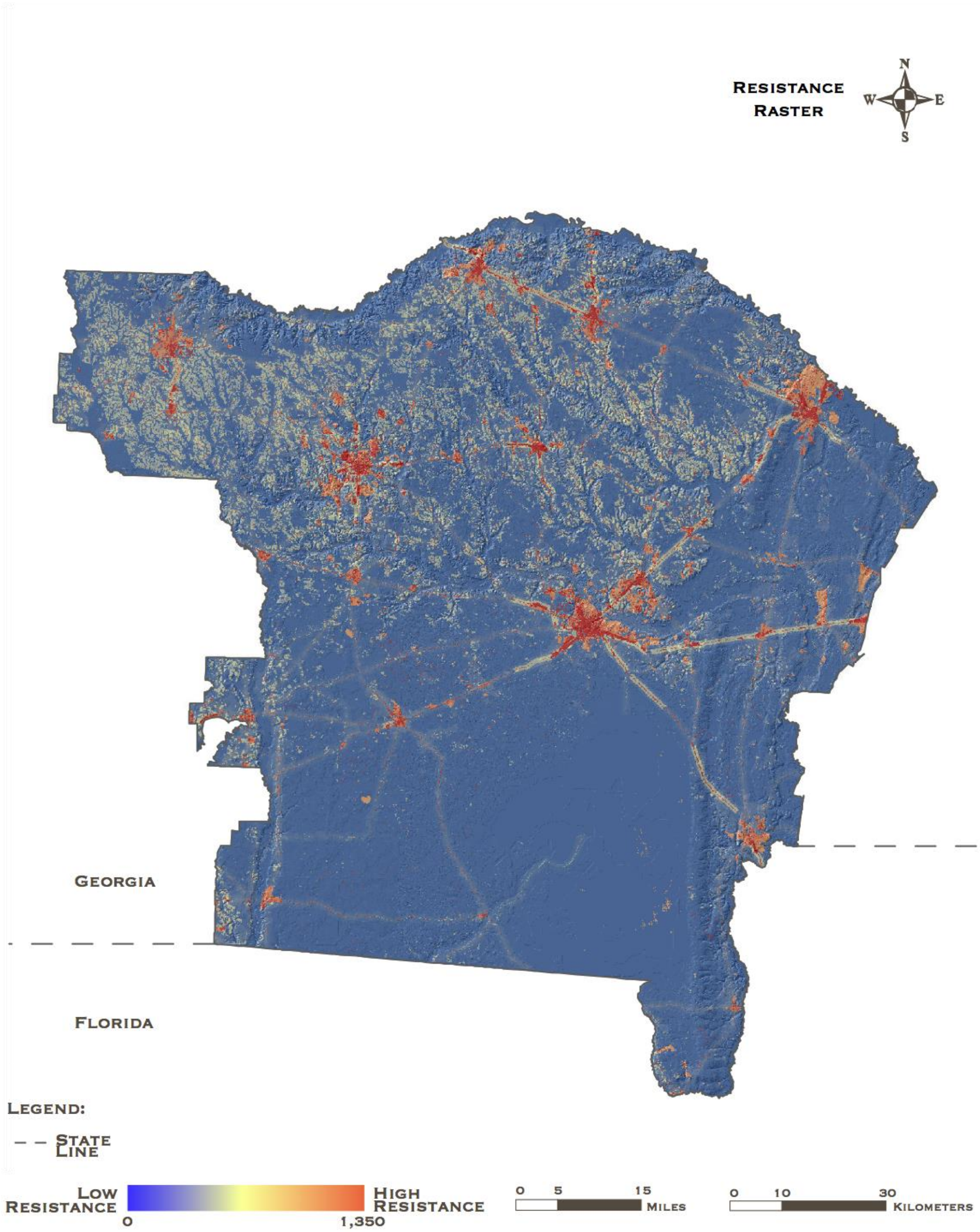


Figure 3.1: Resistance Raster

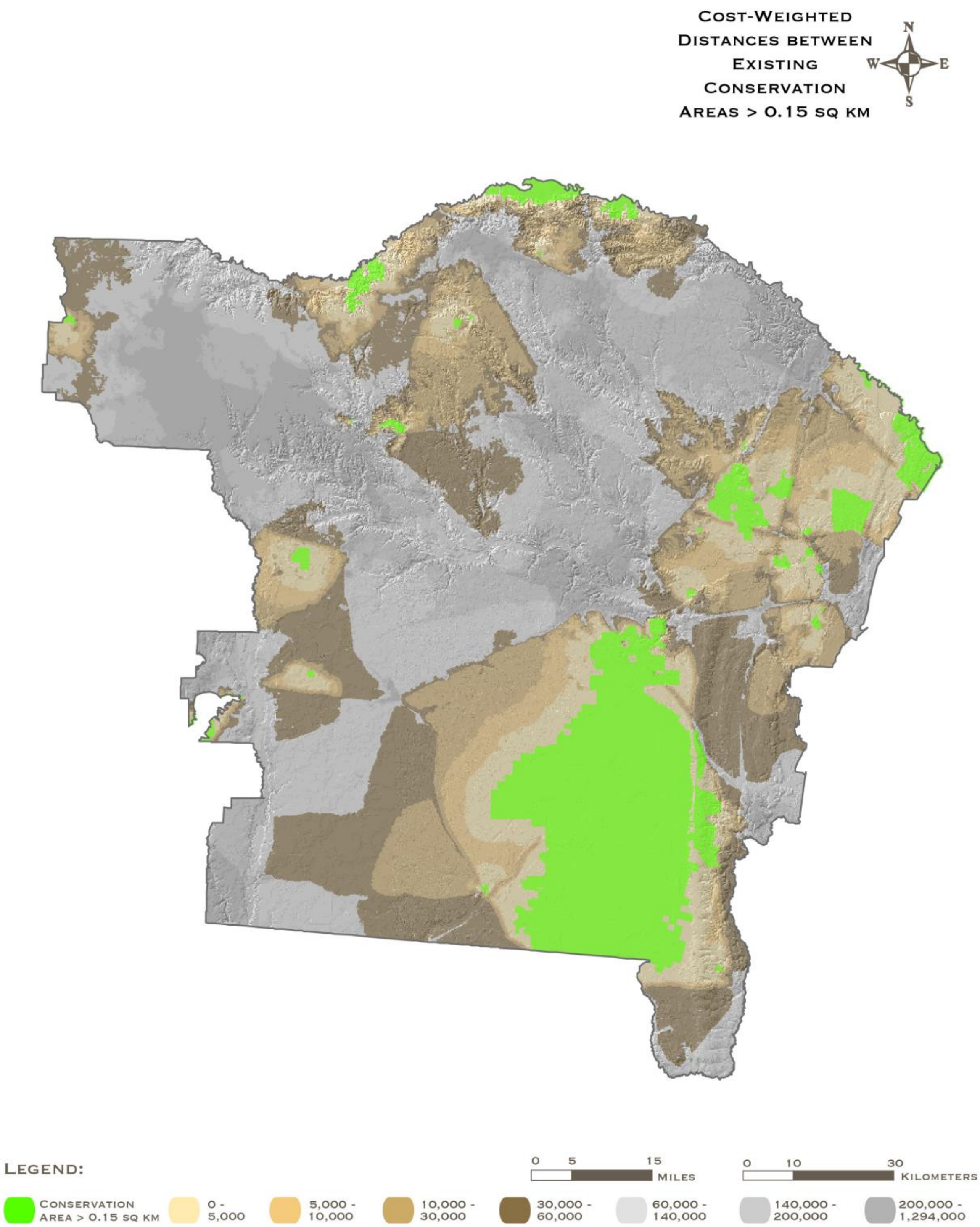


Figure 3.2: Cost-Weighted Distance Output

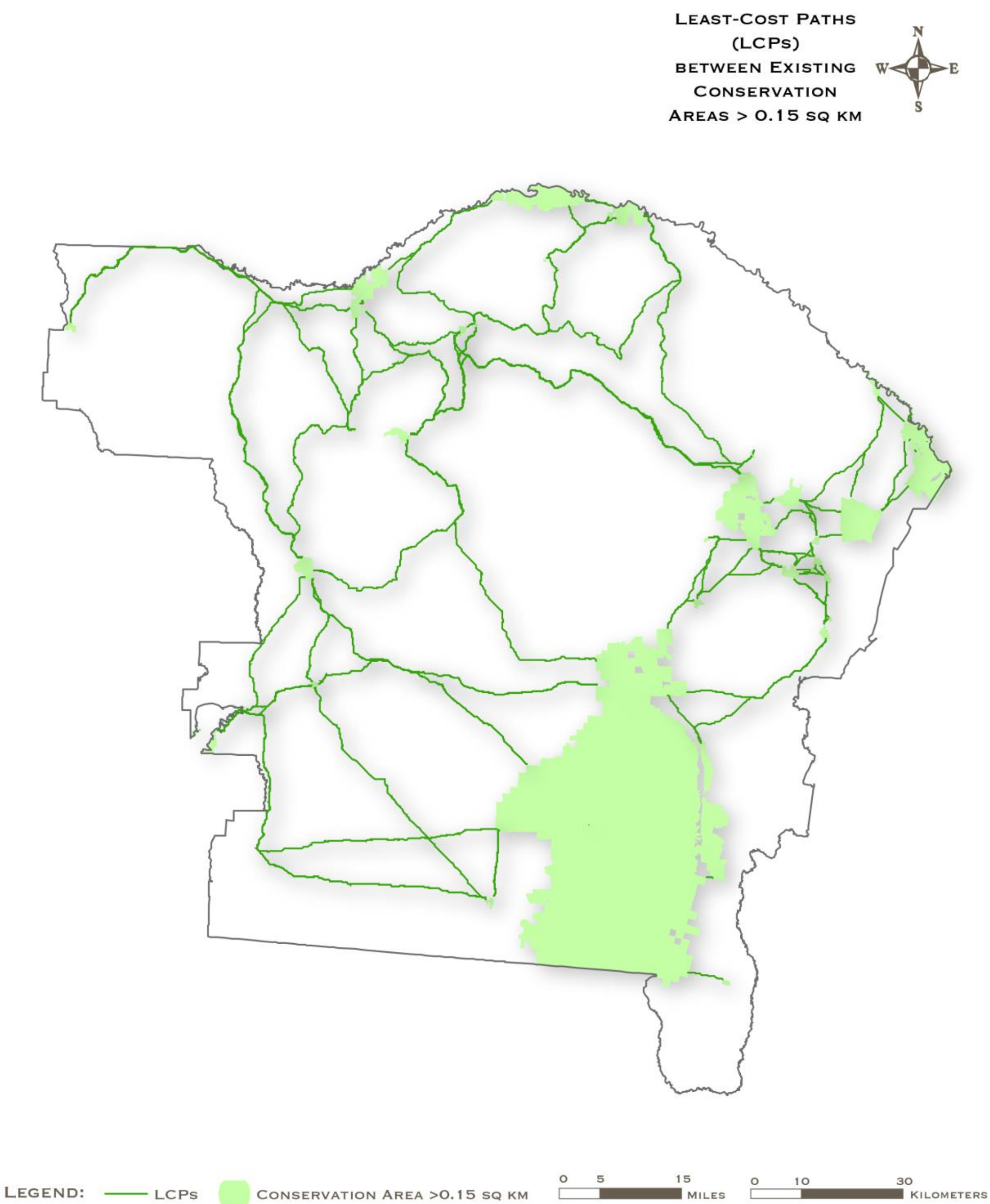


