



Considering Climate Change in Florida's Wildlife Action Planning

A Spatial Resilience Planning Approach



FINAL REPORT

**Considering Climate Change in Florida's State Wildlife Action Planning:
A Spatial Resilience Planning Approach**

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ABSTRACT

Adjusting state wildlife action planning mechanisms to account for climate change is important to Florida's state wildlife managers because even under moderate climate change projections the state is likely to be among the first in the nation to experience significant wildlife impacts. This study was a pilot of a new method which we call "spatial resilience planning" or SRP. This is an extension of more general spatial scenario, approaches, organized specifically for the case of climate change wildlife adaptation planning. We began with 5 "alternative futures" developed by a prior MIT/USGS/FWS research project. They scenarios varied across four dimensions: climate change, human population change, land & water planning policies, and availability of public resources. Each alternative future took the form of a potential land use map, simulating climate and land cover change 50 years into the future at three time steps (2010, 2040 & 2060). Some scenarios reflected only minor differences from existing conditions while others simulated very substantial changes. We then selected a set of species to test the approach. These included the American Crocodile (*Crocodylus acutus*), Key Deer (*Odocoileus virginianus clavium*), Least Tern (*Sternula antillarum*), Atlantic Salt Marsh Snake (*Nerodia clarkii taeniata*), Short-Tailed Hawk (*Buteo brachyurus*), and Florida Panther (*Puma concolor coryi*).

To conduct SRP, we first used a spatial overlay modeling process to identify and map areas of potential habitat loss or gain under each scenario. Next, we summarized common impact patterns based on current land use and land tenure. Working with species and land management experts, we used the results of this spatial vulnerability assessment to inform the identification and location of a series of potential wildlife adaptation management actions. We found that impacts were potentially significant for all of the species considered, although the extent of vulnerability varied widely. The less-vulnerable species were the Florida Panther and the Short-Tailed Hawk, each with under 15% of total habitat at risk. The most vulnerable were the American Crocodile and the Key Deer. Each of the later lost from one third to nearly all of their habitat, depending on the scenario. An unexpected but potentially significant finding was that species conservation situations and recommended management actions tended to cluster into one of three groups defined not by ecological or geographic concerns, but rather by the intersection of these with common management contexts. In cases where appropriate supporting data are available, spatial resilience planning shows potential for providing much more specific and actionable information than conventional wildlife climate action planning methods.

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PENDING CROSSTAB OF SPREADSHEETS FROM JAY LILES

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Executive Summary

Adjusting state wildlife action planning mechanisms to account for climate change is important to Florida's state wildlife managers because the state is likely to be among the first in the nation to experience significant impacts. Spanning tropical and subtropical climate zones, and featuring low-elevation topography with impervious bedrock, there is no question but that the state is vulnerable to even relatively modest climate changes. Even though some of these changes are long term, they affect many current management actions, notably including cooperative conservation efforts, land acquisition and monitoring.

This study was a pilot of one potential approach, which we call "spatial resilience planning" or SRP. The premise of this method is that because climate change is both spatially variant and subject to scientific uncertainties, it should be approached using a special form of planning known as spatial scenario planning. This method has a long history of application in domains where critical decisions must be made under high uncertainty – it was originally developed for military planning applications during the cold war. By simulating what might occur under a wide range of possibilities, strategies can be developed which are robust in the face of exogenous or difficult to predict shocks. This also allows separating out management actions which are needed only under particular contingencies, and which are "no regrets" – useful across a wide range of scenarios.

We undertook to develop and test an application of this method working directly with two critical audiences: wildlife experts who are familiar with details of species ecology, and managers responsible for conservation lands and waters more generally. In consultation with FWC, we selected six species representing a wide range of habitat associations and life history characteristics. We used a facilitated expert workshop approach with heavy technological support in the form of simulation modeling within Geographic Information Systems (GIS). The motivation for this approach was to rapidly and efficiently test the basic steps required, and to do so across a reasonably diverse set of conditions. We understood at the outset that FWC is ultimately responsible

for hundreds to thousands of species, and so any method developed must be scalable in order to be effective. Thus our focus was not on creating optimized methods for the six species selected within this pilot, but rather to use the species selected to test the proposed method across a range of conditions.

This study heavily leveraged prior scenario planning work sponsored by USGS and FWS and developed by MIT (Vargas and Flaxman, 2011; Flaxman and Vargas 2011). Those efforts produced a set of 24 spatial scenarios for the Southernmost 30 counties of the state. The scenarios each look 50 years into the future and simulate various socioeconomic and biophysical changes. They are organized along four dimensions: climate change, human population change, land & water planning policies, and availability of public resources. From the broad set of 24, we selected scenarios which represented plausible extremes along several dimensions, and 1 which represented more moderate “plan / trend” assumptions.

A second major type of input used was species habitat maps and underlying habitat suitability models provided by FWC and consulting experts (FWC 2011). From a set of approximately 68 available HSI models, we selected 6. These included the American Crocodile (*Crocodylus acutus*), Key Deer (*Odocoileus virginianus clavium*), Atlantic Salt Marsh Snake (*Nerodia clarkii taeniata*), Short-Tailed Hawk (*Buteo brachyurus*), and Florida Panther (*Puma concolor coryi*). These models were spatially-explicit estimates of current habitats, reflecting historic to current climate conditions. They were originally built using a combination of species occurrence observations and habitat association rules. For example, the model for the short-tailed hawk was based on the presence of wooded wetlands within a fixed distance of known species occurrences. For the Least Tern (*Sternula antillarum*), no prior wildlife habitat suitability model was available, so a proxy was created based on available data provided by participating experts.

The basic analytic technique used was “Spatial Exposure Vulnerability Analysis” (SEVA). This was implemented in this case using spatial overlay analysis,

namely the combination of a scenario and a species habitat map. This overlay process was conducted 5 times for each species, giving a range of potential “impact” maps (one time for each scenario). In the first of two workshops, we reviewed the input data and initial overlay impact models. Based on expert comments and subject to the limitations of available data, we then revised each impact assessment as necessary so as to more accurately reflect expert opinions about habitat changes within each scenario. The substantive details of these assessments can be found in this report. In terms of planning process, we came to three conclusions. (A) there was substantial variation in the quality of the existing wildlife habitat models, in some cases a reflection of prior data availability and modeling efforts and in others related to species-specific life history characteristics; (B) despite these variations, participating experts found the spatial planning exercise to be a useful method for assessments; and (C) that climate-sensitive vegetation change simulation modeling was agreed to be the most important and commonly missing element.

After some weeks of spatial analysis refinement and processing, a second workshop was conducted. This workshop concentrated on management actions. It included most of the same species experts as the first workshop, but in addition a number of land and wildlife managers were invited. In this session, we reviewed the revised models, and then in partnership with Defenders of Wildlife performed a “conceptual modeling” exercise focused on the development of species management actions appropriate under climate change. A final session concentrated on potential spatial planning options for each species. Using “geodesign” techniques, participants “sketched” various potential management actions on top of base or impact maps under different scenarios. In this way, we were able to identify not only which actions might be required, but also “where” and to some extent “how much.”

We came to several general conclusions. The first is that while a plethora of species exist within the region, species responses and management options in Florida appeared to cluster into three common groups based on the intersection of species life history characteristics and management contexts. First were a set of species with narrow habitat ranges whose habitat is under severe threat from sea level rise, urbanization, or the combination of both. Second were a set of species persisting mostly within Florida’s extensive large conservation areas, such as Everglades National Park. These species are also potentially impacted by climate change, and particularly by sea level rise, but there is room for active habitat management and upslope migration. Third were a set of species whose remaining habitat is reliant on private lands.

Many of these have very large habitat range, and the impacts of climate change on them are less certain than those coming from continued rural residential development.

Management options for these different groups of species were often constrained by management contexts as much as by species biology. For example, in managing narrow-ranging endemic species, preserving remaining potential “climate corridors” is one of the few available options short of translocation.

We found that our prototype methods worked relatively well when appropriate prior data and disaggregate habitat model components were available, but were significantly less useful for species with major variations in habitat quality, seasonality, or life stage habitat requirements. In those cases, we found that active “geodesign” methods such as having experts sketch primary, secondary and tertiary habitat zones were an adequate short-term substitute for more formal modeling. They also provide to the experts visualizations in how, where and when to apply management actions into each of these contexts. The major limitations of our approach were (1) the lack of availability of consistent habitat succession modeling, followed by (2) the lack of freshwater hydrological modeling for some species and (3) the failure of the scenarios to be explicit about fire, storm surge, hurricane frequency and other disturbance regimes.

A resilience planning system could be developed to consider a much larger and broader range of species. However, we would recommend attention to the data and modeling limitations described above either before or within such a process. For example, it would be generally useful to embed vegetation succession and disturbance modeling within spatial scenarios before repeating such an exercise, since this would allow experts to make quicker and higher confidence estimates of scenario impacts on species. Finally, since much of the cost of such efforts is in the logistics of repeated in-person meetings, we would recommend experiments in which modern screen-sharing and GIS server and remote technologies are used to conduct preliminary spatial impact analyses using webinars or similar formats. This could allow initial vetting and refinement of spatial datasets to take place well before in-person meetings, and would allow those meetings to concentrate more efficiently on planning rather than analysis activities.

