Babcock Ranch Regional Connectivity Study

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Executive Summary

This study assesses opportunities for facilitating regional ecological connectivity between Babcock Ranch and surrounding lands of high ecological value to assist the Babcock Ranch Steering Committee with its work. We reviewed existing reports and spatial data and conducted new analyses using currently available land-use data and spatial models, as well as data from new studies. These data are of sufficient resolution for state and regional scale conservation planning and can be particularly useful for such applications, however, the data are not appropriate for use in high accuracy mapping applications such as property parcel boundaries, local government comprehensive plans, zoning, DRI, site plans, environmental resource or other agency permitting, wetland delineations, or other uses requiring more specific and ground survey quality data. The analysis, maps and data in this report were developed for state and regional conservation planning purposes and are not intended, nor sufficient, to be the basis for local government comprehensive plans, environmental resource or agency permitting decisions. They are however relevant for informing decision making as to areas needing more attention and potentially more detailed study.

Issues related to facilitating connectivity, including road crossings and potential corridor bottlenecks were also assessed, as was the need for additional research and analyses. The study area for this research included the lands immediately surrounding Babcock Ranch, nested within a larger landscape that extends, for least cost path analysis, northward to Tampa Bay, east to the Kissimmee River Valley, and south to Big Cypress; for long-term connectivity considerations, a still larger study area is appropriate, north to the Green Swamp and south to the Everglades. Additional analysis and coordination is also needed to determine how best to establish better connectivity, using a broad range of potential tools and working with private and public landowners on implementation strategies.

We begin this report with a review of some functions of ecological connectivity. Connectivity is determined by the intersection of a species' life history characteristics, including its behavior, and the structure of the landscape. For a particular corridor or greenway to provide functional connectivity, we have to know a considerable amount about the species that we hope will benefit from the corridor, as well as about the habitat structure and landscape context of the corridor.

There are many potential functions of connectivity. Besides their value in providing dwelling and breeding habitat for some species, corridors potentially facilitate: (1) movement of animals within home ranges; (2) seasonal migrations or wanderings of animals; and (3) dispersal of juveniles or adults of animal or plant species, which in turn provides for colonization or recolonization of suitable habitat patches and for movement of individuals among populations over a larger area. Large-bodied animals, in particular, have large home ranges, for example on the order of 416.5 km2 for male Florida panthers. We review evidence that the current habitats of three focal species that we consider in this study – Florida panther, Florida black bear, and Sherman's fox squirrel – are becoming fragmented, and that these species would benefit from protection and restoration of functional habitat corridors. Dispersal and colonization of new habitats by many species will be of critical importance for adaptation to climate change, including escape from rising sea level, which we believe is an urgent issue in Florida.

Information used in this study include data on existing conservation lands; Florida Forever projects; the Florida Ecological Greenways Network; Water Management District 2004-2006 FLUCCS Land Use data; Strategic Habitat Conservation Areas for Florida panther and Florida black bear from the Florida Fish and Wildlife Conservation Commission (FWC); data on Florida black bear range, locations, and roadkills from FWC; Highlands-Glades Florida black bear range and telemetry data from University of Kentucky; Florida black bear habitat priority areas delineated by T. Hoctor; data on Florida panther locations and mortality from FWC; U.S. Fish and Wildlife Service (FWS) Panther Subteam Habitat Conservation Zones; Florida panther Habitat Protection Priority Areas; National Hydrography Flowline data; Conservation Lands and Waters Identification Program (CLIP) landscape integrity data; Florida Natural Areas Inventory (2008) Babcock Ranch Ecological Inventories; Johnson Engineering roadkill data and other information from reports; GIS data prepared by Johnson Engineering for the Babcock Ranch Steering Committee; Babcock Ranch Primary Internal Transportation Plan, Primary Greenway Plan, and Preserve Recreation Master Plan; and the primary literature (scientific journal articles, etc.).

The methods of this study included: (1) A review of existing literature, databases, and other information; (2) development and refinement of habitat models for 3 focal species – Florida panther, Florida black bear, and Sherman's fox squirrel; (3) ground-truthing of habitat models and assessment of habitat quality for focal species within Babcock Ranch; (4) collection of roadkill data and observations on roads surrounding Babcock Ranch; (5) identification of regional-scale habitat corridors (high, moderate, and low connectivity options) using least-cost path analysis, visual interpretation of habitat and conservation area patterns, and other methods; and (6) comparison of results to future scenarios, including alternative future development scenarios (e.g., Florida 2060) and sea-level rise scenarios.

Regarding the habitat models for the three focal species, the Florida black bear habitat model was based on 4 variables: land cover type, patch size, distance from primary habitat patches, and connectivity to large habitat patches. Florida panther habitat was identified using all forest cover patches 5 acres or larger and secondary habitat within 200 meters; Fox squirrel habitat was identified using 4 variables: land cover type, patch size, distance from primary habitat patches, and landscape large enough to support potentially viable populations. For the least cost path (LCP) analysis, LCP was defined as the best potential route between a source and destination

based on a cost surface. The least costly route is essentially the path of least resistance, where resistance is defined by unsuitable or low-security habitat for the species in question. We created 6 different cost surfaces for each focal species. Cost surfaces variations included: habitat for focal species reclassified into a cost surface; habitat plus major roads; habitat, major roads, and edge effects; habitat, major roads, edge effects, and sea-level rise; habitat plus CLIP Landscape Integrity layer; and influence of roads, edge effects, and sea-level rise. The destinations included for the LCPs leading outward from Babcock Ranch were Big Cypress National Preserve, Okaloacoochee Slough State Forest, Fisheating Creek Wildlife Management Area, Bright Hour Watershed, the Myakka complex of conservation lands (Myakka), and the Avon Park Air Force Range. Therefore, with 6 cost surfaces and 6 destinations, there were 36 LCP results for each focal species.

We integrated results from these analyses into three conservation options: low, moderate, and high connectivity options. We used the following datasets to create the three connectivity options: The low connectivity option included existing conservation lands; the Caloosahatchee Ecoscape Florida Forever Project; one set of LCP results buffered by 1 mile between Babcock Ranch and the six selected destinations. The moderate connectivity option included existing conservation lands; Florida Forever Projects; two panther and two bear cost surface buffered LCP results buffered by 1 mile; all Critical Linkages within the Florida Ecological Greenways Network; all primary and secondary black bear habitat within primary range identified by FWC, all bear population habitat conservation recommendations delineated by T. Hoctor, or the new FWC bear SHCAs; all panther habitat within the USFWS Panther Subteam Primary and Dispersal Zones, or the older FWC Habitat Protection Plan areas, or the new FWC SHCAs; and the Integrated Habitat Network (given a value of 2 whereas all other areas within the option were given a value of 1). The high connectivity option included existing conservation lands; Florida Forever Projects; two panther and two bear cost surface buffered LCP results buffered by 1 mile; all areas within the Florida Ecological Greenways Network; all potential bear (primary and secondary), panther, and fox squirrel habitat (primary and secondary); all regional and local riparian corridors; and the Integrated Habitat Network (given a value of 2 whereas all other areas within the option were given a value of 1).

The LCPs clearly demonstrate potential options to connect Babcock Ranch to other large conservation areas in the study region. LCP results for the Florida panther and Florida black bear are similar in most cases. Although the fox squirrel LCPs showed some deviation for several destinations, the overall pattern of potential connectivity for fox squirrels is similar to that for panthers and bears; hence, we suggest that fox squirrel connectivity may be suitably addressed at the regional scale by the best options for panthers and bears. In addition, local to landscape-scale connectivity may be more important for fox squirrels within this region due to the fragmented habitat base and lower dispersal capabilities. Further research on fox squirrels in the region could include identification of core habitat areas and the opportunities to restore or maximize connectivity at the local to landscape scales through habitat management, restoration, and protection.

Our analysis of LCP overlap provided an objective method for evaluation of best potential corridors between Babcock Ranch and other large regional conservation areas. However, selection of best corridor options also requires a more subjective expert analysis of factors

potentially critical to population persistence, including the number and location of road crossings, presence of bottlenecks/proximity to areas of intensive development, length of corridors, consistency with existing guiding features in the landscape such as riparian corridors, etc. Before developing the connectivity options, we conducted these additional visual assessments of LCP results to select the best potential corridor options. From this assessment, we determined that LCPs based on two separate cost surfaces for both panthers and bears were most applicable to developing the various conservation scenarios.

The three connectivity options fall along a gradient of political and economic feasibility. The low connectivity option primarily represents the minimum feasible or most constrained effort to functionally connect Babcock Ranch with other larger existing conservation lands in the region. The moderate connectivity option is intended to represent a primary option for protecting and restoring functional connectivity across the region. The high connectivity option represents almost all existing areas that contribute, or could contribute, to protection of a functionally connected ecological network in the study area. All options would require addition of lands to Florida's conservation area network. For example, approximately 1.7 million acres of private land is included in the moderate connectivity option, with approximately 500,000 of those acres within proposed Florida Forever projects, as well as 400,000 acres of wetlands.

Assuming that all potential habitat is suitable habitat and that individual animals can move freely through the corridor network, which is actually unlikely, we made crude estimates of potential population sizes for the three focal species under the three connectivity options. To partially correct for biases, we provided population estimates based on the unrealistic assumption that all potential habitat is suitable and compared these with estimates based on an arbitrary but more realistic assumption that only 75% (for panthers and bears) or 50% (for fox squirrels) of the potential habitat in each connectivity option is suitable. Applying the moderate connectivity option, the 75% suitable habitat assumption, and population densities obtained from a study in Ocala National Forest, for example, the study region could support 1582 to 2331 bears. Under the same option and 75% suitable habitat assumption, and using population densities calculated by Maehr et al. (1991), the study region could support 65 to 89 panthers. And under the same option, a 50% suitable habitat assumption, and density estimates from two studies of fox squirrels, the study region could support 4,609 to 13,829 fox squirrels. Nevertheless, these revised estimates are still highly optimistic, especially so for the fox squirrel, for which so little of the potential habitat is suitable today due to inappropriate management for the fox squirrel. Especially for habitat specialist species such as the fox squirrel, protection of large habitat blocks and connections among blocks is not enough to assure persistence. Ecological management to maintain suitable habitat – both within Babcock Ranch and within other existing and potential conservation areas within the study region – is essential to assure population viability. The fox squirrel, in particular, requires an open understory, as maintained historically by frequent growing-season fire in pinelands.

In summary, we found that options for maintaining connectivity for three focal species – Florida panther, Florida black bear, and Sherman's fox squirrel – between Babcock Ranch and other existing and potential conservation areas within the regional landscape are still relatively abundant and intact. Nevertheless, several problematic corridor bottlenecks are present already in the region and will constrain animal movement unless remedied by increased land protection and

mitigation of impacts from roads and development. Moreover, unless potential conservation areas (e.g., Florida Forever projects) are protected soon, connectivity for our focal species and many other animals will be significantly diminished, especially if human population growth and development continue in the study region and if road impacts (increased traffic volume, road widening, etc.) are not reduced by properly located and designed wildlife crossings and associated barrier fencing. Impacts from sea-level rise, although predicted to be relatively minor in the immediate vicinity of Babcock Ranch, are likely to be severe in the southern and western portions of our study area and in the Lower Peace and Myakka River areas, where some of our identified LCPs will be severed by rising waters. Moreover, even inland areas substantially above 3 meters in elevation will be at high risk as displaced people flee the coasts over the coming decades. This likely phenomenon underscores the need to protect key core areas and landscape linkages soon.

Further work is needed to evaluate available tools to plan and seek to implement any of these connectivity options. Future Florida Forever or other acquisition programs, landowner incentives, private conservation efforts, innovative planning strategies, and other tools will be needed to actually accomplish the creation of a connectivity strategy.

Introduction

The Babcock Ranch, which covers 91,360 acres in Charlotte and Lee counties, Florida, includes 73,239 acres that was purchased by the State's Florida Forever program, the largest acquisition in the program's history. The 73,239-acre conservation area, named Babcock Ranch Preserve, possesses two key kinds of conservation value: (1) on-site values, including high-quality examples of natural communities in large patch sizes and sizable populations of many imperiled and declining species, several of them federally or state listed; and (2) landscape values related to Babcock Ranch's strategic location with respect to surrounding conservation areas, other areas of conservation interest, and riparian networks. Potential connections to other lands of high ecological value exist in all directions – south, north, east, and west. It has also been noted that protection of wildlife corridors in the Babcock Ranch area will assist with Caloosahatchee River protection efforts. For all of these reasons, Babcock Ranch has been identified as a high priority in the Florida Ecological Greenways Network, which identifies the most important conservation corridors and large, intact landscapes in the state (Hoctor et al. 2000; Hoctor 2003; Hoctor et al. 2008).

Our study sought to assess the opportunities for facilitating regional ecological connectivity between Babcock Ranch and surrounding lands of high ecological value by reviewing existing reports and spatial data and conducting new, updated analyses using currently available land-use data as well as new data from such studies as the Highlands County black bear study, the work of the Babcock Ranch Steering Committee, and new surveys of roadkill on the roads surrounding Babcock Ranch. Issues related to facilitating connectivity, including road crossings and potential corridor bottlenecks were also assessed, as was the need for additional research and analyses. The fundamental goal of our study was to identify the best potential ecological connections between Babcock Ranch and other regional conservation areas (existing and proposed) so that biodiversity and functional ecosystem processes are maintained.

Why is Connectivity Important?

Wildlife corridors are well known and popular mechanisms for conservation and have been proposed in Florida for many years, especially for wide-ranging species such as black bears and panthers (Harris 1985, Noss and Harris 1986, Noss 1987, Harris and Gallagher 1989, Harris and Atkins 1991, Harris and Scheck 1991, Hoctor et al. 2000, Maehr et al. 2002; Hoctor et al. 2008). The popularity of corridors as a conservation tool notwithstanding, what conservation biologists are interested in is not corridors per se, but rather *functional connectivity*, which involves the flow of individuals and their genes among habitats and populations (Noss and Cooperrider 1994, Beier and Noss 1998). The connectivity of a landscape can be measured by the degree to which it facilitates or impedes movement of organisms among habitat patches (Tischendorf and Fahrig 2000). Connectivity is determined by the intersection of a species' life history characteristics, including its behavior, and the structure of the landscape. Hence, connectivity is a very species-specific and landscape-specific property (Bennett 1999). Well-designed studies of corridors generally show that they provide connectivity for the species of interest (Beier and Noss 1998). Nevertheless, for a particular corridor or greenway to provide functional connectivity, we have to know a considerable amount about the species that we hope will benefit from the corridor, as well as about the habitat structure and landscape context of the corridor.

Corridors are often conceived as simple swaths of habitat that allow an animal to get from point A to point B. In real landscapes, however, there are many potential functions of connectivity. Besides their value in providing dwelling and breeding habitat for some species, corridors potentially facilitate: (1) movement of animals within home ranges; (2) seasonal migrations or wanderings of animals; and (3) dispersal of juveniles or adults of animal or plant species, which in turn provides for colonization or recolonization of suitable habitat patches and for movement of individuals among populations over a larger area. Large-bodied animals, in particular, have large home ranges, for example on the order of 416.5 km2 for male Florida panthers (Land et, al, 2004; Kautz et al. 2006). Dispersal and colonization of new habitats will be of critical importance in the adaptation of species to climate change (Noss 2001). In Florida, corridors to facilitate functional connectivity from current coastal areas to inland areas, and corridors south to north will both be important aspects of a conservation strategy to enable adaptation to climate change.

To meet their life-history needs across large areas, wide-ranging animals today must move through areas with varying degrees of human development; they must also cross many roads, which often cause mortality (Trombulak and Frissell 2000). Protected corridors that follow expected movement routes – which are generally the paths of least resistance through the landscape, based on habitat preferences, topography, and other factors – are expected to reduce mortality and conflicts with humans and facilitate safe movement among patches of suitable habitat (Noss and Cooperrider 1994). Based on empirical studies of cougars (i.e., the same species as the Florida panther) in California, Beier (1995; 1996) suggested that suitable corridors have the following characteristics: (1) located along natural travel routes (including riparian strips and ridges); (2) have ample woody cover; (3) include underpasses with ample fencing at large/high-speed road crossings; (4) lack artificial outdoor lighting; (5) have less than 1 human dwelling/16 hectares (approximately 40 acres); and (5) should be at least 100 m wide if less than 800 m long, but more than 400 m wide if 1-7 km in length.

In mountainous and northern landscapes, many large mammals make seasonal migrations between summer range and winter range. Elk, for example, typically make seasonal movements in response to forage conditions, and during these migrations they often depend on hiding or escape cover, as provided by forest corridors adjacent to open meadows (Pederson and Adams 1976, Winn 1976). In Florida, on the other hand, large terrestrial animals are not migratory in the traditional sense. Some species, however, make widespread movements at particular times of year. For example, fox squirrels exhibit an "autumn-shuffling" that includes adults as well as juveniles, and small-scale mass migrations are occasionally observed (Koprowski 1994). Sherman's fox squirrel has large home ranges (averaging 43 ha for males and 17 ha for females) and males make long-distance movements in search of food in August-September (Kantola and Humphrey 1990). Black bears in Florida also make seasonal movements to track food abundance and often use riparian corridors, in part, for both daily and seasonal movements (Harris 1985; Harris and Gallagher 1989). Seasonal movements of black bears in Florida include travel outside of normal home ranges to access important food resources such as saw palmetto (*Serenoa repens*) and acorns (Maehr et al. 2001a). These movements can be extensive, as male bears typically have home ranges of 50 to 120 square miles; female ranges generally are 10 to 25 square miles (Maehr et al. 2001a).

Dispersal refers to the movement of individual organisms away from their place of origin (Brown and Lomolino 1998) and is one of the most critical of all biological processes (Bullock et al. 2002). Dispersal often reduces competition within families, reduces inbreeding (when one sex disperses further than the other, i.e., female birds and male mammals), results in gene flow among populations, and can rescue small populations from extinction (Noss and Cooperrider 1994). A corridor can promote dispersal if individual animals or plant seeds travel from one population to another by means of the corridor, or if resident populations in the corridor allow the gradual flow of genes from one end to another.

Plants and animals have evolved many different ways to disperse. Fruits of many plants become attached to the fur of mammals, whereas fleshy fruits are eaten and passed through the gut of animals. Seeds of trees, such as oaks, hickories, and pines, are gathered by squirrels, jays, and other seed predators, but many of the cached nuts are never eaten and later germinate. Hence, as animals move across a landscape, the plants they carry also move. In one study, seeds of fruiting shrubs were dispersed by birds much more effectively when habitat patches were connected by corridors than when they were not. Moreover, movement of butterflies preferentially through corridors resulted in dramatic increases in movement of pollen. As a result, a significantly higher proportion of flowers produced fruit in connected patches than in unconnected patches (Tewksbury et al. 2002). Another study in the same area of South Carolina found that corridors increase plant species richness. Over time, connected patches became more species rich, containing 20% more plant species than unconnected patches over 5 years. Native species increased over time in connected patches, whereas non-native species showed no increase (Damschen et al. 2006).

Many species are distributed as metapopulations, that is, as systems of local populations linked by occasional dispersal (Hanski 1999). It is the fate of local populations in these systems to "wink" off and on over time. Dispersal of individuals across the landscape allows for

colonization of vacated or other suitable habitats, so that the metapopulation as a whole persists despite local extinctions. If too many connections between habitat patches in a landscape are severed, the metapopulation is less likely to persist. Extinctions of local populations under these circumstances signal bit-by-bit extinction of the metapopulation or the entire species (Harrison 1994). The survival of metapopulations thus depends, in large part, on both the rate of local extinctions in habitat patches and the rate at which organisms move among patches, which in turn is affected by connectivity between patches. Corridors can lower the chances of extinction for small, local populations by augmenting population size and by increasing population growth rates (Merriam 1988). Corridors may also increase the likelihood that local extinctions can be reversed through recolonization of vacated patches. This, in turn, increases the chances that the entire metapopulation will survive.

Small, isolated populations are prone to two kinds of detrimental genetic effects: inbreeding depression and random genetic drift. Inbreeding depression is a result of mating between close relatives in normally outbreeding species. It occurs when individuals are not able to disperse and mate with individuals from other populations. By reducing genetic diversity and allowing harmful recessive genes to be expressed, inbreeding can raise mortality rates (especially among juveniles) and reduce individual health, vigor, and fertility. Data from recent studies confirm that inbred populations often experience reduced growth and increased rates of extinction (Keller and Waller 2002). Random genetic drift is a change in gene frequencies in a population due to chance. In small populations, where chance events play a greater role, genetic drift leads to the loss of genetic diversity. Not only do genetically impoverished populations often show reduced viability and fertility, but in the long run they will be less able to adapt to changing environmental conditions. Allendorf (1983) predicted that an exchange of one reproductively successful migrant, on average, between populations per generation is sufficient to avoid the loss of genetic diversity through drift but will still allow populations to diverge as a result of adaptation to local environments through natural selection. To the extent that corridors facilitate an exchange of individuals among populations, they help maintain genetically viable populations.

The Florida panther (*Puma concolor coryi*) and Florida black bear (*Ursus americanus floridanus*) were once found throughout Florida but now are limited to isolated populations over a small portion of their former range. The Florida panther has only one known breeding population, with females presumably limited to areas of southwest and south Florida south of the Caloosahatchee River. The Florida black bear still exists in seven populations across the state, though most of these populations appear to be currently functionally isolated from each other (Maehr et al. 2001a; Hoctor 2003). In the region around Babcock Ranch there are two bear populations, the Big Cypress population south of the Caloosahatchee River and the Highlands-Glades population east and northeast of Babcock; dispersing bears from both populations may occasionally move through the ranch. Re-establishing functional metapopulations is an important goal for both species. For the Florida panther, re-establishment of a breeding population north of the Caloosahatchee River would greatly enhance viability (Maehr et al. 2001b; Kautz et al. 2006; USFWS 2008). For the Florida black bear, a functional regional ecological network in southwest Florida would re-establish connectivity between the Big Cypress and Highlands-Glades populations and would increase the likelihood that connectivity could be re-established between

the bear populations in south Florida with those further north, such as the Ocala population in central Florida (Maehr et al. 2001; Hoctor 2003; Dixon et al. 2006; Dixon et al. 2007).

Another declining animal, perhaps at least as imperiled as the Florida black bear, is the fox squirrel (*Sciurus niger*). Within our study region fox squirrels are currently considered to encompass two subspecies: Sherman's fox squirrel (*S.n. shermani*) north of the Caloosahatchee River and Big Cypress (formerly mangrove) fox squirrel (*S.n. avicennia*) south of the Caloosahatchee River. We suspect that there is gene flow between the Sherman's and Big Cypress fox squirrels across the Caloosahatchee River. Fox squirrels may swim surprisingly long distances (Koprowski 1994, Trauth and Jamieson 1997) and there are also anecdotal reports of fox squirrels on bridges across the Caloosahatchee River. Therefore, these two named subspecies may not be genetically distinct (N. Moncrief, pers. comm.). Regardless of genetic distinctiveness, fox squirrel habitat is currently highly fragmented across peninsular Florida, including in our study region, and the species is vulnerable to roadkill and other mortality when attempting to move between patches of suitable habitat. Hence, a network of protected habitat linking important core areas may be essential to the persistence of this species in the state.

Plant communities over much of North America have developed only within the last 4,000 to 8,000 years (Davis 1981, Webb 1987). Before this time, many of the species now found together were separated geographically; many of the communities (species combinations) we see today did not exist anywhere. Since the Pleistocene (Ice Age) ended about 10,000 years ago, the ranges of many plant species have shifted by over 1000 kilometers (620 miles). Because species migrated northward at different rates and by different routes, community composition has changed continuously over space and time (Davis 1981). A major concern today is that a system of mostly isolated conservation areas may be incapable of maintaining biodiversity during climate change (Peters and Darling 1985; Lovejoy and Hannah 2004). Even natural rates of change pose significant challenges to species confined to reserves surrounded by inhospitable habitat. The increased rates of change that would occur with a warming climate may eliminate all species but the most mobile as they fail to track shifting climatic conditions. Although the role of corridors in conserving species during a time of rapid climate change is not proven, "their incorporation into a strategy for dealing with the effects of climate change adds an option to what is otherwise a rather sparse repertoire." (Hobbs and Hopkins 1991) We predict that connectivity is more likely to be a successful strategy over the relatively small distances that coastal species would need to move in response to sea-level rise, which will have significant impacts in Florida over coming decades. In fact, biological impacts of sea-level rise are already strikingly evident in low-lying areas of Florida, such as the Florida Keys (Ross et al. 2009) and are predicted to become much worse over the next few decades as the current ranges of many species would be inundated with a 1+ m rise in sea level (Noss, Hoctor, Oetting et al. in preparation). Though more challenging, the protection of connected networks of conservation lands on a broad scale may provide the best opportunity to facilitate functional adaptation to climate change for various species that would not be able to negotiate otherwise human-dominated landscapes.

One concern about corridors, especially narrow ones, is that predators, including humans, may learn to concentrate their activity along animal movement routes. Thus, corridors could potentially act as mortality sinks (Simberloff and Cox 1987). For example, predators have been reported hunting in constructed wildlife crossings under roads (e.g., Foster and Humphrey 1995).

Nevertheless, the existing evidence suggests that highway crossings and other corridors designed for wildlife seldom function as prey-traps (Beier and Noss 1998; Little et al. 2002). More generally, greenways and wildlife crossings in developed landscapes should be designed and managed to provide adequate cover for wide-ranging species and to discourage human uses that might result in harassment. In wilder landscapes, intact roadless corridors should be maintained, and, where possible, roads should be closed to minimize conflicts between humans and wildlife.

In summary, the challenge of maintaining or restoring opportunities for animal movement in landscapes fragmented by human activities are best approached through a coordinated connectivity strategy of increasing or maintaining functional connectivity, such as by protecting or restoring specific habitat corridors and networks and preventing or reducing particular barriers or filters to movement, such as by modifying highways or by directing urban development or intensive agriculture to areas outside of specific habitat corridors and networks. We suggest that in the regional landscape surrounding Babcock Ranch, a combination of strategies is needed.

Study Area

The study area for this research included the lands immediately surrounding Babcock Ranch, nested within a larger landscape that extends, for least cost path analysis, northward to Tampa Bay, east to the Kissimmee River Valley, and south to Big Cypress (Fig. 1, red line); for long-term connectivity considerations, a still larger study area is appropriate, north to the Green Swamp and south to the Everglades (Fig. 1, yellow line). The major corridor destinations for least cost paths leading from Babcock Ranch include the Caloosahatchee Ecoscape, Avon Park Air Force Range, Big Cypress National Preserve, Bright Hour Ranch, Myakka State Park and contiguous conservation areas, Fisheating Creek Wildlife Management Area, Okaloacoochee Slough State Forest, and other conservation lands (Fig. 1). This regional landscape is a significant biodiversity hotspot and includes: the scrub and sandhills of the Lake Wales Ridge; the prairies, hammocks, and flatwoods of south-central and southwest Florida; major river and riparian wetland systems including the Peace, Myakka, and Caloosahatchee Rivers and Fisheating Creek; and other large wetland systems of south Florida including Okaloacootchee Slough, Corkscrew Swamp, and Big Cypress.

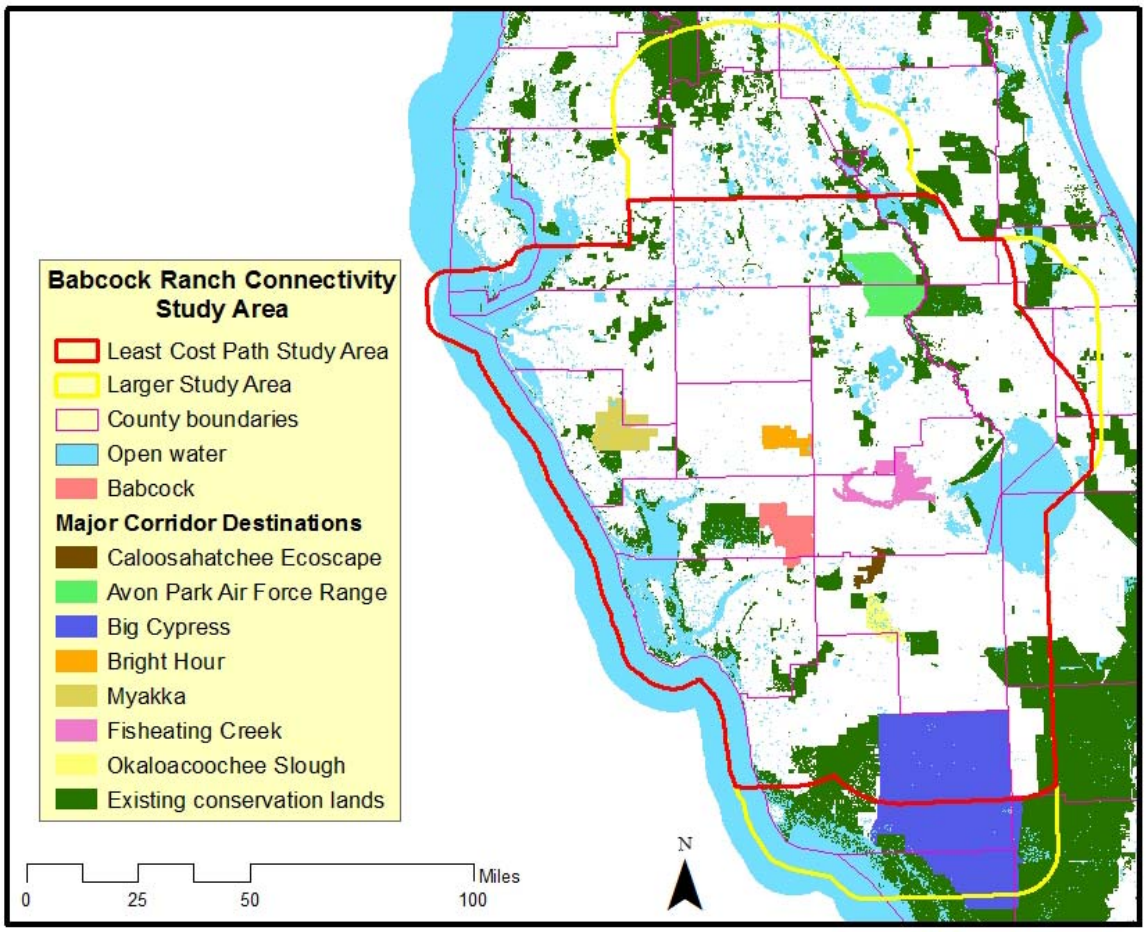

Figure 1. Babcock Ranch Connectivity Study Area, with major corridor destinations for the least cost path analysis (boundary marked in red line) and the broader region for long-term connectivity considerations (boundary marked in yellow line).

Methods

Databases and Literature

We reviewed and applied the following databases and literature in conducting this study:

- Existing conservation lands (from the Florida Natural Areas Inventory managed areas database plus mitigation banks from the Florida Department of Environmental Protection, conservation easements from the South Florida and Southwest Florida water management districts, U.S. Department of Agriculture easements, and additional conservation areas including easements from The Nature Conservancy)
- Florida Forever Projects
- Florida Ecological Greenways Network
- Water Management District 2004-2006 FLUCCS Land Use data
- Florida black bear Strategic Habitat Conservation Areas from FWC
- Florida panther Strategic Habitat Conservation Areas from FWC

- Florida black bear range from FWC
- FWC Black bear location data
- FWC Bear roadkill data
- Highlands-Glades Florida black bear population range from University of Kentucky
- University of Kentucky black bear telemetry data
- Florida black bear population conservation habitat priority areas by T. Hoctor
- FWC Panther location data
- FWC Panther mortality data
- Florida panther USFWS Panther Subteam Report and Habitat Conservation Zones
- Florida panther Habitat Protection Priority Areas from FWC
- National Hydrography Data Flowlines
- CLIP Landscape Integrity
- Florida Natural Areas Inventory (2008) Babcock Ranch Ecological Inventories - Report for FWC (Natural Community Mapping Project, Listed and Rare Plant Inventory, Listed and Rare Animal Inventory, Invasive Exotic Plant Inventory)
- Johnson Engineering roadkill data and other information from reports
- GIS data prepared by Johnson Engineering for the Babcock Ranch Steering Committee
- Babcock Ranch Primary Internal Transportation Plan, Primary Greenway Plan, Preserve Recreation Master Plan
- Primary literature (scientific journal articles, etc. cited in this report)

Habitat Models

Because biodiversity is too immense to measure and manage in its entirety, surrogates for biodiversity are used in conservation planning. Among the commonly applied surrogates, which are particularly useful for determining landscape configuration requirements and habitat management priorities are focal species (Lambeck 1997, Carroll et al. 2001, Noss et al. 2002). Focal species are simply the species that one focuses on in conservation planning, and they are assumed to be among the most sensitive species to the habitat qualities of importance (e.g., core area size, landscape connectivity, habitat quality) within a given planning region. We selected three focal species to investigate in detail in this study: the Florida panther, the Florida black bear, and Sherman's fox squirrel.

We developed and refined habitat models for the three focal species for use in determining source and destination areas and least cost paths for movement across the study region. These habitat models identify potential habitat for each focal species based on known land cover associations and other relevant parameters including patch size and buffer distances to identify areas that are more likely to support suitable habitat conditions. The word "potential" is important, because although these models do identify locations where each of these focal species are documented, identification of habitat in these models does not guarantee occupancy.

Florida panther

The Florida panther requires intact landscapes with no to low human activity dominated by land cover and land use that supports suitable cover and prey (Kautz et al. 2006, USFWS 2008). Various types of forest are of primary significance but panthers also use rural mosaics containing

upland and wetland forest, herbaceous wetlands, dry prairies, pasturelands, and other agricultural land uses (Kautz et al. 2006, Land et al. 2008. USFWS 2008). Panthers require large areas to support functional home ranges and the integrity of home ranges, with respect to impacts from roads and other human land use and activities, is an important consideration for maintaining or restoring suitable habitat (Kautz et al. 2006, USFWS 2008).

The Florida panther habitat model applied in this study was adapted from the potential habitat model created by the Florida Fish and Wildlife Conservation Commission as part of their update to Strategic Habitat Conservation Areas (http://research.myfwc.com/features/view_article.asp?id=29815). The model was created using 2004-2006 Water Management District land-use data at a 10 meter cell size to identify forest patches 2 hectares (approximately 5 acres) or larger and then adding all non developed (natural, semi-natural, agriculture) within 200 meters of such forest patches (Kautz et al. 2006). Forest patches 2 hectares or larger and all other habitats within 200 meters of these patches were all given a value of 1.