Figure 3.3: Least-Cost Paths Between Existing Conservation Lands >0.15 sq km

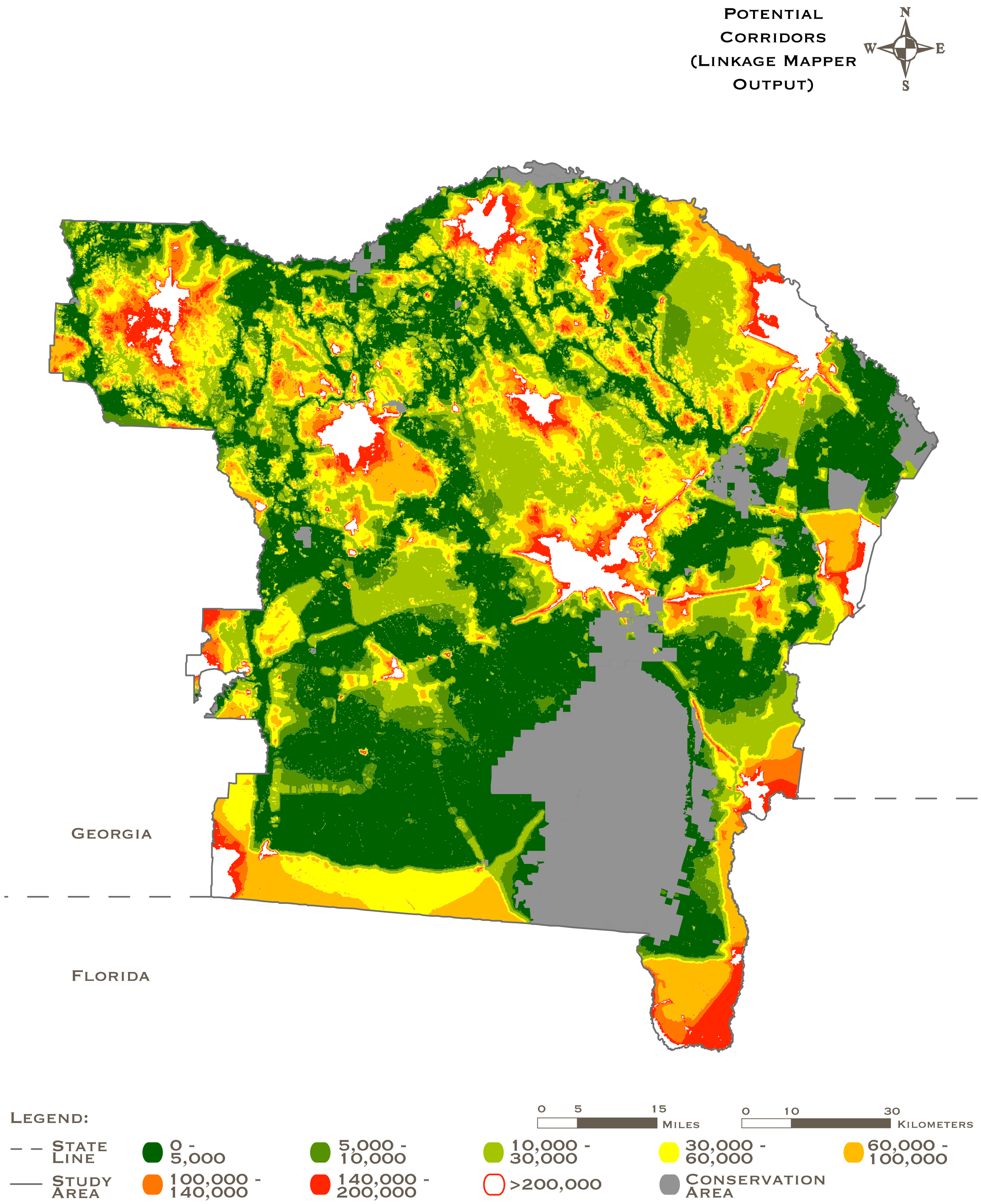


Figure 3.4a: Linkage Mapper Output (Truncated at 200k)