How to Use this Document

This document can be read in two very different ways, depending on the reader's interest and responsibilities. At one level, it assesses 6 individual species, their susceptibility to climate change, and current expert opinion on how wildlife action planning might adapt to related threats and opportunities. At a more strategic level, it represents an example of a new conceptual and technical approach, spatial resilience planning. This concept is generalizable far beyond the individual species selected for the pilot, and must be adjusted for local circumstance and assessed relative to current practice and alternative methods.

For those primarily interested in particular species, the following sequence is recommended:

- 1) Review "Executive Summary" (pages 6-11)
- 2) Scan MIT Scenario Generation Process (Section 2.5, page 19) to understand basic drivers simulated.
- 3) Jump to vulnerability analysis for species of interest (In section 3....)
- 4) Determine the "contextual group" assigned to the species
- 5) Review the expert adaptation findings for that species and its "contextual group"

For those interested in adapting or extending this approach for other areas, a different approach is recommended. This is essentially to read the report in sequence, but to scan or skip over the species detail sections.

Replicating the SRP Approach

In order to replicate the SRP approach, the following general steps are required:

- 1) An appropriate management group must be assembled. This can vary in size and composition, but must include those managers who will be charged with implementation of adaptation actions. This is a general “best practice” to ensure management relevance, and to avoid expending resources to develop an unrealistic or unimplementable plan.
- 2) A set of conceptual scenarios must be generated. These must reflect not only a range of biophysical changes, such as sea level rise, but also a range of local or regional human and management responses. Note that merely down-scaling IPCC or other global scenarios does not meet this test, since these scenarios do not consider local or regional actions.
- 3) Scenarios must be simulated in the form of future land use / land cover. The specific details of the simulation methods used can vary, but at the very least the simulations should consider expected human settlement patterns which are legal under current land use policies and likely based on demographic trends.
- 4) A scoping process should be used to select a subset of species or habitats of greatest interest. Under most imaginable regional scale circumstances, it is not practical to consider all possible species and habitats, so intellectual effort and research is required to develop a defensible subset. Various criteria may be used, including taxonomic diversity, geographic diversity, or species-level vulnerability assessments.
- 5) Spatially-explicit wildlife habitat suitability models must be obtained or generated for selected species. In some cases, these will have previously been created for other purposes; in others they will need to be developed specifically for the project.

6) A pairwise “spatially-explicit vulnerability analysis” (SEVA) process should be conducted considering each species under each scenario. This is the area with the widest range of possible implementation methods. This pilot study relied on one of the simplest and most general methods – spatial overlay. In practice, more sophisticated methods and models can be deployed as warranted. These could, for example, include a full population viability assessment (PVA) for each species.

7) SEVAs should be logically aggregated, in preparation for adaptation planning. Pairwise species/scenario SEVAs by their very nature generate an enormous amount of information. While it is theoretically possible to conduct independent adaptation planning for each species under each scenario, this is not typically desirable. This pilot study developed and introduces the concept of common climate management context types. These should be reviewed for any specific geography, but it is likely that the following are a robust set:

a. “Surrounded on all sides” – Use SEVAs to identify species which are geographically isolated, either by natural barriers such as ocean or elevation, or by anthropomorphic barriers such as cities and transportation corridors. Consider management actions which maintain population viability by restoring/improving existing habitat quality and connectivity. If that is not feasible, habitat creation and translocation are perhaps the only remaining options, so monitoring and research supporting these relatively drastic and difficult management actions are likely highest priorities.

b. “Room to move” – Conversely, use SEVA to identify species which appear to have management and ownership patterns allowing potential habitat range shifts. These species may or may not have the biological means to affect such shifts unaided, but they at least have that possibility. Consider management actions which put into place monitoring along the expected climate gradient, and research on methods for assisting habitat migration and re-establishment. Where necessary, put in place ownership and management agreements which maintain “climate corridors” at least by avoiding irreversible habitat destruction or type conversions in such areas.

c. “Dealing with the Neighbors” – For wide-ranging species, or species with significant portions of their habitat on private lands, rather different climate management actions are required. In particular, fee-

simple acquisition of necessary habitat to maintain viable populations entirely on public lands is likely to be politically and financially infeasible. Sensible strategies in such cases involve very intensive public education and outreach efforts, as well as conservation easements and payment for ecosystem services schemes. In order to be widely accepted and viable, such management actions require widespread public consultation and public/private partnerships.

8) Adaptation Plan GeoDesign. A small groups of experts should be assembled and asked to perform initial spatially-explicit adaptation planning. These experts should include those biologists most familiar with the species of concern, and those land and program managers most familiar with management issues under discussion. We recommend a two-pass approach similar to that taken here, in which actions are first identified systematically in a jointly-created conceptual diagram, and then “placed on the land” in a design exercise creating “adaptation management action scenarios”.

The end results of spatial resilience planning will vary by location, but will likely fall under the heading of management recommendations. The results should not be mistaken for an official land use plan or planning exercise, since these methods and process do not meet such requirements. Instead, they are a mechanism for rapidly exploring and explaining potential management actions in a geographically-realistic context.

The best ideas from such early phase planning should indeed be submitted to further scrutiny within conventional planning systems, existing management procedures, or science research funding and review systems. But climate change adaptation planning represents a unique new area, and it is important to protect opportunities for early idea generation and testing which are not immediately judged only relative to existing formal mechanisms and institutions. After all, these rules and procedures were mostly designed in a pre-climate change era, and may themselves require reconsideration relative to new challenges and opportunities.

The SRP method, while new in detail and as applied to climate change, reflects methods and strategies which have proven effective in a variety of high-change, high-consequence arenas. Thus, in adapting the approach to new areas, the user is advised to explore the broader literature on scenario planning or its more specific applications in ecologically-oriented landscape planning (for references on either, please see literature review below).

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1.0 Introduction

Wildlife Action Plans have always considered the potential of a wide range of stressors to impact species and their habitats (FWC 2011). However given its magnitude and the uncertainties associated with it, climate change presents one of the most complex challenges to conservation planning. Climate change has the potential to directly and deeply alter species habitat and species to species relationships. Because of differential effects on species, including important phenological shifts, climate change is likely to have a range of interacting and difficult-to-predict effects. Compounding this challenge, climate change will also have major effects on human behaviors. In coupled human-natural systems, this will generate major second-order impacts on wildlife, as urbanization, demographic and resource-use patterns change.

This report presents the results of a study developed at the Massachusetts Institute of Technology whose goal was to prototype a spatial vulnerability and adaptation analysis method for a variety of taxa present in the state of Florida. The study combined two approaches. The first was to assess the spatial impacts of climate change on wildlife habitats using alternative future scenarios. The second was to identify adaptation and management mechanisms to respond to those impacts, reducing species vulnerability. We began with a small but diverse set of species representing a range of terrestrial vertebrates. In addition to the species and scenarios considered within this pilot, the state of Florida also has a strong interest in developing methods which are potentially scalable to planning for all of the species and habitats of the state. Thus the approach we developed was explicitly designed so as to be replicable to a much larger set of species in future implementations.

In order to accomplish these goals, the study leverages a large body of pre-existing MIT research which generated a set of comprehensive “alternative futures” for South Central Florida. In addition to considering scenario simulation outputs, this process also benefitted from a second type of information – a set of species-centric climate vulnerability indices and conceptual habitat models produced by the Defenders of Wildlife. These used the Nature Serve Climate Change Vulnerability Index (CCVI) process. These two processes are very complementary. The CCVI develops and organizes species-level exper-

tise, but ignores species habitat arrangement and other management factors such as competing land uses. The MIT scenarios provide “future land use” maps under a wide variety of climate, population and policy contexts, but do not discuss impacts.

The basic method proposed by this study combines these two inputs using a two-step process: “exposure assessment” followed by “geodesign.” The exposure assessment phase identifies the impacts of scenarios on species habitats using spatial overlay modeling within a geographic information system (GIS). The geodesign phase engages habitat managers and species experts in a systematic investigation of potential adaptation strategies. In contrast to non-spatial approaches, this is done “to scale” and “in place” based on the combination of impacts and management contexts

The results from this study indicate the locations, and extents of the impacts associated with climate and urban change. They also support investigation of the relative impacts of each of these drivers, and how they vary across space and time. In addition to these species-level assessments, the study identifies some broader emerging patterns which raise important strategic considerations for the Action Plan.

Lastly, while the study has proven effective and robust in identifying the nature, extent and timing of the impacts associated with climate and land use change, it has also highlighted some limitations of currently available data and scientific knowledge. While a number of these are species-specific, most are actually more general, and this allows us to develop some specific recommendations for the next steps required to improve the quality and scalability of future efforts.

2.0 Background

2.1 Species Vulnerability to Joint Climate and Urban Change

Florida's Landscape is one of the most rapidly changing and climate-vulnerable regions in the U.S. Its low elevation, geographic location and configuration makes it very susceptible to sea level rise and severe events. Its fragile subtropical ecosystems are very sensitive to temperature and precipitation fluctuations. At the same time, the population of the Florida Peninsula is expected to increase by 13.5 million inhabitants over the next 50 years, requiring as much as 1.7 million acres for urban land use (Vargas-Moreno & Flaxman, 2010). This demand will create unprecedented landscape changes which will trigger additional impacts to natural systems. Therefore, it is our contention that both climate change and population dynamics should be considered in an integrated fashion when considering species vulnerabilities. We review here briefly the scientific basis for this approach.