Florida black bear

The Florida black bear uses a wide variety of forest types such as pine flatwoods, hardwood and mixed swamps, cabbage palm forests, sand pine scrub, hardwood hammocks, and even mangroves (Maehr et al. 2001a, Hoctor 2003). The Florida black bear is omnivorous, but plant matter dominates as a food source. Black bears typically follow the phenology of plants in selecting food items seasonally (Maehr et al. 2001a, Hoctor 2003). Saw palmetto (*Seronoa repens*) fruits are heavily used in late summer and fall; cabbage palm (*Sabal palmetto*) hearts, tupelo (*Nyssa* spp.) fruits, acorns (*Quercus* spp.), blueberries (*Vaccinium* spp.), blackberries (*Rubus* spp.), and gallberry (*Ilex glabra*) are also important **(**Maehr and Wooding 1992, Maehr et al. 2001a, Hoctor 2003). Like the Florida panther, the Florida black bear has large home ranges and is sensitive to habitat fragmentation and human disturbance (Cox et al. 2004, Maehr et al. 2001a, Hoctor 2003).

The Florida black bear potential habitat model applied here was creating using documented information about Florida black bear habitat preferences and assessment of connectivity thresholds based on distance from primary habitat and land use type (Maehr et al 2001, Hoctor 2003, Orlando 2003). Habitat was identified using 2004-2006 Water Management District land-use data at a 10 meter cell size. Three types of habitat/land use were identified:

1) Primary habitat—forest cover including flatwoods, hammocks, scrub, and forested wetlands. All patches of primary habitat greater than 6 hectares (approximately 15 acres) were identified (Cox et al. 1994).

2) Secondary habitat—sandhills, shrub and brush, and freshwater shrub wetlands and freshwater herbaceous wetlands. Patches of secondary habitat or smaller patches of primary habitat that are near larger primary habitat (15 acres and larger) can also be used by bears. However, patches separated by intensive land uses that cannot be reached or easily reached may not be used. Therefore, “traversable matrix” land cover and land uses were also identified to determine which secondary patches were functionally connected to primary patches. All secondary habitat types

and all smaller patches of primary cover within 1.5 kilometers of primary patches and connected by traversable matrix were identified as potential habitat.

3) Traversable matrix—almost all other land use types that bears are capable of moving through when proximal to primary habitat including agriculture, mining lands, and saltmarsh. Roads also were included to model habitat patches across roads that bears might be able to access (Larkin et al. 2004). Large water bodies were not included as potential habitat, but narrow channels that might be crossed were identified and included within the traversable matrix. Narrow water gaps were defined as <100 meters (Dave Maehr, personal communication).

Then, all primary and secondary habitat were combined to identify connected blocks >10,000 acres. This was done to identify areas that are more likely to be large enough to serve as minimum functional habitat units for black bear (Hellgren and Maehr 1992). Within these areas, primary habitat was given a value of 1, secondary habitat was given a value of 2, and traversable matrix was given a value of 3.

Sherman's fox squirrel

It is a credible hypothesis that within peninsular Florida, fox squirrels have suffered more pronounced declines than any other mammal in the state over the last several decades. Regardless of taxonomy (see above), the Sherman's and Big Cypress fox squirrels (indeed all of the southern fox squirrels) have very similar habitat requirements and life histories (Weigl et al. 1989, Koprowski 1994). Fox squirrels require large tracts of sandhills, natural pine flatwoods, adjacent rangelands, and hardwood or wetland forests to meet their habitat requirements (Weigl et al. 1989; Kantola 1992; Cox et al. 1994). Fox squirrels are associated primarily with open, mature pinelands (pine flatwoods or sandhills) but also are found in open cypress stands and in oak hammocks, bottomland hardwood areas, and tropical hardwood hammocks. Although dense hardwood areas are not considered primary habitat, in some situations the squirrels make high use of ecotones between hammocks and pine savannas, to the extent that Kantola and Humphrey (1990) concluded that "proximity of longleaf pine savanna to live oak forest may define highest-quality habitat for this squirrel."

We used the following habitat model steps to identify fox squirrel habitat in the study area:

1) All potential primary suitable cover including upland coniferous forest (4100), pine flatwoods (4110s), longleaf pine-xeric oak (4120s), pine-mesic oak (4140), other pines/hunting plantations (4190), xeric oak (4210), and oak-pine-hickory (4230) that are in patches 50 acres and larger are identified as primary habitat blocks (Kantola and Humphrey 1990; Cox et al. 1994).

2) Then rangeland (3000s) and mixed hardwood-pine (4340) within 1000 meters of these primary cover types are identified as additional primary habitat.

3) All open lands (1900-1999), pasturelands (2100-2130), all rangelands (3000-3999), all upland forests (4000-4500), and all wetland forests (6100-6300s) other than mangroves within 200 meters of primary patches identified in step 1 are also identified (Cox et al. 1994). Other land use types (open lands, agriculture, all forest and wetlands, disturbed lands, and pipeline, rail, and electrical transmission corridors) are included as potentially traversable areas since fox squirrels

are capable of moving long distances to integrate habitat patches across a large landscape (Weigl et al. 1989).

The distances of 1000 and 200 meters used to identify additional habitat are at least somewhat arbitrary. Cox et al. (1994) used a distance of 120 meters but do not cite a source. Weigl et al. (1989) and Kantola (1992) indicate that other forest adjacent to longleaf pine flatwoods and sandhills can be very important habitat components but do not indicate specific distances fox squirrels venture into adjacent land cover types. Therefore, the distance of 1000 meters is based loosely on the minimum dispersal distance observed by Wooding (1997) and the distance of 200 meters is a slightly more ambitious version of the 120 meter distance used by Cox et al. (1994).

4) All identified habitat was separated into two patch classes to delineate patches more likely to support viable populations (Kantola and Humphrey 1990, Cox et al. 1994, Wooding 1997). Patches 5,000 acres or larger were given a value of 1 and patches between 250-5,000 acres were given a value of 2. Matrix land cover connected to patches at least 250 acres and larger are given a value of 3.

Ground-truthing of habitat models and assessment of habitat quality for focal species within Babcock Ranch

Connectivity to habitat blocks in the regional landscape surrounding Babcock Ranch is not especially meaningful if suitable habitat is not available for our focal species within the boundaries of the ranch. Florida panthers and black bears, relative to many other animal species, are habitat generalists and use habitat features at relatively coarse scales. Therefore, panther and bear habitat is readily assessed through remote sensing (aerial photos, satellite images, etc.), coarse maps of land use and land cover, and other geographically widespread GIS data. In contrast, fox squirrels are more specialized and have more demanding habitat and microhabitat requirements at the site level, which cannot be evaluated adequately without ground surveys in the field. Therefore, one of us (Noss) made four tours through Babcock Ranch during the course of this study (February 3 - April 30, 2009), evaluating and documenting with photographs habitat quality for fox squirrels. Of special interest was the quality of the understory and herbaceous vegetation. Fox squirrels favor open, well-burned understories in order to travel quickly between trees and remain vigilant for predators. As discussed later, a legacy of fire exclusion or dormant season burning, which allows undergrowth such as saw palmetto to grow high and dense, can make otherwise suitable habitat unusable by fox squirrels.

In addition to assessing habitat quality within Babcock Ranch for fox squirrels, we wanted to verify use of the ranch by black bears and panthers. Our field technician, David Hammel, recorded all observations of tracks of these species within Babcock Ranch during the study period. Although, due to budget and time limitations, these were not comprehensive surveys, they help validate habitat model data, radio-telemetry locations, and other information suggesting use of the ranch by these species.

Roadkill Surveys

We monitored roadkills and made observations of focal species along roads surrounding and within Babcock Ranch within the period February 3 - April 30, 2009. We focused our most intensive effort on 3 areas determined from maps, surveying the roads surrounding Babcock Ranch, and evaluating properties adjacent to roads as potential habitat (Fig. 3):

- Area 1- From intersection of Rts. 31 and 74, for 4 miles on SR 74 EAST
- Area 2 - From intersection of Rts. 31 and 74, for 4 miles on SR 31 SOUTH
- Area 3 - From intersection of SR 31 and SR 78, east from Telegraph Creek and Cypress Creek.

We monitored the roads twice weekly during the study period and documented roadkills of large herpetofauna (snakes, turtles, alligators), large birds, and medium-sized to large mammals. In addition, we monitored the roads around the entire perimeter of Babcock Ranch once per week, beginning in late March. The data collected for each individual roadkill was species, GPS location, lane (in road or side of road), sex and age class if possible, travel direction if possible, and weather at the time of survey. We also made an effort to survey for fox squirrels within Babcock Ranch and elsewhere within the surrounding landscape. Although the time and budget of this study did not allow a comprehensive study, our field technician, David Hammel, recorded sightings and noted GPS locations of all fox squirrels observed during the course of this study.

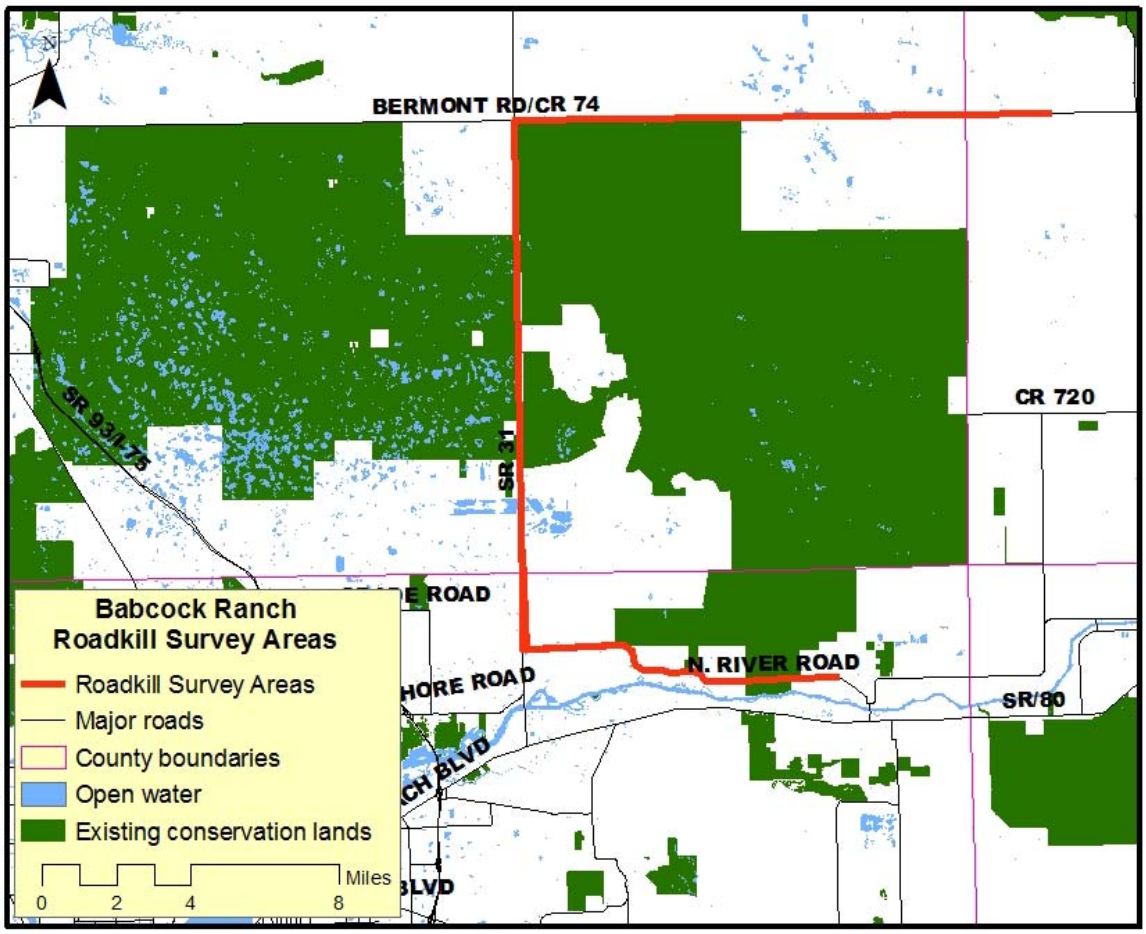

Figure 2. Map of roadkill survey areas.

<u>Riparian Habitat/Corridors, Greenways and Habitat Combination Models</u>

Since the Florida Ecological Greenways Network (FEGN) focuses on state and regional corridor priorities, at the regional to local scale there can be other significant corridors that are not included within the FEGN. Riparian networks including rivers, streams, lakeshores and associated wetlands, floodplains, and forests, are important guiding landscape features used by many species. Therefore, any intact riparian corridors that might provide additional connectivity within the study area were identified. The riparian corridor layer was created by combining all forested wetlands from Water Management District land use data with streams from NHD flowlines data. Then, we identified all additional natural or semi-natural land cover (defined as all FLUCCS values from 3000 to 7399) within 400 meters of these forested wetlands and streams. Values are:

1 = riparian habitat/corridor
0 = not riparian habitat/corridor

To serve as a starting point for evaluating potential connectivity, we combined the identified riparian habitat/corridors with the FEGN and the Florida black bear and Florida panther habitat models. First, we combined riparian habitat/corridors with the FEGN and identified all combined

areas that were 1,000 acres or larger. Then, we took this combined data set and combined it with all bear and panther habitat and again identified all combined areas that were 1,000 acres or larger.

Least Cost Path Models

Least Cost Path (LCP) is a useful tool for assessing potential connectivity. LCP is a raster-based algorithm available in ESRI's ArcView Spatial Analyst or ArcGIS software. It is an optimization function that seeks the least costly route between a source and a destination. Typically this algorithm has been used to find the optimal path for linear infrastructure (including roads and transmission lines). LCP analysis can also be applied to wildlife corridor analysis where the best potential travel route between a source and destination is identified based on a cost surface ranking each cell's corridor suitability (Hoctor 2003; Larkin et al. 2004). The least costly route is essentially the path of least resistance, where resistance is defined by unsuitable or low-security habitat for the species in question.

Identifying LCPs requires the development of a cost surface, which is a raster map in which every cell (or pixel) is ranked for its potential suitability for accommodating a particular function. In the case of ecological connectivity, a cost surface ranks each cell based on its potential to support a functional ecological connection. Cells within the study area can be ranked using as many variables as deemed relevant for determining connectivity potential. These variables can include intrinsic qualities (such as the land use of the cell) or landscape or context values (such as whether the cell is part of a large forest block or near a large urban area).

We ran LCP analyses for all three focal species. In addition, we also tested the effects of using different cost surfaces in LCP results. Hoctor (2003) found that the structure of cost surfaces in interaction with the landscape structure can significantly influence LCP results. Therefore, for each of the three focal species, we constructed six different cost surfaces. The cost surface variations included:

1) Habitat for focal species reclassified into a cost surface
2) Habitat plus major roads
3) Habitat, major roads, and edge effects
4) Habitat, major roads, edge effects, and sea-level rise
5) Habitat plus CLIP Landscape Integrity layer
6) Habitat, Landscape Integrity, roads, edge effects, and sea-level rise

For each of the focal species the potential habitat models were reclassified to turn them into cost surfaces. For example, for the Florida black bear primary habitat was given a cost of 1 (which is the lowest possible cost and therefore the highest suitability), secondary habitat was given a cost of 5, and traversable matrix was given a cost of 10. In addition, all non-habitat was assigned as "No Data" which means that an LCP could not be located in these areas. However, for the Florida panther and fox squirrel, non-habitat was assigned a cost of 10 instead of No Data because these habitat models were not constructed to assess landscape-scale connectivity as in the black bear habitat model.

Major roads were included in the relevant cost surfaces by identifying to sets of highway segments included in the Florida Department of Transportation's Major Roads GIS data layer (obtained from the Florida Geographic Data Library, i.e., FGDL). Highways with four or more travel lanes or Average Daily Traffic (ADT) of 5,000 vehicles or greater were assigned a cost of 100 and all other highways were assigned a cost of 50. In the cost surfaces including highways, more emphasis is placed on avoiding such road crossings.

Edge effects were identified as areas proximal to residential or commercial land uses that could fragment potential corridors or cause various disturbances (i.e., human-caused mortality) that could reduce functional connectivity. In the appropriate cost surfaces, areas within 100 meters of such development was assigned No Data, areas from 100-300 meters from such development was assigned a cost of 100, and areas 300-1000 meters from such development was assigned a cost of 50. Therefore, lower cost areas more suitable for facilitating connectivity would have to be at least 1 kilometer away from intensive development.

Sea level rise (SLR) could affect potential corridors where water bodies will be widened as sea level inundates low-lying areas adjacent to current surface water levels near the sea. Examples in the Babcock Ranch study area include the lower Caloosahatchee and Peace Rivers. Since all of our focal species can cross water but avoid water crossings when possible, it is assumed that wider water bodies are less suitable for a corridor crossing than narrow water bodies. To account for increased water body width that could affect potential corridors crossing, we assigned areas that would be inundated by a 1 meter SLR a cost of 100 (including existing open water), and areas that would be inundated by a 3 meter SLR were assigned a cost of 50. The SLR data was created using the National Elevation Data and identifying areas adjacent to existing sea level with elevations either 1 meter or less or 3 meters or less (UA citation; Noss et al., unpublished data).

The Landscape Integrity layer from the CLIP project (Hoctor et al. 2008) was used to create the final two cost surfaces. In the first cost surface, the Landscape Integrity layer's values of 10 to 1 (where 10 signifies the highest landscape integrity and 1 the lowest) were inverted to match cost surface values. These inverted Landscape Integrity costs were then averaged with the reclassified potential habitat model costs to result in a cost surface with values of 1 to 10, where a cost of 1 occurs in areas of primary habitat that also had the highest landscape integrity (defined as areas within large natural and semi-natural patches with little impact from intensive land uses).

The final cost surface included all elements described above where major roads and SLR were assigned costs of 100 or 50 as described above. However, potential habitat, Landscape Integrity, and edge effects were averaged together to create a different combination of habitat and landscape suitability. In this averaging, the reclassified habitat costs and Landscape Integrity values were assigned the same values as described above. However, the edge effect costs were modified, such that areas within 100 meters of intensive development were assigned No Data, areas within 100-300 meters were assigned a cost of 10, areas with 300-1000 meters were assigned a cost of 5, and areas beyond 1000 meters of intensive development were assigned a cost of 1. These reclassified edge effect costs were then averaged with the habitat and Landscape Integrity costs to create one corridor suitability index with costs of 1 to 10, with other areas

assigned costs of 50 or 100 where they overlapped with major roads or areas affected by SLR (See Fig. 2).

These six cost surfaces were created for each of the three focal species, since the potential habitat models were different for each species. In addition, we selected six regional destinations to determine LCPs between Babcock Ranch and other key existing conservation lands within the study region that would likely serve as major "hubs" in a regional ecological network. The destinations included: Big Cypress National Preserve, Okaloacoochee Slough State Forest, Fisheating Creek Wildlife Management Area, Bright Hour Watershed, the Myakka complex of conservation lands (Myakka), and the Avon Park Air Force Range (see Fig. 1). Therefore, with 6 cost surfaces and 6 destinations, there were 36 LCP results for each focal species.

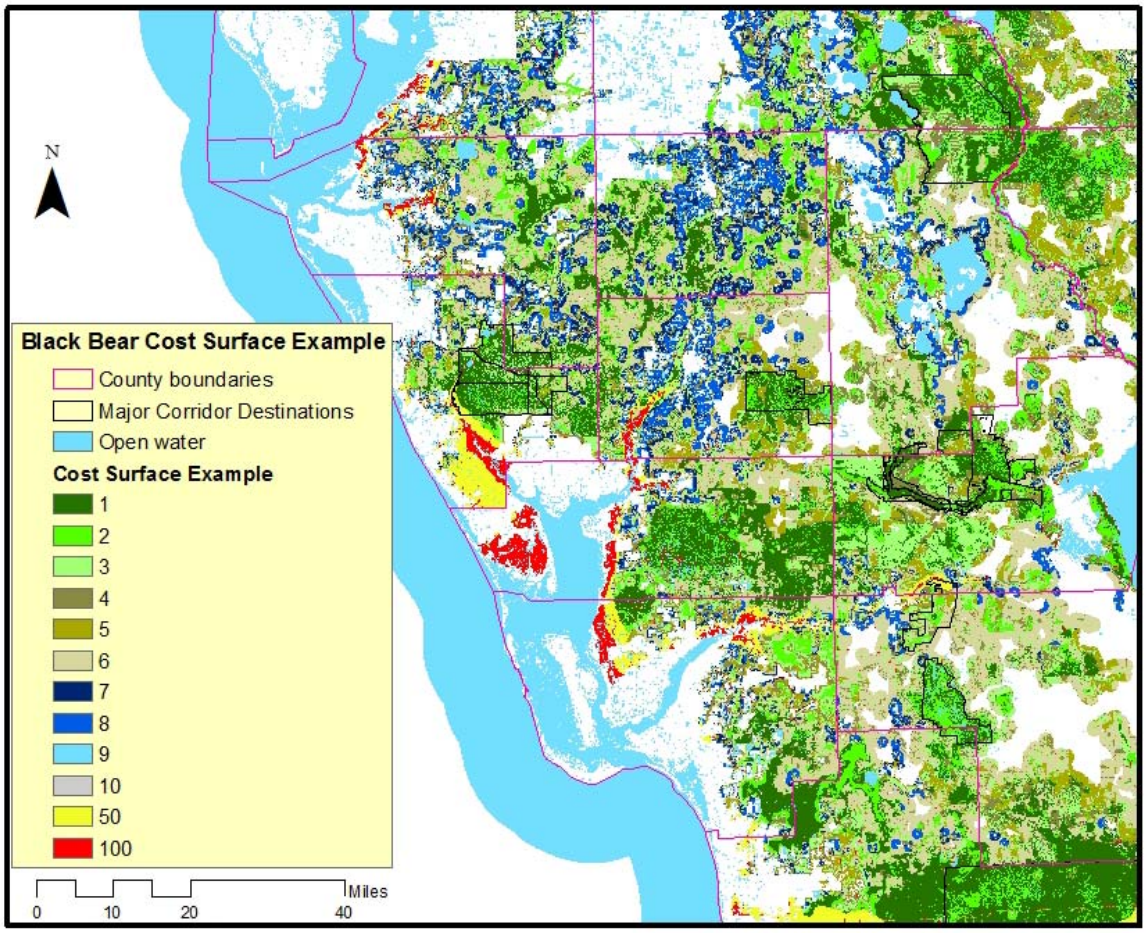

Figure 3. Example cost surface, which is the final of the 6 cost surface variations combining potential habitat, CLIP Landscape Integrity, and edge effects with costs ranging from 1-10 and then assigning highways or areas potentially affected by sea level rise costs of either 50 or 100. Roads that have been assigned costs of 50 or 100 do not show up on this map because of the scale.

Identification of Regional-scale Habitat Corridor Network Options

We identified three habitat corridor network (ecological network) options through a collective analysis and assessment of potential habitat model results for the three focal species, the LCP model results, the roadkill surveys, and other relevant data including the Florida Ecological Greenways Network, the Florida Panther Subteam report and Panther Habitat Conservation Zones, the Panther Habitat Protection Priorities, panther and bear telemetry and roadkill locations, bear range maps, and Integrated Habitat Network from Florida Department of Environmental Protection. The goal of the three connectivity options was to identify the best opportunities to maintain or restore ecological connectivity in the region surrounding Babcock Ranch. The connectivity options range from low, moderate, to high, with more proposed conservation acreage and more, and generally wider, corridors in the moderate and high connectivity options.

We first examined the patterns in potential habitat for each of the focal species, including larger areas of habitat and patterns of habitat connectedness in the habitat model results. LCP model results were assessed in several ways. First, we conducted an analysis of the overlap of LCP results for each of the focal species and then for all three focal species combined. The overlap analysis was conducted by examining the intersection of each LCP GIS shapefile with a shapefile of the study area that separated into square mile cells. The number of times each of these cells was crossed by an LCP was then counted for each of the focal species and then for all species combined. We also compared the LCP results visually with the focal species habitat model results, existing and proposed conservation lands, riparian corridors and networks, road and water body crossings, and potential bottlenecks near developed areas. Based on the LCP assessments, we then selected LCP results that we considered to be the most suitable for representing connectivity opportunities for the low, moderate, and high connectivity options.

Finally, we considered other relevant data for inclusion in the three connectivity options. Existing conservation lands were considered necessary areas to include where they contributed to a connectivity option. Florida Forever projects are also potentially significant for facilitating connectivity, and those considered important in this respect were included in the various connectivity options. Specifically, the Caloosahatchee Ecoscape Florida Forever Project is considered essential to providing functional connectivity between conservation lands south and north of the Caloosahatchee River; therefore, the Caloosahatchee Ecoscape was included in all of the connectivity options. The Florida Ecological Greenways Network (FEGN) identifies state and regional priorities for protecting large, intact landscapes and ecological corridors across Florida. It is therefore an essential dataset for assessing connectivity at all scales within the state, including regional and local.

Although the boundaries of the FEGN are general and should not be used as the basis for site-scale conservation boundary delineation, areas within the FEGN do represent important opportunities to protect ecological and focal species connectivity. In addition, although the FEGN is prioritized, these priorities are meant to guide state to regional scale planning; areas within the FEGN should be considered potentially significant at regional to local scales. For this analysis, we used the FEGN highest priorities in delineating the moderate connectivity option, and all areas within the FEGN were used in delineating the high connectivity option.

We also used data on habitat conservation priorities for the Florida black bear and Florida panther to delineate the moderate and high connectivity options. Given that funding and time constraints prevented us from conducting a regional, spatially explicit population viability analysis for bears and panthers, existing data on habitat conservation priorities constitute the best available information for identifying significant areas for maintaining/restoring functionally connected habitat blocks that will contribute to population viability for both species. We used the new Florida Fish and Wildlife Conservation Commission (FWC) Strategic Habitat Conservation Areas for both the Florida black bear and Florida panther, as well as the U.S. Fish and Wildlife Service's MERIT Panther Subteam's Primary and Dispersal Habitat Conservation Zones for this analysis. In addition, the Florida Panther Habitat Preservation Plan areas from 1993 were included since these are the best available data for delineating potential habitat conservation priorities north of the Caloosahatchee River to augment the Panther Subteam's Conservation Zones, which are largely limited to areas south of the river (except for a small portion of the Dispersal Zone). Finally, the primary range for the Florida black bear identified by FWC and habitat protection priorities for the Highlands-Glades bear population identified by Tom Hoctor were used (see Fig. 4). In all cases, only areas of habitat identified in our Florida panther and Florida black bear potential habitat models that also were within these various habitat conservation priorities were included in the appropriate connectivity option.

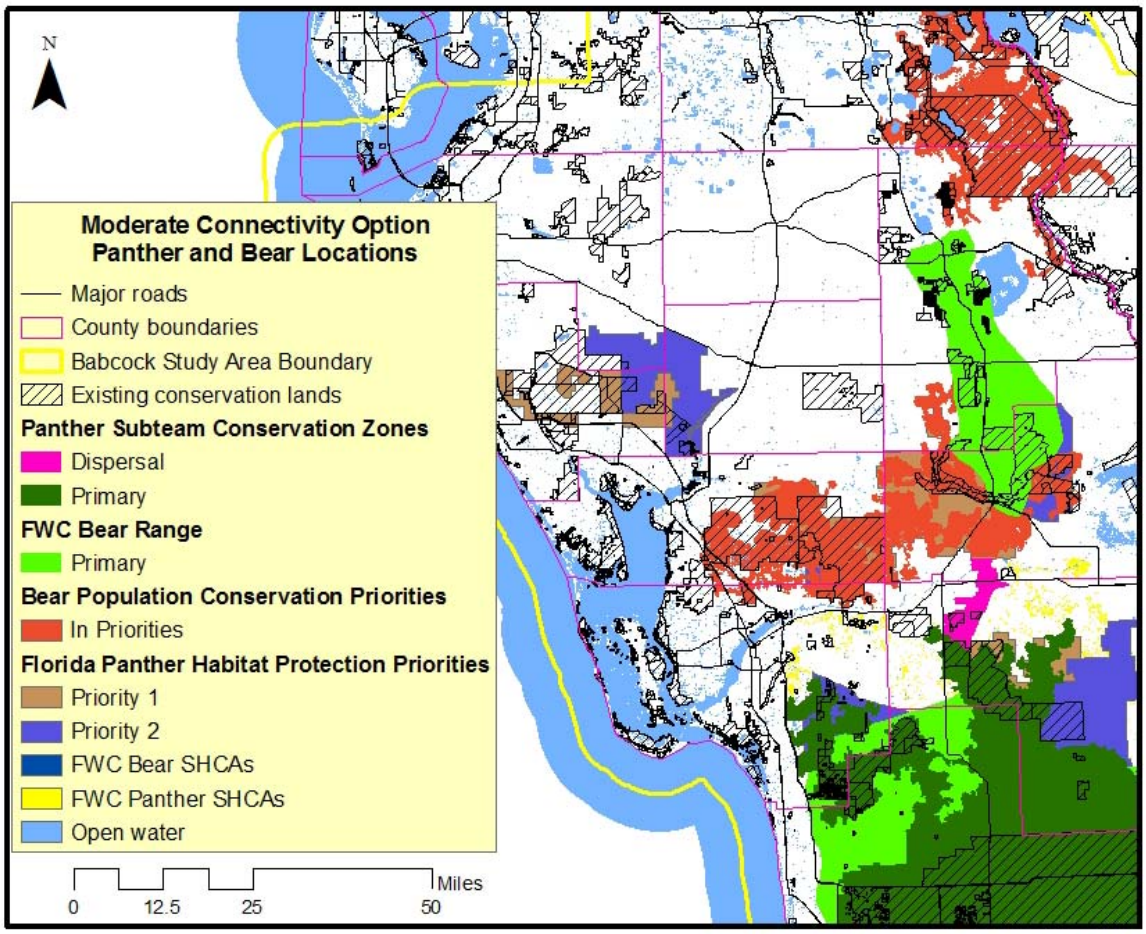

Figure 4. Florida panther and Florida black bear habitat conservation priority areas used to delineate the moderate and high connectivity options.

After discussions with the Wildlife Corridor Study Steering Committee and the Lands Surrounding Babcock Ranch Steering Committee, we added one more data layer, the Integrated Habitat Network (IHN), to identify additional riparian networks in both the moderate and high connectivity options. The IHN identifies existing and proposed protected riparian corridor networks in southwest and west-central Florida, focused on the Peace River and Myakka River watersheds and several other river systems. The IHN riparian networks augment the primary areas identified in the moderate and high connectivity options further to the south with additional northern corridor options and a potential corridor of statewide significance between southwest Florida and the Green Swamp.

We used the following datasets to create the three connectivity options:

1) Low Connectivity Option
a. Existing conservation lands
b. Caloosahatchee Ecoscape Florida Forever Project
c. One set of LCP results buffered by 1 mile for the three focal species between Babcock Ranch and the six selected destinations (Myakka, Bright Hour, Avon Park Air Force Range, Fisheating Creek Conservation Easement, Caloosahatchee Ecoscape, Okaloacoochee Slough State Forest, and Big Cypress National Preserve).

2) Moderate Connectivity Option
a. Existing conservation lands
b. Florida Forever projects
c. Two panther and two bear cost surface buffered LCP results buffered by 1 mile.
d. All Critical Linkages within the Florida Ecological Greenways Network
e. All primary and secondary black bear habitat within: all potential habitat within primary range identified by FWC, or all bear population habitat conservation recommendations delineated by T. Hoctor, or the new FWC bear SHCAs.
f. All panther habitat within: the USFWS Panther Subteam Primary and Dispersal Zones, or the older FWC Habitat Protection Plan areas, or the new FWC SHCAs
g. Integrated Habitat Network (given a value of 2 whereas all other areas within the option were given a value of 1)

3) High Connectivity Option
a. Existing conservation lands
b. Florida Forever Projects
c. Two panther and two bear cost surface buffered LCP results buffered by 1 mile.
d. All areas within the Florida Ecological Greenways Network
e. All potential bear (primary and secondary), panther, and fox squirrel habitat (primary and secondary)
f. All regional and local riparian corridors
g. Integrated Habitat Network (given a value of 2 whereas all other areas within the option were given a value of 1)

Comparison of Results to Future Scenarios

Future urban and suburban development and sea level rise (SLR) are two important potential impacts that could significantly affect the integrity of focal species habitat and corridors in the study area. To serve as coarse examples of what these impacts might be, we compared the moderate connectivity option results to data representing potential future development and SLR in the study area. We used the Florida 2060 growth projection model results to represent potential future development that might threaten potential priority conservation areas (Zwick and Carr 2006). It should be noted that the Florida 2060 model is a coarse, statewide model that projects future development based on current county-level human population densities and predicted future county population growth. Therefore, the amount and pattern of development is at best an approximate representation of future growth based on little to no consideration of sustainable development patterns. However, overlap between potential future growth and the moderate connectivity option does serve to highlight areas that might be most susceptible to future growth conflicts if sound planning practices and growth plans with conservation planning strategies are not enacted. We used the same SLR data described above regarding creation of our LCP cost surfaces to compare with the moderate connectivity option. SLR impacts could be extremely severe and wide-ranging in south and southwest Florida including the inundation of large areas of public conservation land. However, in the SLR comparison for this study, we focused on the potential impact of SLR on potential corridor crossings of the Caloosahatchee River and Peace River. We will discuss additional implications of SLR on focal species and corridor conservation in the Discussion section below.