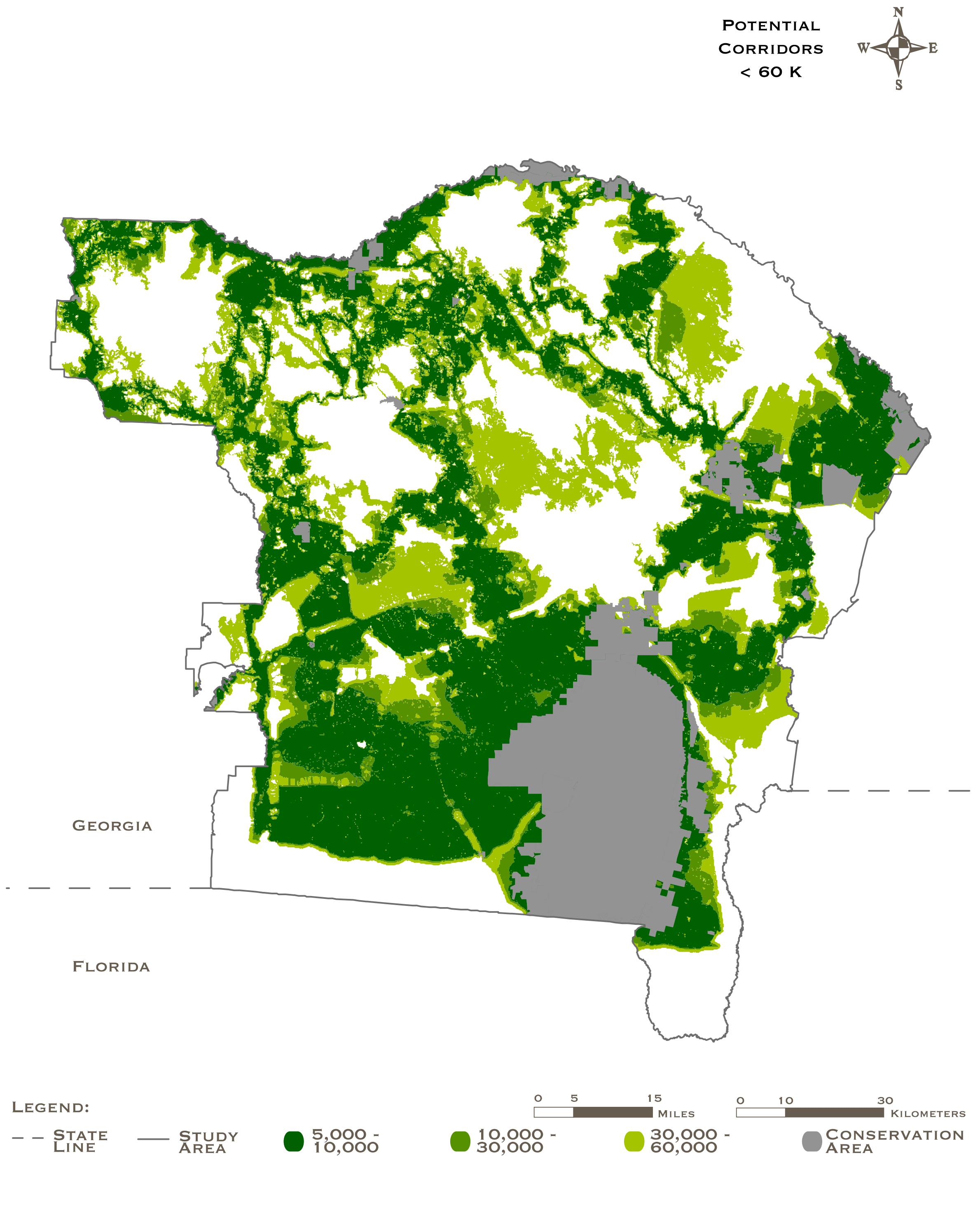


Figure 3.4b: Linkage Mapper Output (Truncated at 60 k)