To start with, it has long been recognized that climate in general is a major determinant of the distribution, abundance, and behavior of organisms. For this reason, climatic change is likely to trigger responses in these ecosystem attributes. Indeed, recent rapid climate change is already affecting a wide variety of organisms (Edwards and Richardson, 2004; Parmesan, 1996). Climate changes over the past half-century have been shown to impact the physiology, distribution, and phenology of a variety of species, as consistent with theoretical predictions (Hughes, 2000).

Projected changes under various climate change scenarios will cause a variety of problems to conservation efforts depending on scale (Vos, Berry et al. 2008) and the rate of change (Thomas, Cameron et al. 2004). Habitats will change and species will have to migrate to new "climate spaces" – if available (Pearson, Dawson et al. 2002). Critically, this availability is a function not only of new climate spaces alone, but of the combination of climate with other required factors. For example, Lee and colleague (2005) found that climate-induced tree migration was constrained by soil substrate. Florida's Pine Rocklands ecosystem important to the Key Deer is likely analogous: it is composed

of one element which could likely move over time (Pine) and another which is a function of geological history not subject to easy translocation (Rocklands). This example is purposefully simple. However, it is important to recognize that species persistence under climate change is complex, and subject to many variables and relationships which are well beyond current scientific understanding.

Finally, for effective habitat migration to occur, not only must all functionally-required elements be mobile, but also there must be landscape connectivity between current and future habitats. This later requirement is the basic motivation for a spatially-explicit planning approach. For planning purposes, it is not enough to know that a particular amount of potential habitat exists within a projected future climate zone. Wildlife planners need to know that the spatial relationship between current subpopulations and future potential habitat relative to climate gradients.

A vulnerability assessment method which ignores the spatial distribution of species subpopulations cannot assess landscape ecology related vulnerability, such as pockets of otherwise viable habitat isolated or fragmented by highways and urban development. Iverson et al. (2010) summarize their 16 years of experience in species distribution modeling under climate change by emphasizing the need to move from models of “potential habitat” to “consider dispersal and land use to arrive at ‘potentially colonizable’ habitat.”

For these reasons, our argument is that climate change should not be studied in isolation, since there is every reason to believe that combinatorial effects with land use change will be significant. Fortunately, the methods developed here support cumulative impact assessments, and do so in a manner which does not require wildlife managers to become urban growth modeling experts or climatologists. We can use map overlay techniques to leverage independently-conducted work in those two fields, allowing wildlife planners to concentrate on the task at hand, while simultaneously being well informed about the joint effects of these common and major drivers.

2.2 Climate Change and Species Distributions

There are two general spatial approaches to climate change impact assessment. The first is to work at the scale of species ranges, and to focus on changes in boundary conditions (Erasmus et al., 2002; Huntley et al., 1995; Peterson et al., 2002 and Thuiller, 2004). This is known as “climate envelope” modeling. It works best for species which have well-characterized climate-related limits to their distributions, for example those tied to tropical habitats intolerant of frost.

The second major approach is to focus on habitat quantity, quality and configuration at a more finer grain, which we would call a “landscape ecology” approach (Gottfried, 1995, Guisan and Theurillat, 2000). Iverson (2010) argues persuasively for this approach, given the availability of appropriate supporting data. Ideally, systematic abundance sampling data is required rather than simple presence/absence, or more common presence-only data. The statistical and modeling advantage is that it becomes possible to gather information and build statistical regression descriptions based on the most important habitat areas, with less statistical influence from near-boundary conditions. In those cases where the approaches can be compared, the landscape ecology approach is quantifiably better performing. However, such data are not systematically collected for the species of greatest conservation interest in Florida.

Rather than characterizing the differences in terms of data availability, it is perhaps more useful to consider them in terms of scale and grain of data. These distinctions have been well characterized in the literature by Opdam & Wascher (2004). They developed a conceptual model which makes the point that key interactions occur at two scales. At biogeographic scales, climatic factors are well known to limit species ranges, either directly through biological sensitivities or indirectly through impacts on habitat and intraspecific competitive advantage. Meanwhile, at landscape scales, species metapopulation theory indicates that the availability and organization of habitat can influence species viability. In a habitat-constrained, climate-changing world, these two scales interact. As Opdam & Wascher put it “the response chain from climate change to distribution pattern is mediated by landscape cohesion. (idib)”

In this context, earlier work by Iverson and Prasad (1998) with better data availability came to similar recommendations. They used regression tree modeling techniques to predict future vegetation ranges under various climate change scenarios, concluding that “given these potential future distri-

butions, actual species redistributions will be controlled by migration rates possible through fragmented landscapes.” (emphasis ours).

Finally, recent work in a very different region re-affirms the potential importance of climate-land use interactions at landscape scales. Working in the Andes (Feeley & Silman 2009) predicted the distributional responses of hundreds of plant species to changes in temperature incorporating population density distributions, migration rates, and patterns of human land use. In this landscape, they found an “overriding influence of land-use on the predicted responses of Andean species to climate change” (ibid.).

While this work validates and emphasizes the potential importance of landscape-scale factors, there are of course numerous studies which consider how individual species life history characteristics may affect particular species under climate change. Numerous examples for Florida can be found in the companion study conducted by Defenders of Wildlife (DuBois 2011).

Besides these ecological factors, we must also stress that climate adaptation or mitigation mechanisms taken by humans might well have significant negative biodiversity impacts. In the Florida context specifically, many climate-related risks are clustered along the coasts, which have disproportional population density. Even relatively small shifts in human “habitat preference” toward inland areas could have significant wildlife effects. In addition, behavioral and physical changes along the coasts are likely. Of particular relevance are studies which investigate the impacts of existing mechanisms for coastal “armoring.” This is a potentially likely response in certain parts of Florida, although its utility is severely limited in many cases by very pervious limestone geology. (In such areas, measures such as installing rip-wrap can be somewhat effective in mitigating storm surge, but not base tidal inundation.)

An example of the known effects, based on a paired “natural experiments” method, show significant effects on shorebirds (2x less species richness and 3x less abundance on armored segments) (Dugan 2008). Birds which use beaches primarily for roosting showed even stronger effects (ranging from 4x to 7x reductions on armored segments)(ibid.). Clearly, there is room for concern that single-purpose adaptation mechanisms designed to protect property could have significant inadvertent impacts on wildlife. While specific results are likely to vary highly dependent on local context, the combination of climate change and land use change are pervasive enough to merit the development of a consistent set of analysis methods which consider these factors jointly.

2.3 NatureServe Climate Change Vulnerability Index

(Portions Contributed by Natalie, Dubois, Defenders of Wildlife)

As a parallel coordinated process to the SRP, FWC also commissioned the Defenders of Wildlife to conduct a second and complementary vulnerability assessment approach. The approach, known as the Climate Change Vulnerability Index, or CCVI is described here so that it can conveniently be compared and contrasted with SRP. For a more detailed description of the CCVI process results for Florida, please see Dubois 2011.

Background and key characteristics of vulnerability assessments

Vulnerability of a conservation target (e.g. species, habitat, ecosystem) to climate change is a product of exposure to climate change (the magnitude, intensity and duration of the climate changes experienced), the sensitivity of the target to these changes, and the capacity to adapt to these changes. Vulnerability assessments provide the scientific basis for developing adaptation strategies by combining future climate scenarios with ecological information about climate sensitivity and adaptive capacity of conservation targets. The relative vulnerability of a species, habitat or other conservation target can then be used to set goals, determine management priorities and inform design of appropriate adaptation strategies.

IUCN biological traits that make species more vulnerable to climate change:

1. Specialized habitat and/or microhabitat requirements. The vulnerability associated with high habitat specialization is compounded when a species has several life stages, each with different specialized habitat or microhabitat.
2. Narrow environmental tolerances or thresholds that are likely to be exceeded under climate change
3. Dependence on species environmental triggers or cues that are likely to be disrupted by climate change (phenology, e.g. rainfall or temp. cues for migration, breeding or hibernation).
4. Dependence on interactions between species that are likely to be disrupted
5. Inability or poor ability to disperse quickly or to colonize a new, more suitable range.

The NatureServe Climate Change Vulnerability Index (CCVI) is an Excel-based tool that uses readily available natural history, distribution, and management information to provide a relative assessment of species vulnerability in relation to climate change. The CCVI assigns scores based on a species' predicted exposure to climate change within its range and the following factors associated with vulnerability to climate change: 1) indirect exposure to

climate change, 2) species-specific factors that determine sensitivity (e.g. dispersal ability, physiological constraints, physical habitat specificity, interspecific interactions, and genetic factors) and 3) species’ documented response to climate change (when available). “Indirect climate change exposure” includes exposure to sea level rise, predicted impact of land use changes from mitigation activities, species distribution relative to natural topographic or geographic habitat barriers, and distribution relative to anthropogenic barriers such as urban sprawl. Using a combined score based on this information, the CCVI classifies each species on a scale of vulnerability: Extremely Vulnerable / Highly Vulnerable / Moderately Vulnerable / Not Vulnerable—Presumed Stable / Not Vulnerable—Increase Likely / Insufficient Evidence. The CCVI indicates both relative vulnerability and the relative importance of factors contributing to that vulnerability. This information allows managers to group species based on similar drivers of vulnerability and potential management needs, reducing the complexity of managing large numbers of species under climate change. As with any vulnerability assessment, the CCVI can help inform priorities for conservation action, but the assessment alone does not identify priorities or management strategies, nor will it provide an estimate of extinction risk in response to climate change. The CCVI requires knowledge about the current distribution and natural history of the species being assessed, as well as use of GIS, TNC’s Climate Wizard and other readily available online data and tools.