Results

Data Products

The results of this study include the production of a series of GIS data products, which can be used for conservation planning by Babcock Ranch and other identified parties within the study region and beyond. These products include:

- Black bear habitat
- Florida panther habitat
- Fox squirrel habitat
- Riparian corridors
- Florida Ecological Greenways Network and Riparian Corridors
- Greenways, Riparian Corridors, and Focal Species Habitat Combined
- Least Cost Path modeling results
- Low Connectivity Option
- Moderate Connectivity Option
- High Connectivity Option

Habitat Models

Regarding habitat models, we are interested in major patterns of potential available habitat with respect to existing conservation areas, large habitat patches, areas dominated by potential habitat,

and potential connectivity suggested by habitat configurations. All three focal species have significant areas of potential habitat available in the study area, with the fox squirrel having the most limited potential habitat base. However, there is an important difference between potential habitat and occupied habitat. For all three focal species, we know that there is significantly more potential habitat identified in these models than there is occupied habitat. This is likely due to either the habitat models not identifying all of the landscape, land-use, and land cover characteristics required to support populations, or to potentially suitable habitat being unoccupied because of past or current human pressures including historic hunting and poaching (e.g., Williams 1978). Sherman's and Big Cypress fox squirrels are habitat specialists that require well managed pine uplands in large landscapes. Our habitat model, which identifies all pine flatwoods and pine uplands as one of the modeling steps, likely overestimates suitable habitat because many pine flatwoods and uplands are not burned appropriately to maintain suitable or high quality habitat. Regarding panther and bear, both species are relative generalists in terms of types of suitable land cover, but they are both wide-ranging species requiring large areas with low human land-use intensity and activity to support individuals and populations. In some cases, our identification of potential habitat for these species may not be sensitive enough to the unknowns about suitability thresholds; therefore, potential habitat may be identified in areas that are not suitable. However, due to historic hunting of both species throughout Florida, it is also feasible that other areas of potential habitat identified in our habitat models are suitable but are currently unoccupied by breeding populations because resident animals were hunted out in the past. Below we will summarize the major habitat patterns in the habitat models for each focal species with these important caveats in mind.

The only known breeding population of the Florida panther is relegated to areas south of the Caloosahatchee River. However, there are significant areas of potential habitat for this species north of the Caloosahatchee River that were identified in this study as well as others (e.g., Kautz et al. 2006). In addition, telemetry and other data indicate that at least sub-adult male panthers have traveled extensively and occupied potential habitat throughout south-central Florida (Maehr et al. 2002, unpublished Florida Fish and Wildlife Conservation Commission panther telemetry and GPS panther location data). Our panther habitat model confirms that, based on proximity to breeding range and the extent and connectedness of potential habitat, Babcock Ranch is central to a hub of potential habitat that ranges from Cecil Webb WMA west of Babcock Ranch, east through Babcock Ranch, and then east and northeast through large areas within and surrounding conservation easements along Fisheating Creek (Fig. 5 and Fig. 6). This area is likely the most relevant for efforts to expand the existing breeding population to areas north of the Caloosahatchee River, which the USFWS Panther Subteam stated would significantly increase the viability of the population if such an expansion was successful (Florida Panther Subteam 2002). Farther north there are three areas of potential habitat that are potentially significant based on the extent of potential habitat and location relative to existing conservation areas. Northwest of Babcock Ranch, the Myakka complex of existing conservation lands and additional lands in the Myakka River and lower Peace River watershed support a network of potential habitat in Sarasota, Desoto, Hardee, and Manatee counties (Fig. 5 and Fig. 6). Northeast of Babcock Ranch and north of Fisheating Creek, a network of potential habitat occurs through the Lake Wales Ridge, including Archbold Biological Station, various scrub reserves on the Ridge, Highlands Hammock State Park, Lake Wales Ridge State Forest, Avon Park Air Force Range, and further north along the upper Kissimmee River watershed (Fig. 5 and Fig. 6). This habitat

network has demonstrated use based on available FWC panther telemetry and GPS location data (Fig 7). Further north, the Green Swamp supports a large area of potential habitat, which might be accessible to panthers through narrow corridors either through the upper Peace River watershed or the upper Kissimmee River watershed (Fig. 5).

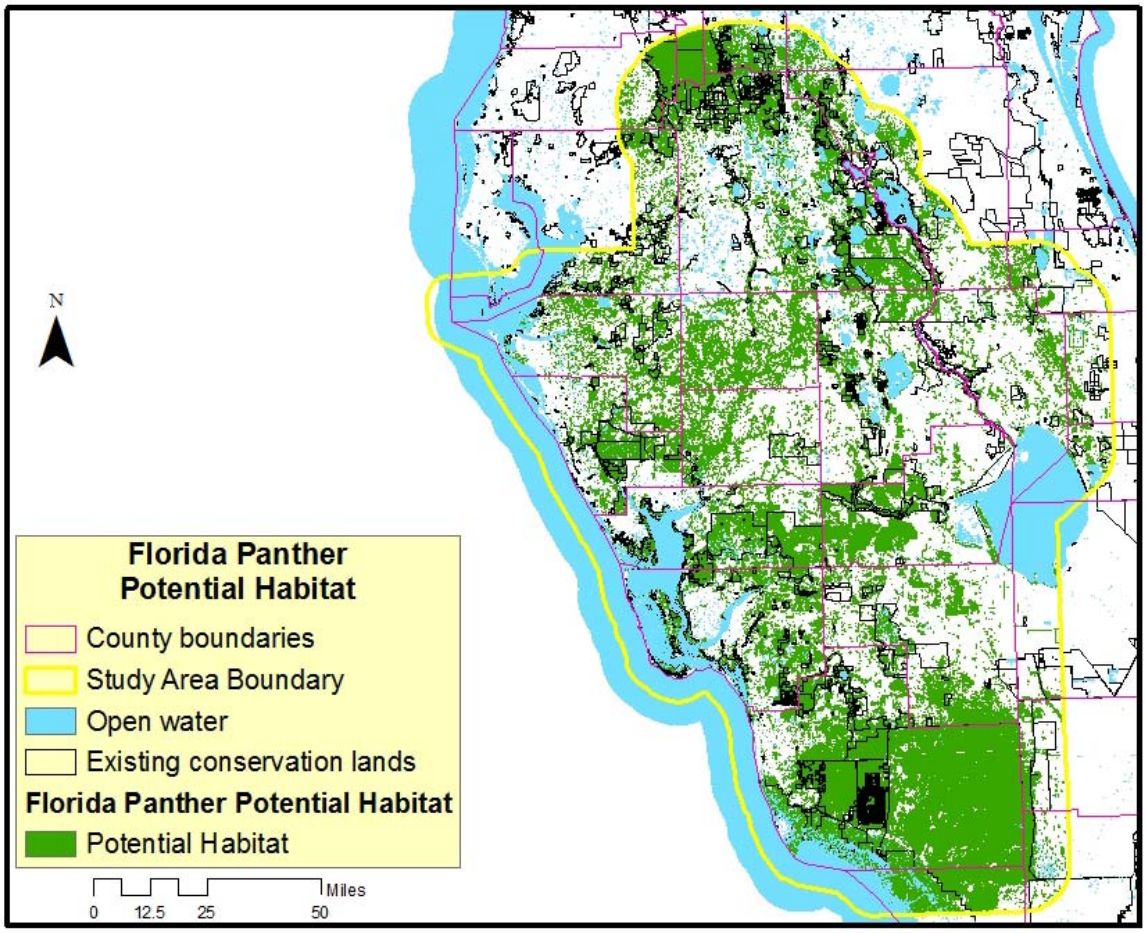

Figure 5. Map of potential Florida Panther habitat within the Babcock study area.

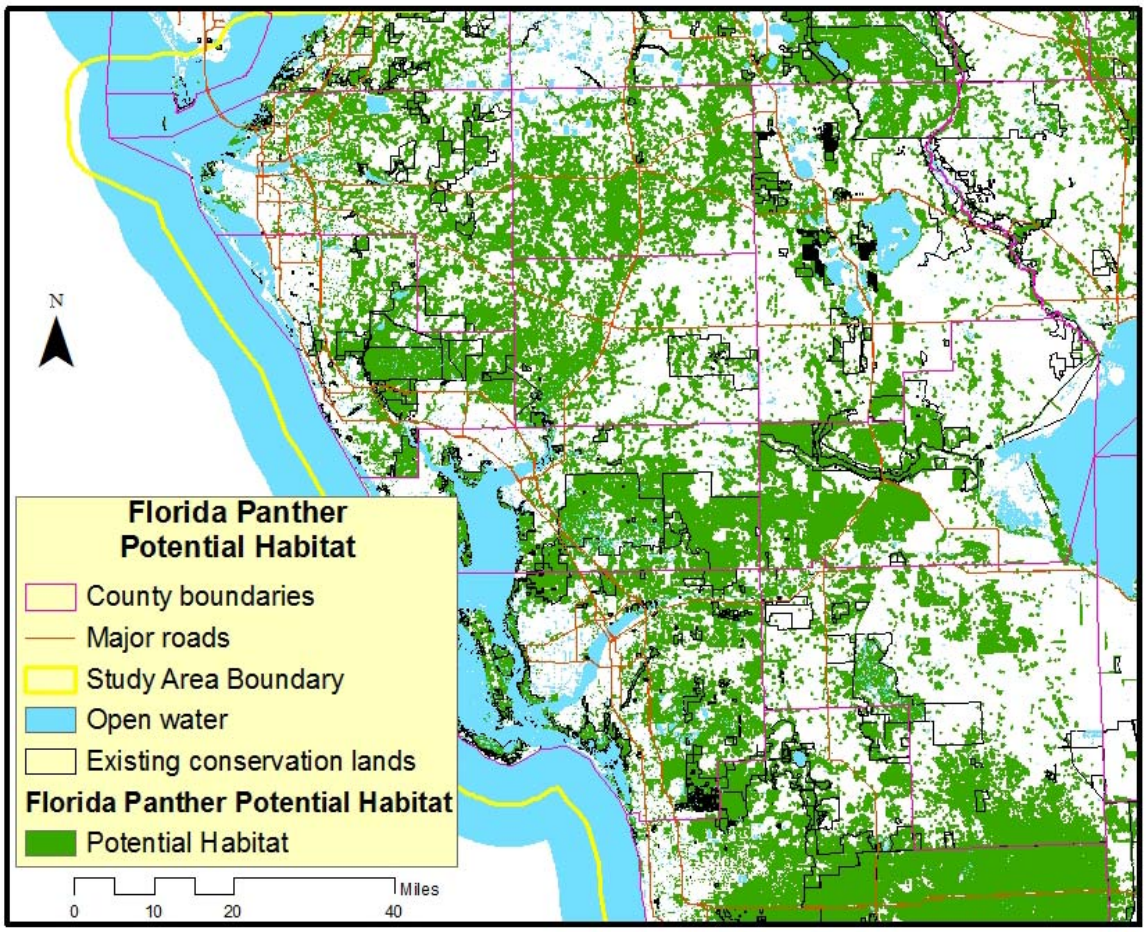

Figure 6. Zoom-in map of potential Florida Panther habitat within the Babcock study area.

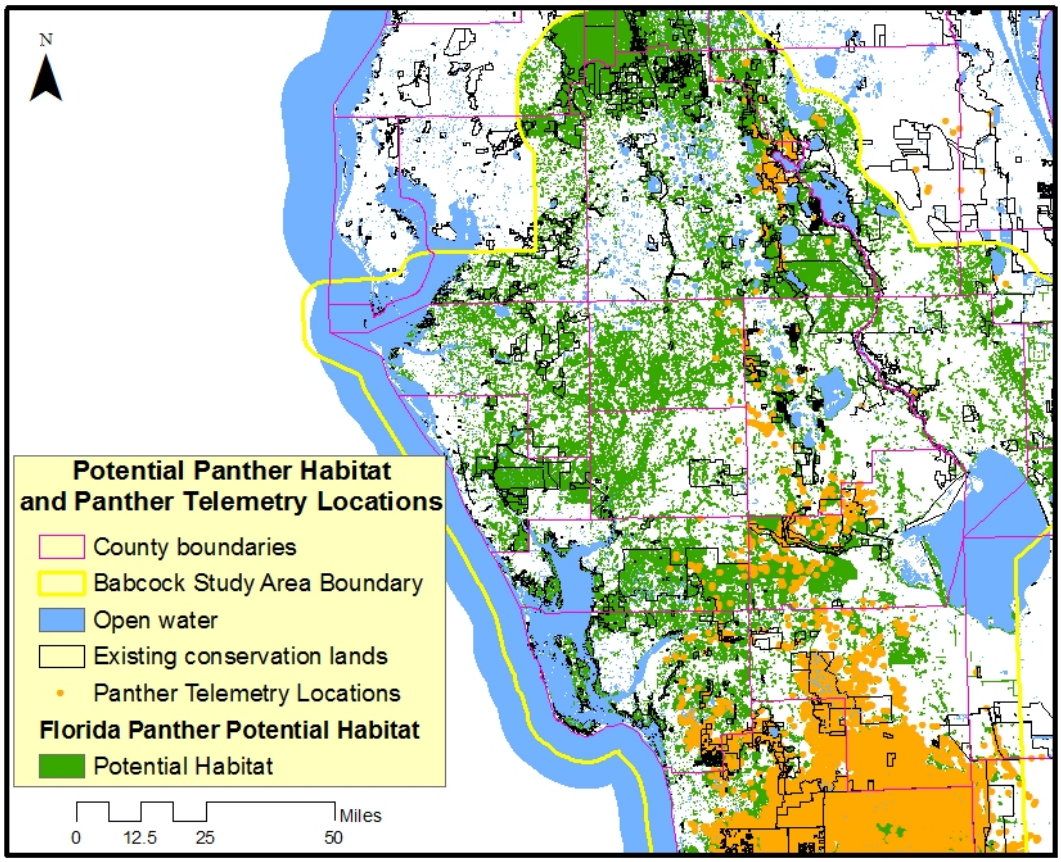

Figure 7. Potential panther habitat and telemetry locations.

Potential Florida black bear habitat exhibits an extent and distribution similar to potential panther habitat. One key difference between the bear and panther habitat models is the inclusion of traversable matrix and a large area size threshold in determining potential bear habitat suitability. Traversable matrix includes land uses that bears may not use for foraging or denning, but which they are capable of moving through. The size threshold criterion in the bear habitat model requires that, to be considered potential habitat, at least 10,000 acres of primary or secondary bear habitat must be within one patch connected at least by traversable matrix. This criterion eliminates the identification of isolated patches that bears are unlikely to find or use within a home range or during dispersal. However, the potential habitat map shows that relatively broad areas still support potential habitat, despite these relatively stringent connectedness and size thresholds (Fig. 8 and Fig. 9). Between Big Cypress National Preserve and the Caloosahatchee River, larger patches of potential habitat exist in Okaloacoochee Slough State Forest, Corckscrew Swamp, and, interestingly, in eastern Lee County due south of Babcock Ranch and north of Corkscrew Swamp. The status of this potential habitat in Lee County, which is outside of primary bear range but within secondary bear range, should be investigated in the near future (Fig. 10). This area will also be discussed below with respect to the Least Cost Path modeling results and in the connectivity option results.

North of the Caloosahatchee River the potential bear habitat distribution is similar to that for panthers: a large patch of connected potential habitat from Cecil Webb Wildlife Management Area to Fisheating Creek; more potential habitat in the Myakka conservation complex and Myakka and Peace River watersheds; a network of potential habitat from Fisheating Creek north to Avon Park Air Force Range and even further north along the upper Kissimmee River watershed; and a large swath of potential habitat in Green Swamp. Comparison of the potential bear habitat model results and current bear range suggests that the potential for functional connectivity between the Highlands-Glades bear population and the Big Cypress population is at least relatively high (Fig. 10). However, recent genetic analysis of these populations suggests that they are differentiated genetically to the extent that, at least in the recent past, there apparently has not been widespread interchange between the populations, although these populations are more similar genetically to each other than they are to other Florida black bear populations (Dixon et al. 2007). The Highlands-Glades population is one of three remaining small Florida black bear populations, and restoring functional connectivity between it and the Big Cypress population is an important goal for protecting a viable population north of the Caloosahatchee River (Maehr et al. 2001a, Hoctor 2003). Although occasional bears may travel through Babcock Ranch, it is considered outside current bear range (Fig. 10). Nevertheless, expansion of the Highlands-Glades population to the southwest into Babcock Ranch could significantly increase the size of the population and protected habitat. In addition, if a breeding bear population could be supported in the Myakka-Peace area, this could also significantly increase regional bear population viability.

Until 2004 the black bears of Highlands and Glades counties (HG) were the last unstudied population of this threatened species in Florida. These bears inhabit the southern portion of the highly biodiverse and globally imperiled Lake Wales Ridge Ecoregion (LWRE) that forms an important linkage within a statewide bear metapopulation. During the past 30 years the LWRE has been severely fragmented and altered by agricultural and urban development. Unlike other major bear populations in Florida that occur on public lands, research has indicated that bears in this area primarily inhabit private lands, particularly cattle ranches (Ulrey 2008). A patchwork of public lands has facilitated movements of individual bears (particularly males) outside of core habitat, and some of these lands support a few resident individuals in more urbanized areas (J. Cox, pers. comm.).

The black bear's wide-ranging movements (Maehr 1997) and diverse food requirements (Maehr and DeFazio 1985) incorporate virtually all native habitats in the region to some degree. At the landscape scale these bears select forest, scrub, and citrus, but avoid urban areas; within home ranges they select bay swamp and hardwood hammock, but avoid urban areas and grassland (Ulrey 2008). Private ranches in this area that support bears are typically several thousand acres or larger in size, relatively unfragmented as compared to surrounding lands, and contain a mosaic of diverse native habitats that includes upland forest, bayhead, and scrub components, which collectively provide a temporal variety of soft and hard mast, as well as suitable denning sites (Ulrey 2008).

Some connectivity between the HG bear population and other protected lands has been documented, with Maehr et al. (1988) noting interchange with the Big Cypress population. In 2007 a radio-collared HG male bear made a circuitous movement to Babcock-Webb WMA and

back. Despite these documented linkages to other protected areas, Dixon et. al (2007) found that HG bears were relatively isolated, with the second lowest level of genetic diversity of all of Florida's major bear populations. Re-establishing a functional connection to the Big Cypress bear population is an important goal for maintaining, and potentially increasing, the genetic diversity of the HG population and enhancing the viability of the bear population north of the Caloosahatchee River in south-central Florida. In addition, achieving functional connectivity between the HG and Big Cypress bear populations can significantly complement efforts to conserve a viable Florida panther population in south Florida by improving connectivity between panther habitat south and north of the Caloosahatchee River and securing additional habitat for panthers north of the Caloosahatchee River.

Babcock Ranch is a potential keystone site for these efforts given its size, suitable habitat, and location between Cecil Webb WMA and conservation lands in the Fisheating Creek watershed. Habitat management objectives should incorporate landscape-based approaches that balance restoration of suitable habitat conditions for fox squirrels, which prefer open pine stands with grassy understory, and bears, which need saw palmetto and other shrubby plant species for foraging and den cover. HG bears currently occupy habitat within easy dispersal distance of Babcock Ranch; therefore, with appropriate population and habitat management, Babcock Ranch could become an important part of an expanded occupied habitat base for the HG bear population.

However, land use changes in south-central Florida significantly threaten efforts to achieve these conservation goals. For example, the Highlands County human population grew by 27.7% from 1990 to 2000, a 4% faster rate than the mean for Florida (U.S. Census Bureau 2002). The loss of citrus groves as the result of recent severe winter freezes in central Florida has resulted in the conversion of former agricultural land to residential development. This has created rapidly growing highway traffic. Highways are a significant feature of the modern landscape and represent potential barriers between important bear habitats. Vehicle collisions were the cause of 82% of mortality to adult bears in the HG area (Ulrey 2008). As highways are enlarged to accommodate burgeoning vehicle use, regional highways will become increasingly problematic barriers to dispersal and seasonal movements of the HG bear population. Further curtailment of movements to access food, mates, and winter den sites will reduce the capacity of the region to support the black bear.

Conservation of bears and other threatened and endangered species in south-central Florida presents unique conservation challenges for wildlife managers and land use planners. The findings of current research on the HG bear population will be important for conservation planning and management that utilize the black bear as a focal species, as well as planning for human population growth. In a region that is experiencing both rapid human population growth and significant land acquisition and stewardship actions by governmental and non-governmental organizations, understanding the habitat and spatial requirements of the wide-ranging black bear will be crucial to identifying important landscape linkages.

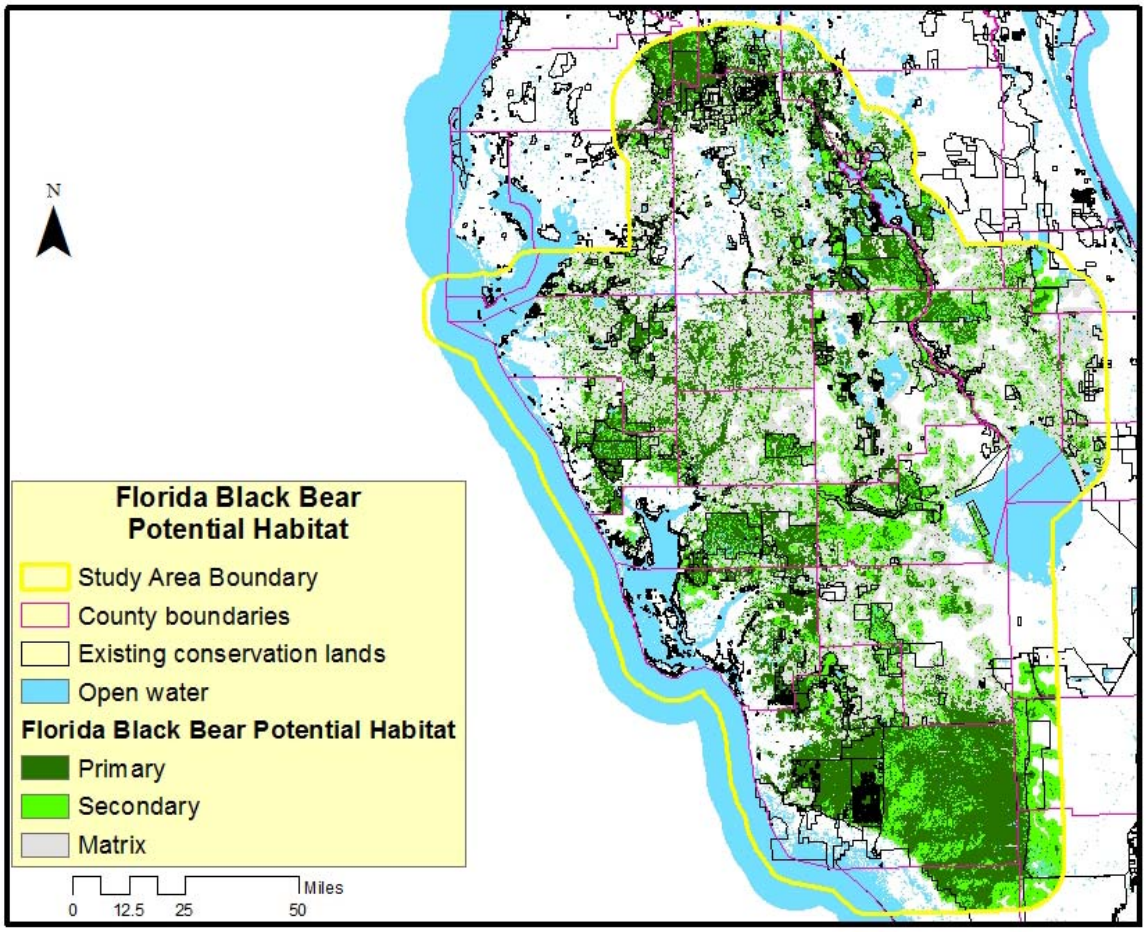

Figure 8. Map of potential Florida black bear habitat within the Babcock study area.

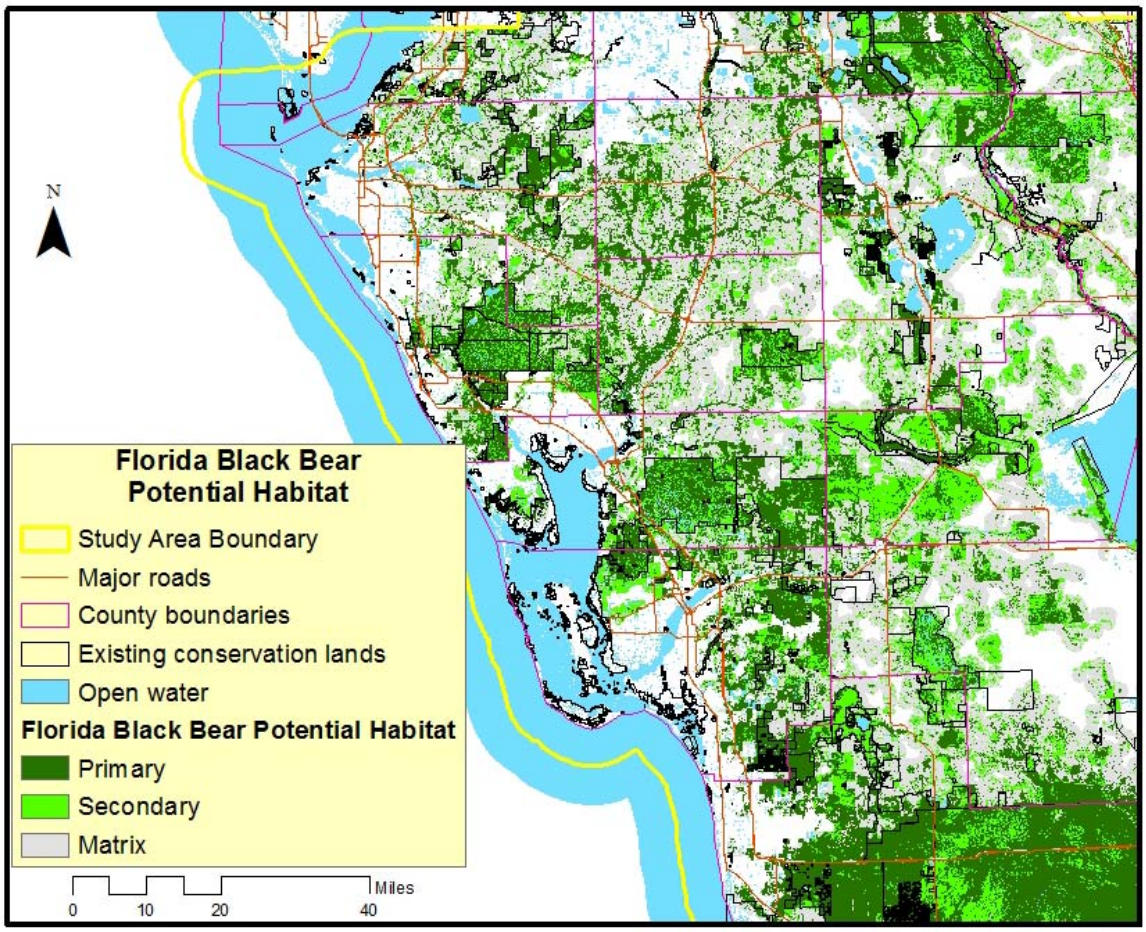

Figure 9. *Zoom-in map of potential Florida black bear habitat within the Babcock study area.*

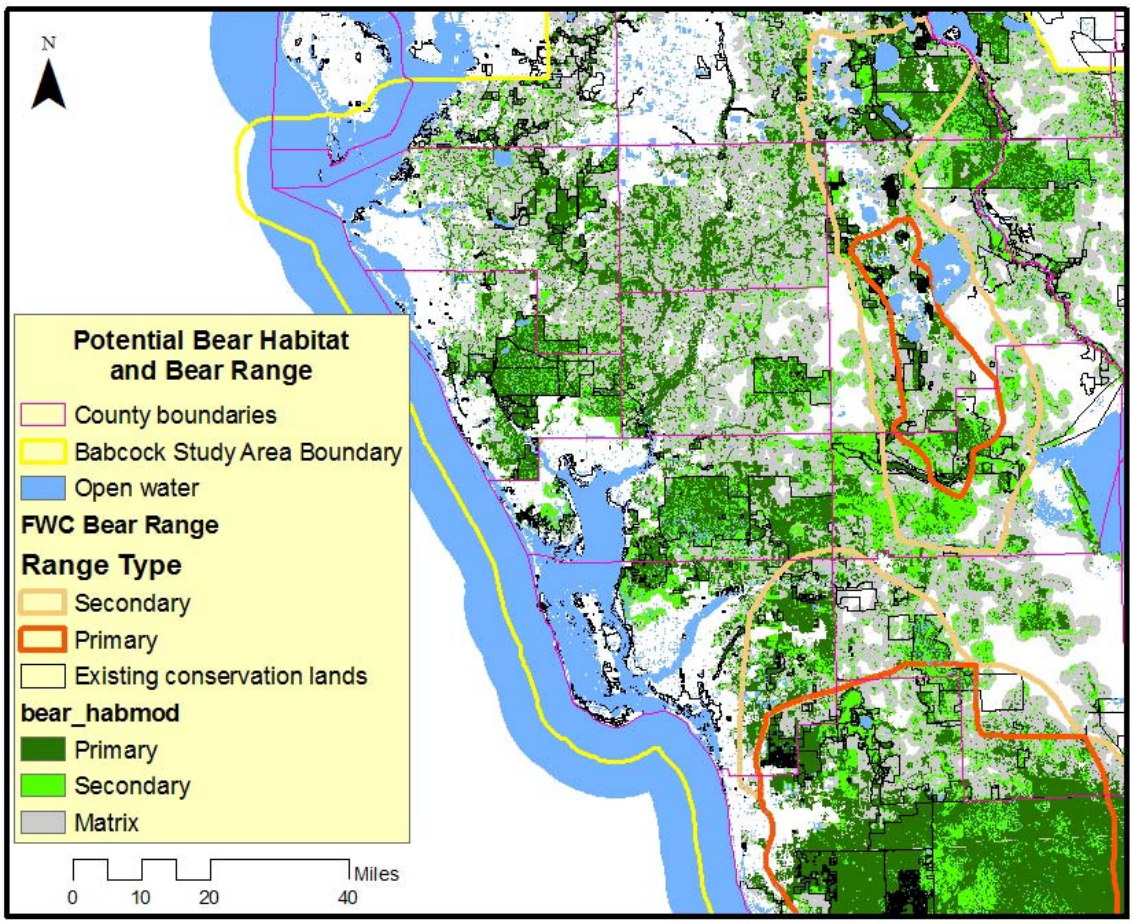

Figure 10. Potential bear habitat and the range of the Big Cypress and Highlands-Glades Florida black bear populations.

Fox squirrel potential habitat is much less extensive and much more fragmented than potential panther and bear habitat (Fig. 11 and Fig. 12). Almost all of the larger patches of potential habitat are found on existing conservation lands including, from south to north, Big Cypress National Preserve, Okaloacoochee Slough State Forest, Babcock Ranch and Cecil Webb Wildlife Management Area, the Myakka complex of conservation lands, Duette Park in Manatee County, several of the Lake Wales Ridge reserves, Lake Wales Ridge State Forest, Avon Park Air Force Range, and the Green Swamp. Several notable large patches of potential habitat exist on private lands, including areas in Hendry County, areas north and south of Corkscrew Swamp (including the potential bear habitat area in Lee County between Corkscrew and Babcock Ranch), areas east and northeast of Myakka River State Park, and on the Bombing Range Ridge Florida Forever Project north of Avon Park Air Force Range. Finally, as state above, many of these areas may potentially support fox squirrels, but habitat suitability is dependent on the maintenance of open pineland areas with grassy understory. Due to fire suppression or dormant-season burning, many natural or semi-natural pinelands are either low quality or unsuitable for fox squirrels. Thorough survey work is needed to establish fox squirrel presence/absence and develop management recommendations to improve habitat quality.

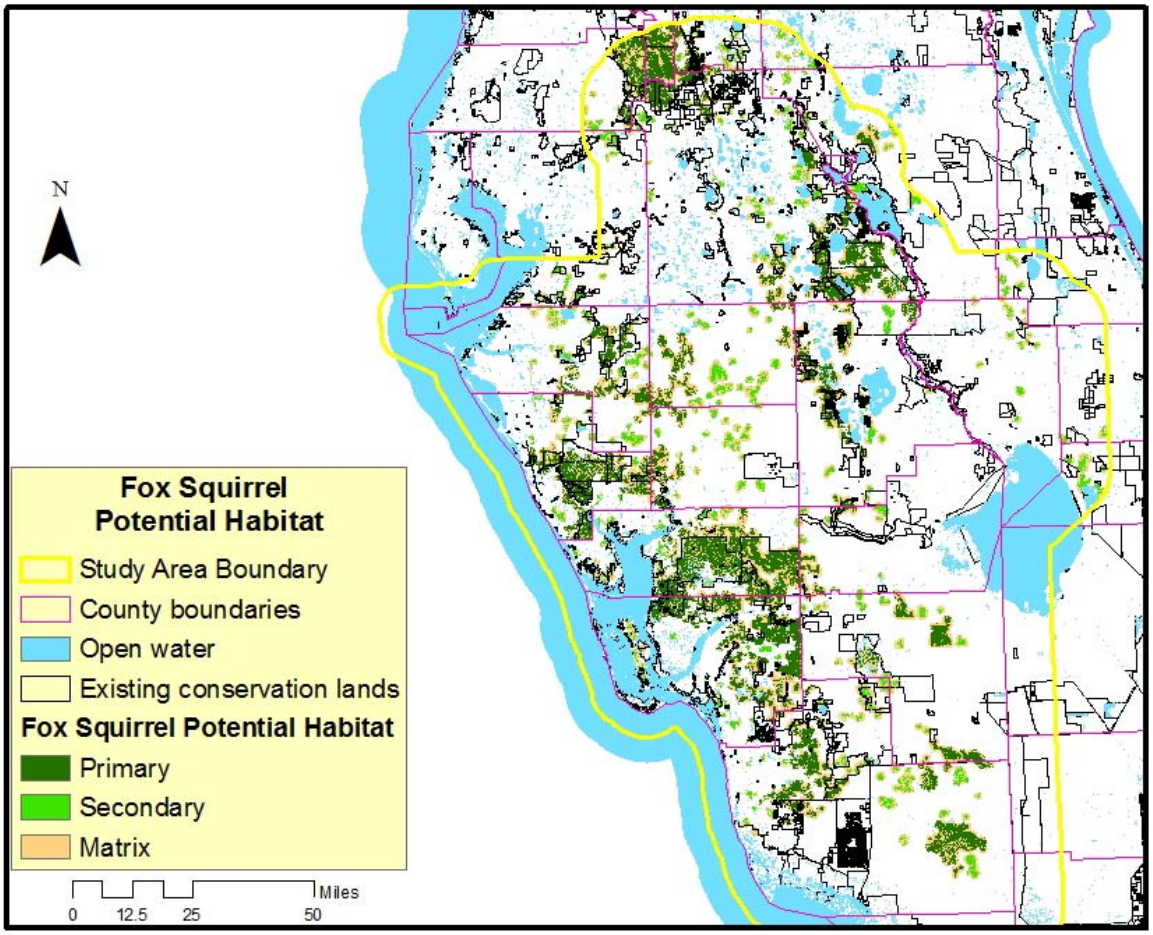

Figure 11. Map of potential Sherman's fox squirrel habitat within the Babcock study area.