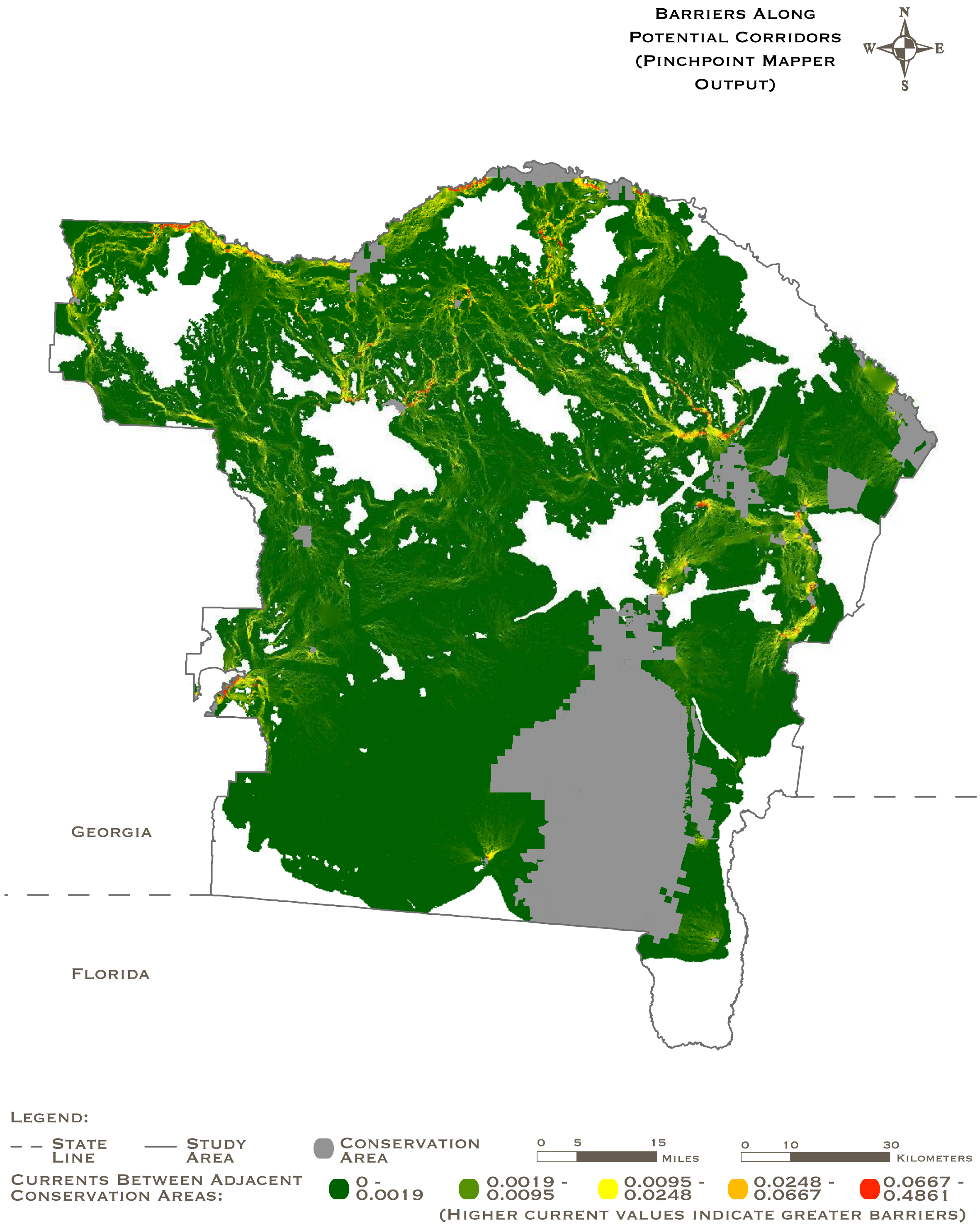


Figure 3.5: Pinchpoint Mapper Output

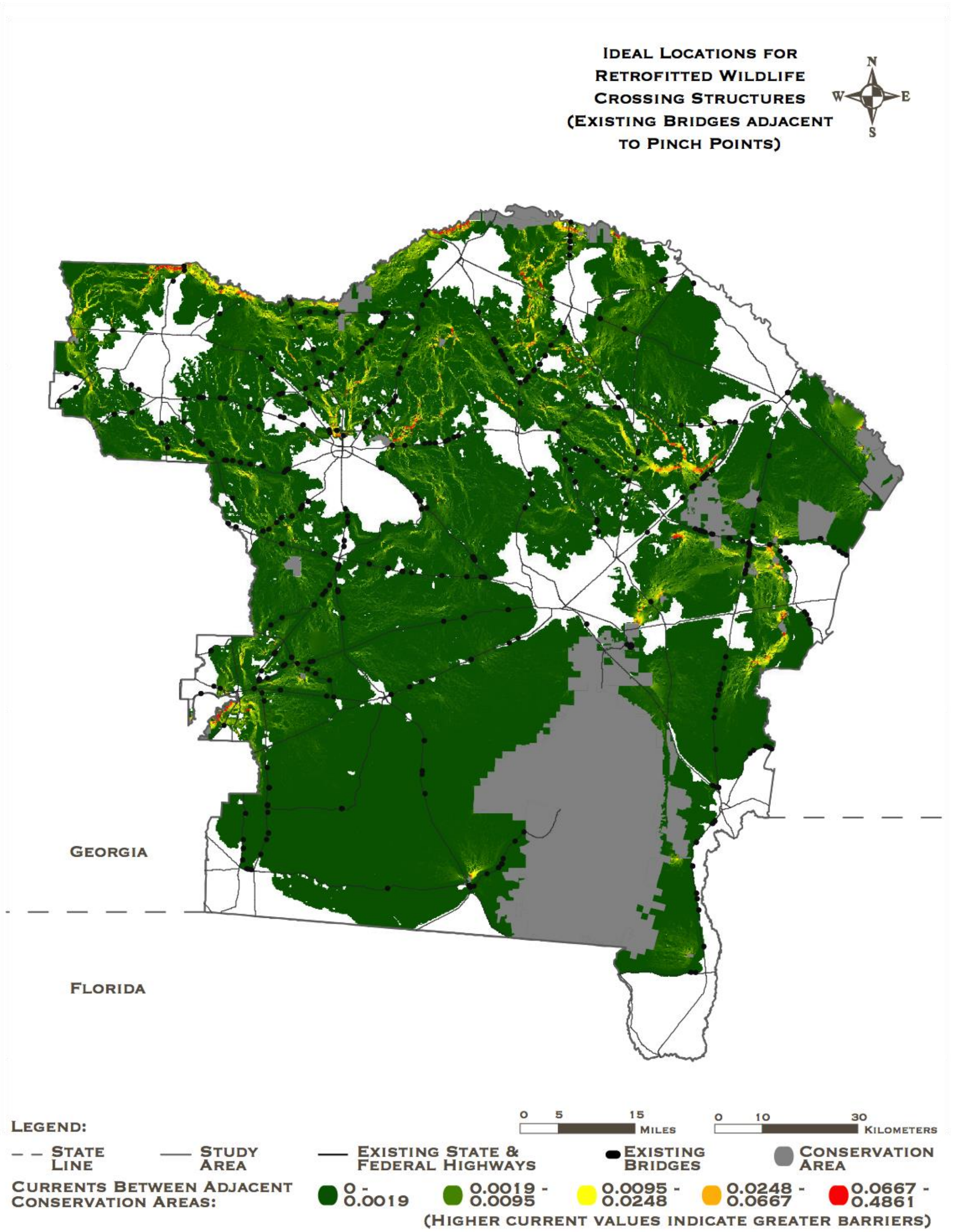


Figure 3.6: Pinchpoint Mapper Output with Existing Bridges Along Major Highways

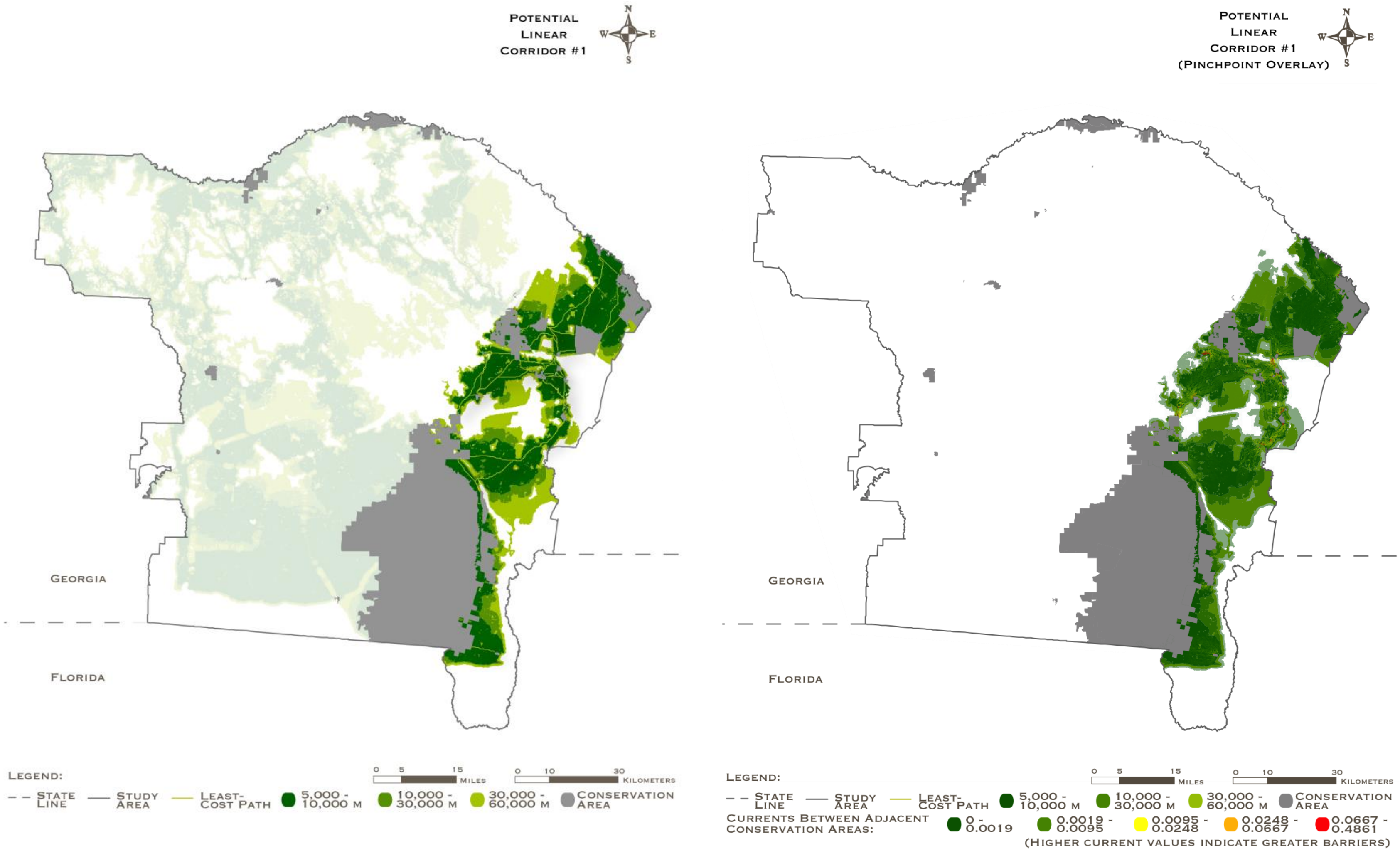


Figure 3.7: Potential Corridor 1

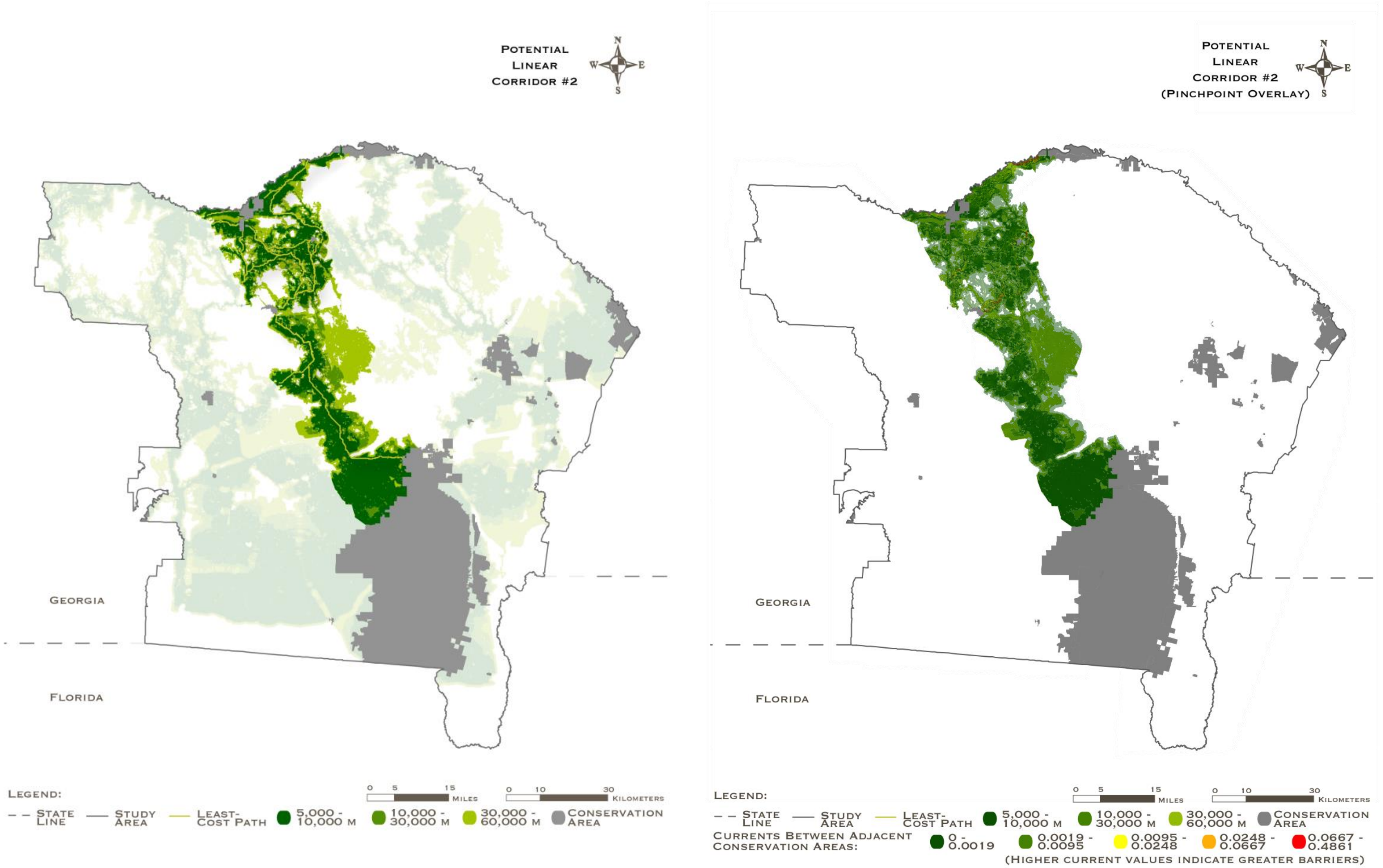


Figure 3.8: Potential Corridor 2

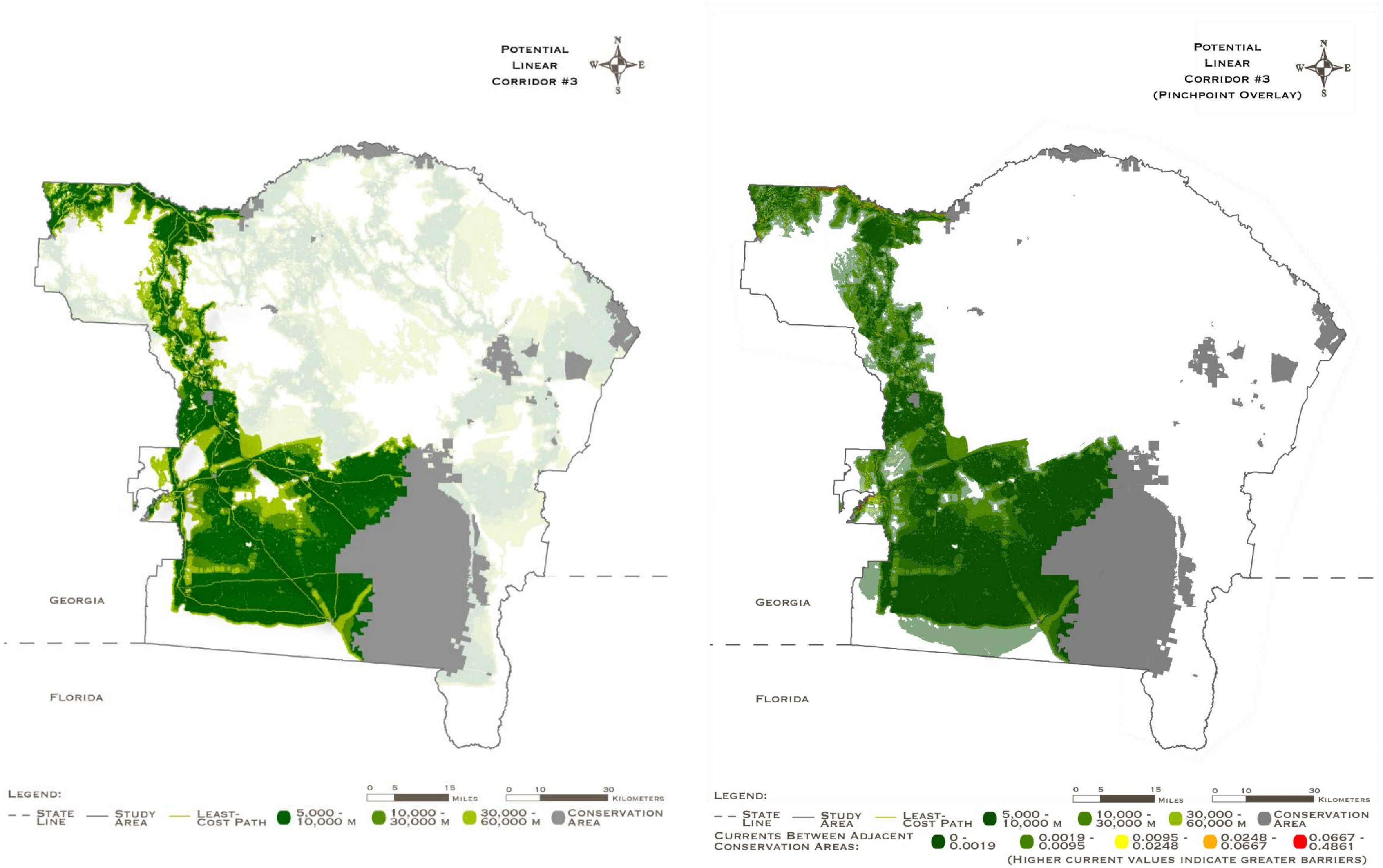


Figure 3.9: Potential Corridor 3

CHAPTER 4

DISCUSSION

Conclusion

This project utilized a series of geospatial analyses to identify a network of potential wildlife corridors connecting ONWR to the Altamaha River with black bear as the focal species. The analyses identified a variety of potential corridors with three main corridor sections. These results indicates flexibility in creating a final wildlife corridor design. It will allow the final plan to optimize use of existing available land, habitat quality, and areas distanced from urban development. Urban development is growing throughout the United States. While southern Georgia remains primarily rural, projected population growth indicates future urban expansion throughout the state. It is essential to create a wildlife connectivity plan that will protect portions of the currently un-urbanized region from development.

The state of Florida has already begun to implement their comprehensive wildlife plan. With Georgia as the primary landmass connecting Florida to the rest of North America, it is essential that a corridor plan be implemented to account for future influxes of a variety of species.

Large carnivores, like black bear, should be highlighted in the final plan because they tend to suffer most from human conflict. Human development quickly fractures large predators' wide-ranging populations. These species often have difficulty recovering because of their comparatively low overall populations. Their wide-ranging nature also predisposes these large animals, particularly black bear, to cross through urban areas. These ventures frequently result in injury or death. Vehicle-wildlife collisions are a significant source of fatalities, as are poaching and euthanasia in response to nuisance behavior. A finalized corridor plan can use the highway-caused pinch points, identified in Chapter 3, to locate