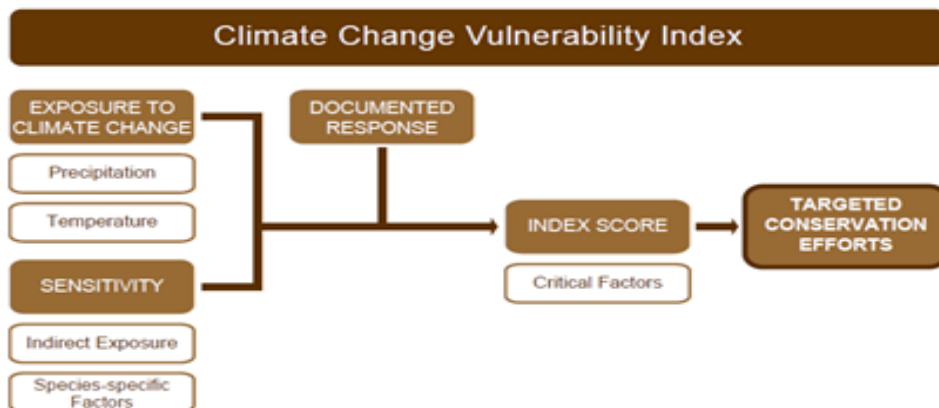


Figure 1: Climate Change Vulnerability Index

Stakeholder and expert workshops

Although the CCVI can be populated by an individual expert, the Defenders of Wildlife and FWC chose instead to develop a facilitated approach with a group of experts. This allows a more a transparent process in achieving consensus, can reduce uncertainty and should improve repeatability. The Defender’s process was conducted in parallel with the MIT SRP process, considering a larger number of species, and using a superset of the same experts.

2.4 Climate Change and the Need for Scenario-based Conservation Planning

Recent scientific studies confirm that climate change is occurring, but still provide wide-ranging estimates of its likely impacts. Most researchers agree on the major mechanism at work: rising concentrations of Greenhouse Gases (GHG), and on the causes of these emissions (largely burning of fossil fuels and of forests)(IPCC 2007). There is also agreement that we have reached a point of no return, in that historic and current GHG emissions guarantee continued climate change even were world policy and development practices to shift abruptly (Easterling 2004). A recent report commissioned by the U.S. Congress from the National Academy of Sciences' National Research Council concludes:

“Aggressive emissions reductions would reduce the need for adaptation, but not eliminate it. Climate change is already happening, and additional changes can be expected for all plausible scenarios of future greenhouse gas emissions.” (NRC 2011)

Considering these factors jointly, it is apparent that conservation planning must as a matter of due diligence incorporate some form of climate change planning. However, the specific formulations required remain contested.

Most traditional conservation planning methods are based either on assumptions of climate stationarity (no change), or a single “plan/trend” model of the future (for example, continue urban growth at historic rates). Most of the wildlife habitat suitability modeling efforts to date were originally calibrated against recent historic species occurrence distributions. A fundamental management challenge is that such assumptions are often implicit, and that robust methodological alternatives can be difficult and time-consuming to develop, as well as hard to generalize. We review some of the core scientific work in the next section. However, first we must consider the issue of developing conservation plans in an era in which climate change is already known to be a significant issue, but one whose extent, magnitude and timing remain uncertain.

For decisions which can safely be put off into the future, one strategy would be to simply wait until uncertainty is reduced by normal scientific processes. However, current indications are that such an approach may involve waiting a very long time. Unfortunately for those tasked with protecting our essential wildlife resources, the domain of conservation planning rarely has this option.

Many conservation decisions involve irreversible decisions and extended time frames. Species extinction is by definition irreversible, as are in practice most major human settlement and infrastructure choices. The only common exceptions to the irreversibility of land use decisions are agricultural, ranching and large-lot private land use stewardship practices compatible with particular species habitat requirements. Where these specific practices exist, a “future option” may sometimes be maintained - but this too generally requires long range planning, for example the purchase of conservation easements.

Mirroring the basic science described above, recent work in conservation planning has concentrated on how shifting habitats and species populations may affect biodiversity conservation (Parmesan 2006, Parmesan and Yohe 2003, Iverson 2008, Iverson 2010, for review: McCarty 2001). However, in our view it is equally important to recognize that ecological stressors are now themselves being altered by climate change. First, there is reason to believe that human populations will adapt and shift in response to climate change (McDonald 2011). Those responses potentially affect not only settlement patterns, but also many other sectors and land uses impacting conservation, for instance including fisheries, agriculture and forestry. Second, as supplies of natural resources such as water become less reliable, ecological systems will likely face additional competition from human consumptive uses (Vörösmarty 2000, Diamond 2005). Third - and more positively - human choices and policies for climate change mitigation provide an opportunity to alter economic, transportation and land use decisions in ways which might much better support conservation.

These are technically second order effects of climate change, and are thus subject to significant propagation uncertainties. This again leads some to adopt a “wait and see” position, attempting to defer such analyses until climate change science is more definitive. We believe that this is fundamental strategic mistake.

Conservation planning is a social process, not simply a matter of technical analysis. New issues and information must be deliberated within a number of public and private decision-making processes before actions can be initiated. The key challenge of conservation planning under climate change is not to come up with single decision based on new information or analysis. The challenge is to develop planning methods and decision-making structures which are able to routinely incorporate uncertainty, changes in science and conflicting human values. While climate science is improving rapidly, human adapta-

tion and political decision-making is integral will remain inherently unpredictable. Therefore, we must develop and test planning methods now which are capable of routinely incorporating new information and which are robust in the face of both scientific and political uncertainty.

It is important to realize that methods do exist for such planning – they are simply uncommon in wildlife action planning. The major step is to move to a “scenario-based” approach which incorporates human behavior and choices into the scenarios. Within the realm of climate change planning, this is a recommended best practice, sanctioned by the National Academy of Science (ibid.) The national scientific leadership, including USGS and USFWS are also on the record as promoting scenario-based planning.

The logical starting point of such efforts is the Intergovernmental Panel on Climate Change (IPCC), which has for more than a decade published and regularly-updated the Special Report on Emissions Scenarios (SRES). The scenarios are plausible combinations of variables consistent with what we know about human-induced climate change. There are 40 different scenarios, each making different assumptions for future greenhouse gas pollution, land-use and other driving forces at global scales. For example, the “B1 scenario” has the following description (IPCC Fourth Assessment Report):

“World more integrated, and more ecologically friendly. Rapid growth, but changes towards a service and information economy. Population rising to 9 billion in 2050.... Reductions in material intensity and the introduction of clean and resource efficient technologies. An emphasis on global solutions to economic, social and environmental stability”

Assumptions about future technological development as well as the future economic development are embedded within each scenario, but there are no major new climate-specific policies simulated. For example, none of the scenarios reflects a carbon tax, or emissions trading schemes. These scenarios are used by a number of large scientific research groups as the input parameters for global circulation models (GCMs). The outputs of most of these models and ensemble averages from multiple models are available in digital GIS data form from NCAR, the National Center for Atmospheric Research (gisclimatechange.org). However, there are three challenges in direct application of these globally-derived models to climate change planning for Florida.

The first issue is technical: GCMs provide only very coarse resolution estimates for future climate anomalies. This is not a problem for sea level rise, which can be computed given a single scalar value. However, it is a problem when considering habitat impacts. Second, model outputs describe raw primary climate variables at a monthly time step. They do not directly predict habitat change, much of which is dependent on vegetative cover. Third, there is an awkward conceptual gap between a global scenario and a statewide or regional one. This can most clearly be illustrated with the issue of human population. There is no necessary or direct relationship between world population trends and Florida population. For example, it is not evident that proportionally-scaling global population growth to Florida's share of world population would lead to a useful estimate.

All of these issues were at least partially resolved during the development of the original MIT scenarios used within this study (Vargas-Moreno and Flaxman, 201). The scenarios described in detail below employ down scaled data from the IPCC scenarios for the region of study, and Florida-specific sea level rise estimates. They use human population estimates from State-level studies, and generally add a range of other local factors, input variables and assumptions that are necessary for wildlife action planning. Notably, they simulate urban land cover change and future conservation acquisitions, both of which are drivers of potentially major importance.



Figure 2. Study Region

2.5 MIT Scenarios for Peninsular Florida*

As discussed above, the long term future is inherently uncertain, not only because of scientific uncertainty, but also because of human decision-making. In order to deal with the associated uncertainties in climate change and human responses to it, MIT worked with USGS and the Federal Fish and Wildlife Service (FWS) to develop a regional scenario process for Southcentral Florida. This work was conducted in period immediately prior to this study and is re-visited here so that readers can understand this component of the overall SRP process.

The initial scenario process had two major phases. In the first, a broad group of conservation stakeholders was organized and conceptual scenarios generated. In the second phase, researchers at MIT simulated each resulting scenario using spatial modeling inside of geographic information systems. The resulting products are in the form of future land use maps at three future time steps (2020, 2040, 2060). These maps are known as “alternative futures” and express a range of possible future conditions under different planning and macro-scale assumptions.