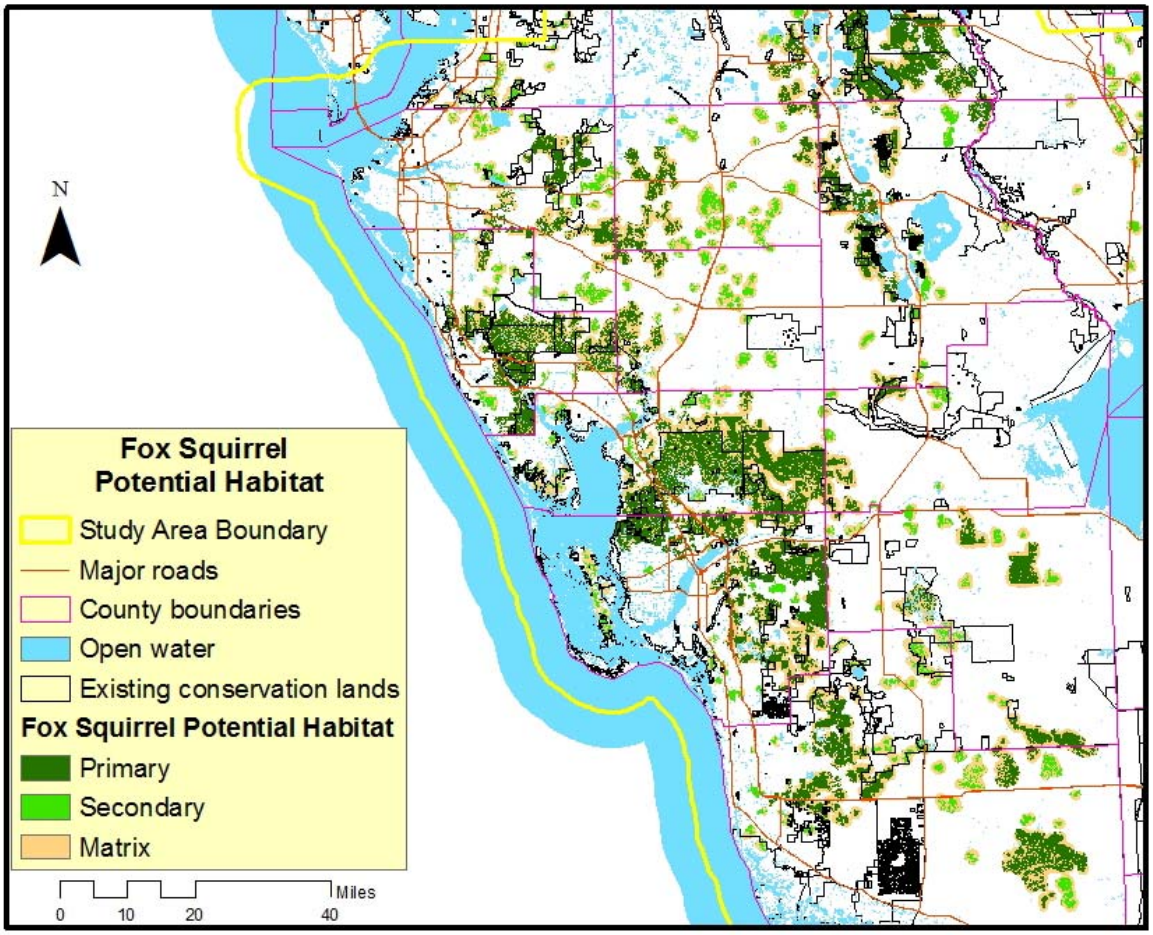

Figure 12. Zoom-in map of potential Sherman's fox squirrel habitat within the Babcock study area.

Roadkills and Fox Squirrel Sightings

As noted earlier, we collected data on roadkills of large herpetofauna (snakes, turtles, alligators), large birds, and medium-sized to large mammals. While conducting these surveys we also recorded all sightings of fox squirrels. Our results are shown in the following three figures, with Fig. 13 showing the general pattern of roadkills and fox squirrel sightings, Fig. 14 showing the species-level breakdown of roadkills and sightings (i.e., all fox squirrel points are sightings, not roadkills), and Fig. 15 showing data for species of particular interest, with bobcat roadkills and fox squirrel sightings indicated by larger circles. The data show that roadkills are broadly distributed along the roads surveyed, but with greatest concentrations on CR 74 near the junction with SR 31, on SR 31 along an approximately 4-mile stretch south of that intersection, and finally on SR 31 along a stretch approximately 7-10 miles south of that intersection. Fox squirrel sightings are within Babcock Ranch and along SR 78 (N River Rd.) in the area adjacent to the Caloosahatchee River Regional Park.

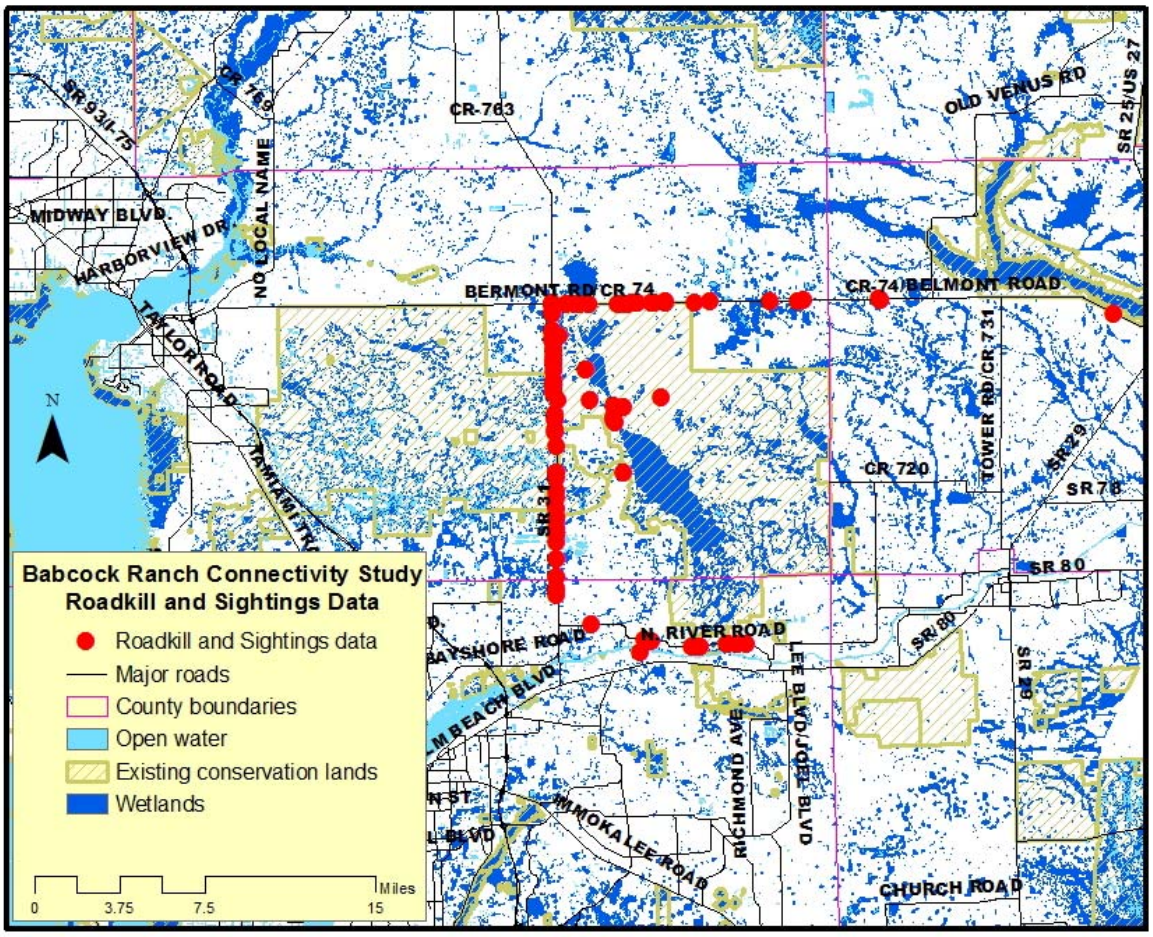

Figure 13. Summary map of GPS point locations of roadkill (plus fox squirrel sightings) data collected in areas surrounding the Babcock study site.

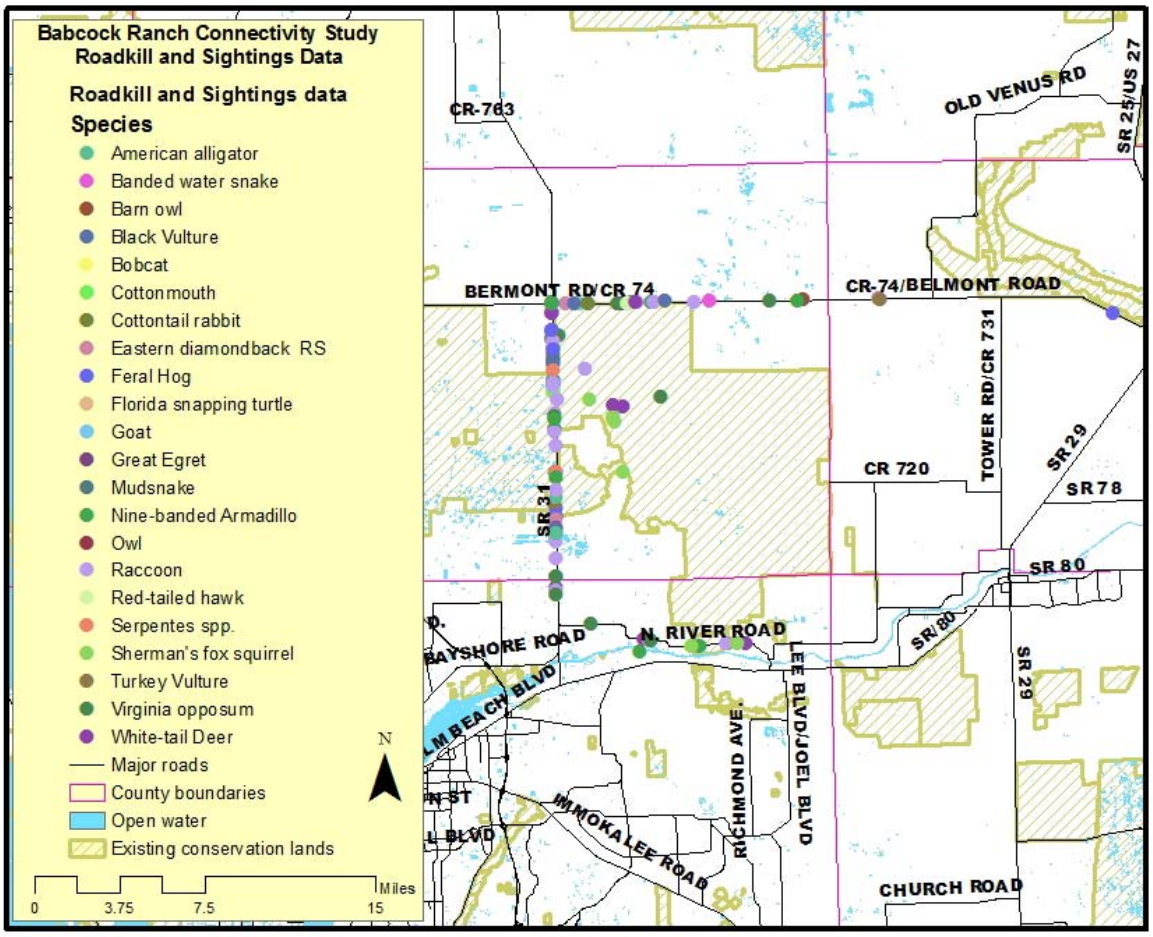

Figure 14. Species map of GPS point locations of roadkills (and fox squirrel sightings) collected in areas surrounding the Babcock study site.

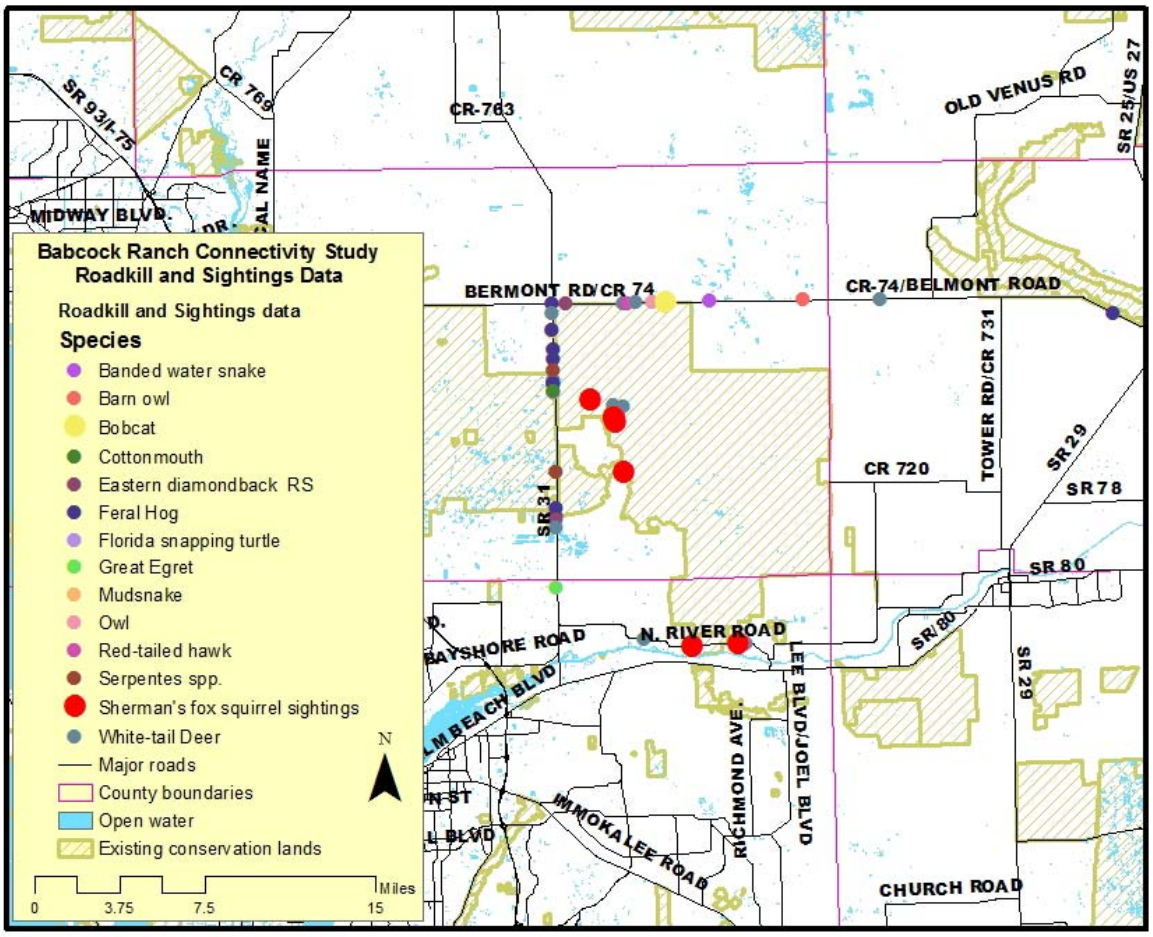

Figure 15. Species map of GPS point locations of roadkill and fox squirrel sightings collected in areas surrounding the Babcock study site, with species of particular interest highlighted by larger circles.

Riparian Corridor, Greenways and Habitat Combination Models

These data layers were created to aid the decision-making process regarding development of the three connectivity options. These models represent various existing corridors and ecological linkages including forested corridors along waterways, major landscape-scale ecological greenways in the Florida Ecological Greenways Network, and larger patches of focal species habitat within or connected to these ecological networks.

The riparian habitat and corridors identifies both forested stream corridors and larger forested wetlands with surrounding natural and semi-natural buffers. These areas represent corridors in some cases but also blocks of forested riparian habitat (Fig. 16 and Fig. 17). Many of the larger existing conservation lands in the study region contain large areas of riparian habitat or riparian corridors. The most obvious riparian corridor network appearing in our results includes riparian habitat along the Peace River and its major tributaries.

The Florida Ecological Greenways Network (FEGN) identifies landscape connections of state and regional significance. The FEGN is prioritized into 8 priority levels, with the two highest priorities called Priority 1 Critical Linkages and Priority 2 Critical Linkages. Within the study area, a combination of Priority 1 Critical Linkages and Priority 2 Critical Linkages form an ecological network from Big Cypress National Preserve on the south end, then north through Okaloacoochee Slough State Forest, the Caloosahatchee Ecoscape Florida Forever Project, Babcock Ranch, and Fisheating Creek (Fig. 18 and Fig. 19). At Fisheating Creek, the Priority 1 and Priority 2 Critical Linkages split into eastern and western corridors. The eastern corridor follows the lower Kissimmee River to Avon Park Air Force Range and Kissimmee Prairie Preserve State Park. The western corridor includes Archbold Biological Station, Bright Hour Ranch, Highlands Hammock State Park, Lake Wales Ridge State Forest, and then Avon Park Air Force Range before heading northeast towards the St. Johns River basin and out of our study area. Though a lower priority at the state scale, the Peace River and Myakka River watersheds include a Priority 3 ecological network within the FEGN that is also important within the study area.

The combination of riparian habitat and corridors with natural and semi-natural areas within all priority levels of the FEGN reveals a pattern similar to the riparian habitat and corridors by themselves, but with several additional features of potential significance. These features include a potential corridor between Big Cypress National Preserve and Okaloacoochee Slough State Forest; the large hub of significant habitat north of the Caloosahatchee River from Cecil Webb Wildlife Management Area to the west and Fisheating Creek to the east; the connections between the large Myakka conservation complex hub and the riparian network of the Myakka River and Peace River watersheds; a potential corridor between the Peace River basin and Avon Park Air Force Range; and a potential ecological network from Avon Park Air Force Range and Kissimmee Prairie Preserve State Park north through the upper Kissimmee River watershed.

The dataset combining riparian habitat and corridors, the FEGN, and panther and bear habitat accentuates the overall patterns described in the data layers above in this section. In addition, this combination also identified the potential corridor due south of Babcock Ranch through eastern Lee County, Corkscrew Swamp, and within and west of Camp Keais Strand.

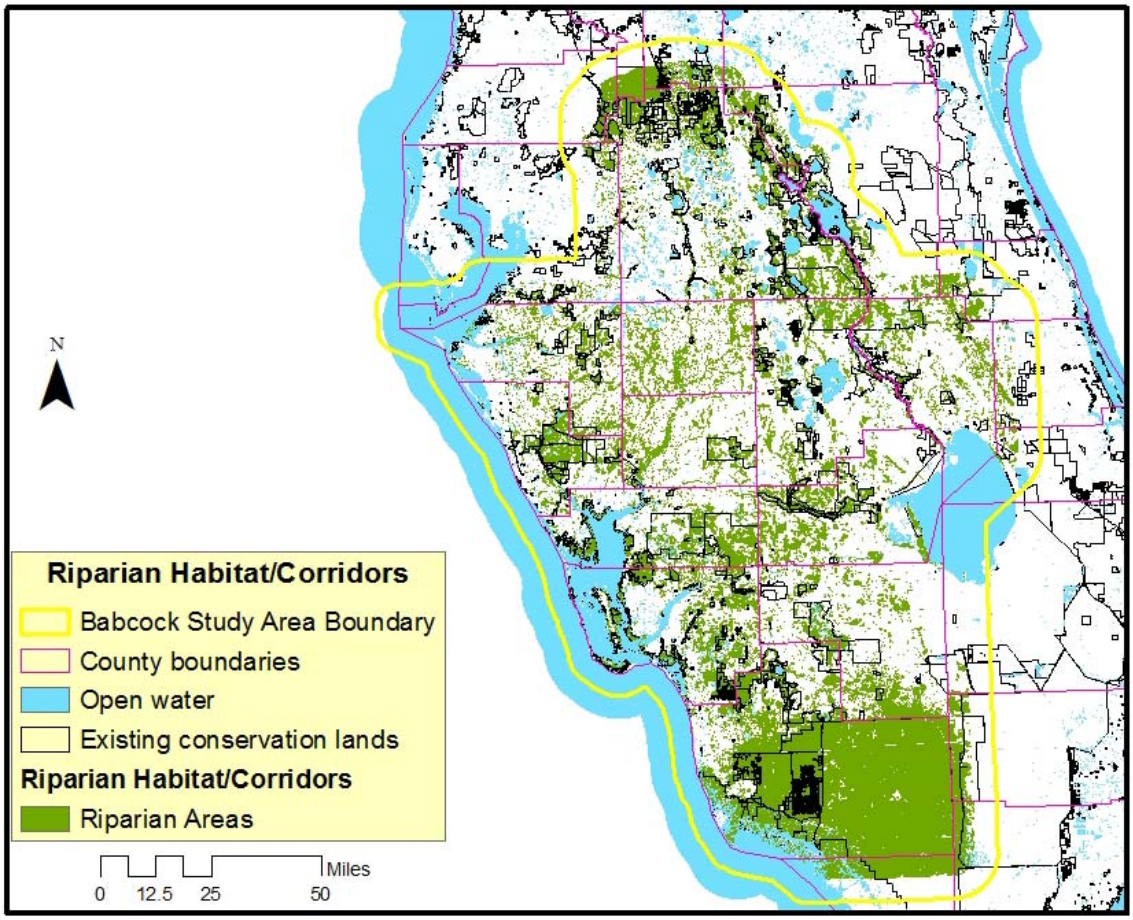

Figure 16. Map of riparian habitat and corridors within the Babcock study area.

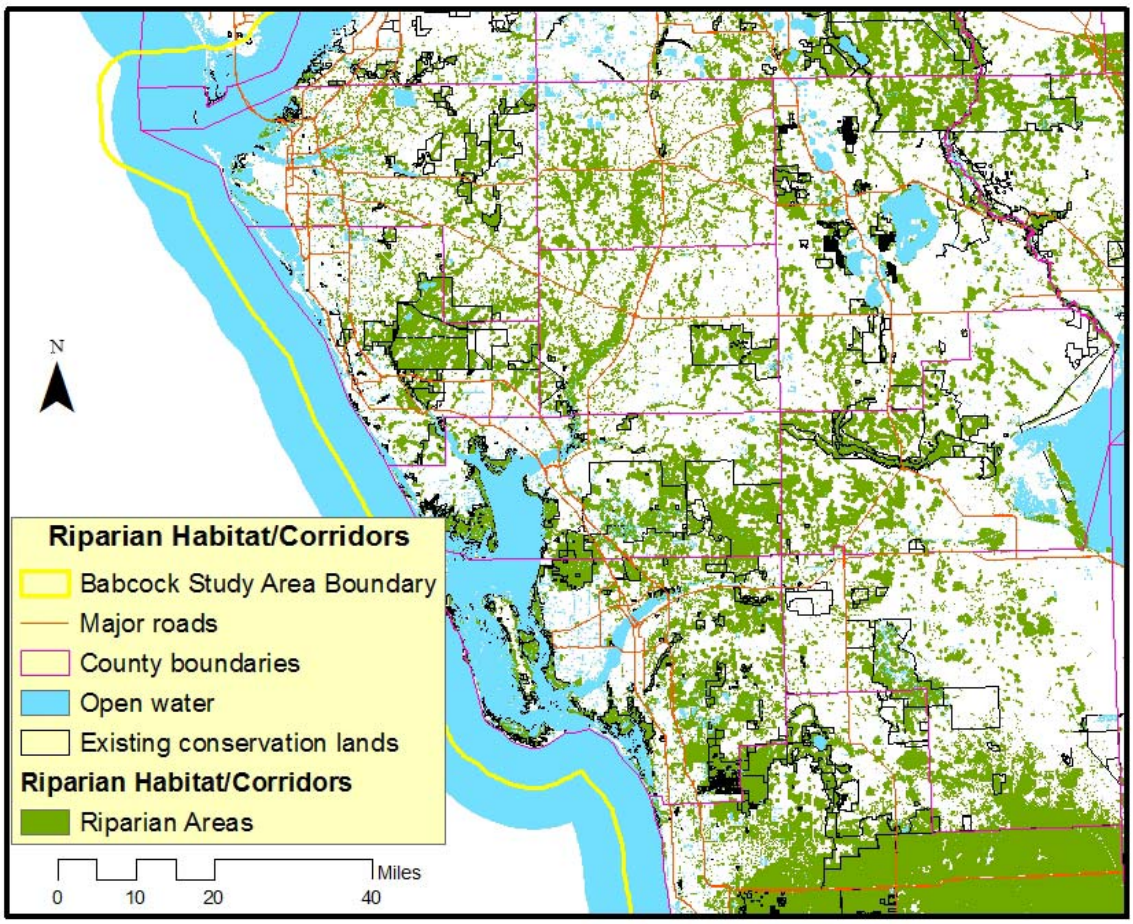

Figure 17. Zoom-in map of riparian habitat and corridors within the Babcock study area.

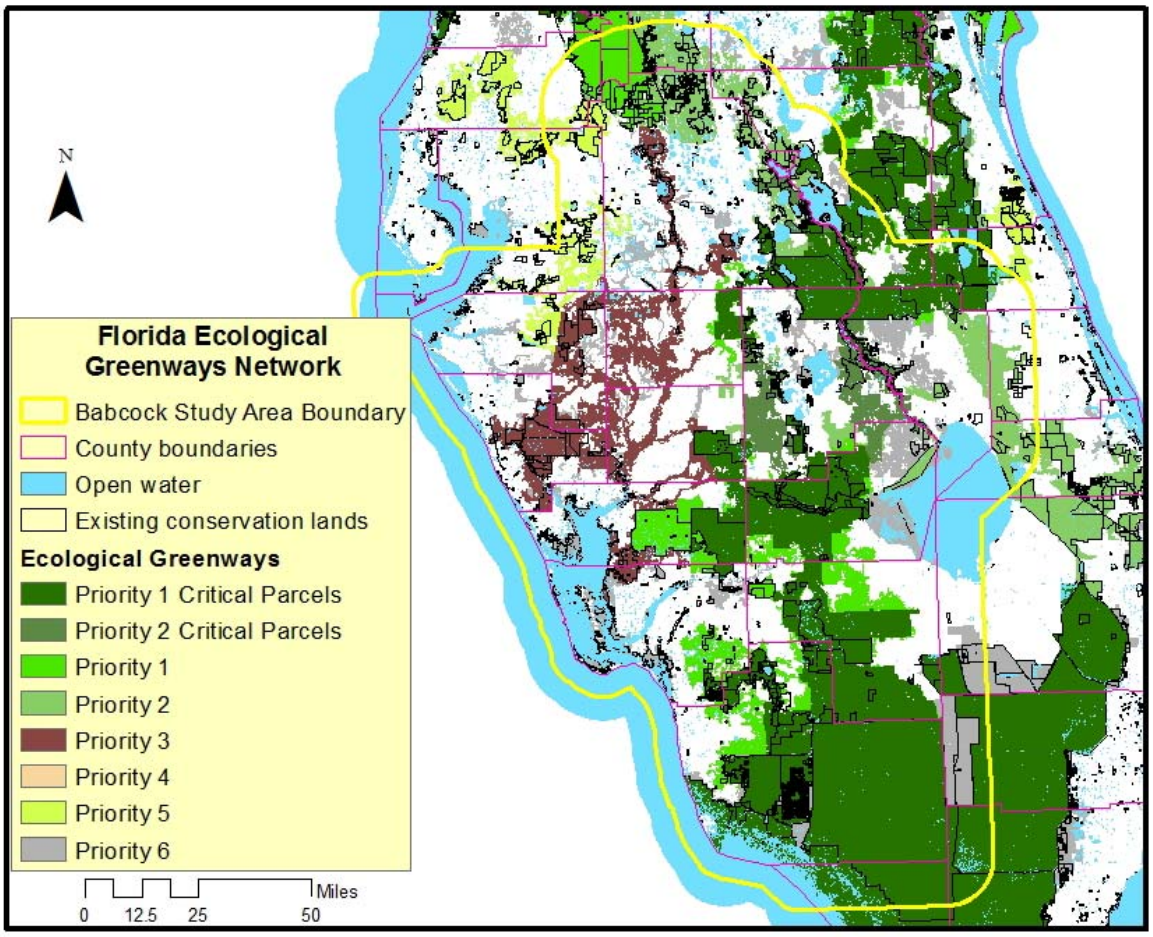

Figure 18. Map of the CLIP priority status of the Florida Ecological Greenways Network and riparian corridors within the Babcock study area.

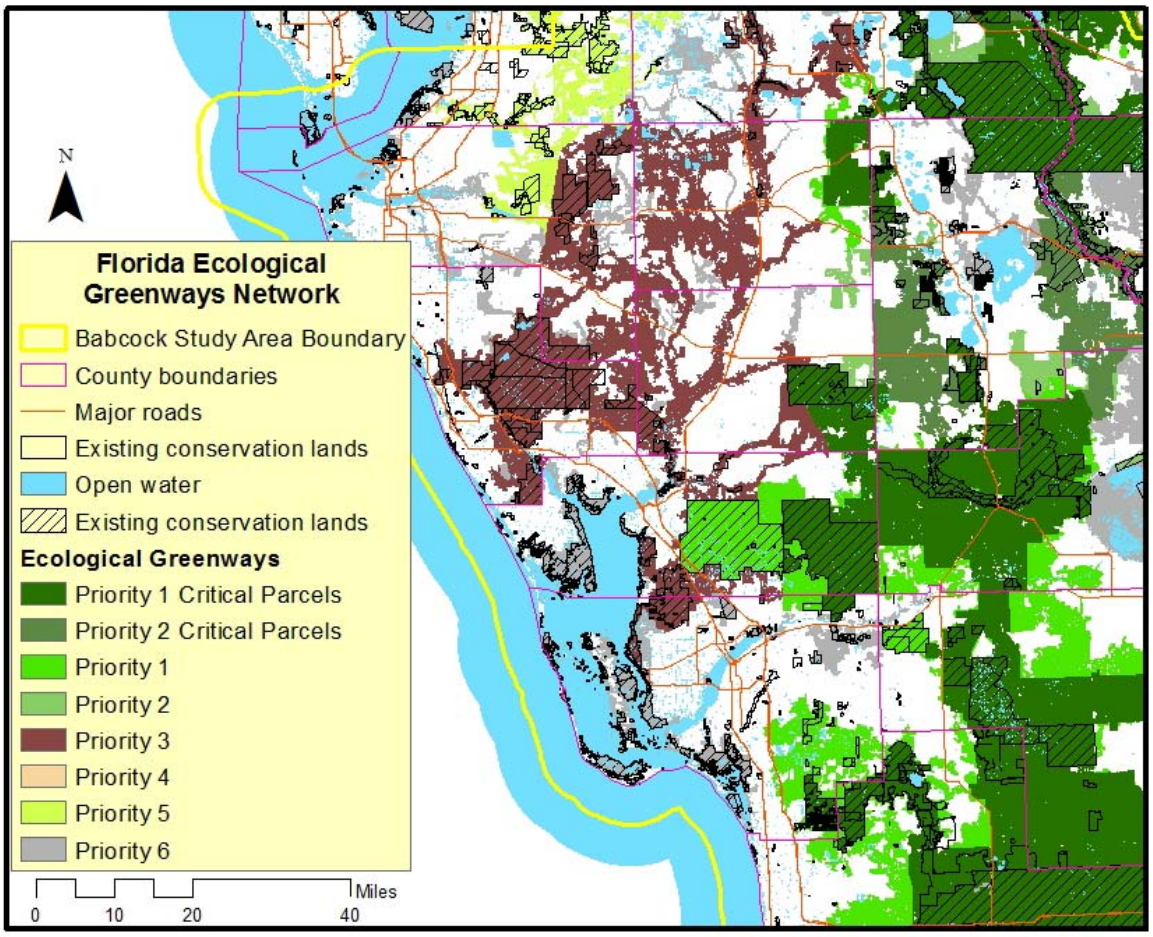

Figure 19. Zoom-in map of the CLIP priority status of the Florida Ecological Greenways Network and riparian corridors within the Babcock study area.