likely important wildlife road crossings and catalyze successful implementation of mitigation measures along roadways. Special attention should also be paid to pinch points or sections of corridors adjacent to urban areas. These areas may require active diversion mechanisms such as fencing or other forms of barriers to deter wildlife from wandering into human developments.

A wildlife-monitoring plan must be included in the final design, particularly if road crossings are installed. Monitoring studies ensure that black bear are utilizing the corridors and can encourage participation in the protection and management of corridor lands. Once black bear are determined to be traveling up to the Altamaha, the possibility of a corridor extension to the central black bear population should be investigated.

The variety of possible routes identified in this study should be used as an advantage. The design should maintain plasticity until a corridor that optimizes cost, minimizes implementation effort, and accounts for stakeholder needs and opinions is identified. Further assessment of existing land conditions, specific black bear locations, and more extensive landowner data will help identify an ideal network of pathways and additional conservation lands.

Limitations

Black bear telemetry, sighting, road-kill, or other location data would enhance the corridor design. These data would help better suit the corridor to the existing pockets of black bear in the area. These data types have been used in previous projects to help identify which areas of existing habitat are most used by black bear and what stretches of road create highest conflict (WHCWG, 2010; Cox et al., 1994). Genetic testing and telemetry data has also been used in validating resistance values across a landscape and identifying significant barriers (Cushman, et al., 2006; Cushman, et al., 2012). Home ranges of females with cubs would indicate areas of high importance for the species since they tend to establish more permanent home ranges and are indicative of successful breeding populations (G. Nelms, personal communication, February 24, 2014). Identification of current black bear patterns in the region would be extremely valuable in identifying which corridor sections would have the greatest impact.