The scenario development process took two years and involved several hundred stakeholders. These scenarios are consonant with IPCC global climate change scenarios, using statistically downscaled models to estimate regional climate change. However they go well beyond climate scenarios, since they incorporate comprehensive modeling of land use change patterns, including the simulation of urban growth as constrained by local rules and policies. The “high climate change” scenarios also go beyond IPCC SRES estimates in terms of sea level rise projections. Our conservation stakeholders were concerned that IPCC had not included a significant body of literature published since 2007 in which the melting of ice sheets appears to be generating significantly higher levels of sea level rise than previously projected. For this reason, they elected to use estimates developed and published by a local climate change expert which reflect this phenomenon.

The Scenario Architecture

The scenarios were constructed based on four main drivers: climate change, shifts in planning approaches and regulations, human population change, and variations in public financial resources. The project integrated the best available scientific information on climate change as of 2010 with local knowledge and expertise. Each Alternative Future visualizes land use patterns and landscape changes such as coastal inundation, urbanization, and infrastruc-

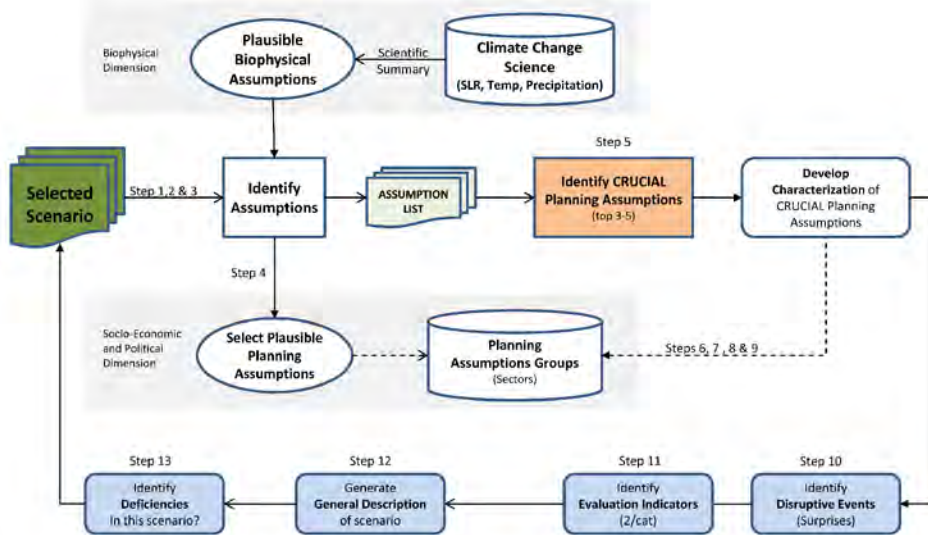


Figure 3: A framework for Assumption-based Climate Change Planning (Vargas-Moreno, J.C., 2010)

ture expansion. Future changes in conservation lands were also modeled and/or designed based on the input from local experts and managers.

Each scenario is composed of two elements. This first is a set of internally-consistent and explicit biophysical and socioeconomic assumptions. The second is a set of rules for simulating the consequences of these assumptions, in the form of a spatial model. The MIT scenarios were not generated based on their likelihood or desirability - they are not plans or policies. They are possible futures representing in many cases extremes in which major driving forces lead towards unbalanced and unsustainable paths.

Participatory Scenario Development

Within the original MIT scenario planning process, a total of twenty-four scenarios were developed for the study region. This is the logical combination of three levels of climate change, two levels of human population change, two sets of land and water management policies, and two levels of public resource availability (3 x 2 x 2 x 2). These variables were identified, scoped, specified and quantified during an extensive participatory process involving the managers actually responsible for implementing conservation in the region.

Once the assumptions process was developed the stakeholders identified four top-level dimensions: climate change, human population demographics and preferences, availability of financial resources, and land and water policies (including conservation strategies). For each dimension, stakeholders developed a bounded set of parameter values or assumptions and picked a small set of measurable indicators. The intent here was that qualitative descriptions

Climate Change	Population (in millions)	Planning Assumptions	Financial Resources
Low (+3.6" SLR)	Trend (25)	Business as Usual (B.A.U.)	Low (\$)
Medium (+18.4" SLR)			
High (+39.1" SLR)	Double (29)	Proactive	High (\$\$\$)

Figure 4. Scenario dimensions and corresponding values and units

Scenario	Climate Change	Population	Planning Assumptions	Financial Resources
A	LOW	DOUBLE	Business as Usual (B.A.U.)	LOW \$
B	LOW	TREND	PROACTIVE	HIGH \$\$\$
C	HIGH	DOUBLE	B.A.U.	LOW \$
E	MEDIUM	DOUBLE	B.A.U.	HIGH \$\$\$
I	HIGH	DOUBLE	PROACTIVE	LOW \$

Figure 5. Top 5 MIT scenario bundles for the Greater Everglades Landscape.

NOTE: An additional 19 scenario bundles have been modeled as well, but are not included in this Project Summary Sheet.

remain relatively consistent through time, while their mappings to specific parameter values can be adjusted regularly based on the best available science. The land, water and conservation rules dimension was the most complex, with over 100 separate policies considered and packaged into two major grouping: "business as usual" and "proactive." The final scenario input assumptions (as selected by stakeholders) are shown in Figure 3.

We used the policy-sensitive land use change simulation model AttCon to simulate future land cover under these scenarios. We provide only an overview of this process here (for details on the model, please see Flaxman and Li 2009, and for description of the modeling process within the Everglades, Flaxman and Vargas, 2011). AttCon is a deterministic spatial allocation model. It takes three major forms of input. The first are "demand" assumptions, in the form of exogenous future population and employment projections. The second are "supply" assumptions, in the form of zoning maps and environmental constraint layers. These characterize the available land supply for each simulated land use type. Within these constraints, attractiveness to each landuse is estimated using classical GIS suitability modeling. These suitabilities are based on the last 50 years of land cover change as recorded in a combined parcels data-

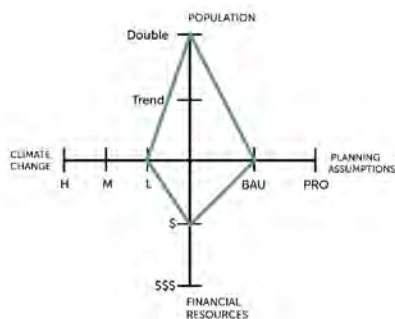


Figure 6: Graphic Representation of Scenario dimensions

base covering of all 30 counties in the study region. The final input is a policy rule set. This arbitrates conflicts over land use according to pre-determined economic or social rules. For the “plan/trend” scenarios, the basic rule is “willingness to pay determines use.” This rule simulates normal free-market conditions, in which land is sold to the highest bidder. For “proactive” scenarios, the allocation sequence and priorities are adjusted to allow for government to get first pick of lands identified for either conservation or public infrastructure. The model runs stepwise over time, and over each simulated land use. At each step, it computes the most attractive legally available land for a particular

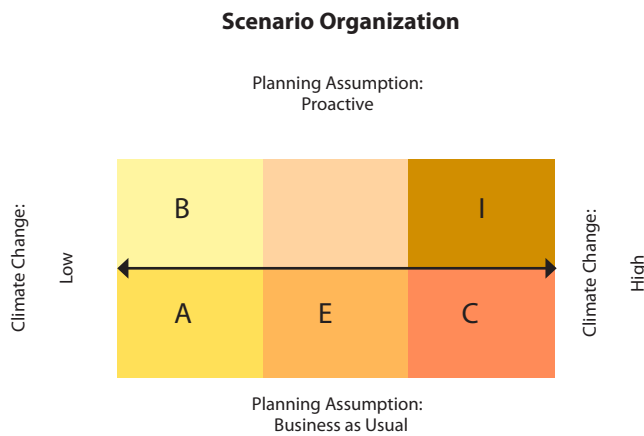


Figure 7: Climate Change vs. planning assumptions for priority five scenarios

land use. If there is no conflict, that land is allocated to that use. If there is a conflict, it is resolved using the scenario ruleset. The resulting allocations are relatively realistic and robust when tested using backcasting techniques. The primary limitations of this modeling approach is that demand is treated as fully exogenous, and the approach does not account for non-willing sellers. Because of these two limitations, this modeling approach is better suited for long-term simulations, since over generational timeframes business-cycle variations in demand and the idiosyncratic behavior of individual landowners average out.

The final set of priority scenarios employed in the project and its composition are shown in Figures 4 and 6 below. This subset of the full 24 were used in

MIT Everglades Scenarios	Scenario A	Scenario B	Scenario C	Scenario E	Scenario I
(Change Relative to 2010)	%	%	%	%	%
Agriculture	0%	8%	0%	0%	5%
Conservation	7%	33%	7%	19%	20%
Urban	37%	21%	37%	36%	27%

Figure 8: Percentage allocation in aggregate land area relative to 2010.