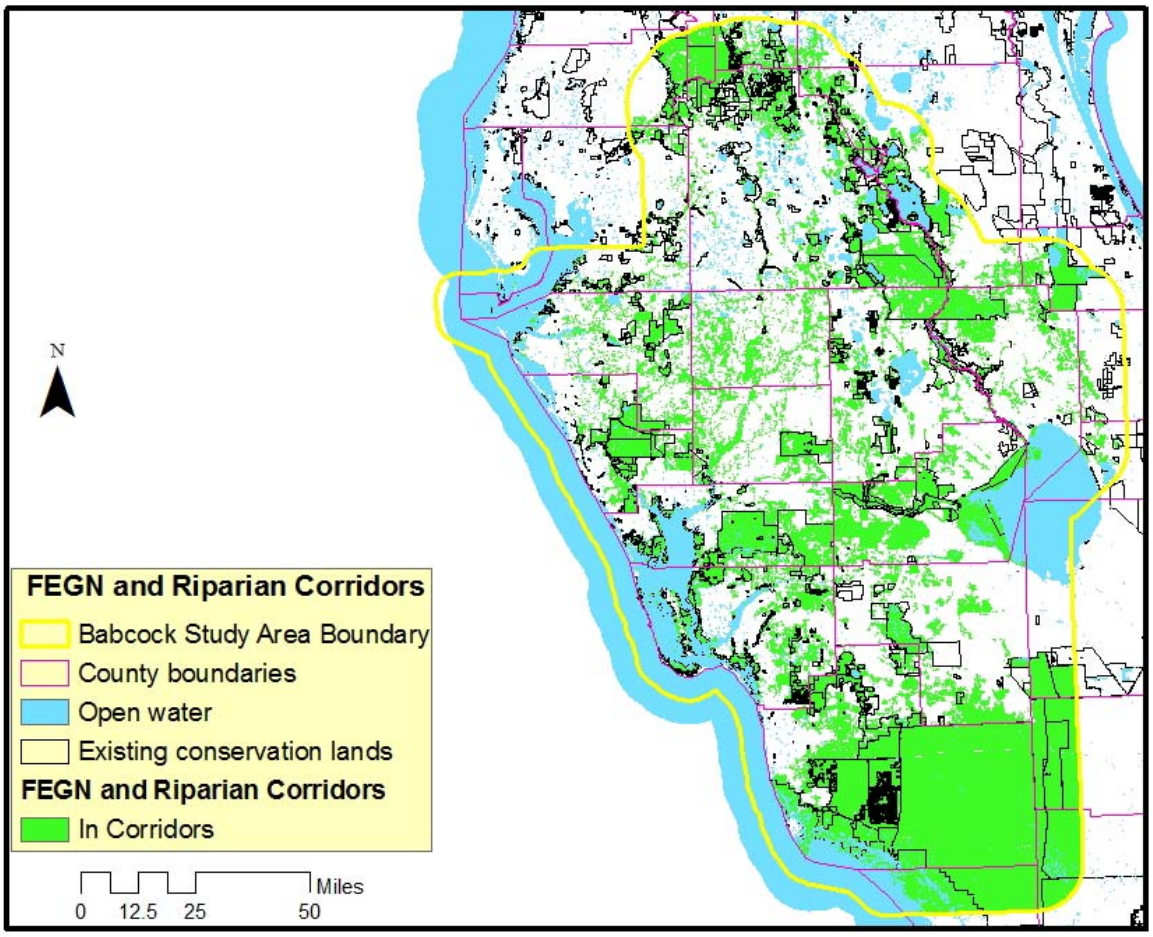

Figure 20. Map of the Florida Ecological Greenways Network and riparian corridors combined within the Babcock study area.

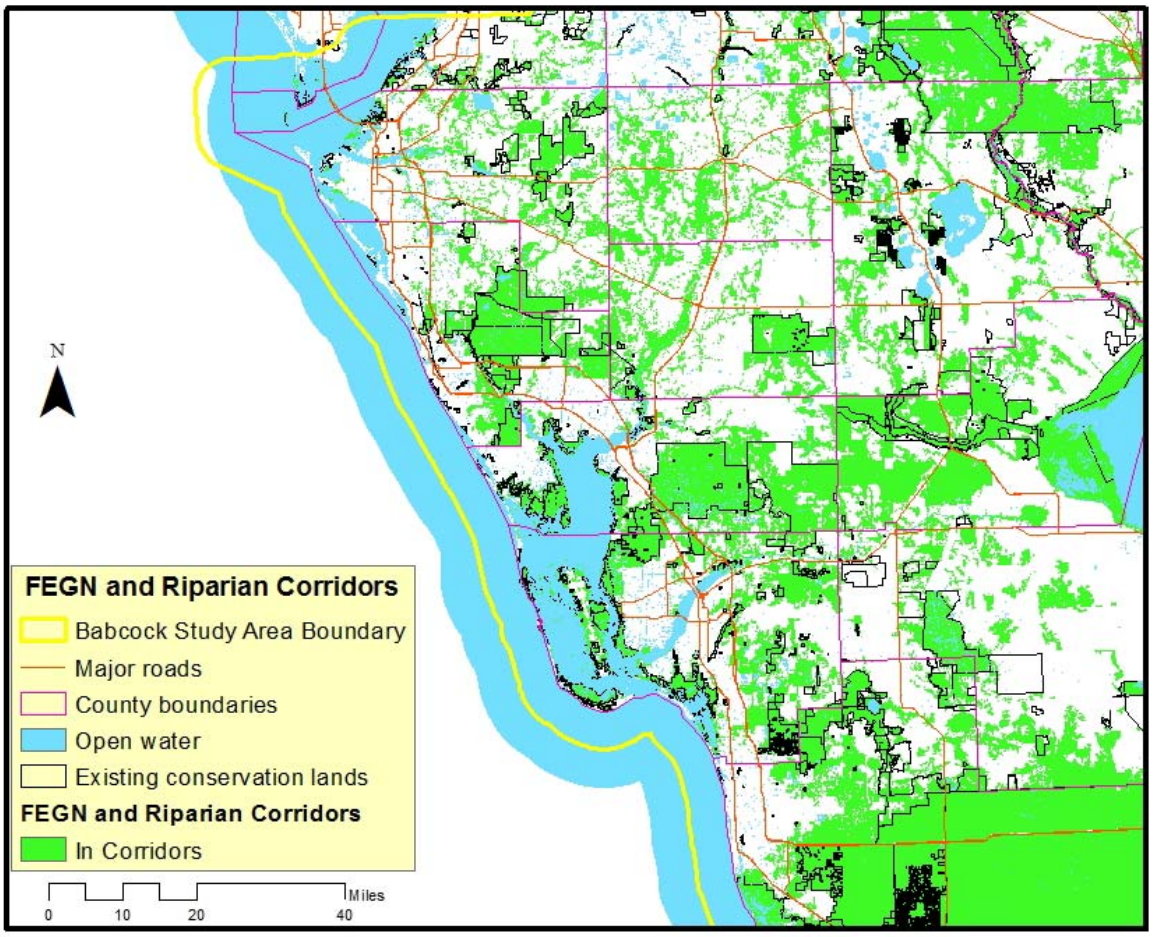

Figure 21. Zoom-in map of the Florida Ecological Greenways Network and riparian corridors combined within the Babcock study area.

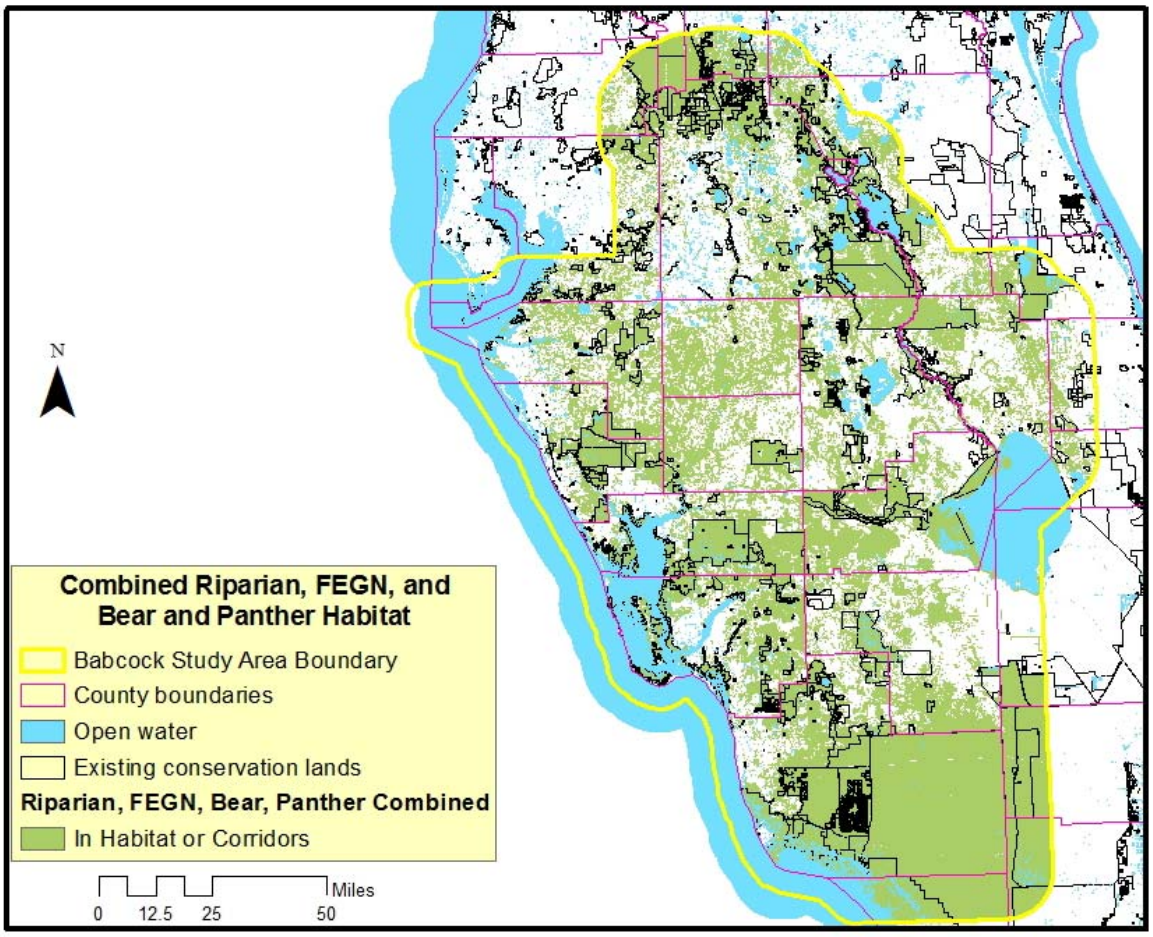

Figure 22. Map of the Florida Ecological Greenways Network, riparian corridors, and Florida Black Bear and Florida Panther habitat that fall within the boundaries of at least one habitat connectivity scenario the within the Babcock study area.

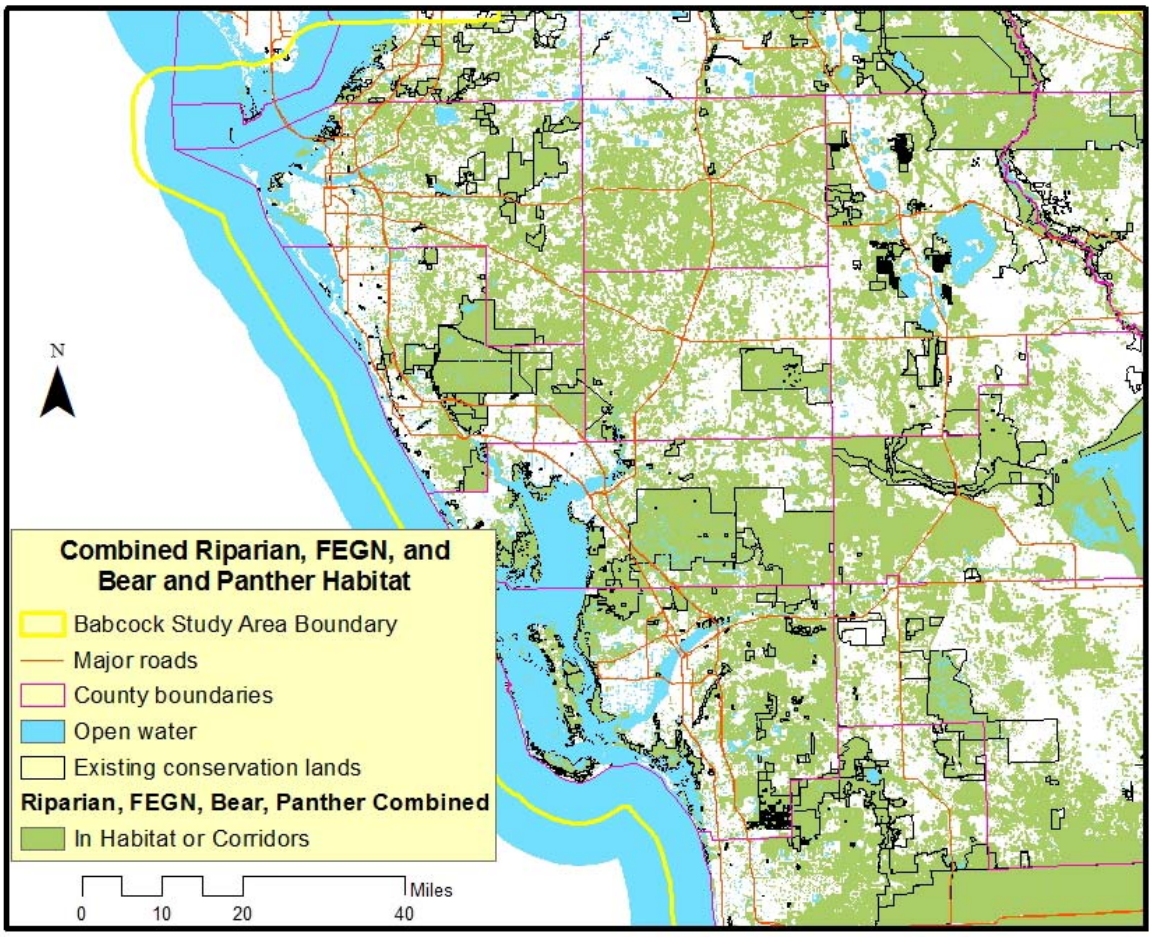

Figure 23. Zoom-in map of the Florida Ecological Greenways Network, riparian corridors, and Florida Black Bear and Florida Panther habitat that fall within the boundaries of at least one habitat connectivity scenario the within the Babcock study area.

Least-Cost Path Models

For each focal species we ran six Least Cost Path (LCP) models using 6 different cost surfaces from Babcock Ranch to six destinations. Therefore, for each focal species there are 6 different LCP results between Babcock Ranch and each destination and a total of 36 LCPs overall for each species. Each LCP is a one cell wide (a cell was 10 meters wide in our modeling) but the LCPs were turned into GIS shapefiles that result in some buffering to a larger width to aid in viewing the maps. The six destinations were Big Cypress National Preserve, Okalaocoochee Slough State Forest, Fisheating Creek, Bright Hour, Avon Park Air Force Range, and the Myakka conservation complex. Below we briefly describe the major patterns of results for each focal species.

The Florida panther LCPs demonstrate options to potentially connect Babcock Ranch to other large conservation areas in the study area. As expected, different cost surfaces sometimes result in LCPs that are remarkably different (Fig. 24). Overall, when evaluating these cost surface results we tend to consider the more thorough cost surface-based LCPs to be the most reliable, given that they factor in more variables that could affect corridor suitability such as major roads, negative edge effects, land-use intensity and integrity, sea-level rise, etc. However, all results help determine options for connectivity and the assessment of best corridor options to include in the connectivity options. For the two destinations to the south of Babcock Ranch, there were two primary paths selected in the LCP analyses. For Okaloachoochee Slough, almost all of the LCPs run east-southeast from Babcock and primarily cross the Caloosahathchee River where the Caloosahatchee Ecoscape Florida Forever Project is located, which was considered the primary panther corridor in the work of the USFWS Panther Subteam (Kautz et al. 2006). One LCP heads due south from Babcock Ranch and then turns east to reach Okaloacoochee Slough. The LCPs between Babcock Ranch and Big Cypress also follow this due-south route through eastern Lee County, then through Corkscrew Swamp and Camp Keais Strand to reach Big Cypress. This incorporates a second potential crossing area of the Caloosahatchee River evaluated by the Panther Subteam but not adopted because of concerns about ongoing and future development that could either degrade or completely fragment this potential corridor. However, our habitat models and these LCP results suggest that given land-use conditions in 2004-2005 (which is the time frame of the Water Management District land-use data) these areas still have some potential to support a functional corridor. The Fisheating Creek LCPs are by far the shortest and they all are primarily clustered within the Fisheating Creek Florida Forever project boundaries to reach the Fisheating Creek conservation easement. The LCPs between Babcock and Bright Hour are the most consistent with each other; they all follow an area almost due north of Babcock to reach Bright Hour, and this same pattern is also seen for the Florida black bear and fox squirrel LCPs between Babcock and Bright Hour. This tight clustering of six different LCPs for all three focal species suggests that this route is the best option for a functional connection between these two conservation areas.

The LCP results for the potential connection between Babcock and Myakka may be the most interesting. In general, the LCPs for cost surfaces that did not include negative edge effects associated with intensive land uses tended to follow the shortest distance route by crossing the Peace River near its mouth. However, LCPs based on cost surfaces with edge effects included followed more northerly routes, with the LCP based on the cost surface with the highest costs

assigned to edge effects selecting the most northerly route. Closer examination of these results confirm that the shortest route crossing near the mouth of the Peace River traverses areas of scattered development that serve as potential bottlenecks for the corridor. The route further to the north also passes scattered development along US 17 but less development than the southerly route. The most northerly route avoids almost all existing intensive development. In addition, the more northerly routes are less influenced by sea-level rise (which increases the cost of southerly routes), because the mouth of the Peace River is likely to become wider, presenting a larger water gap that is less likely to be crossed by panthers or other species. These results suggest that one approach to the Myakka connection would be closer examination of the potential issues with the more southerly route, since it does have the advantage of being a much more direct route between the two conservation areas, but that protection of a functional corridor may require investment in a longer route through more rural landscapes with less potential for being degraded by future development and sea-level rise.

Finally, the LCP results between Babcock Ranch and Avon Park Air Force Range exhibit various options for functionally connecting these conservation areas that are all consistent with observed movement patterns of bears in the Highlands-Glades population and panther telemetry data collected from sub-adult males traversing these areas. There are three options demonstrated: 1) a western route along the west side of the Lake Wales Ridge that passes through various scrub reserves, Highlands Hammock State Park, the Charlie Creek watershed, and Lake Wales Ridge State Forest to connect to the northwest corner of Avon Park Air Force Range; an eastern route that passes on the east side of the Lake Wales Ridge from Fisheating Creek north through several scrub reserves on or near the western shore of Lake Istokpoga and then follows part of Arbuckle Creek to reach the southwest corner of Avon Park Air Force Range.; and 3) a hybrid route that combines most of the two options above by first following the western route but then turns east and crosses US 27 along the Josephine Creek corridor and merges with the eastern route near Arbuckle Creek.

For black bear, the LCPs are very similar to the panther LCPs for Big Cypress, Okaloacoochee Slough, Fisheating Creek, and Bright Hour (Fig. 25 and Fig. 27). The LCP results for Myakka are also similar, except the most southerly routes taken by LCPs without edge effects included areas further north than those for the panther LCPs. The bear LCPs for the Avon Park Air Force Range connection are most different from the panther LCPs. One set of LCPs follow the “hybrid” route described for panther LCPs above, but most of the bear LCPs follow a much more westerly route. This route heads through Bright Hour ranch and then north-northeast along tributaries of the Peace River to reach the upper Charlie Creek watershed, and then cross US 27 to reach the Lake Wales Ridge State Forest and Avon Park Air Force Range following the same path as the western route for the panther LCPs.

The fox squirrel LCPs are similar in pattern to the panther and bear LCPs but with some deviation for several destinations (Fig. 26 and Fig. 27). First, the fox squirrel LCPs for the corridor to Big Cypress tend to be further west than the panther and bear LCPs, especially south of Corkscrew Swamp. The fox squirrel LCPs to Avon Park Air Force Range follow the western and “hybrid” routes generally found in the panther and bear LCPs but also tend to be further west in both cases over parts of their paths. Finally, some of the fox squirrel LCPs to Okaloacoochee Slough State Forest head almost due southeast of Babcock Ranch to reach the state forest versus

the Caloosahatchee Ecoscape pathway taken by most of the panther and bear LCPs. All of these differences are likely explained by the more limited potential habitat distribution for fox squirrels. Nevertheless, overall, the pattern of potential connectivity is similar to that for panthers and bears, and we suggest that fox squirrel connectivity may be suitably addressed at the regional scale by the best options for panthers and bears. In addition, local to landscape-scale connectivity may be more important for fox squirrels within this region due to the fragmented habitat base and lower dispersal capabilities. Further research on fox squirrels in the region could include identification of core habitat areas and the opportunities to restore or maximize connectivity at the local to landscape scales through habitat management, restoration, and protection.

The next step in the analysis of the LCP model results was to examine the overlap between the LCP models for each destination for each focal species and all three focal species cumulatively. This approach helps to indicate how often a potential path was selected. To conduct this analysis, we developed a grid representing the entire study area in one square mile cells. These cells were then used as "selection units" where we intersected each of the LCP results for each destination with the selection units to determine how often they were selected. The assumption of this analysis is that paths selected more frequently are potentially more suitable for facilitating connectivity.

Figures 28-31 show the results of the selection unit analysis for each of the focal species individually (Figs. 28-30) and then cumulatively for all three focal species (Fig. 31). On all of these maps, the lightest pink color represents paths selected least frequently and the darkest red represents paths selected most frequently. These results indicate that the most overlap across LCPs occurs for the route between Babcock Ranch and Bright Hour Ranch. Other potential corridor routes that are frequently selected across species include Fisheating Creek (although panther LCPs show a slightly different pattern than bear or fox squirrel). For panther and bear LCPs, the southern half of the route to Avon Park Air Force Range is also generally consistent across LCPs. For panthers, the LCPs to Big Cypress uniformly follow Camp Keais Strand south of Corkscrew whereas bear LCPs follow a more westerly route south of Corkscrew.

The analysis of LCP overlap provided an objective method for evaluation of best potential corridors between Babcock Ranch and other larger regional conservation areas. However, selection of best corridor options also requires a more subjective expert analysis of factors potentially critical to population persistence, including the number and location of road crossings, presence of bottlenecks/proximity to areas of intensive development, length of corridors, consistency with existing guiding features in the landscape such as riparian corridors, etc. Before developing the connectivity options discussed below, we conducted these additional visual assessments of LCP results to select the best potential corridor options. From this assessment, we determined that LCPs based on two separate cost surfaces for both panthers and bears were most applicable to developing the various conservation scenarios. The selected corridor options will be discussed in more detail below in the connectivity options section.

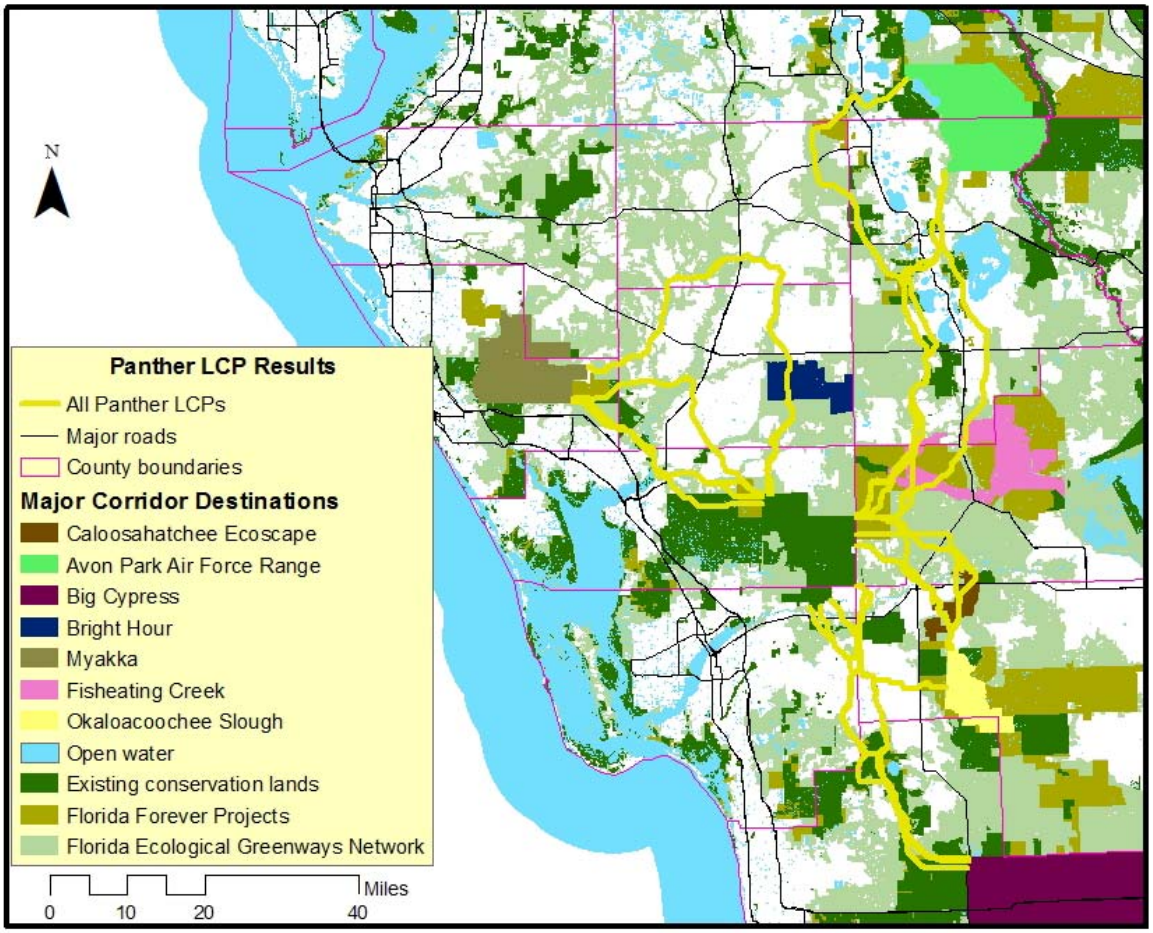

Figure 24. Map summarizing the predicted Least Cost Paths for Florida Panther movement from the Babcock study site to each of the six selected habitat patch destinations.

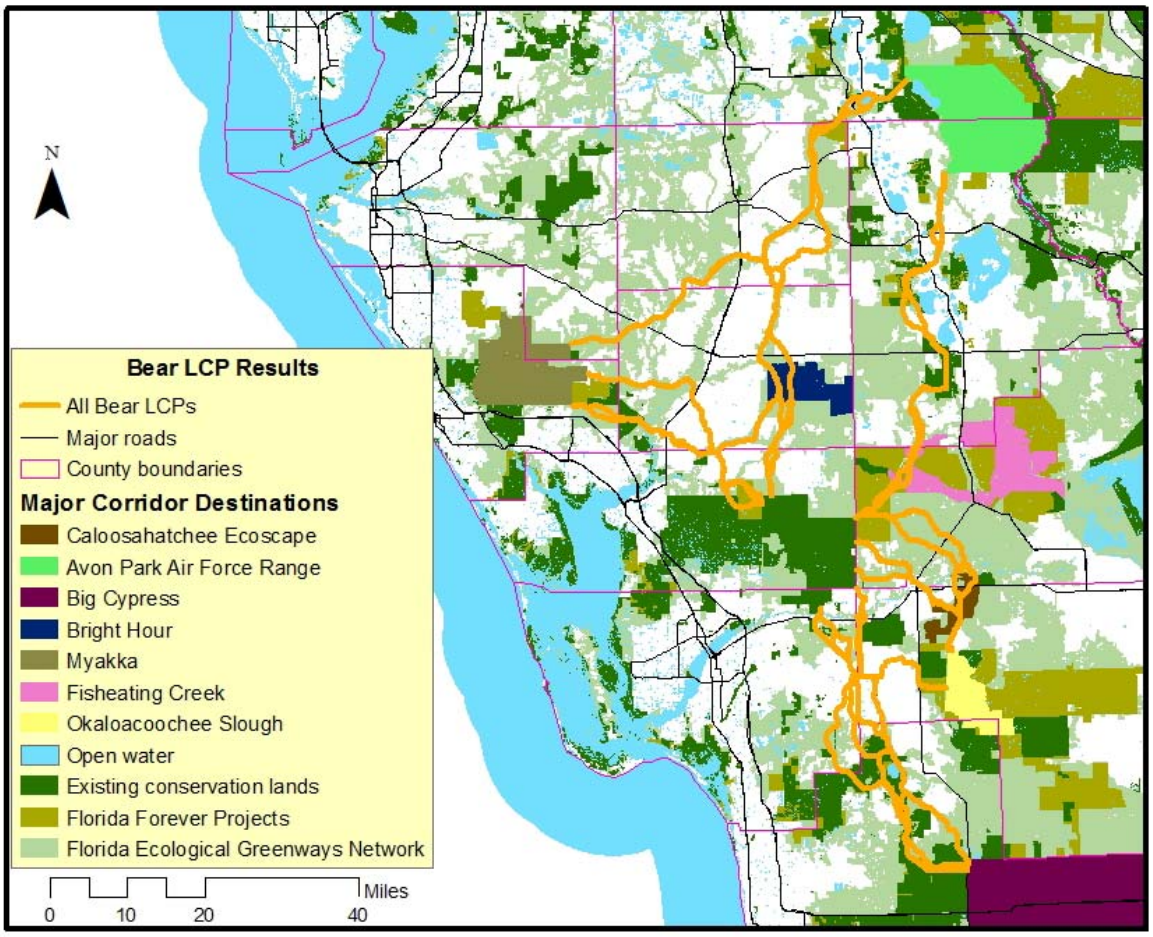

Figure 25. Map summarizing the predicted Least Cost Paths for Florida black bear movement from the Babcock study site to each of the six selected habitat patch destinations.

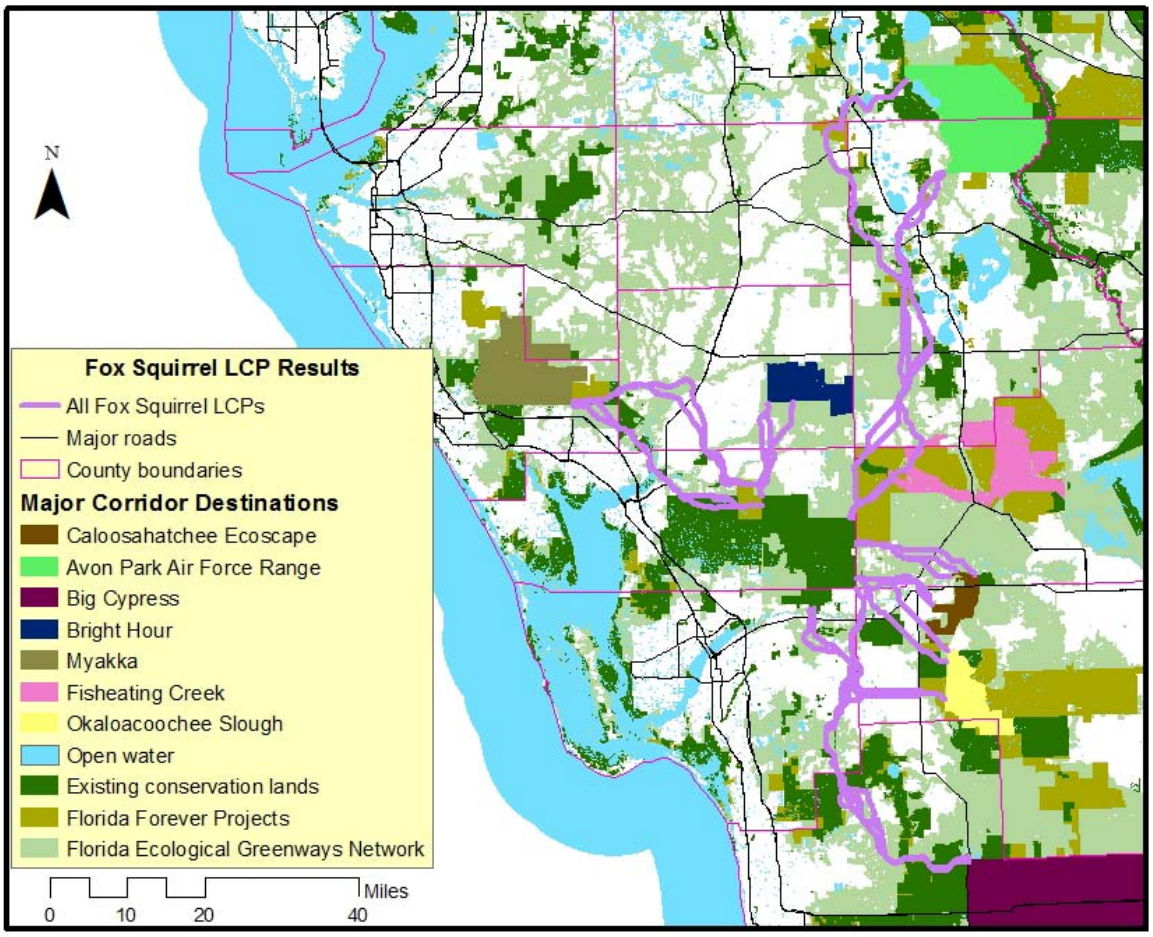

Figure 26. Map summarizing the predicted Least Cost Paths for fox squirrel movement from the Babcock study site to each of the six selected habitat patch destinations.

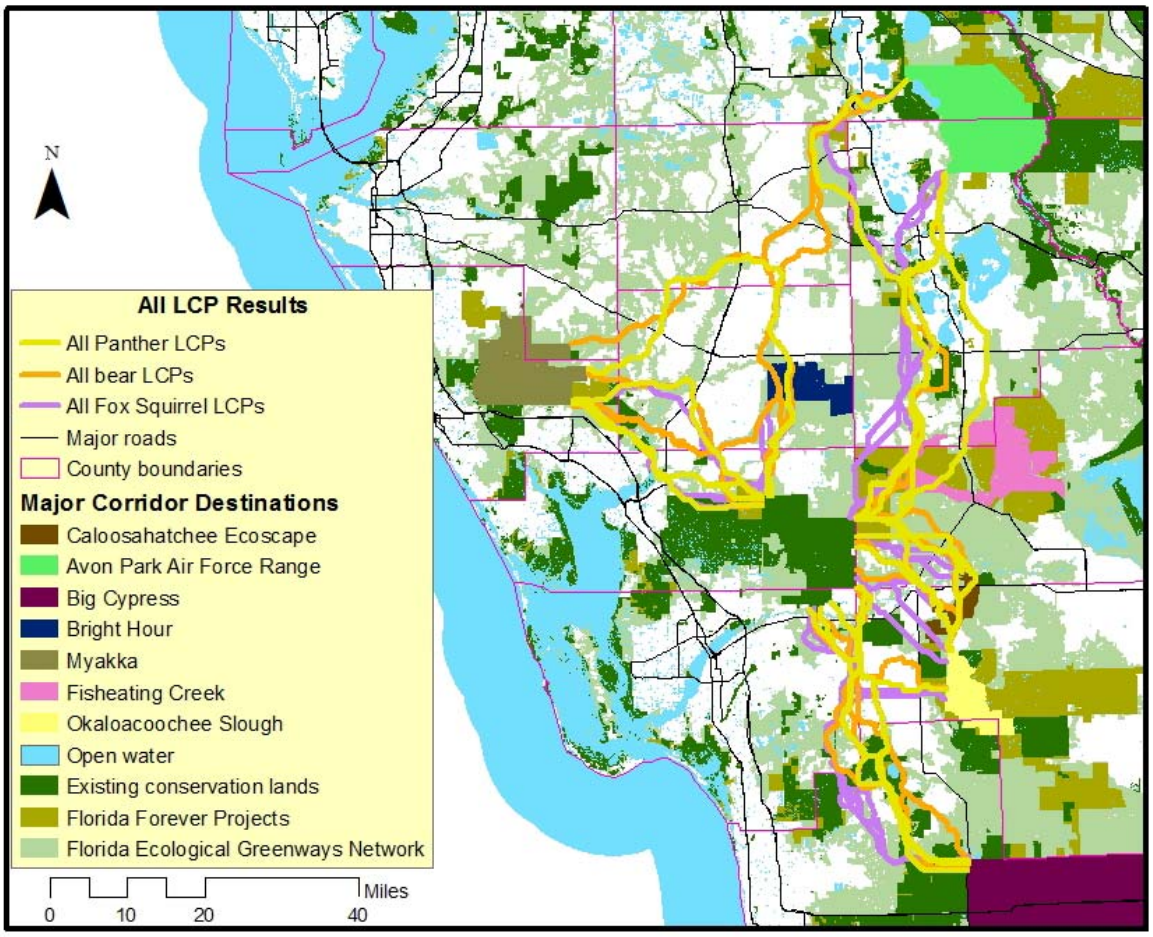

Figure 27. Map summarizing the predicted Least Cost Paths for all three species (panther, bear, fox squirrel) movement from the Babcock study site to each of the six selected habitat patch destinations.