A lack of up-to-date land cover data was another issue. Due to the ever-changing nature of human-altered environments, it is nearly impossible to characterize an entire region without some degree of error in the spatial data. Furthermore, the existing land cover data does not capture the complexity of existing forest and habitat conditions. For example, a commercial pine stand managed for wildlife is much different in character than one simply managed for maximal harvest. Site visits and ground truthing are necessary to validate existing habitat quality. Forest structure data also could improve this analysis.

The seasonality of black bear forages requires species-specific vegetation studies to assess where food will be available within corridor sections throughout the year There is no existing vegetation data for the area that goes into such detail. Conservation areas should serve as starting points for this data development since the final corridor will run between them. Many areas already have this information, to some degree, but it has not been converted into spatial data. Detailed characterization of existing vegetation within these plots could help guide future land management that would promote black bears and other species. This would create optimal habitat within the corridor's focal points. A comprehensive vegetative analysis would also guide the creation of habitat sections previously lacking along the corridor. Native vegetation completely missing from the region should be identified and restoration plans drawn up.

Parcel data for the area is highly restricted. Downloadable parcel data was publicly available for only one of the fifteen counties in the study area. Landowner data for most counties can be viewed online but the interface does not allow for regional assessment of land prices and landownership. A number of counties charge a fee for parcel data downloads; others simply do not have the means or technology to provide county data. The Southern Georgia Regional Commission shared data for four counties in the study area but did not have access to the eleven remaining. This lack of complete study area data and project funding negated the option to pay for county data. Other states, such as Florida, have gone to great efforts to make landownership data available to the public. Access to such data would facilitate future conservation projects. Researchers in Georgia should work with counties to create accessible parcel data.

The incorporation of other focal species would have increased the significance of identified corridors. Data limitations for black bear are likely similar for other species in Georgia. In order to distinguish the highest value corridors, parallel studies that address the habitat requirements and dispersal abilities of other native species should be performed. Corridor data overlays for black bear and other species will identify which areas overlap and how to best address the needs of multiple species in the area. Most other terrestrial species are more sedentary than black bear and will likely have more restricted corridor connectivity outputs. Species that tend to remain within a single habitat or small area are important to include in the final corridor analysis since they can be most sensitive to fragmentation. Specific habitat needs of such species should be met within existing conservation areas or within segments of the corridor.

The resistance raster values were based on a single West Coast based study. It would be ideal to have land cover values scaled according to local black bear habitats. There is a gap in literature identifying how to properly scale resistance values for Linkage Mapper and Circuitscape. Fine-tuning of input data was not possible due to limited access to hardware that can efficiently run the GIS toolkits for this project. In developing a final corridor, it could be useful to do a number of runs with different resistance values and observe any significant changes that may appear.

The brief time-line of this project was an overarching limitation. It restricted the extent of computer-based analysis, professional interviews and input, data creation, and ground truthing that could be performed. Consultation with regional land managers, local landowners, and other stakeholders to identify what areas have the highest potential for implementation should be included in a longer-term project.

Future Implications

Community Benefits and Education

Areas along the corridor with lower quality land cover or in closer proximity to urban areas can serve as dual-purpose property. Hiking, biking, equestrian, and other outdoor recreation is easily incorporated into wildlife corridor sections. This can also prompt additional funding by addressing the greenspace needs of a local community or private landowners. Additional funding and community interest would be particularly valuable in degraded areas that require environmental restoration. Active public education and garbage disposal programs would be essential for these areas to reduce conflict with black bear and other wildlife along the corridor. Maximized corridor widths along these sections would also help reduce the human disturbance of wildlife passing through the area.

Regulated hunting of black bear along certain portions of the corridor, or within larger areas connected by the corridor, would increase revenue for DNR via increased permitting and ammunition sales. The wildlife corridor would most likely attract other game species into the area as well. Turkey (*Meleagris spp.*), white-tailed deer (*Odocoileus virginianus*), northern bobwhite (*Colinus virginianus*), and many other popular game species in Georgia, are attracted to the mix of forest and edge-habitat that black bear require. This would improve the department's ability to manage existing lands and purchase additional areas along the corridor while better monitoring and modeling populations to set appropriate take limits.

Once a corridor plan is completed, a public outreach program should be implemented that explains the initiative and its importance. Government, non-profit, and private organizations should be aware of land availability along the finalized plan. Landowners within the corridor sections should be actively educated on the available tax credit, conservation easement, and other government programs that assist participating landowners with restoration and conservation. Many of these programs fall under the Farm Bill and provide federal assistance to owners with wetlands, protected species, or restoration projects on their land.

Regional or statewide credit programs are another mechanism to facilitate environmental protection in the region. These programs connect landowners with businesses that have been required by the state to offset the environmental footprint of a project. New development that disrupts a protected wetland or sensitive area must invest in the protection of a similar area offsite. A number of companies within Georgia have set up mitigation banking programs that simplify the process for both parties.

Public-private partnerships can also be voluntary. Ecotourism is a popular example of privately owned businesses that focus on providing public and environmental benefits. Often featuring outdoor activities and locally provided lodging and amenities, ecotourist destinations are defined by their protection of natural spaces and benefit to the surrounding community. Little Saint Simons Island, off the Georgia coast, is an excellent example of an ecotourist destination that has protected an area from development and encouraged environmental education and appreciation. Businesses centered on conservation efforts and environmental education would be a valuable asset to the region.

Zoning regulations regarding the subdivision of parcels and proportions of developed to undeveloped land guide development and encourage the protection of vegetated areas. Restrictive covenants, such as those on Jekyll Island, off the coast of Georgia, can identify minimum ratios of development to natural areas. Unified development codes can require that developers purchase land to remain in conservation proportional to the intensity and size of their project. A regional master plan is necessary in order to uphold many of these zoning regulations. This emphasizes the close relationship planners and wildlife managers must have in order to promote future land conservation.

Takeaway Message

The GIS models used for this project are powerful conservation tools. They expedite the labor-intensive tasks involved in overlaying and calculating spatial data by hand, allowing land managers and planners to operate more efficiently. In order to create a resistance layer that fully characterizes the region, up-to-date land cover data and forest structure, among other habitat components, are necessary. The limitations of this project denote the lack of spatial data for southern Georgia.

Regardless of spatial data quality, it will remain important to reassess the output data of these programs and arrive at the most realistic and appropriate solution. The GIS-created corridor outputs are strictly based on the land cover and land use inputs provided to the program. Synthesis of all contributing factors will guide the identification of a final corridor network. The incorporation of wildlife corridor plans into regional Master Plans should be an overarching goal since it would provide legal and regulatory backing for the design.

REFERENCES

Alig, R., Stewart, S., Wear, D., Stein, S., & Nowak, D. (2010). Conversions of forest land: trends, determinants, projections, and policy considerations. *Advances in threat assessment and their application to forest and rangeland management/[edited by] John M. Pye...[et al.]*.

Altamaha River Partnership. *History*. Retrieved February 26, 2014, from http://www.altamahariver.org/history.html

Arizona Department of Transportation. (2007). *Synthesis of animal-vehicle collision mitigation measures.* (Report No. FHWA-AZ-07-612). Springfield, VA: Reuer, C. Retrieved from http://www.ttap.colostate.edu/downloads/safety/AZ%20AnimalVehicle%20collisions.pdf

Beckmann, J.P. & Lackey, C.W. (2004). "Are desert basins effective barriers to movements of relocated black bears (*Ursus americanus*)?" *Western North American Naturalist*, 64(2), 269-272.

Brody, A.J. & Pelton, M.R. (1989). "Effects of roads on black bear movement in western North Carolina." *Wildlife Society Bulletin*, 17(1), 5-10.

Centers for Disease Control and Prevention (CDC) (2011). *CDC transportation recommendations*. Retrieved February 20, 2014, from http://www.cdc.gov/transportation/recommendation.htm

Clevenger, T. (2007, March-April). Highways Through Habitats: The Banff Wildlife Crossings Project. *TR News* 249. http://onlinepubs.trb.org/onlinepubs/trnews/trnews249hwyhabitats.pdf.

Collinge, S.K. (2009). *Ecology of fragmented landscapes*. Baltimore, MD: Johns Hopkins University Press.

Cook, K.L. (2007). *Space use and predictive habitat models for american black bears (Ursus americanus) In central Georgia, USA* (MS thesis). University of Georgia.