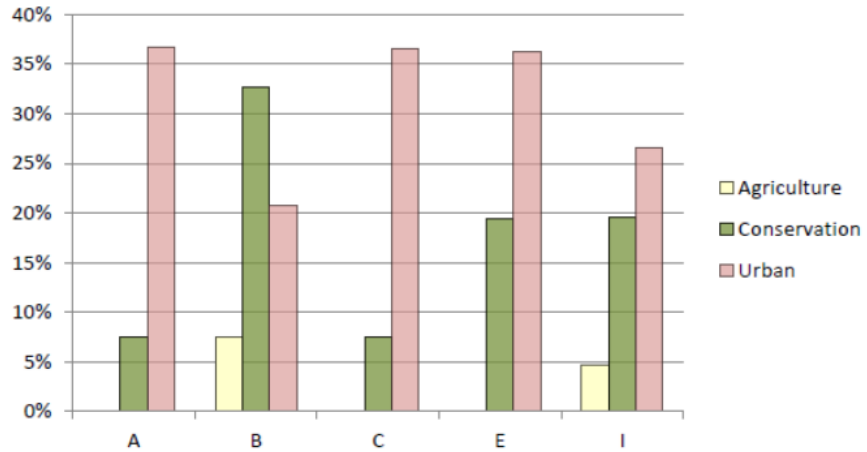


Figure 9: Percentage of Additional Area Allocated by Scenario

the FWC Pilot. Through an individual and then group validated consultative process the stakeholder group explored and discussed the different bundles of assumptions and discussed their relevance for decision making. It is important to highlight that the priority scenarios were selected by the stakeholders with the explicit idea of developing bundles of assumptions that they would be interested in seeing spatially simulated. The selected scenarios did not necessarily reflect any individual personal stakeholder's values or beliefs, but the set was approved by unanimous consensus of all participants as being appropriate for planning purposes.

In practice, the selected scenarios included some which might be characterized as "likely futures" and others which explored bracketing or boundary conditions. The two of the four dimensions which contain most of the variance are climate change and planning assumptions. Plotted against these two dimensions, all of the picked combinations can be more compactly represented (See Figure 9). -This plot thus forms a useful visual aid in considering the five scenarios used here.

Scenario Results

The resulting “alternative futures” represent a range of plausible future land use and land cover configurations for each of the time series explored. Each Alternative Future visualizes land use patterns and landscape changes such as coastal inundation, urbanization, and infrastructure expansion. These maps also quantify and distill a complex range of conditions under which conservation strategies may operate, allowing managers to make strategic decisions despite considerable individual and compound uncertainties. This set of spatially-articulate potential future land use maps allows us to explore the interaction between global climate change, human population settlement preferences, and state and local policies. In particular, we can begin to judge the effectiveness of current conservation strategies against a landscape in which people -as well as species -are likely to relocate in response to climate change.

The selected scenarios are depicted in the table and bar chart above (Figure 7). From the table, we see that in Scenarios A & C, population doubles, and urban area increase by just under 40%. On the lower end of urbanization pressure and with the highest urban densities, Scenario B makes a large difference in total greenfield urbanization. Similar populations to the prior two scenarios are on average accommodated in a little more than half of the space (21% vs 37% growth). It should be noted that while optimistic in terms of adoption of transit-oriented development practices, Scenario B used planned densities confirmed by interview with local county planners from across the region. It thus reflects and conforms to current plans, not any radical densification of the region.

In terms of conservation, even wider differences in possible futures are represented. At the low end, in scenarios A and C, conservation lands increase by only 7% over 50 years. On the high end, in Scenario B, conservation increases by 33%. In Scenario E & I, approximately 20% of additional conservation land is acquired. These summary numbers are largely a consequence of a single assumption: the amount of conservation funding available. They are “realistic” in that they span the range of conservation funding which local and national taxpayers have supported in the last 50 years. The “low public resources” scenarios assume conservation funding at 25% of historic mean, and the “high” assume funding 25% above that mean. Scenarios do not account for the potential of increasing relative land prices in the future. There is some variation based on conservation strategy, which affects whether very expensive conservation lands are purchased. But overall, this variance is very small (<1%) whereas funding uncertainty is clearly a driving force. The non-spatial

version of this finding is thus primarily a reflection of input assumptions and the methods used to estimate historical conservation funding.

The second issue of note relative to conservation findings is that of spatial patterning. Under all scenarios, the general pattern followed reflects the prior work of others, particularly the University of Florida's "CLIP" program (Oetting & Hoctor 2007) and the state's "Florida Forever" initiative. This primarily locates conservation priorities toward the center of our study area, with a second concentration in the Saint John's watershed in the Northeast. There are two forms of important differences apparent. The first is that under low to moderate levels of funding, no cohesive and connected conservation network can be achieved at regional scale, regardless of strategy. Our "proactive" allocation scheme prioritized within corridors identified by the Florida Greenways project. Based on stakeholder guidance, we placed significantly higher priority on connectivity than is done under current programs. We used a 50% weighting of this decision criterion, as compared to the "Florida Forever" program's 10% weight. Nonetheless, there was not enough funding available in this time frame to achieve regional connectivity except at the highest funding levels. We looked for alternative upland areas, especially those connected to current conservation areas.

Limitations of Overall Process and Generated Scenarios

While we feel that the scenarios created are broadly useful and do reflect a wide range of conditions, we did run into a variety of data and modeling limitations which bear some scrutiny. Most of these will be detailed later in review expert's surveyed opinions on the overall process.

Our decision to work comprehensively across a wide area meant that we built models which are regional in character, and in many particularities reflect aggregate average behaviors. This is mitigated to some extent by the use of very fine-scale data relative to most prior regional studies. In particular, our use of parcel-scale data allowed us much better spatial and temporal accuracy than studies dependent on land characteristics measured using remote sensing methods. Our database included roughly 6 million parcels with development timestamps taken annually over 50 years. This is a very large sample, spanning many subregional markets and many economic cycles. Similarly, we were able to take advantage of point-level business and employment data sources which represent the dispersed economic patterns of this region much better than the aggregated information typically available.

2.6 Relationship of Scenario Planning to Florida's Wildlife Action Planning Process

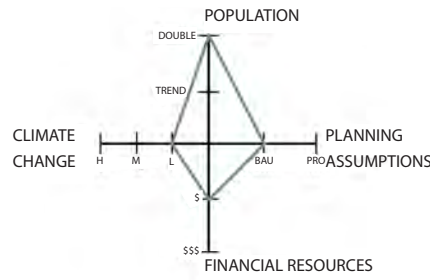
The Florida Fish and Wildlife Conservation Commission (FWC) is currently in the process of updating its statewide Wildlife Action Plan (previously known as the Comprehensive Wildlife Conservation Strategy). One of the purposes of this pilot study is to test potential approaches to incorporating climate adaptation planning within this broader process.

Existing methods treat each stressor individually, and are not consistent in terms of their spatial consideration of either threats or opportunities. They also do not link to either broader-scale scenarios, such as those provided by IPCC, and to trends analysis. For example, the current state plan references the importance of population growth generally, but does not use the state's demographic projections to prioritize actions.

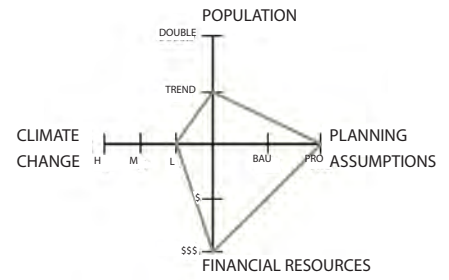
We elected to develop a new approach, tailored to the particular needs of Florida, but broadly generalizable. In particular, we wished to leverage an extensive body of prior available geospatial work, namely the scenarios we had previously constructed, and the wildlife habitat suitability models generated by dozens of experts coordinated by FWC. These two resources allow a much more detailed and systematic look at species-level climate adaptation options than is typically the case.

MIT SCENARIOS SUMMARY

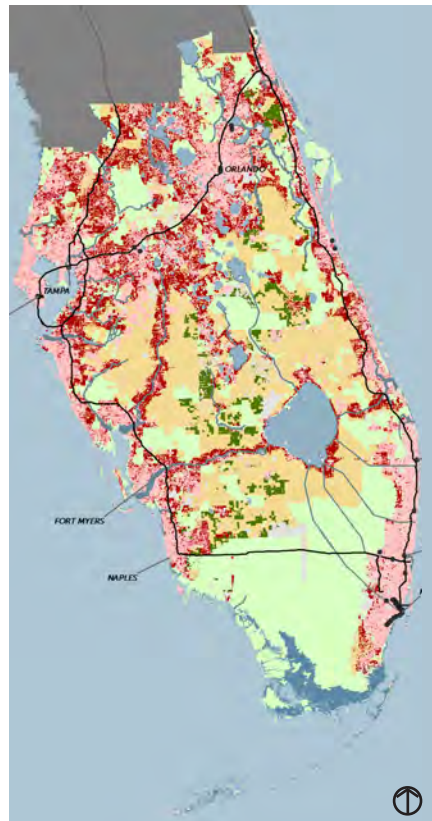
Scenario A



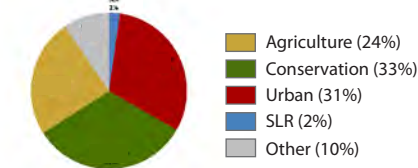
Scenario B



Scenario A Land Cover 2060

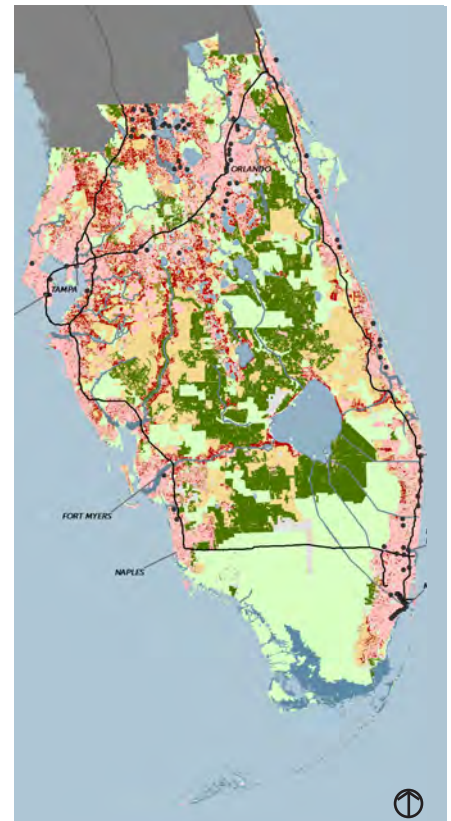


Land Use Composition 2060

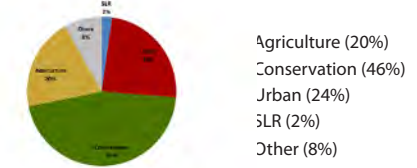


Total Land Use Area (in millions of acres)	2020	2040	2060
Agriculture	6.19	5.52	4.69
Conservation	6.00	6.16	6.32
Urban	4.51	5.20	5.98
Sea Level Rise	0.33	0.38	0.44
Other	2.26	2.03	1.86