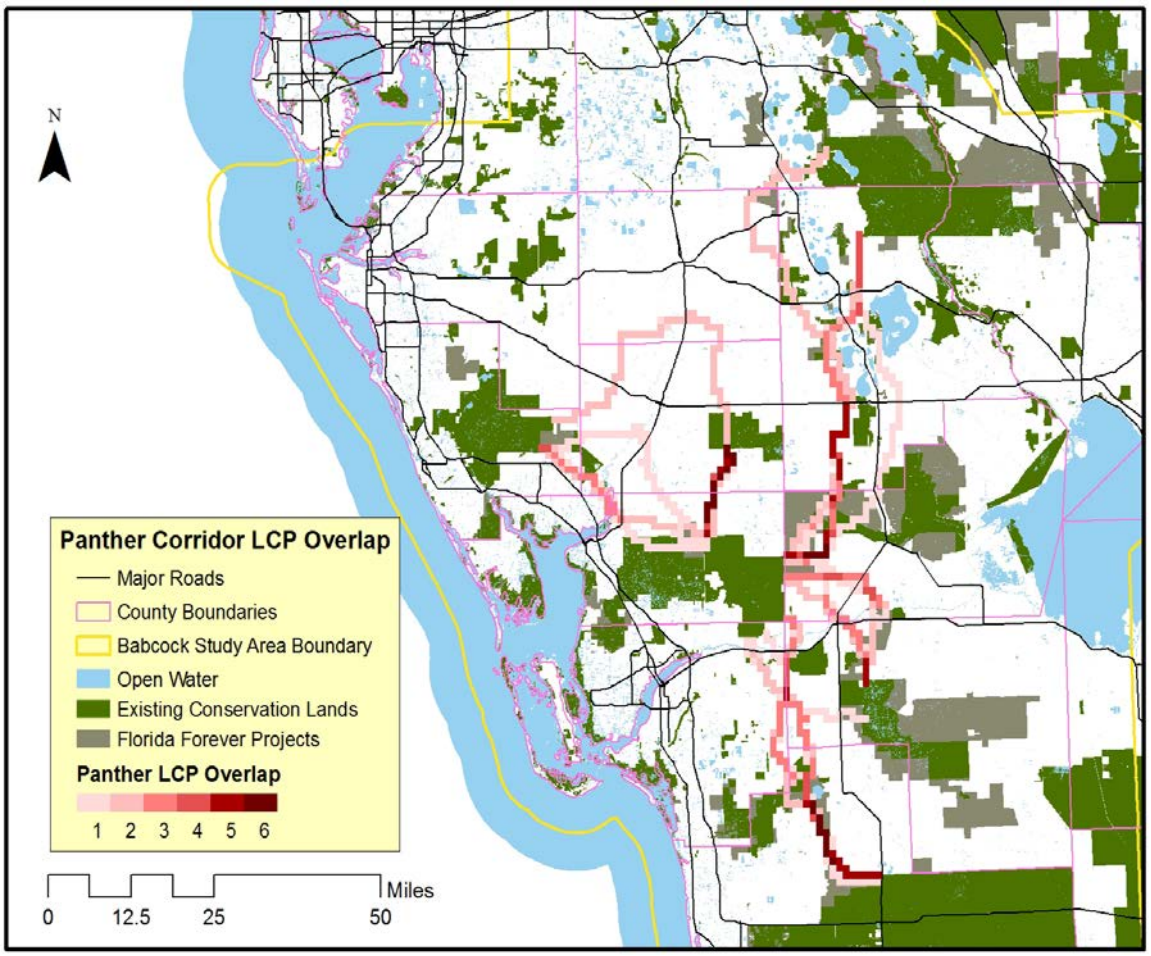

Figure 28. Map summary of the frequency of overlap of the predicted Least Cost Paths for Florida Panther movement from the Babcock study site to each of the six selected habitat patch destinations.

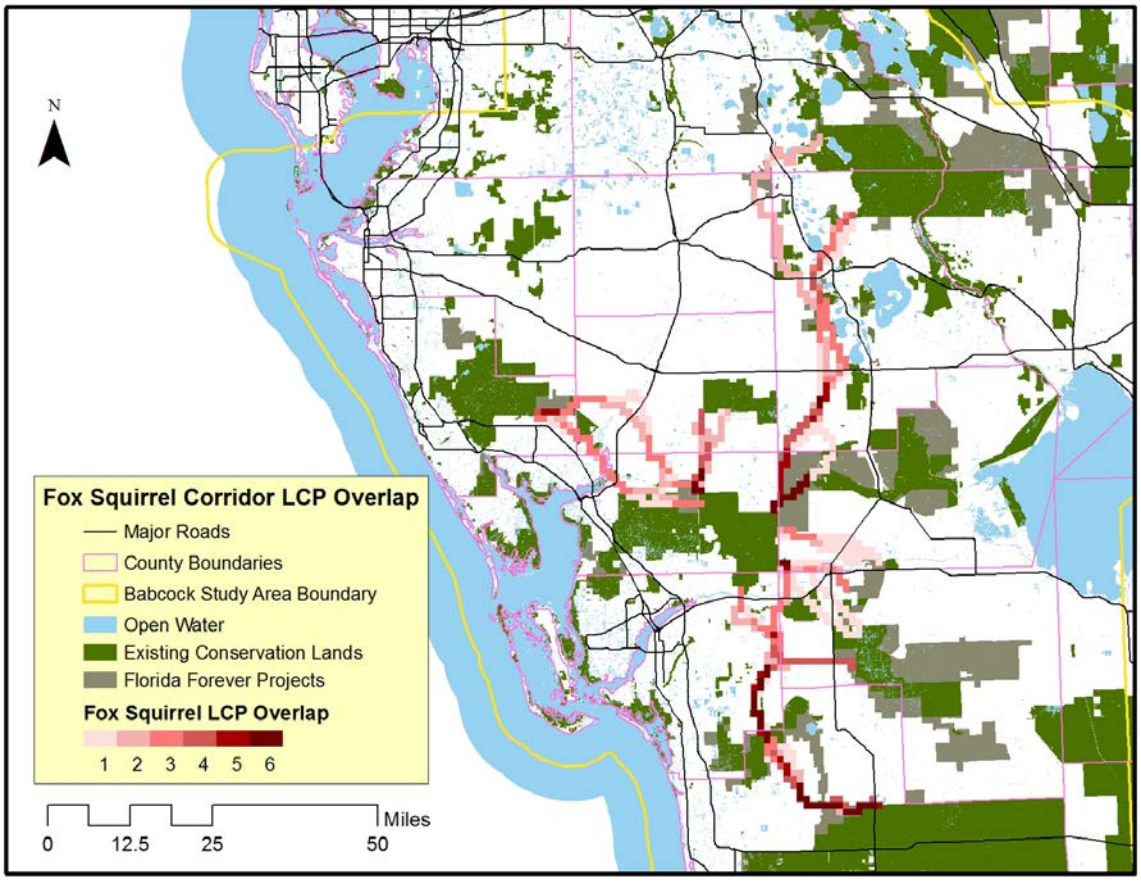

Figure 29. Map summary of the frequency of overlap of the predicted Least Cost Paths for Florida black bear movement from the Babcock study site to each of the six selected habitat patch destinations.

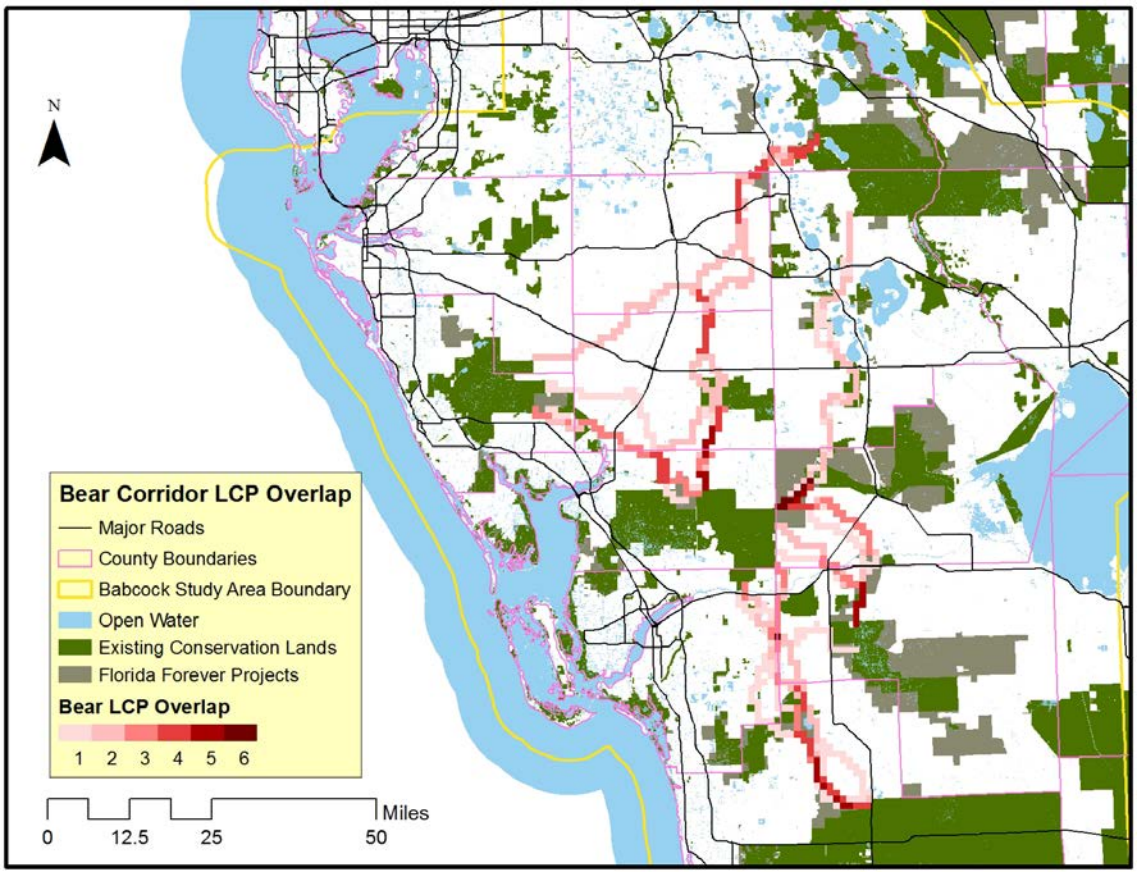

Figure 30. Map summary of the frequency of overlap of the predicted Least Cost Paths for fox squirrel movement from the Babcock study site to each of the six selected habitat patch destinations.

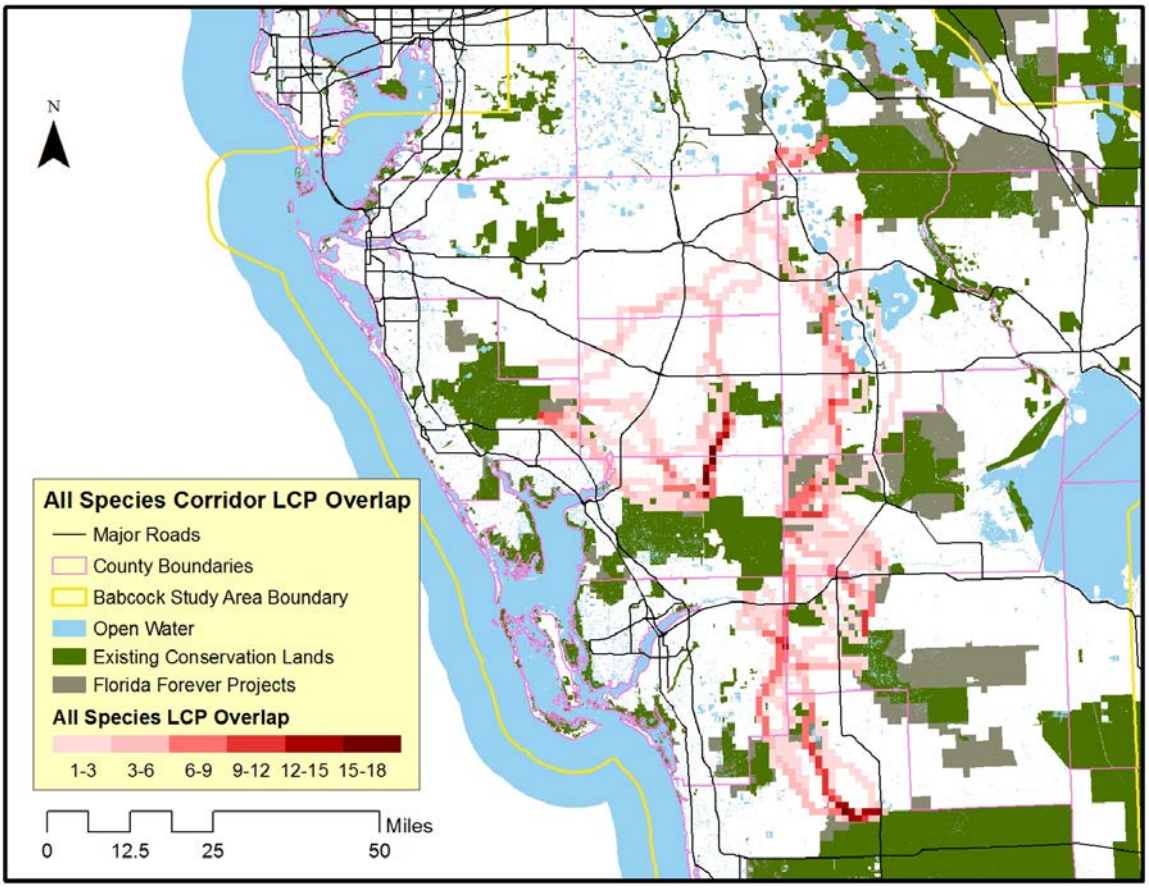

Figure 31. Map summary of the frequency of overlap of the predicted Least Cost Paths for all three study species (panther, bear, fox squirrel) movement from the Babcock study site to each of the six selected habitat patch destinations.

Regional Connectivity Options

We identified three habitat corridor network (or ecological network) options through a collective analysis and assessment of the three focal species potential habitat model results, the Least Cost Path (LCP) model results, the roadkill surveys, and other relevant data. The goal of the three connectivity options was to identify, under three alternative conditions of feasibility, the best opportunities to maintain or restore ecological connectivity in the region surrounding Babcock Ranch. The connectivity options range from low, moderate, to high, with more proposed conservation area and more, and generally wider, corridors in the moderate and high connectivity options.

The low connectivity option primarily represents a minimum feasible or most constrained effort to functionally connect Babcock Ranch with other larger existing conservation lands in the region (Fig. 32). To accomplish this, we identified the one set of LCP results that appear to represent the best potential option for achieving functional connectivity, which was the panther LCPs for the most inclusive cost surface (the cost surface with habitat, landscape integrity, edge effects, roads, and sea level rise). The LCPs for each destination include the due south corridor from Babcock to Big Cypress through eastern Lee County, Corkscrew Swamp, and Camp Keais Strand; the Caloosahatchee Ecoscape corridor to connect to Okaloacoochee Slough State Forest; an east-northeast corridor to connect to the nearby Fisheating Creek Conservation Easement; the "hybrid" corridor to Avon Park Air Force Range that follows the western side of the Lake Wales Ridge before turning east along Josephine Creek and then north along Arbuckle Creek; the due north corridor selected in virtually every LCP analysis to connect to Bright Hour Ranch; and a corridor to Myakka that does not cross near the mouth of the Peace River but also does not veer as far north as some of the other LCP results. To complete the depiction of this option we buffered each of the selected LCPs by one mile to represent an approximate relevant corridor width appropriate to the scale and distance of the various corridors. Then we included all of the existing conservation lands connected to the LCPs, including Babcock Ranch and the six destination conservation areas. Finally, due to its importance for completing a functional corridor across the Caloosahatchee River, we also included all areas within the Caloosahatchee Ecoscape Florida Forever Project within the low connectivity scenario.

The moderate connectivity option is intended to represent a primary option for protecting and restoring functional connectivity in the region (Figs. 33-35). This is achieved by including additional LCP-based options for additional corridors between Babcock and the six destinations and by including priority areas of potential habitat for both the Florida panther and Florida black bear that will result in better opportunities to protect viable populations of each focal species. We also include all Critical Linkages within the FEGN. These priority habitat areas and Critical Linkages also provide wider corridors to connect many of the destinations to Babcock Ranch, which increases the likelihood of achieving functional connectivity. All existing conservation lands and Florida Forever projects connected to these LCPs and priority habitat areas were also included in this option. Finally, to better represent potential connectivity in the Peace River and Myakka River watersheds, we added the Integrated Habitat Network (IHN) to an alternative version of the moderate connectivity option. The IHN fills in potentially important gaps in the large riparian networks in these watersheds, provides some additional corridor redundancy to potentially increase connectivity, and suggests the opportunity to protect a corridor between

Babcock Ranch and Green Swamp through the upper Peace River basin. For more detailed views of the moderate connectivity option, see Figures 39-44.

The high connectivity option represents almost all existing areas that contribute, or could contribute, to protection of a functionally connected ecological network in the study area (Figs 36-38). This scenario is not intended to represent a prioritization of connectivity option, but instead shows the optimal alternative for protection of regional green infrastructure if there were no constraints for protecting such a large area. To delineate this option, we combined all existing conservation lands, all Florida Forever Projects, the two panther and two bear cost surface buffered LCPs used in the moderate connectivity option, all areas within the Florida Ecological Greenways Network, all potential panther, bear (primary and secondary), and fox squirrel habitat (primary and secondary), and all regional and local riparian corridors. As with the moderate connectivity option, we also included the IHN in an alternative version of the high connectivity option.

To help compare the three connectivity options, we generated statistics indicating how acres within relevant conservation status or land-use categories in Table 1. These statistics show that there is a large increase in area included in the three options including both existing conservation and private lands. Approximately 130,000 acres of private land is included in the low connectivity option, with approximately 43,000 of those acres within Florida Forever projects as well as 26,000 acres of wetlands; approximately1.7 million acres of private land is included in the moderate connectivity option, with approximately 500,000 of those acres within Florida Forever projects as well as 400,000 acres of wetlands; and approximately 3.9 million acres of private land is included in the high connectivity option, with approximately 700,000 of those acres within Florida Forever projects as well as 900,000 acres of wetlands (Table 1).

Finally, based on a request by the Babcock Ranch Steering Committee, we also created basic assessments of the number of individual panthers, bears, and fox squirrels that could be potentially supported in the three connectivity options (Tables 2-4). It is extremely important that all users of this report understand that these are coarse analyses based on several estimates of population densities for each focal species contained in the scientific literature and the acres of potential habitat contained within each connectivity option. As discussed above regarding the potential habitat models, the assumption that all potential habitat is suitable is unreasonable, and therefore these population size estimates must be considered optimistic. To partially account for this bias, we provided population estimates based on the unrealistic assumption that all potential habitat is suitable and, alternatively, based on an assumption that only 75% (for panthers and bears) or 50% (for fox squirrels) of the potential habitat in each connectivity option is suitable. Though these percentage estimates are arbitrary, they are likely more realistic than the population estimates based on the assumption that all potential habitat is suitable. Nevertheless, these revised estimates are still quite optimistic, especially so for the fox squirrel, for which, as noted earlier and discussed further below, so little of the potential habitat is likely to be suitable due to management issues. Further data gathering and analysis on this topic would be necessary before accurate predictions could be made.

It is important to understand that these are modeling results and that additional work is needed, including site specific analysis of corridor locations and widths, to create the actual corridors.

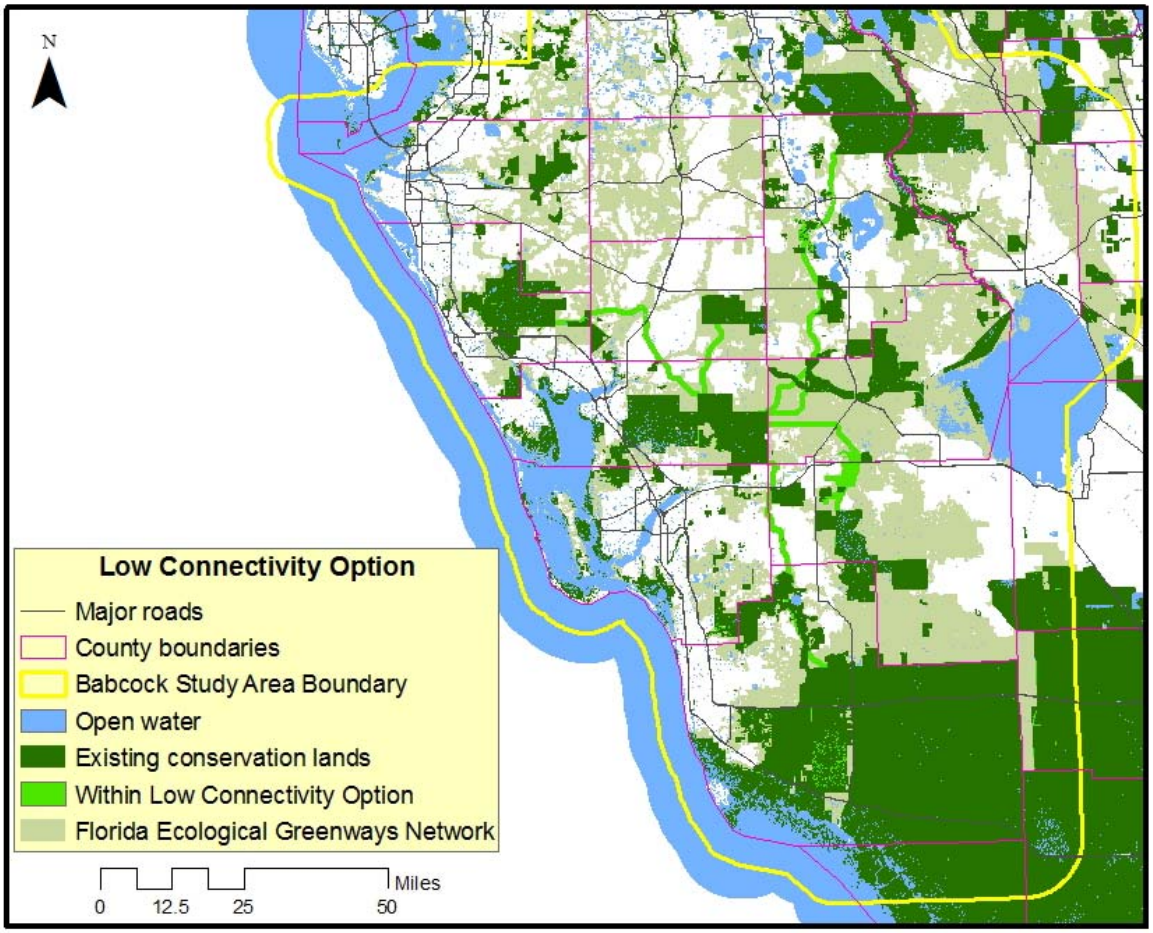

Figure 32. Map of the low connectivity scenario within the Babcock study area.

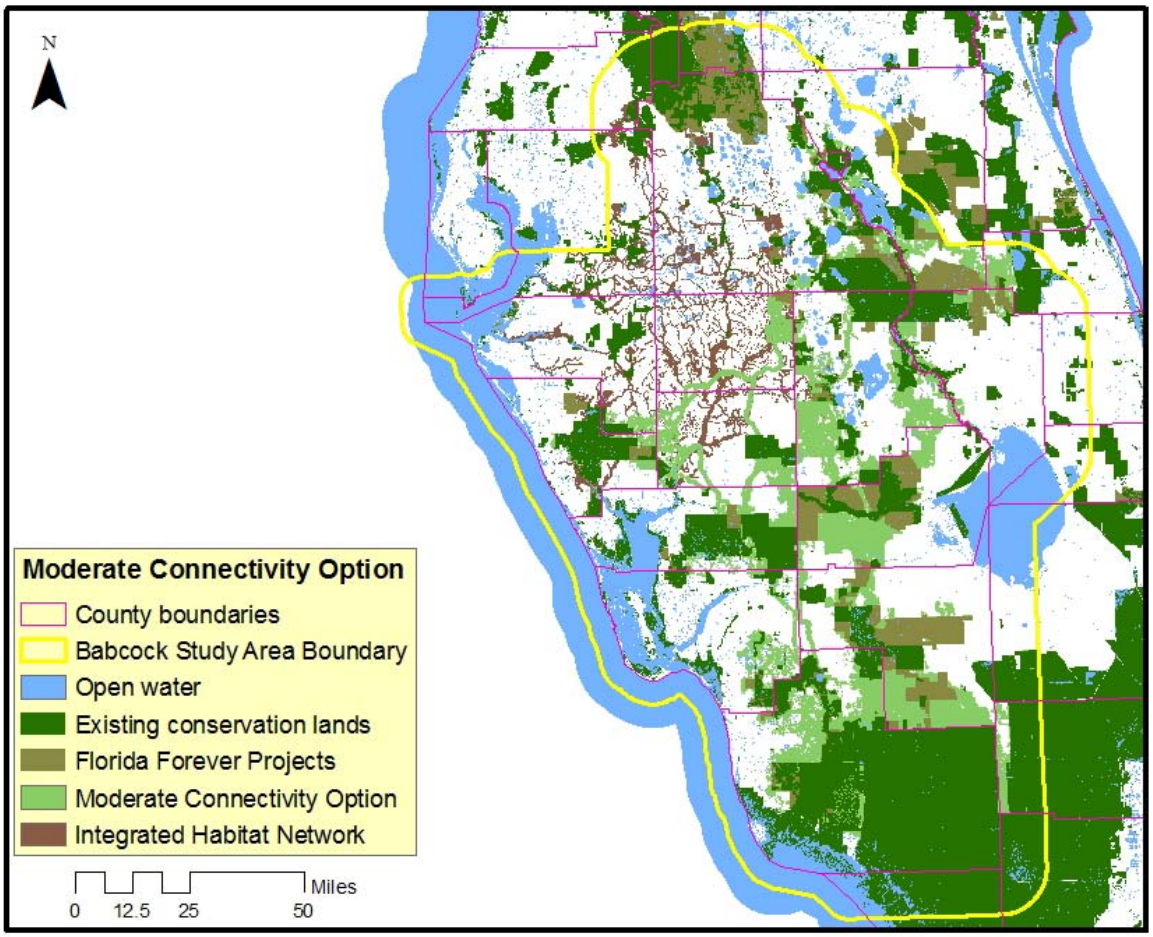

Figure 33. Region-wide map of the moderate connectivity scenario plus the integrated habitat network within the Babcock study area.

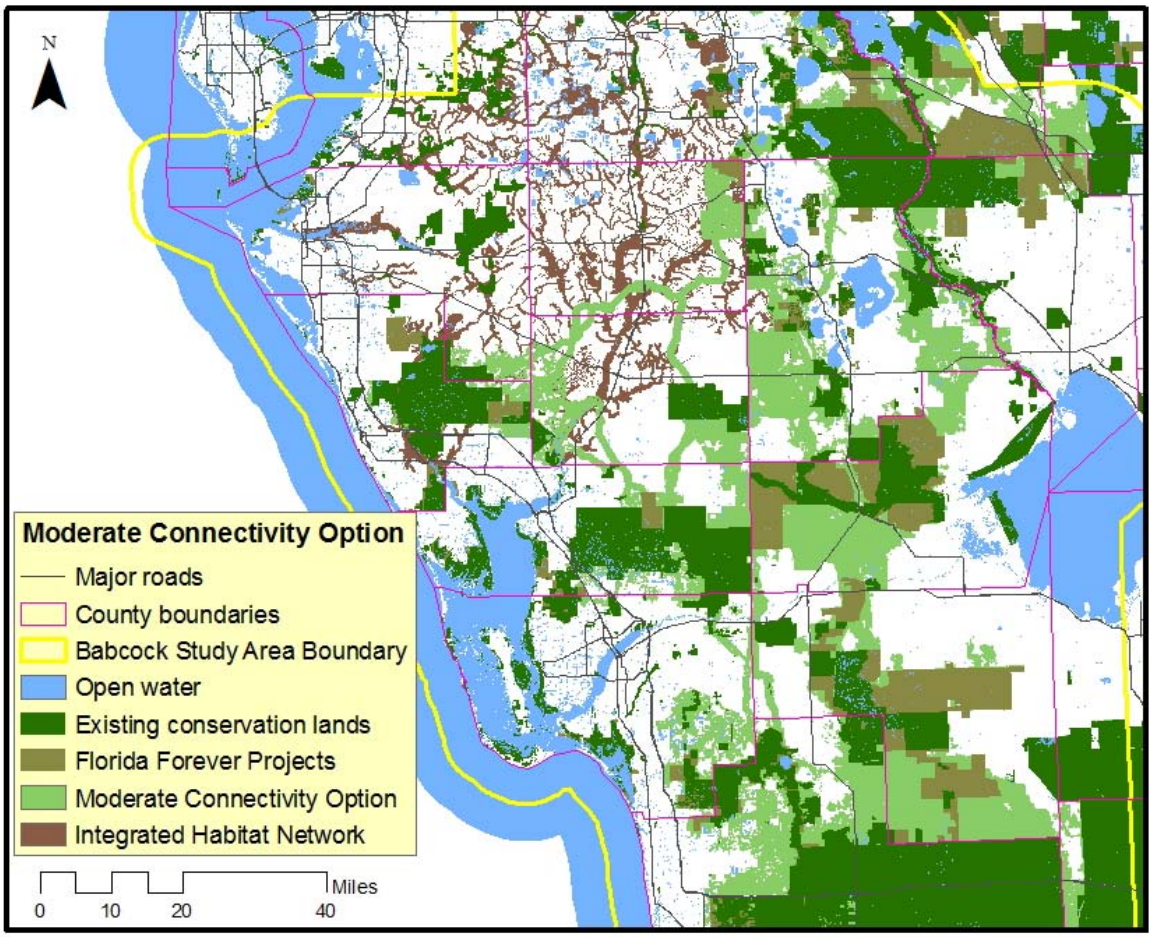

Figure 34. Zoom-in map of the moderate connectivity scenario plus the integrated habitat within the Babcock study area.

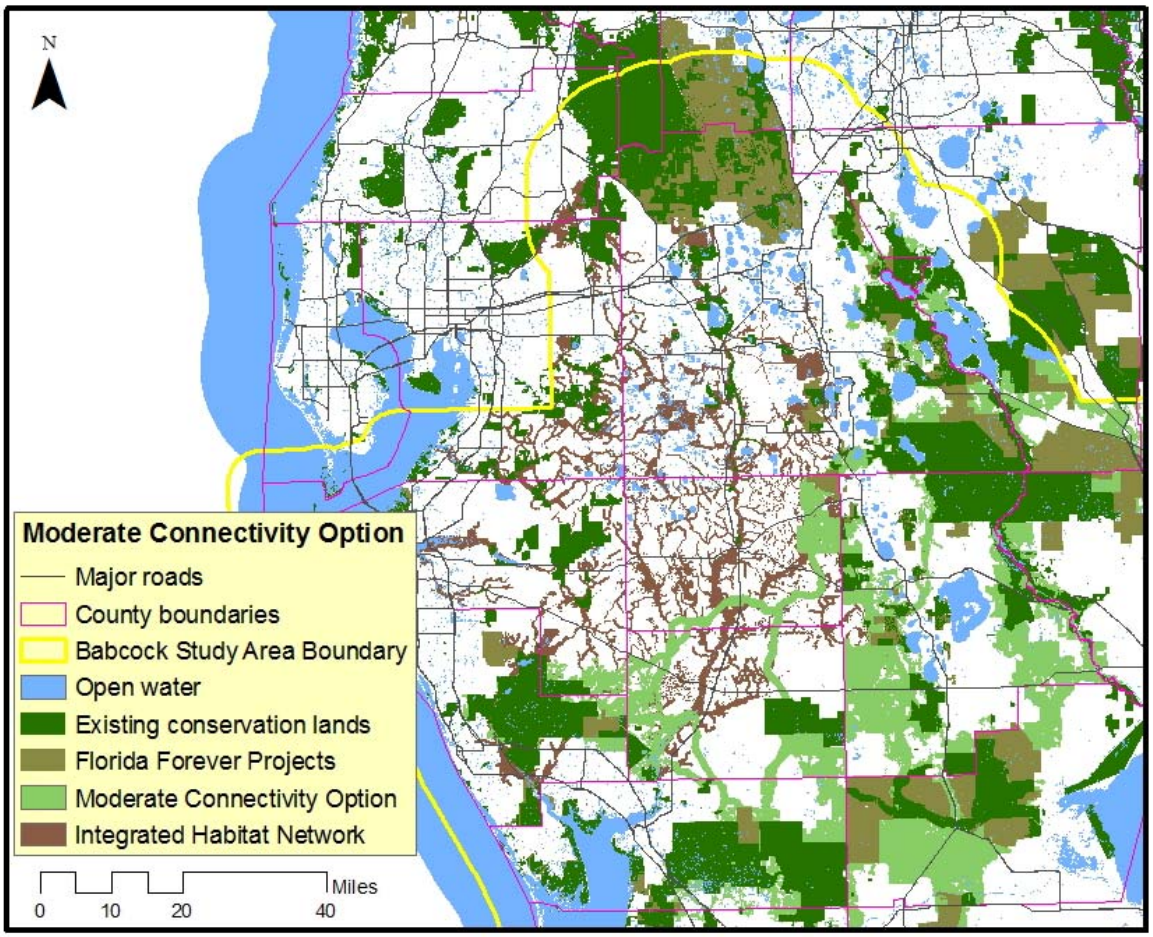

Figure 35. Zoom-in map of the moderate connectivity scenario plus the integrated habitat within the Babcock study area.