Cox, J., Kautz, R., MacLaughlin, M., & Gilbert, T. (1994). *Closing the gaps in Florida's wildlife habitat conservation system*. Tallahassee, FL: Florida Game and Freshwater Fish Commission. Retrieved from http://research.myfwc.com/engine/download_redirection_process.asp?file=94cox%5F4122%2Epdf&objid=48583&dltype=publication

Cushman, S.A., Landguth, E.L., & Flather, C.H. (2012). "Evaluating the sufficiency of protected lands for maintaining wildlife population connectivity in the U.S. northern Rocky Mountains." *Diversity and Distributions*, 18, 873-884.

Cushman, S.A., McKelvey, K.S., Hayden, J., & Schwartz, M.K. (2006). "Gene flow in complex landscapes: Testing multiple hypotheses with causal modeling." *The American Naturalist*, 168(4), 486-499.

Cushman, S.A., McKelvey, K.S., & Schwartz, M.K. (2009). "Use of empirically derived source-destination models to map regional conservation corridors." *Conservation Biology* 23(2), 368-376.

Dixon, J.D., Madan O.K., Wooten, M.C., Eason, T.H., McCown, J.W. & Paetkau, D. (2006). "Effectiveness of a regional corridor in connecting two Florida black bear populations." *Conservation Biology*, 20(1),155-162.

Doan-Crider, D.L. (2003). *Movements and spaciotemporal variation in relation to food productivity and distribution, and population dynamics of the Mexican black bear in the Serranias del Burro, Coahuila, Mexico* (PhD Diss.). Texas A&M University-Kingsville.

Florida Department of Environmental Protection (FL DEP) (2014). *Florida forever*. Retrieved January 27, 2014, from http://www.dep.state.fl.us/lands/fl_forever.htm.

Florida Fish and Wildlife Conservation Commission (FFWCC) (2012). *Florida black bear management plan*. Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida.

Florida Wildlife Corridor (2014). *Route map*. Retrieved from http://www.floridawildlifecorridor.org/about/about-expedition/route-map/

Forman, R.T.T. (2000). "Estimate of the area affected ecologically by the road system in the United States." *Conservation Biology*, 14(1), 31-35.

Forman, R.T.T., Sperling, D., Bissonette, J.A., Clevenger, A.P., Cutshall, C.D., Dale, V.H., Fahrig, L., France, R., Goldman, C.R., Heanue, K., Jones, J.A., Swanson, F.J., Turrentine, T., & Winter, T.C. (2003). *Road ecology*. Washington DC: Island Press.

Foster, M.L. & Humphrey, S.R. (1995). "Use of highway underpasses by Florida panthers and other wildlife." *Wildlife Society Bulletin*, 23(1), 95-100.

Georgia Department of Natural Resources (GA DNR) (2013). *Black bear fact sheet*. Melissa Cummings. Retrieved from http://georgiawildlife.com/sites/default/files/uploads/wildlife/pa/pdf/presskits/Bear%20Press%20Folder%20June2013.pdf

Georgia Department of Natural Resources (GA DNR) (2005). *Georgia Comprehensive*

Wildlife Conservation Strategy. Social Circle, GA. Retrieved from http://www1.gadnr.org/cwcs/Documents/strategy.html

Georgia Department of Transportation (GDOT) (2012). *Geographic transportation reporting analysis and query system (GeoTRAQS)*. Retrieved from http://www.dot.ga.gov/informationcenter/maps/geotraqs/Pages/default.aspx

Georgia Department of Transportation (GDOT) (2013). *Statewide transportation improvement program FY 2014-2017*. Atlanta, GA: Walkder, R. Retrieved from http://www.dot.ga.gov/Projects/programs/transportation/Documents/STIP/2014-2017/STIP14-17.pdf

Georgia Department of Transportation (GDOT). *Active projects*. Retrieved February 10, 2014, From http://www.dot.ga.gov/informationcenter/gastimulus/Pages/ActiveProjects.aspx

Georgia Water Coalition (2012). *2012's worst offenses against Georgia's water*. Retrieved from http://www.garivers.org/gawater/pdf%20files/Altamaha6.pdf

Gibbs, J.P. & Shriver, W.G. (2002). "Estimating the effects of road mortality on turtle populations." *Conservation Biology***,** 16(6), 1647-1652.

Gilbert, F., Gonzalez, A., & Evans-Freke, I. (2014). "Corridors maintain species richness in the fragmented landscapes of a microecosystem." *Proceedings: Biological Sciences*, 265(1396), pp. 577-582.

Gunter, J.E. (1987). *Georgia forest landowners manual*. Retrieved from the University of Georgia Warnell School of Forest Resources: http://warnell.forestry.uga.edu/SERVICE/LIBRARY/index.php3?docID=47&docHistory%5B%5D=6&docHistory%5B%5D=24

Harper, R.A. (2012). *Georgia, 2011 – forest inventory and analysis facesheet.* e-Science Update SRS-053. Asheville, NC: US Department of Agriculture Forest Service, Southern Rsearch Station.

Hastings, A. & Harrison, S. (1994). "Metapopulation dynamics and genetics." *Annual Review of Ecology & Systematics*, 25, 167-188.

Herrero, S., Higgins, A., Cardoza, J.E., Hajduk, L.I., & Smith, T.S. (2011). "Fatal attacks by American black bear on people: 1900-2009." *The Journal of Wildlife Management,* 75(3), 596-603.

Hilty, J.A., Lidicker, W.Z. Jr., & Merenlender, A.M. (2006). *Corridor ecology*. Washington DC: Island Press.

Huijser, M. P., McGowen, P. T., Fuller, J., Hardy, A., & Kociolek, A. (2007). *Wildlife-*

vehicle collision reduction study: report to congress (No. FHWA-HRT-08-034).

Jaeger, A.G.J. & Fahrig, L. (2004). "Effects of road fencing on population persistence." *Conservation Biology,* 18(6), 1651-1657.

Johnson, E.A. & Klemens, M.W. (2005). *Nature in fragments*. West Sussex, NY: Columbia University Press.

Kambourova-Ivanova, N., Koshev, Y., Popeorgiev, G., Ragyov, D., Pavlova, M., Mollov, I., & Nedialkov, N. (2012). "Effect of traffic on mortality of amphibians, reptiles, birds and mammals on two types of roads between Pazardzhik and Plovdiv region (Bulgaria) - Preliminary results." *ACTA Zoologica Bulgarica,* 64(1), 57-67.

Kociolek, A.V., Clevenger, A.P., St. Clair, C.C., & Proppe, D.S. (2011). "Effects of road networks on bird populations." *Conservation Biology,* 25(2), 241-249.

Land, D., & Lotz, M. (1996). Wildlife crossing designs and use by Florida panthers and other wildlife in southwest Florida. *Trends in Addressing Transportation Related Wildlife Mortality,* 323.

Levins, R. R. (1969). Some demographic and genetic consequences of environmental heterogeneity for biological control. *Entomol Soc Amer Bull*, (3), 237-240.

Lindenmeyer, D.B. & Fischer, J. (2006). *Habitat fragmentation and landscape change*. Washington DC: Island Press.

MacArthur, R.H. & Wilson, E.O. (1967). *The Theory of Island Biogeography*. Princeton, NJ: Princeton University Press.

Maehr, D.S., Hoctor, T.S., Quinn, L.J., & Smith, J.S. (2001). Black bear habitat management guidelines for Florida. Technical Report No. 17. Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida, USA.

Mata, C. (2003). *Effectiveness of wildlife crossing structures and adapted culverts in a highway in Northwest Spain*. Retrieved from University of California, eScholarship Web Site: http://escholarship.org/uc/item/3t24s427#page-1

McRae, B.H. (2012). *Pinchpoint mapper connectivity analysis software.* The Nature Conservancy, Seattle WA. Available at: http://www.circuitscape.org/linkagemapper.

McRae, B.H. (2013). *Pinchpoint mapper user guide version 1.0*. Seattle, WA: The Nature Conservancy. Retrieved from https://code.google.com/p/linkage-mapper/downloads/detail?name=LinkageMapper1_0_8.zip

McRae, B.H., Beier, P., Dewald, L.E., Huynh, L. Y. & Keim, P. (2005). "Habitat barriers limit gene flow and illuminate historical events in a wide-ranging carnivore, the American puma." *Molecular Ecology,* 14(7), 1965-1977.