Scenario B Land Cover 2060



Land Use Composition 2060



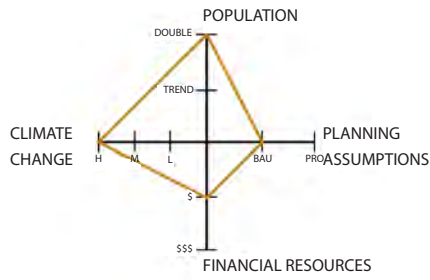
Total Land Use Area (in millions of acres)	2020	2040	2060
Agriculture	6.00	4.96	3.85
Conservation	6.50	7.65	8.80
Urban	4.29	4.47	4.62
Sea Level Rise	0.33	0.38	0.44
Other	2.18	1.83	1.58

Map Legend

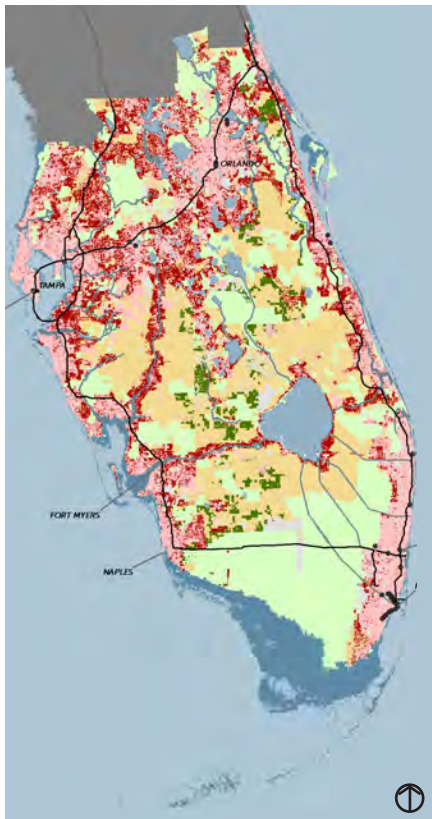
Current Land Use	Projected Land Use
Agriculture	Agriculture
Conservation	Conservation
Urban	Urban

Figure 10: MIT Scenario Summary

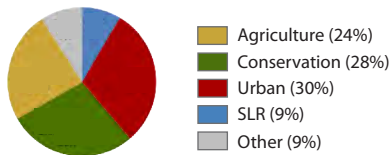
Scenario C



Scenario C Land Cover 2060

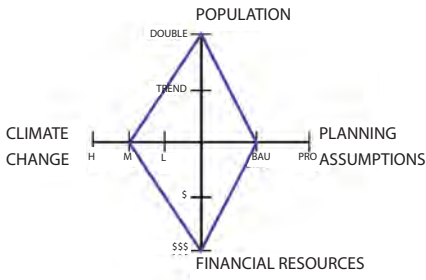


Land Use Composition 2060

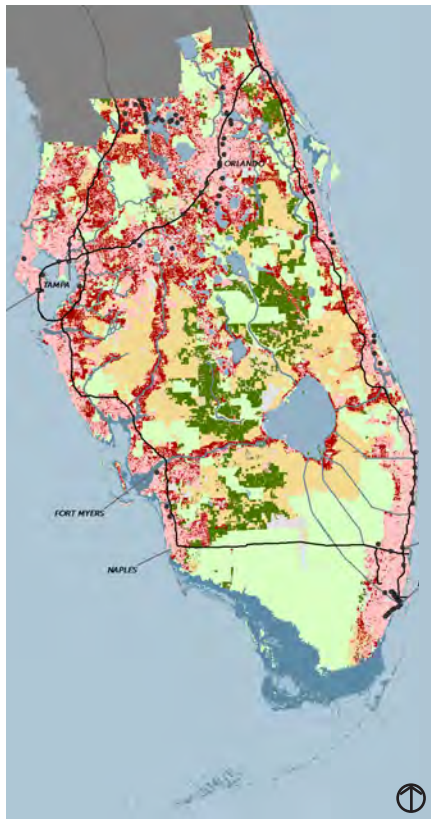


Total Land Use Area (in millions of acres)	2020	2040	2060
Agriculture	6.19	5.51	4.66
Conservation	5.77	5.40	5.40
Urban	4.48	5.09	5.81
Sea Level Rise	0.63	1.34	1.64
Other	2.22	1.95	1.77

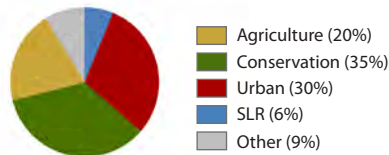
Scenario E



Scenario E Land Cover 2060

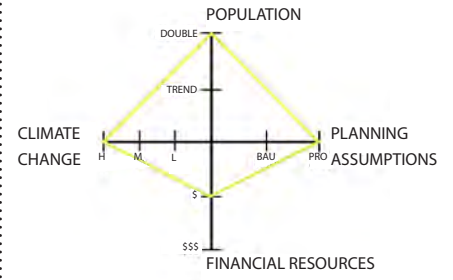


Land Use Composition 2060

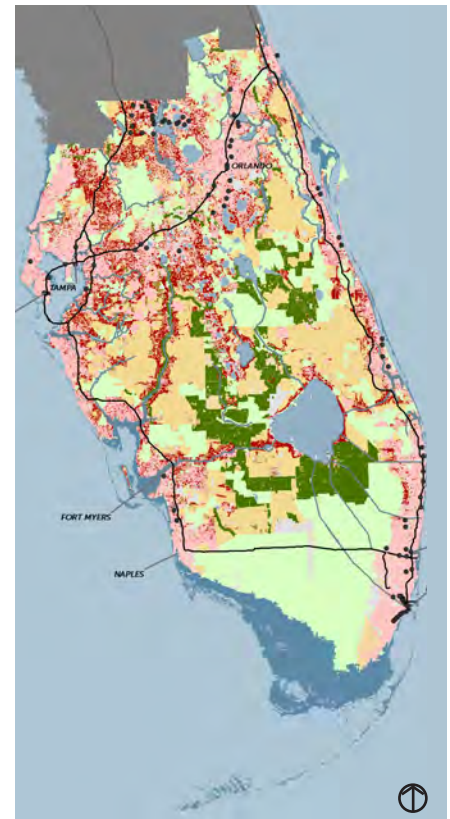


Total Land Use Area (in millions of acres)	2020	2040	2060
Agriculture	6.05	5.04	3.87
Conservation	6.12	6.40	6.69
Urban	4.47	5.10	5.83
Sea Level Rise	0.44	0.82	1.20
Other	2.21	1.92	1.70

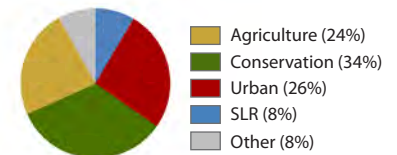
Scenario I



Scenario I Land Cover 2060



Land Use Composition 2060



Total Land Use Area (in millions of acres)	2020	2040	2060
Agriculture	6.12	5.38	4.54
Conservation	5.97	5.99	6.39
Urban	4.37	4.70	5.05
Sea Level Rise	0.63	1.34	1.64
Other	2.21	1.87	1.67

3.0 The Spatial Resilience Planning Approach

3.1 Prior Approaches and the Need for Improved Vulnerability Methods

Considering different climate scenarios in vulnerability assessments allow agencies to measure the sensitivity of their species to a wide range of stressors and conditions. It furthermore permits testing the need and effectiveness of their potential adaptation strategies under different trajectories of change.

This study develops a pilot approach to develop vulnerability assessment and adaptation planning, which we call “spatial resilience planning” or SRP. The premise of this method is that because climate change is both spatially variant and subject to scientific uncertainties, it should be approached using a special form of planning known as spatial scenario planning. This method has a long history of application in domains where critical decisions must be made under high uncertainty – it was originally developed for military planning applications during the cold war.

This approach contrasts distinctly with the CCVI approach described above, in that its basic unit of analysis is geographic, rather than being species-based. The CCVI approach uses expert interviews to qualitatively rank a structured set of factors hypothesized to lead to climate vulnerability. It results in a single aggregate index score per species, as well as subcategory and sensitivity tests if desired. By contrast, the map-based methods employed in the SRP, develop depictions of current and future habitat which vary over space and time. The basic distinction between methods which must be made is between species-oriented vulnerability protocols and spatial ones. We selected the map-based method to develop the SRP. This method aggregates into a single characterization at species level, but is fundamentally designed to assess variation over space and to plan potential management actions which themselves vary over space.