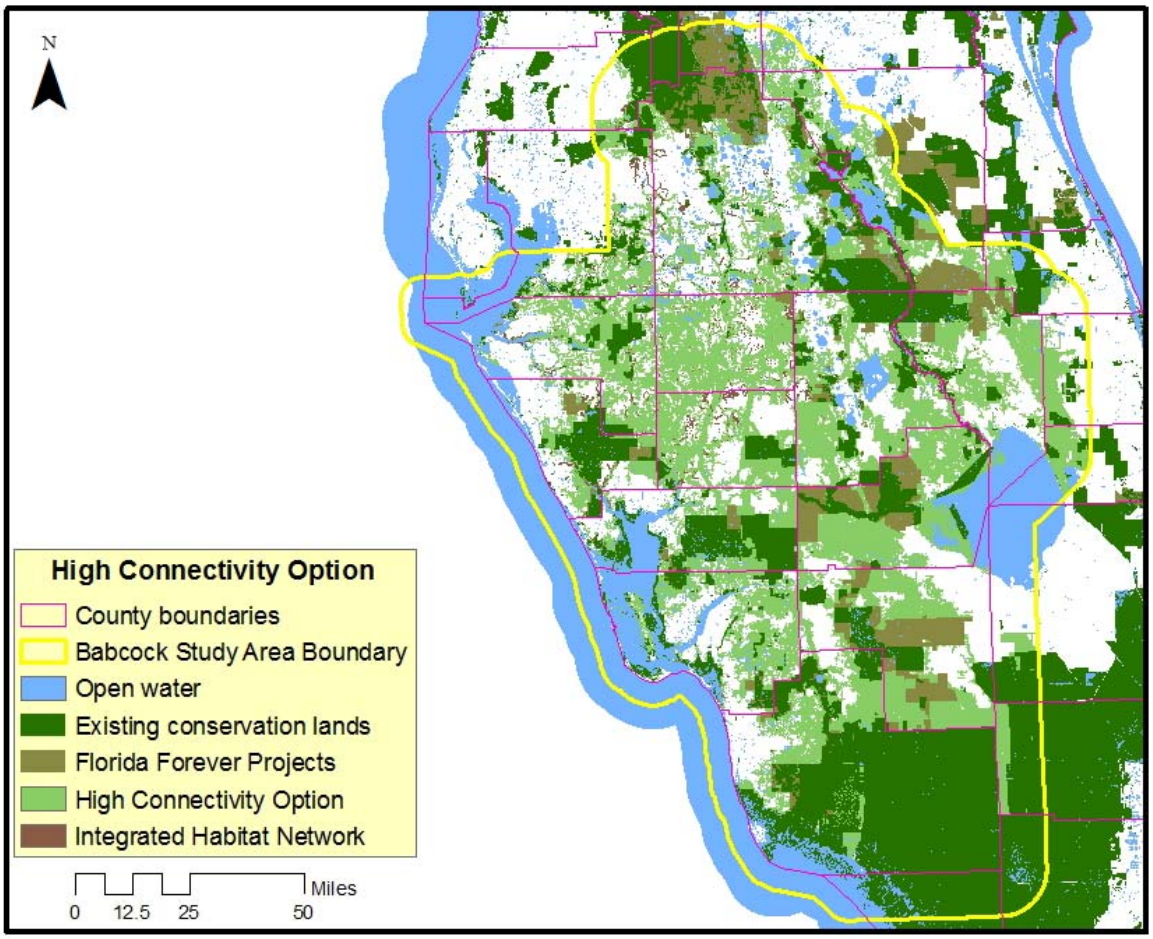

Figure 36. Region-wide map of the high connectivity scenario plus the integrated habitat network within the Babcock study area.

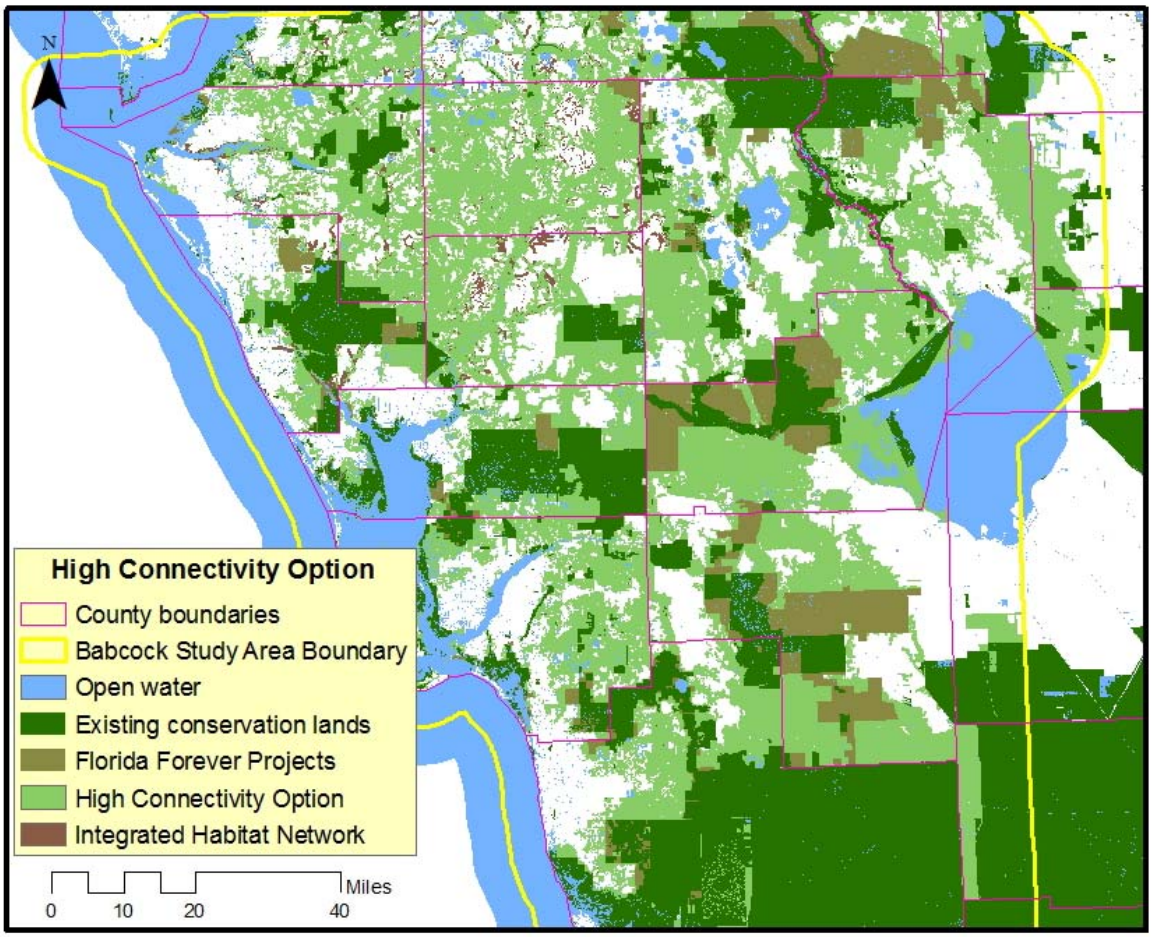

Figure 37. Zoom-in map of the high connectivity scenario plus the integrated habitat within the Babcock study area.

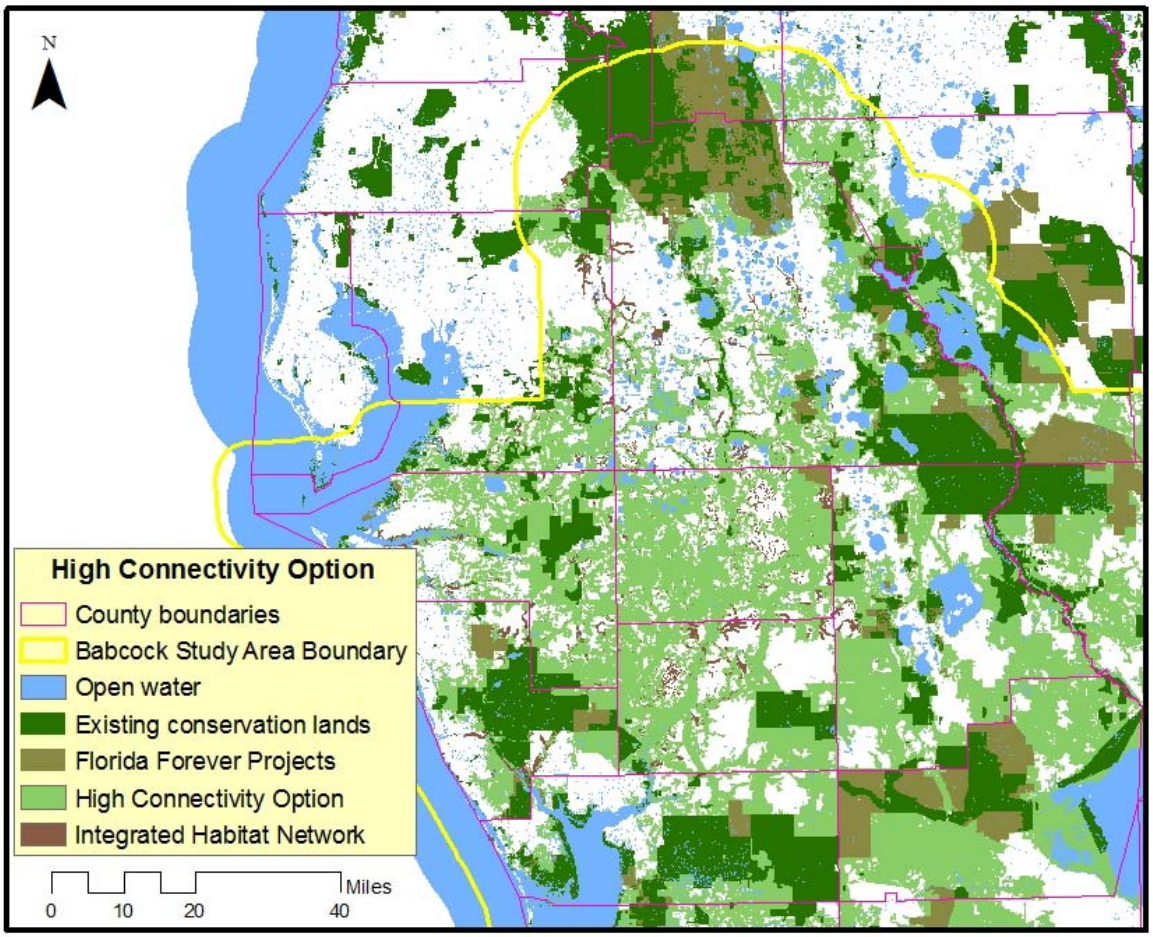

Figure 38. Zoom-in map of the high connectivity scenario plus the integrated habitat within the Babcock study area.

Table 1. Summary of acres of five habitat/land-use classes within each connectivity scenario.

	Conservation Status within Connectivity Scenarios (Acres)					
Connectivity Scenario	**Existing Conservation Land**	**Proposed Florida Forever Project Land**	**Open Water**	**Other Terrestrial Land**	**Other Wetlands**	**Total Private Lands**
Low Connectivity	2,199,448	42,943	1,731	61,694	25,915	130,552
Moderate Connectivity	2,439,105	511,636	20,820	785,435	374,775	1,671,846
Alternative Moderate Connectivity	2,501,586	521,492	40,936	1,083,432	488,916	2,093,840
High Connectivity	2,990,571	698,962	578,114	2,355,037	892,961	3,946,960
Alternative High Connectivity	2,991,697	699,217	581,738	2,443,884	901,545	4,044,646

Table 2. Estimated Florida back bear population supported within potential bear habitat (ac) encompassed by each of five connectivity scenarios. For each connectivity scenario population estimations were calculated based on 100% and 75% of the total available potential habitat. Population estimations were determined by utilizing density calculations obtained from previous Florida black bear studies completed within Ocala National Forest, Eglin Air Force Base and across the Highlands-Glades region.

		Bear Population Estimation (95%CI)		
Connectivity Scenario	**Available Habitat (ac)**	**Based on Ocala Study**	**Based on Eglin Study**	**Based on Highlands-Glades Study**
Minimum (100% habitat)	1,720,917	1324 - 1951	209 - 348	1425 - 1436
Minimum (75% habitat)	1,290,687	993 - 1463	157 - 261	1069 - 1077
Moderate (100% habitat)	2,741,431	2109 - 3108	333 - 555	2272 - 2287
Moderate (75% habitat)	2,056,073	1582 - 2331	250 - 416	1704 - 1716
Moderate: Alternative Areas (100% habitat)	*219,836*	*169 - 249*	*28 - 45*	*155 - 182*
Moderate: Alternative Areas (75% habitat)	*164,877*	*126 -187*	*20 - 33*	*137 - 137*
High (100% habitat)	4,155,684	3197 - 4712	505 - 841	3443 - 3468
High (75% habitat)	3,116,763	2398 - 3534	379 - 631	2583 - 2601
High: Alternative Areas (100% habitat)	*9,975*	*8 - 11*	*1 - 2*	*7 - 8*
High: Alternative Areas (75% habitat)	*7,481*	*6 - 8*	*1- 2*	*6 - 6*

Table 3. Estimated Florida Panther population supported within potential panther habitat (ac) encompassed by each of five connectivity scenarios. For each connectivity scenario population estimations were calculated based on 100% and 75% of the total available potential habitat. Population estimations were determined by utilizing density calculations obtained from previous Florida Panther studies completed in south west Florida.

		Panther Population Estimation (95%CI)	
Connectivity Scenario	**Available Habitat (ac)**	**Based on Maehr et al. 1991 Study**	**Based on McBride 2000 Study**
Minimum (100% habitat)	1,635,377	53 - 73	51
Minimum (75% habitat)	1,226,533	40 - 55	29
Moderate (100% habitat)	2,664,109	86 - 119	83
Moderate (75% habitat)	1,998,082	65 - 89	47
Moderate: Alternative Areas (100% habitat)	*291,934*	*10 - 13*	*9*
Moderate: Alternative Areas (75% habitat)	*218,950*	*7 - 7*	*7*
High (100% habitat)	4,485,883	145 - 200	141
High (75% habitat)	3,364,412	109 - 150	79
High: Alternative Areas (100% habitat)	*12,227*	*0 - 1*	*0*
High: Alternative Areas (75% habitat)	*9,170*	*0 - 0*	*0*

Table 4. Estimated Sherman's fox squirrel population supported within potential Sherman's fox squirrel habitat (ac) encompassed within each connectivity scenario. For each connectivity scenario population estimations were calculated based on 100% and 50% of the total available potential habitat. Population estimations were determined by utilizing density calculations obtained from previous Sherman's Fox Squirrel studies.

		Sherman's Fox Squirrel Population Estimation	
Connectivity Scenario	**Available Habitat (ac)**	**Based on Moore 1957 Study**	**Based on Kantola and Humphrey 1990 Study**
Minimum (100% habitat)	310,006	5,020	15,063
Minimum (50% habitat)	155,003	2,510	7,532
Moderate (100% habitat)	569,211	9,218	27,658
Moderate (50% habitat)	284,606	4,609	13,829
Moderate: Alternative Areas (100% habitat)	*54,278*	*878.99*	*2,637*
Moderate: Alternative Areas (50% habitat)	*27,139*	*439.495*	*1,319*
High (100% habitat)	1,048,857	16,986	50,965
High (50% habitat)	524,428	8,493	25,482
High: Alternative Areas (100% habitat)	*876*	*14*	*43*
High: Alternative Areas (50% habitat)	*438*	*7*	*21*

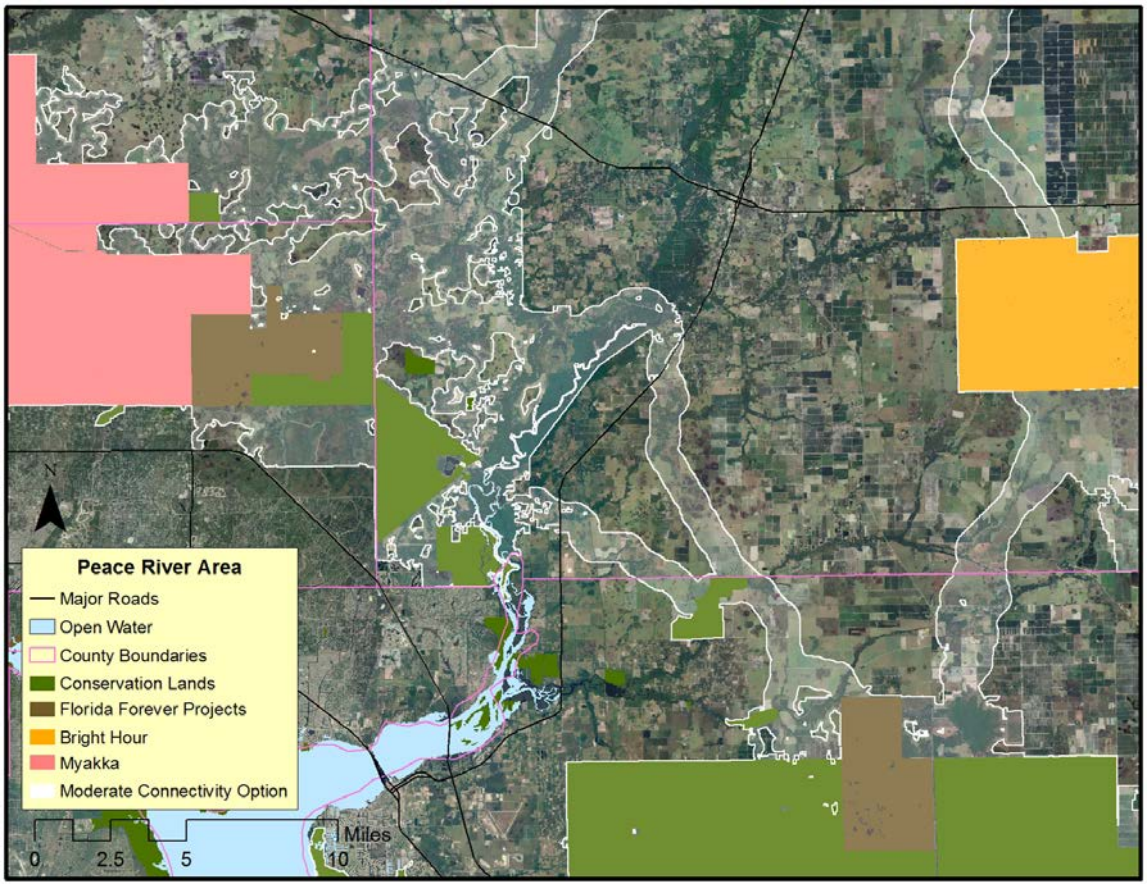

Figure 39. Overlay of the moderate habitat connectivity scenario onto 1-meter resolution Digital Ortho Quarter Quads in the Peace River region of the Babcock study area.

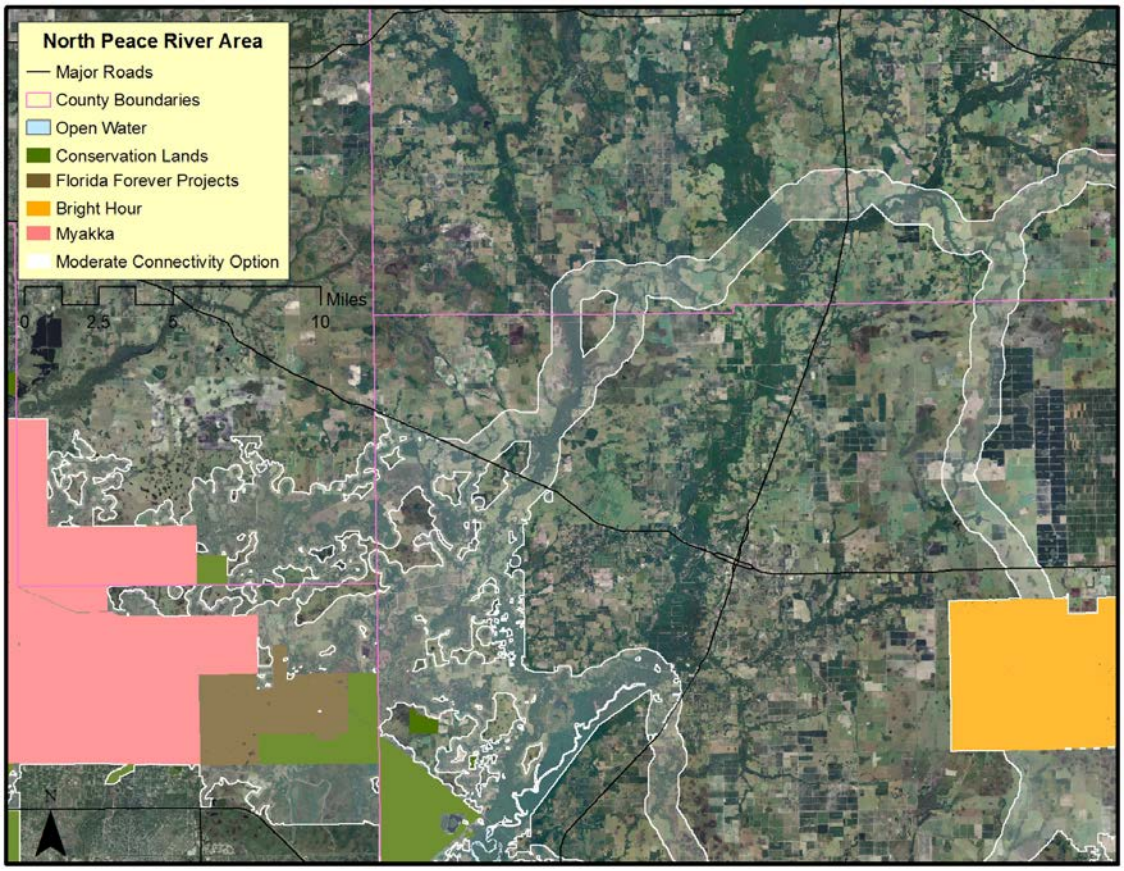

Figure 40. Overlay of the moderate habitat connectivity scenario onto 1-meter resolution Digital Ortho Quarter Quads in the northern Extent of Peace River region of the Babcock study area.

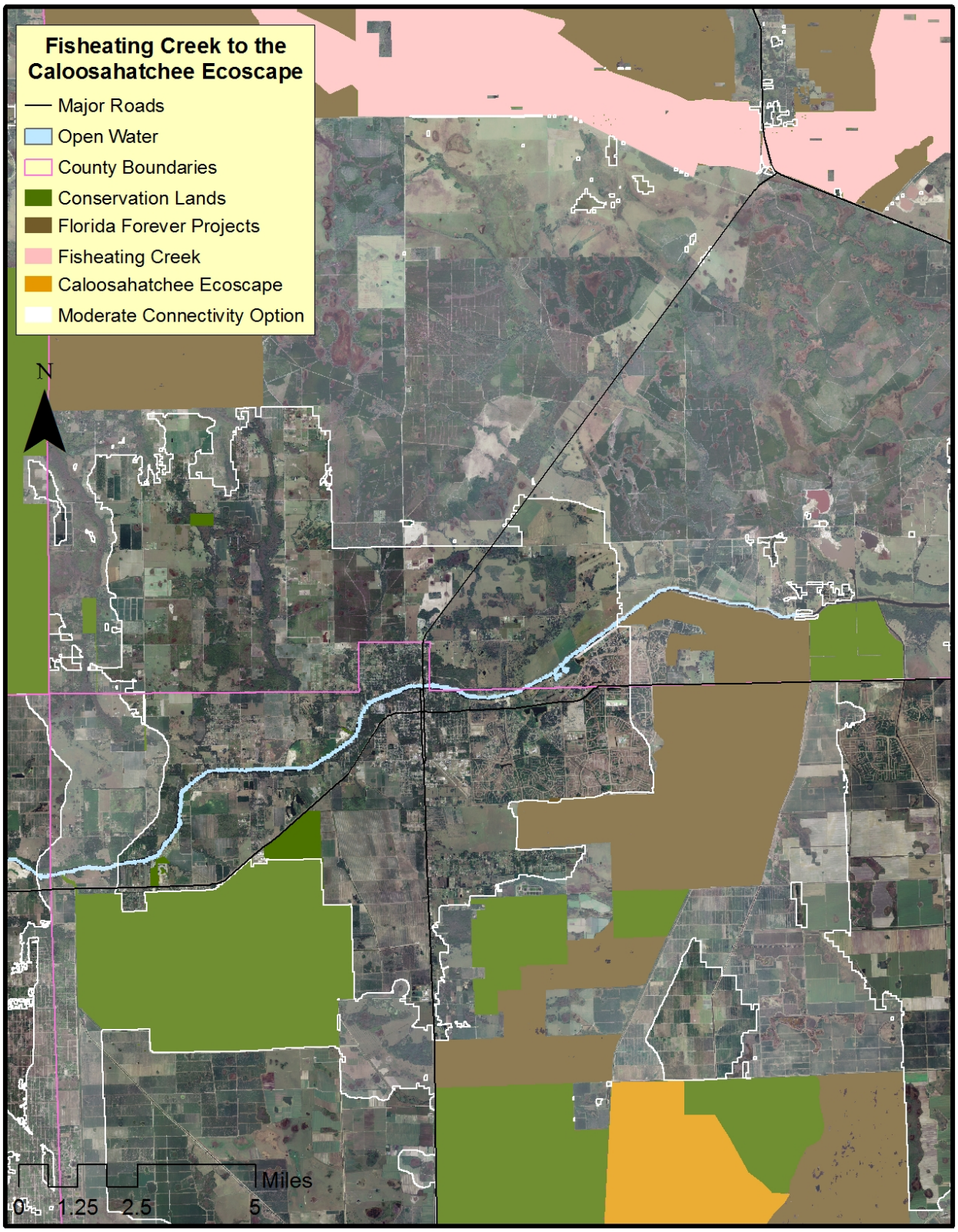

Figure 41. Overlay of the moderate habitat connectivity scenario onto 1-meter resolution Digital Ortho Quarter Quads for the Caloosahatchee Ecoscape region of the Babcock study area.

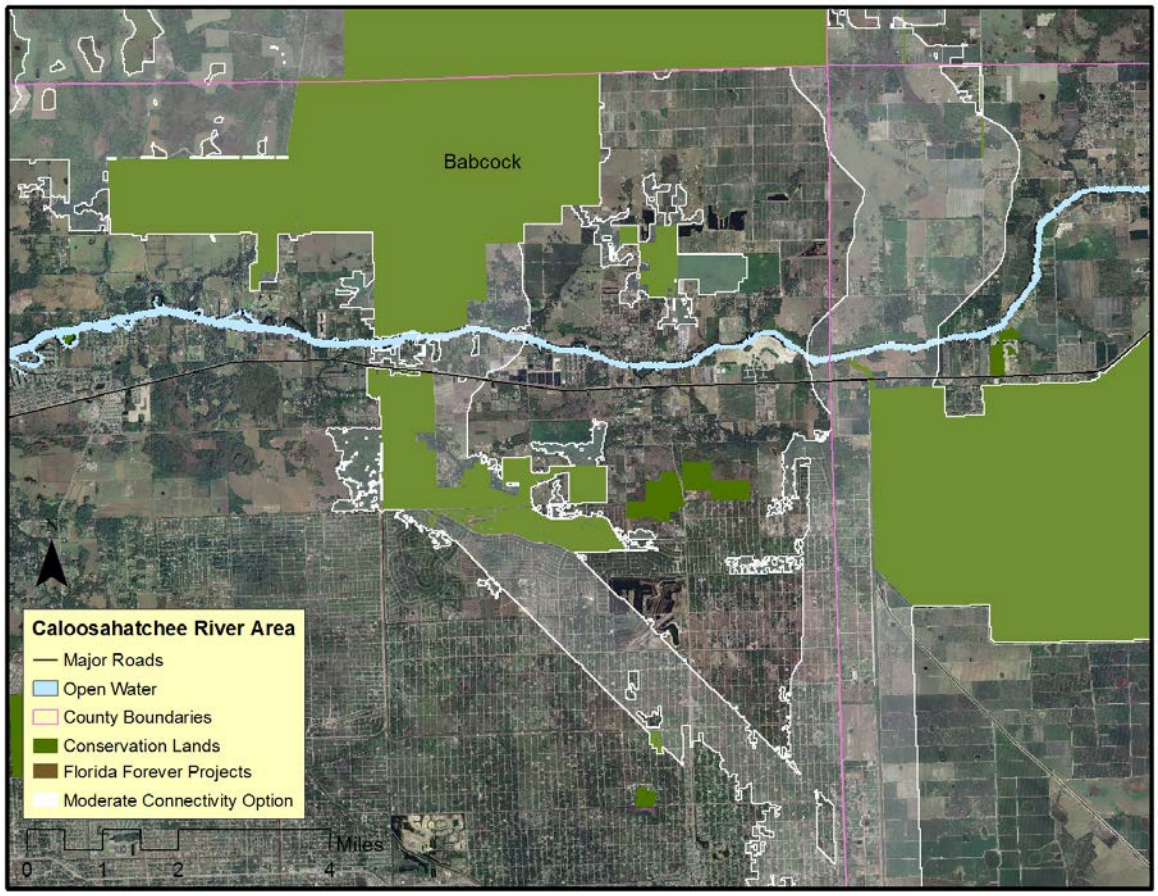

Figure 42. Overlay of the moderate habitat connectivity scenario onto 1-meter resolution Digital Ortho Quarter Quads for the Caloosahatchee River region of the Babcock study area.

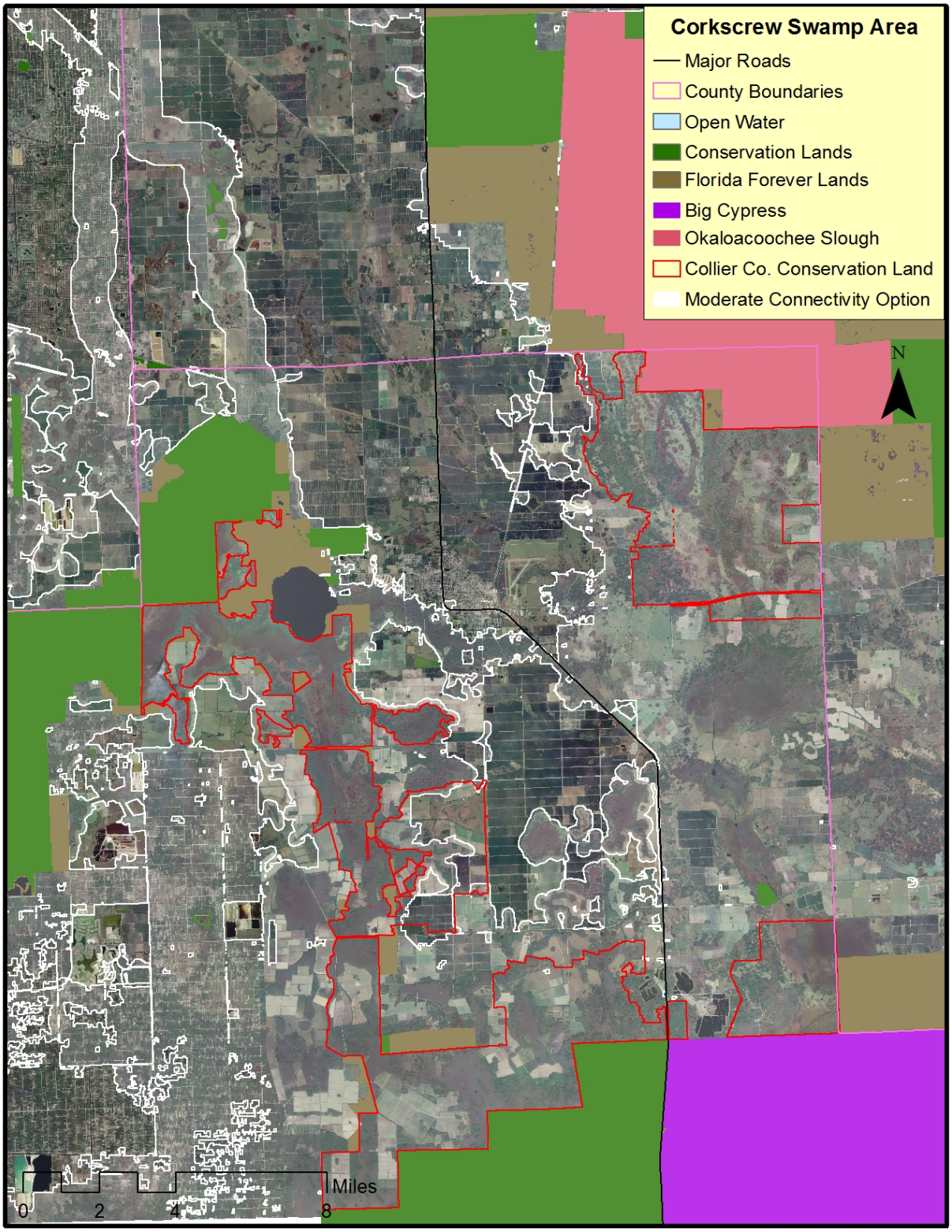

Figure 43. Overlay of the moderate habitat connectivity scenario onto 1-meter resolution Digital Ortho Quarter Quads for the Corkscrew Swamp region of the Babcock study area.