McRae, B.H., Hall, S.A., Beier, P., & Theobald, D.M. (2012). “Where to restore ecological connectivity? Detecting barriers and quantifying restoration benefits.” *PLoS ONE,* 7(12), e52604. doi:10.1371/journal.pone.0052604

McRae, B.H. & Kavanagh, D.M. (2011). *Linkage mapper connectivity analysis software*. The Nature Conservancy, Seattle WA. Available at: http://www.circuitscape.org/linkagemapper.

McRae, B.H. & Kavanagh, D.M. (2014). *Linkage mapper user guide version 1.0*. Seattle, WA: The Nature Conservancy. Retrieved from https://code.google.com/p/linkage-mapper/downloads/detail?name=LinkageMapper1_0_8.zip

McRae, B.H. & Shah, V.B. (2013). *Circuitscape user’s guide.* Santa Barbara, CA: University of California. Retrieved from https://circuitscape.googlecode.com/files/Circuitscape_3.5.8_User_Guide_rev3.pdf

Moritz, C. (2002). “Strategies to protect biological diversity and the evolutionary processes that sustain it.” *Systematic Biology* 51(2), 238-254.

Natural Resources Spatial Analysis Labratory (NARSAL), University of Georgia. (September, 2012). *Conservation lands of Georgia, 2012.* Retrieved from http://narsal.uga.edu/conservation-lands

Natural Resources Spatial Analysis Lab (NARSAL). *Georgia landcover trends.* Retrieved February 21, 2014, from http://narsal.uga.edu/glut/data-stats/georgia-landcover-trends

Natrual Resources Spatial Analysis Lab (NARSAL). *Georgia land use trends.* Retrieved February 23, 2014, from http://narsal.uga.edu/glut

The Nature Conservancy (2013). *6,277 new acres protected along Altamaha River*. Retrieved February 26, 2014, from http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/georgia/newsroom/6277-new-acres-protected-along-altamaha-river.xml

North Carolina Wildlife Resources Commission (NCWRC) (2012). *North Carolina black bear management plan*. NCWRC, Raleigh, North Carolina.

Nowak, D. J., & Walton, J. T. (2005). Projected urban growth (2000–2050) and its estimated impact on the US forest resource. *Journal of Forestry*, *103*(8), 383-389.

Pelton, M. R., Coley, A.B., Eason, T.H., Doan Martinez, D.L., Pederson, J.A., van Manen, F.T., & Weaver, K.M. (1999). American black bear conservation action plan. In Servheen C., Herrero S., & Peyton, B. (Eds.), *Status survey and conservation action plan. Bears* (pp. 144-156). Gland, Switzerland: IUCN.

Powell, R. (1986). "Black bear home range overlap in North Carolina and the concept of home range applied to black bears." *Bears: Their biology and management* 7, 235-242.

Rudis, V.A. & Tansey, J.B. (1995). "Regional assessment of remote forests and black bear habitat from forest resource surveys." *The Journal of Wildlife Management*, 59(1), 170-180.

Ruth, D. (2011). South Carolina black bear management and conservation strategy. Retrieved from http://www.dnr.sc.gov/wildlife/publications/pdf/blackbearmanagmentDRAFT.PDF

Sandell, M. (1989). The mating tactics and spacing patterns of solitary carnivores. In J. Gittleman (Ed.), *Carnivore behavior, ecology, and evolution* (pp. 164-182). Ithaca, NY: Cornell University Press

Smith, D. J., Harris, L. D., & Mazzotti, F. J. (1996). *A landscape approach to examining the impacts of roads on the ecological function associated with wildlife movement and movement corridors: problems and solutions* (No. FHWA-PD-96-041).

Southeast Gap Analysis Project. (2007). *Descriptions of ecological systems for modeling of LANDFIRE biophysical settings*. Retrieved from http://www.basic.ncsu.edu/segap/datazip/region/se_lc_systems_descriptions.pdf

Southeast Gap Analysis Project (2011). *Species analysis report: American black bear*. Retrieved from http://www.basic.ncsu.edu/segap/datazip/reports/SppReport_mABBE.pdf

Spencer, R.D., Beausoleil, R.A., & Martorello, D.A. (2007). "How agencies respond to human-black bear conflicts: A survey of wildlife agencies in North America." *Ursus*, 18(2), 217-229.

Tewksbury, J.J., Levey, D.J., Haddad, N.M., Sargent, S., Orrock, J.L., Weldon, A., Danielson, B.J., Brinkerhoff, J., Damschen, E.I., & Townsend, P. (2002). "Corridors affect plants, animals, and their interactions in fragmented landscapes." *Proceedings of the National Academy of Sciences of the United States of America*, 99(20), pp. 12923-12926.

Transportation Research Board (2011). *Guidelines for the preservation of high-traffic-volume roadways*. (No. S2-R26-RR-2). Washington, DC: Peshkin, D., Smith, L., Wolters, A., Krstulovich, J., Moulthrop, J., & Alvarado, C.

Treves, A. & Karanth, K.U. (2003). "Human-carnivore conflict and perspectives on carnivore management worldwide." *Conservation Biology*, 17(6), pp. 1491-1499.

University of Virginia Weldon Cooper Center for Public Service. (2013) *Observed and Total Population for the U.S. and the States, 2010-2040.* Retrieved January 27, 2014. www.coopercenter.org/demographics

US Census Bureau (2010). *State & country quick facts.* Retrieved February 14, 2014. http://quickfacts.census.gov/qfd/index.html#

US Department of the Interior: U.S. Geological Survey. (2012). *Southern coastal plain.* Drummond, M.A. Retrieved from http://landcovertrends.usgs.gov/east/eco75Report.html.

US Department of Transportation Federal Highway Administration (US FHWA) (2008). *Wildlife-vehicle collision reduction study*. (Publication No. FHWA-HRT-08-034). McLean, VA: Huijser, M.P., McGowen, P., Fuller, J., Hardy, A., Kociolek, A., Clevenger, A.P., Smith, D., & Ament, R.

US Department of Transportation Federal Highway Administration (US FHWA) (2009). *Manual on uniform traffic control devices*. Retrieved from http://mutcd.fhwa.dot.gov/pdfs/2009r1r2/pdf_index.htm

US Department of Transportation Federal Highway Administration (US FHWA) (2010). *Highway statistics 2010.* Washington, DC. Retrieved from https://www.fhwa.dot.gov/policyinformation/statistics/2010/

US Department of Transportation Federal Highway Administration (US FHWA). (2012). *Deficient bridges by state and highway system*. Available from the National Bridge Inventory database, http://www.fhwa.dot.gov/bridge/deficient.cfm

US Department of Transportation (US DOT) (2011). *Wildlife crossing structure handbook design and evaluation in North America* (Publication No. FWHA-CFL/TD-11-003). Lakewood, CO: Clevenger, A.P. & Huijser, M.P. Retrieved from http://www.cflhd.gov/programs/techdevelopment/wildlife/

US Fish and Wildlife Service (USFWS). *Okefenokee national wildlife refuge*. Retrieved March 30, 2014, from http://www.fws.gov/okefenokee/

US Fish and Wildlife Service (USFWS) (2013). *Threatened and endangered species*. Retrieved February 6, 2014, from http://www.fws.gov/athens/endangered.html

US Fish and Wildilfe Service (USFWS) (2012). *Partners for fish & wildlife*. Retrieved January 16, 2014, from http://www.fws.gov/athens/partners.html

Washington Wildlife Habitat Connectivity Working Group (WHCWG). (2010). *Washington connected landscapes project: Statewide analysis.* Retrieved from http://waconnected.org/wp-content/themes/whcwg/docs/statewide-connectivity/2010DEC%2017%20WHCWG%20Statewide%20Analysis%20FINAL.pdf

Weldon Cooper Center for Public Service (WCCPS) (2013). *Observed and total population for the U.S. and the States, 2010-2040.* Retrieved January 27, 2014, from University of Virginia Demographics Research Group.

Westemeier, R.L., Brawn, J.D., Simpson, S.A., Esker, T.L., Jansen, R.W., Walk, J.W., Kershner, E.L., Bouzat, J.L., & Paige, K.N. (1998). "Tracking the long-term decline and recovery of an isolated population." *Science*, 282(5394), 1695-1698.

Wooding, J.B., Cox, J.A., & Pelton, M.R. (1994). Distribution of black bears in the southeastern coastal plain. In *Annual Conference of Southeastern Association of Fish and Wildlife Agencies* (Vol. 48, pp. 270-275).