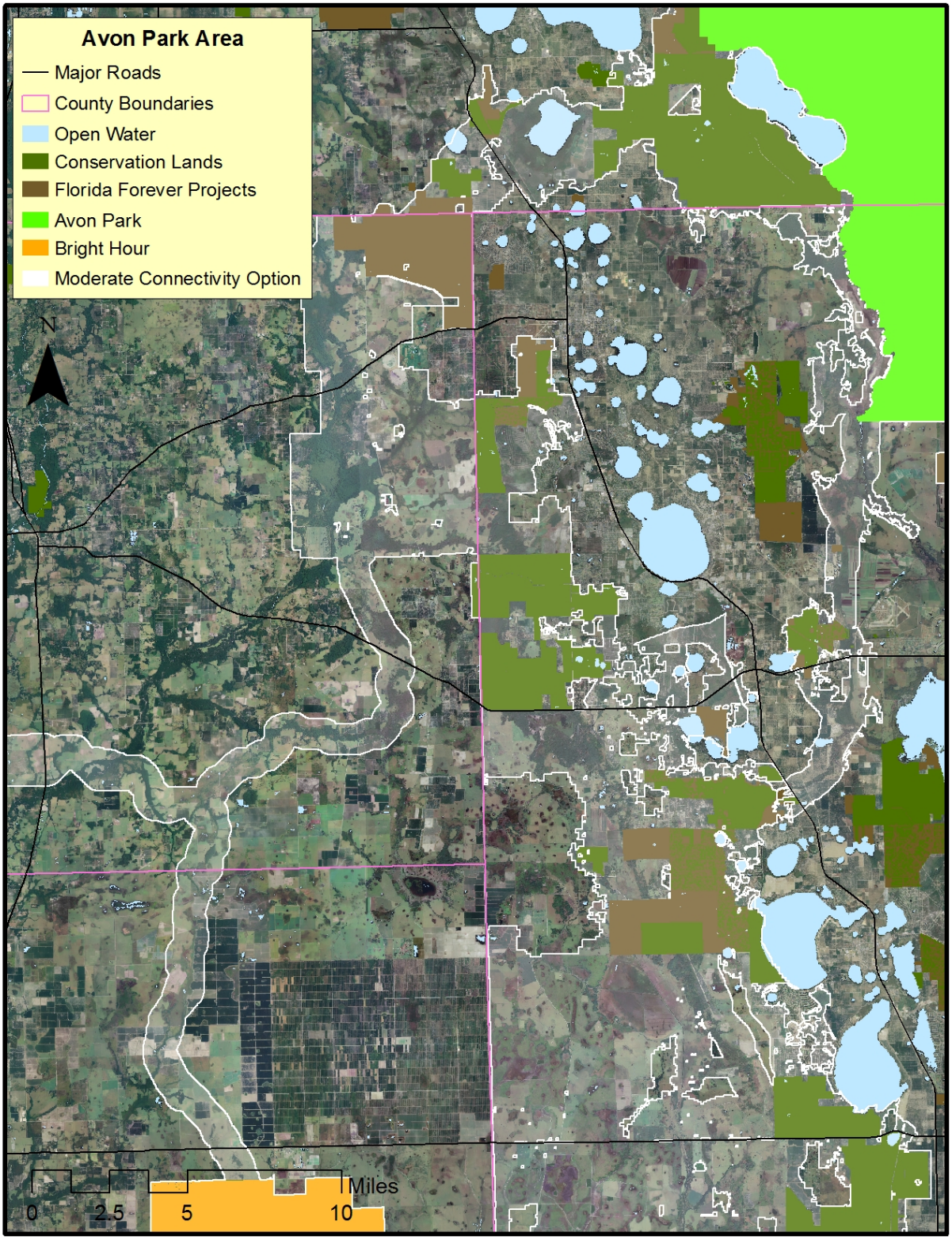

Figure 44. Overlay of the moderate habitat connectivity scenario onto 1-meter resolution Digital Ortho Quarter Quads for the Avon Park-Lake Wales Ridge region of the Babcock study area.

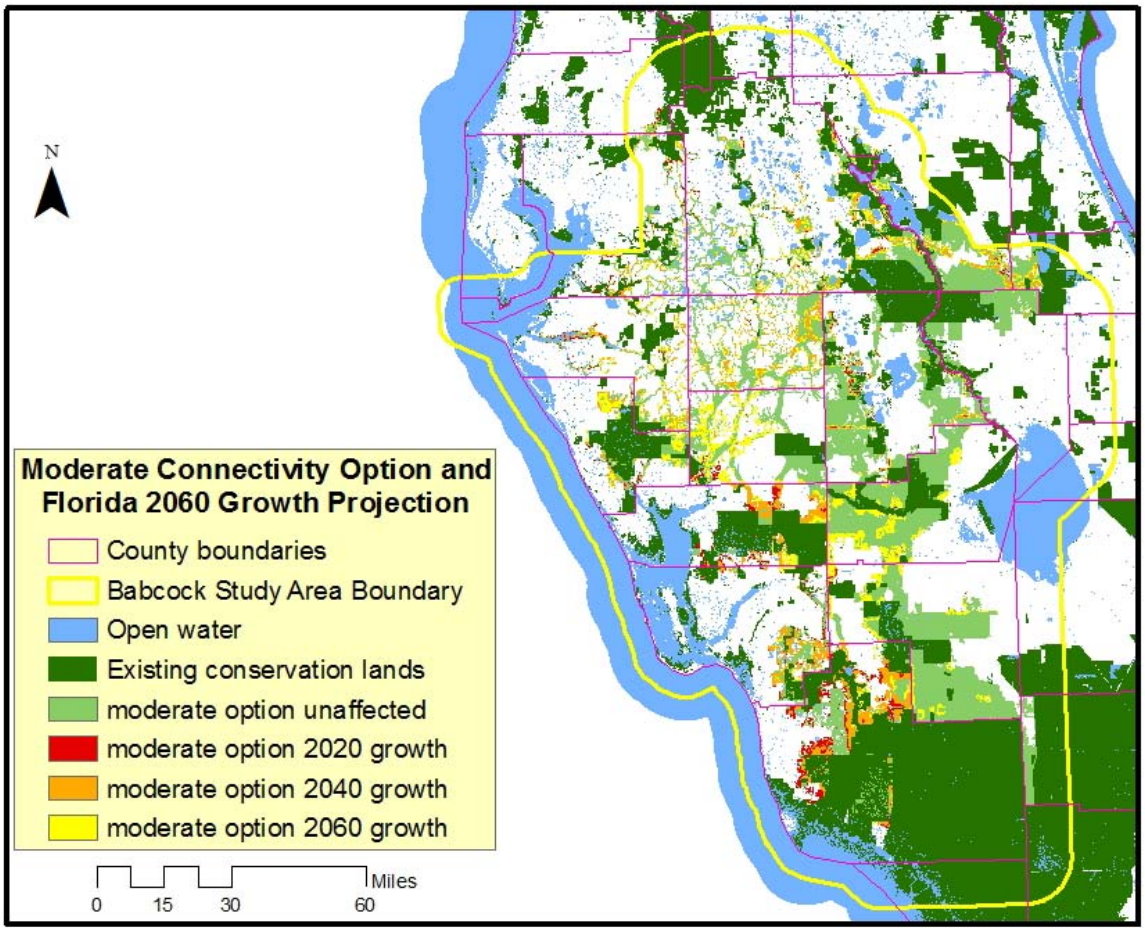

Figure 45. Comparison of the moderate connectivity option with the Florida 2060 growth projection model.

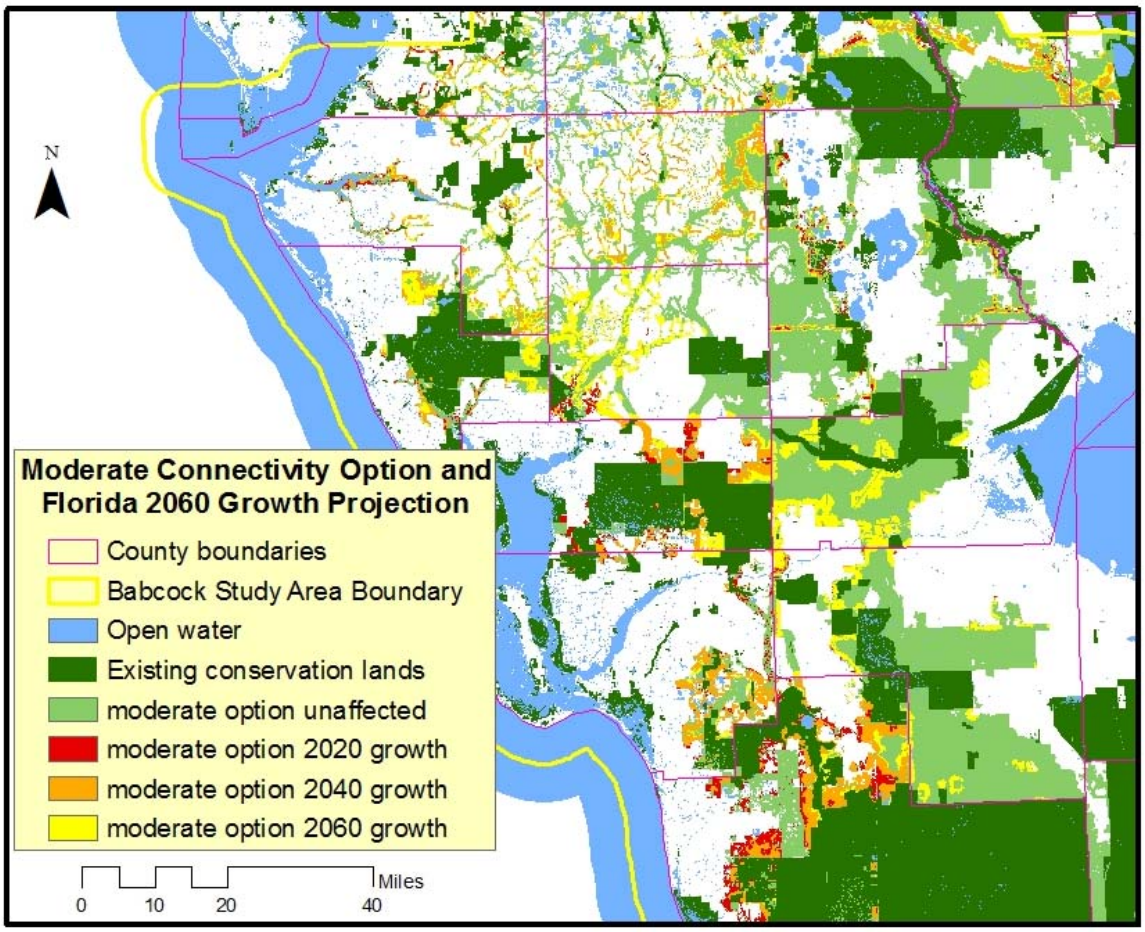

Figure 46. Comparison of the moderate connectivity option with the Florida 2060 growth projection model.

Connectivity Options in the Face of Projected Regional Urban Growth and Sea-Level Rise

Future residential, commercial, and industrial development could preclude protection of any of the connectivity options without appropriate planning. To indicate the potential conflict between ecological connectivity and future growth, we compared the moderate connectivity option to the Florida 2060 growth projection. The results of the comparison suggest that there is significant potential for conflict with future growth (Figs. 45-46). The two areas that might be affected the most are within Collier County and between Babcock Ranch and Myakka.

Sea level rise (SLR) may also have significant negative impacts on conservation efforts in the study area. These impacts could include the loss of core habitat for all three focal species on conservation lands in the southernmost part of the study area (Fig. 47). In addition, SLR could degrade or fragment corridors across the lower Peace River (Fig. 48) and the Caloosahatchee River (Fig. 49).

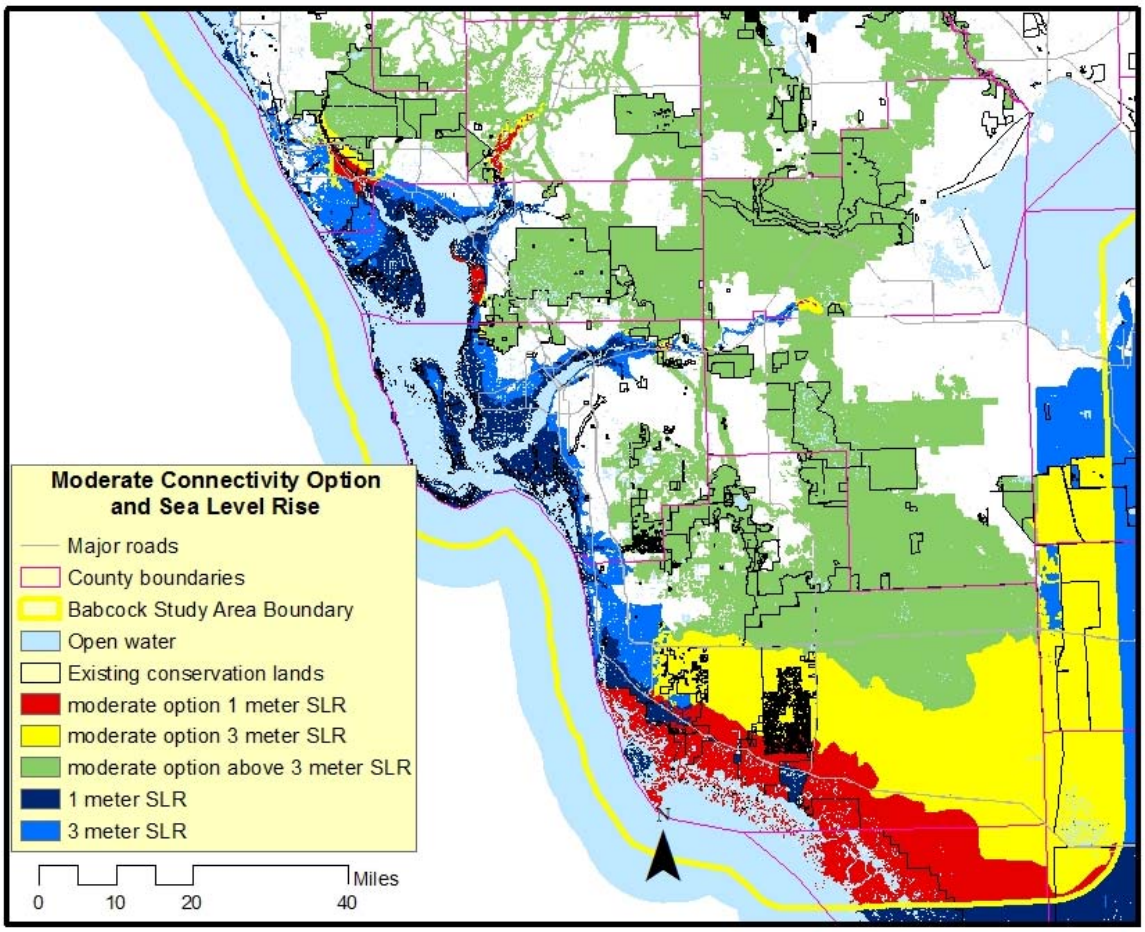

Figure 47. Comparison of the moderate connectivity option with Sea Level Rise projections.

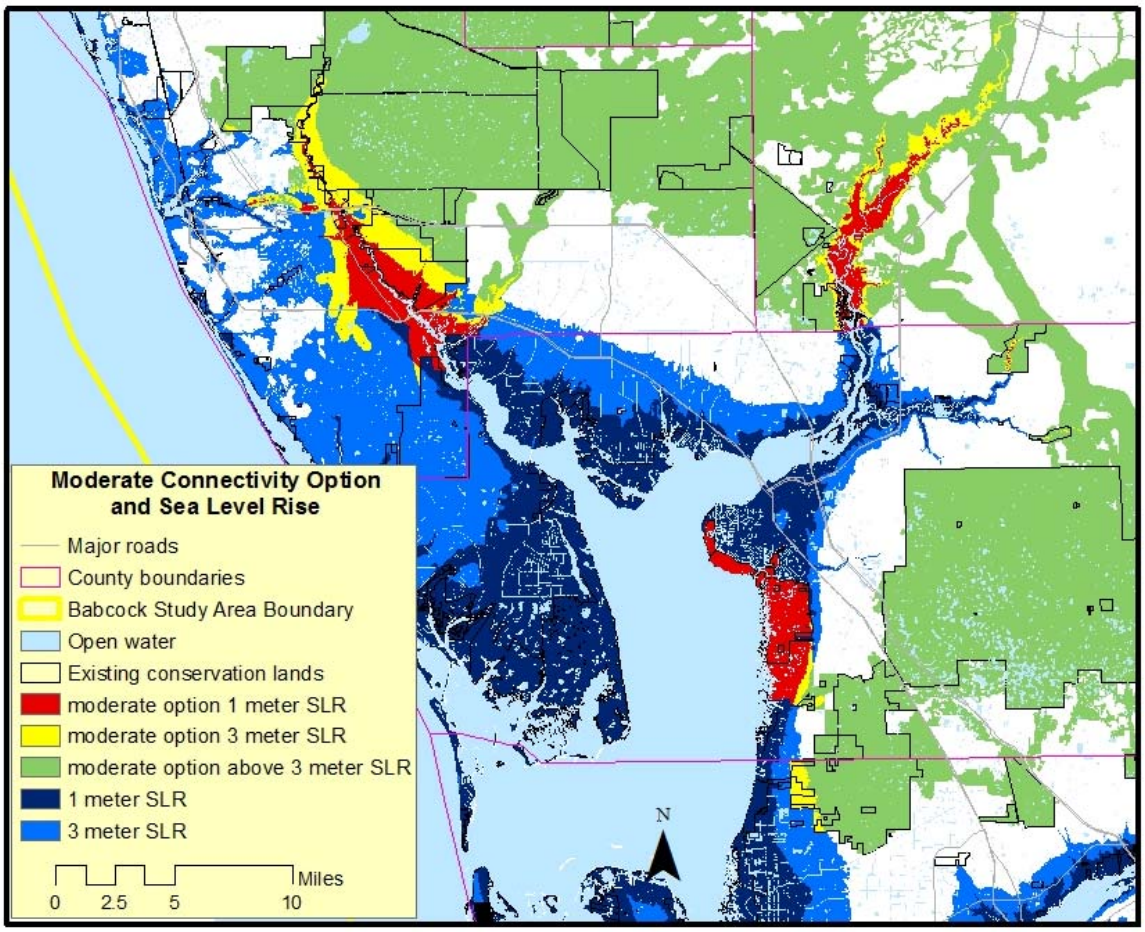

Figure 48. Comparison of the moderate connectivity option with Sea Level Rise projections for the lower Peace and Myakka Rivers.

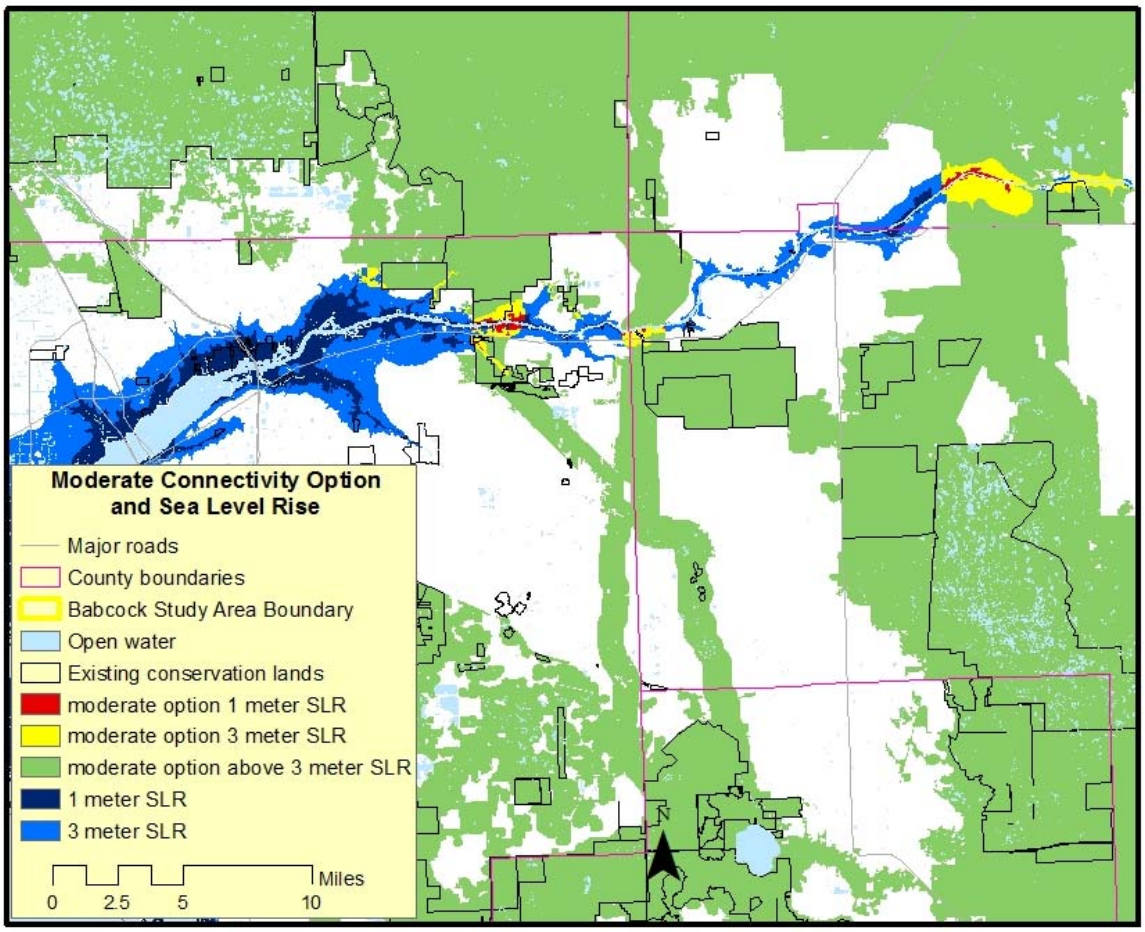

Figure 49. Comparison of the moderate connectivity option with Sea Level Rise projections for the Caloosahatchee River.

Discussion and Recommendations

A distinct and reassuring finding from this study is that options for maintaining connectivity for three focal species – Florida panther, Florida black bear, and Sherman's fox squirrel – between Babcock Ranch and other existing and potential conservation areas within the regional landscape are still relatively abundant and intact. Quite extensive areas of potentially suitable habitat are available for the black bear and panther, but somewhat less for the fox squirrel. We must issue the reminder, however, that occupied habitat is a generally unknown but consistently smaller subset of the potential habitat identified in habitat models, either because the habitat models fail to identify all potential limiting factors to a species' distribution, or because potentially suitable habitat is unoccupied today due to past or current human pressures, including hunting, poaching, and road impacts.

A less optimistic finding from our study is that several problematic corridor bottlenecks are present already in the region and will constrain animal movement unless remedied by increased land protection and mitigation of impacts from roads and development. Most worrisome, unless potential conservation areas (e.g., Florida Forever projects) are protected quite soon, connectivity for our focal species and many other animals will be significantly diminished, especially if human population growth and development continue in the study region and if road impacts

(increased traffic volume, road widening, etc.) are not reduced by properly located and designed wildlife crossings and associated barrier fencing. Sea-level rise is also a threat. Impacts of sea-level rise in the immediate vicinity of Babcock Ranch, and on corridors to the east and northeast, are expected to be relatively minor – certainly much less severe than in areas closer to the coast, especially in low-lying areas of extreme South Florida, e.g., the lower Everglades and the Florida Keys (Noss et al. in preparation). On the other hand, the southern and western portions of our study area could experience extreme impacts of even a 1-meter rise in sea level, as will the Lower Peace and Myakka River areas to the northwest of Babcock Ranch, where some of our identified LCPs would be severed by rising waters. Moreover, even inland areas substantially above 3 meters in elevation will be at high risk as displaced people potentially move inland from the coasts over the coming decades. This phenomenon underscores the need to protect key core areas and landscape linkages in advance of this displacement of people and other species from low-lying coastal areas (Noss et al. in preparation).

Although we made the best use we could of available data within the short time span and limited budget of this study, we acknowledge several limitations of our research that should be addressed through further studies. Most importantly, we were not able to assess population viability directly for the three focal species, but rather could only estimate population sizes and viability based on habitat conditions and knowledge of home range sizes and life histories. Such estimates make the implicit assumption that the size and configuration of individual habitat patches are unimportant and that individual animals can move freely through the corridors identified in each connectivity option. Hence, static habitat and corridor models typically produce an optimistic portrayal of potential population size and viability in comparison with dynamic models.

Assessment of population viability is best accomplished through spatially explicit population modeling (Dunning et al. 1995, Carroll et al. 2003, Akcakaya et al. 2004). In these dynamic models, information on demography (age-specific birth and death rates, dispersal, etc.) for a species is integrated with GIS-based information on habitat quality (e.g., from habitat models of the type developed in our study) and spatial configuration to simulate births, dispersal, reproduction, and deaths of individuals across a study landscape. Output from these models includes predictions of source (recruitment > mortality) vs. sink (mortality > recruitment) status of specific habitat patches, dispersal and other movements among patches, and probabilities of extinction vs. recovery under alternative future scenarios of land cover, land use, and even climate change (Carroll 2007). Surprisingly, although our focal species have been relatively well studied, no spatially explicit population models have been produced for these species in Florida, other than the work of the USFWS Panther Subteam for panthers in south Florida.. We view this as a high priority for future research, and should include modeling of alternative future scenarios of landscape conditions.

Another caveat concerns our modeling of movement paths among habitat blocks. Least-cost path modeling, though widely used and found acceptable in many conservation plans, has limitations. The logic of least-cost path modeling is sound: Intelligent animals will try to follow a path of least resistance through a landscape, minimizing energy expenditure and maintaining adequate security. However, the resistance of each class of land use, vegetation, topography, or human disturbance is usually based on expert opinion and/or literature review on habitat suitability. Expert opinion performs poorly if not combined with literature review. The assumption in LCP analysis that animals choose travel routes on the basis of the same factors they use to choose

habitat (e.g., for home ranges) is not always valid. In the case of this study, however, we made intensive use of the literature; moreover, our three focal species have been well enough studied that estimation of least cost paths can be considered reasonably accurate.

The three connectivity options that we developed from the habitat and LCP models applied in this study represent a political or economic feasibility gradient from highly to minimally constrained. All options would require addition of lands to Florida's conservation area network. For example, approximately 130,000 acres of private land is included in the low connectivity option, with approximately 43,000 of those acres within Florida Forever projects, as well as 26,000 acres of wetlands; approximately 1.7 million acres of private land is included in the moderate connectivity option, with approximately 500,000 of those acres within Florida Forever projects, as well as 400,000 acres of wetlands; and approximately 3.9 million acres of private land is included in the high connectivity option, with approximately 700,000 of those acres within Florida Forever projects, as well as 900,000 acres of wetlands.

Assuming that all potential habitat is suitable habitat and that individual animals can move freely through the corridor network, which as noted above is unreasonable, we made crude estimates of potential population sizes for the three focal species under the three connectivity options. To partially correct for biases, we provided population estimates based on the unrealistic assumption that all potential habitat is suitable and compared these with estimates based on an assumption that only 75% (for panthers and bears) or 50% (for fox squirrels) of the potential habitat in each connectivity option is suitable. Although these percentage estimates are arbitrary, they are likely more realistic than estimates based on the assumption that all potential habitat is suitable. Applying the moderate connectivity option, the 75% suitable habitat assumption, and population densities obtained from a study in Ocala National Forest, for example, the study region could support 1582 to 2331 bears. Under the same option and 75% suitable habitat assumption, and using population densities calculated by Maehr et al. (1991), the study region could support 65 to 89 panthers. And under the same option, a 50% suitable habitat assumption, and density estimates from two studies of fox squirrels, the study region could support 4,609 to 13,829 fox squirrels. Nevertheless, these revised estimates are still highly optimistic, especially so for the fox squirrel, for which, as noted earlier and is discussed further below, so little of the potential habitat is suitable today due to inappropriate management.

Especially for habitat specialist species such as the fox squirrel, protection of large habitat blocks and connections among blocks is not enough to assure persistence. Ecological management to maintain suitable habitat – both within Babcock Ranch and within other existing and potential conservation areas within the study region – is essential to assure population viability. Fox squirrels are associated primarily with open, mature pinelands, but also are found in open cypress stands and in oak hammocks, bottomland hardwood areas, and tropical hardwood hammocks. As noted, the squirrels make high use of ecotones between hammocks and pine savannas (Weigl et al. 1989, Kantola and Humphrey 1990). The seeds of longleaf pine and slash pine, as well as acorns from oaks, are the staple food items for fox squirrels in Florida (Wooding 1997). Pine seeds are often more dependable than acorns from oaks, which sometimes (e.g., for turkey oak) are available only in occasional mast years (Kantola and Humphrey 1990). On the other hand, acorns are more storable (although not highly so) than pine seeds, which are available for only about 4 months of the year and do not store well (Wooding 1997). Squirrels eat many other food items, but probably do not depend on them to the extent that they depend on pine seeds and acorns (Koprowski 1994, Kantola and Humphrey 1990). A scarcity of suitable, storable food in

large quantities may explain the low densities of fox squirrels in the southeastern coastal plain compared to the Midwest (Wooding 1997). One common, potentially important and interesting food item is fungi. It appears likely that the fox squirrel serves as a keystone species by consuming and dispersing the spores of hypogeous mycorrrhizal fungi, which develop symbiotic relationships with the roots of pines and other trees. Pines may depend on this symbiosis to obtain essential soil nutrients and water (Weigl et al. 1989, Earley 2004).

Probably the most frequently cited habitat feature essential for southeastern fox squirrels is an open understory, which under natural conditions is usually maintained by frequent, low-severity fires during the early growing season and are typical of pine savanna ecosystems (Kiltie 1989, Wooding 1997, Earley 2004). Brown (1978) observed that "complete fire protection in pine woodlands has resulted in the growth of dense understory vegetation which is not suitable as fox squirrel habitat." Ironically, because of past fire exclusion, many conservation areas that once were excellent habitat now have few fox squirrels. Extensive surveys for Big Cypress fox squirrels in the Big Cypress National Preserve and other natural areas yielded few fox squirrels (Jodice and Humphrey 1992, Ditgen et al. 2007, Eisenberg et al. in review). Instead, the squirrels are mostly found today in residential areas, golf courses, and pastures with artificially maintained open understories. Importantly, however, these anthropogenic habitats will not remain suitable for fox squirrels indefinitely due to lack of recruitment of new pines and oaks to the overstory (Wooding 1997, Eisenberg et al. in review). When the present overstory trees die, these habitats will no longer be suitable for fox squirrels.

Besides fire exclusion, another problem that makes many natural areas unsuitable for fox squirrels is a history of management burning during the dormant season rather than during the growing season, when virtually all lightning-ignited fires occur. Fires during the dormant season favor dense saw palmetto and other shrubs (Tanner et al. 1999), which repel fox squirrels, presumably because the squirrels favor open understories in order to travel quickly between trees and remain vigilant for predators. In areas of Babcock Ranch where the flatwoods have developed dense palmetto understories due to a history of fire exclusion or winter burning, restoration will be needed to restore the open understory conditions essential for fox squirrels. A return to a natural growing season fire regime often will not suffice to restore understory quality. Instead, studies (primarily in dry prairie) show that a mix of roller chopping and fire works better to reduce palmetto and other shrub cover, and allow recovery of essential warm-season grasses and native forbs, than either practice alone (Watts et al. 2006). On the other hand, heavy treatment to maintain and open understory, to the extent that oaks and other hardwoods are strongly diminished, could be harmful to fox squirrels. Perkins et al. (2008) observed that the highest quality habitat for Sherman's fox squirrel is comprised of 88.2% mature pine savanna to 11.8% hardwood cover. These authors expressed concern that the restoration and management model for longleaf pine savannas is almost exclusively longleaf in the overstory and midstory with virtually no hardwoods, a condition that is far from optimal for fox squirrels.

Unfortunately, suitable habitat for fox squirrels is difficult to model because their presence and abundance are closely tied to habitat structural and compositional features, as described above, that are essentially impossible to evaluate accurately from aerial photographs, satellite imagery, or available GIS maps of land use and land cover. Existing habitat models, including the one produced in this study (See Figs. 11 and 12) necessarily carry the assumption that primary, secondary, and matrix habitat are not necessarily in suitable condition that today, but might

become suitable if restored and managed in such a way as to maintain the large pines, hardwoods, and open understory essential to fox squirrels.

To summarize, we conclude that the moderate connectivity option, especially when augmented by the integrated habitat network focused on riparian areas, would provide a reasonably high probability of protecting the Florida panther, Florida black bear, and Sherman's and Big Cypress Fox Squirrel within the study region including and surrounding Babcock Ranch. This hypothesis should be tested through further field research and modeling (especially spatially explicit population modeling for the focal species), but provides a good working hypothesis for planning. Our recommendations for implementing this option and serving the broader goal of maintaining biodiversity include:

- Seek increased land acquisition and conservation easements in high-priority areas identified through this study and through other credible science-based planning.
- Corridors should be as wide as feasible. Although corridor design questions such as width, width to length ratio, and optimal structure are landscape- and species-specific issues that should be investigated empirically, in the absence of case-specific data we suggest that, at the landscape scale, corridors at least 3 times the width of edge effects (which commonly extend 100 m) should be protected. At the regional scale (> ca. 10 miles long) corridors should average 1 mile wide, and that a 1 to 10 rule for width to distance should be applied as distance increases.
- Multiple corridors (networks) and other pathways for animal movement are preferred over single corridors between core areas.
- Planners should use the best available science for "conservation development" through the Rural Land Stewardship program or other programs. Mitigation banking sites should be selected through defensible conservation prioritization methods and managed to maintain habitat for focal species and communities.
- Further empirical study is needed to determine hotspots of wildlife mortality on roads in the region, and to determine where and how to construct wildlife crossings, barrier fencing, and other options such as wildlife movement detectors to reduce roadkill.
- Habitat within core areas (i.e., conservation areas) and corridors should be actively managed to maintain required habitat structure for the focal species of interest. For animals such as fox squirrels, which depend on open habitats with minimal understory, frequent fire during the early growing season (April-June) at intervals of 2-3 years is optimal. If habitats have gone a long time without fire or with dormant season burning only, mechanical treatments such as roller chopping, in addition to fire, may be necessary to reduce palmetto or other shrub cover.
- Due to threats related to human population growth, development, and sea-level rise within the study region, there is some urgency in implementing the conservation actions suggested here.

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