3.2 The SRP Method

The SRP method has two subcomponent methods: 1) spatially-explicit vulnerability assessment (SEVA) and 2) the Spatially-explicit adaptation planning process (SEAP). The first represents a diagnostic approach, and the second a prognostic. SEVA generates maps illustrating the spatial vulnerabilities of the species habitat, including a characterization of the causes, extent, and magnitudes. SEAP generates sketch plans relating potential management actions to geographies.

Both processes rely on experts and managers familiar with the species or their habitat. The process organization is depicted in Figure 11

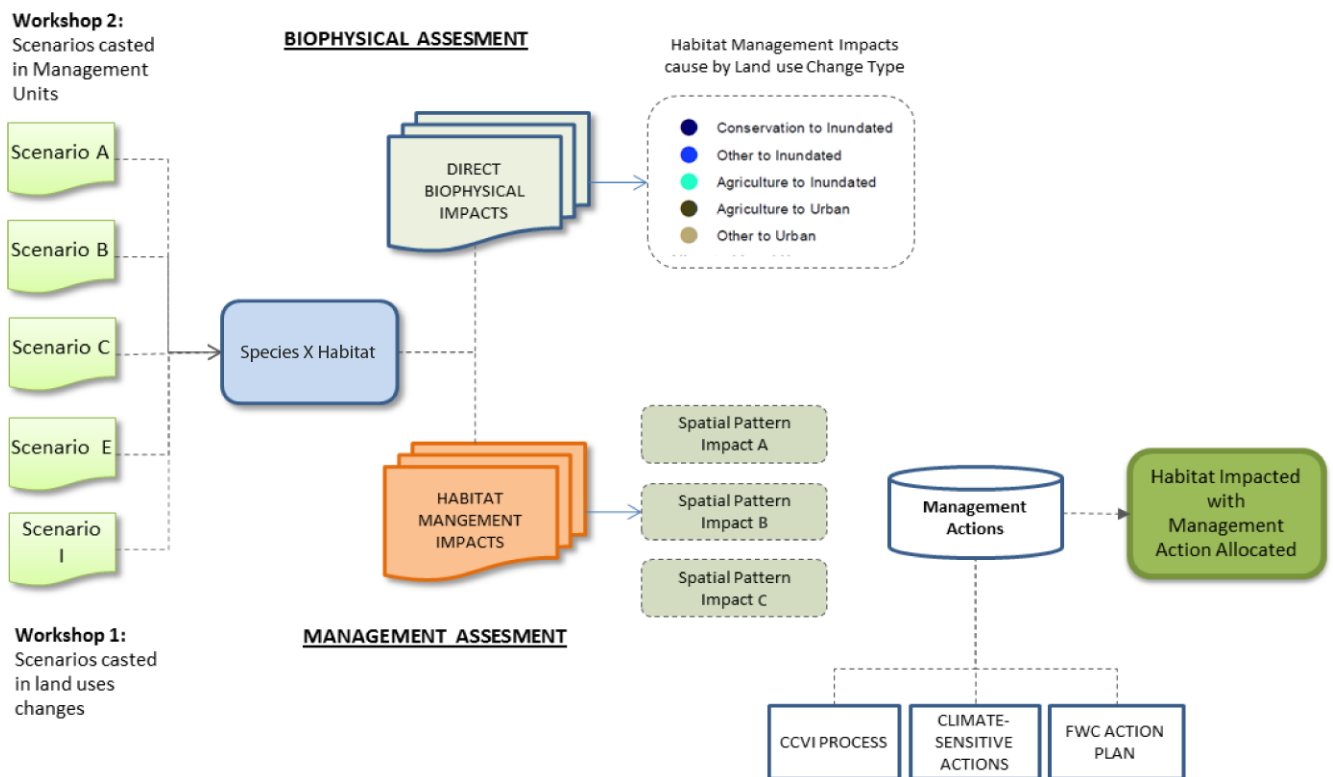


Figure 11: Spatially-explicit Scenario Vulnerability Assessment

3.2.1 Selection of Species

Six animal species were selected based on their status as Species of Greatest Conservation Need within the Florida Conservation Action Plan, and on the basics of representation of a range of habitat types and locations. They were selected by FWC experts and filtered by data and expert availability. The species selected were: American Crocodile (*Crocodylus acutus*), Key Deer (*Odocoileus virginianus clavium*), Least Tern (*Sternula antillarum*), Atlantic Salt Marsh Snake (*Nerodia clarkii taeniata*), Short-Tailed Hawk (*Buteo brachyurus*), and Florida Panther (*Puma concolor coryi*).



Figure 12: Species Selected

Several additional species were considered for selection, but dropped from this pilot simply due to logistical availability of appropriate experts.

One additional species was discussed extensively with invited experts, but not explicitly modeled: the common snook (*Centropomus undecimalis*). This species would have significantly added to the taxonomic diversity of the set. The expert meetings conducted on this species fleshed out several potential approaches, and this species is of interest from multiple points of view. However, species habitat suitability modeling has not been completed for the species. With the limited resources available to the pilot, and the lack of habitat models for the Least Tern, it was determined that selecting a second non-modeled species was not feasible.

3.2.2 Data Sources and Data Assembly

FWC and other agencies have developed extensive information about the distribution, natural history, and conservation status of rare species and habitats. Following review of the existing information, data gaps were identified and a literature search was conducted as needed to complete the basis level of information for to proceed with the assessment. The primary source of spatial data came from FWC suitability models. The first set of Habitat Suitability Index (HSI) modeling was developed by the U.S. Fish and Wildlife Service (USFWS) in the early 1980s as part of the Habitat Evaluation Program. The models were used to support rapid decision-making in data-poor situations. Expert-opinion and literature sources were used to develop suitability indices (SI) indicative of habitat preferences across gradients (FWC, 2011).

GEOGRAPHIC DATA SOURCES FOR THE VULNERABILITY ANALYSIS	
Data Layer	Data Source
2060 Land Use Scenarios	Massachusetts Institute of Technology. Department of Urban Studies and Planning. (Vargas-Moreno and Flaxman 2011)
Species Habitat Models (Key Deer, Panther, Salt-Marsh Snake, American Crocodile)	Florida Fish and Wildlife Commission. Strategic Habitat Modeling, 2009.
Least Tern (roofs and beach combination)	Species occurrence data from FWC rooftop data provided by participating experts (unpublished). C-CAP land cover data from Landsat classification obtained from NOAA. Photo-interpreted land cover merged by MIT from multiple water management districts (2002 - 2008)

Figure 13: Study Data Sources

3.2.3 Spatial Analysis

In order to identify, analyze and measure species vulnerabilities and potential adaptation mechanisms, this project employed several spatial analytical techniques. The first, used in SEVA, was what is known in GIS as an “overlay analysis using map algebra” This was conducted 30 times, once for each of six species under five scenarios. These overlays represent an initial estimate of species-level vulnerability. The technique is powerful, efficient and scalable, and the MIT team has developed automated scripts which support the exploration of any number of species and scenarios.

Two important limitations over map algebra overlay must be noted. The first is that existing available habitat models do not internally account for climate change effects. For instance, we expect changes in seasonal precipitation under some climate scenarios to reduce the amount of wooded wetlands important to the Short-tailed Hawk. However, the components of the Short-tailed Hawk habitat model were not available to us during this pilot. Therefore, this type of change in habitat value was not well-captured in the resulting overlay models. Second, overlay analyses ignore adjacency and metapopulation dynamic effects. Again, this was a limitation of the input habitat model component availability. Some habitat models, according to their documentation, included “buffers” from various forms of human activity, such as residential development. However, overlay analyses do not account for such impacts. Thus the resulting vulnerability assessments should – in general – be expected to underestimate indirect impacts of climate change. Were additional information available, such as minimum patch size, this could be incorporated into future work.

Two rounds of spatial analysis of exposure were developed. In the first one, the scenarios were represented using their land use land cover conditions. In this round, impacts were characterized and quantified expressing the vulnerabilities in specific land use changes or inundation. This form of reporting allowed us to quantify the “fate” of current habitat under various scenarios in terms of eventual land use. For example, we mapped which habitat areas would be developed or inundated.

In the second round, vulnerability assessments were expressed scenarios were represented in management units (ex. protected private or protected public). The impacts in this round were expressed in terms of changes in relative to current management conditions. This was done because the first round impacts showed a complex pattern of changes which we felt were best

simplified generalized by considering broad management classes rather than specific land use details. This allowed us to split out which impacts were occurring on which kinds of lands. For example, how this form of output allowed us to calculate how much habitat loss under a given scenario was due to inundation of existing conservation areas versus urbanization.

3.2.4 Consultative Workshops

Because of data and analytic limitations described above, a critical major component of our vulnerability assessment and adaptation planning process involved extensive expert review. In order to maximize feedback and enhance institutional learning, this was conducted using an in-person workshop process. Two general types of expertise were sought. The first were species and habitat specialists, including where possible the original authors of any available species habitat models. The second were land and programmatic managers with responsibility or interest in particular land areas or relevant programs. The coordination, invitations and logistics of both workshop was managed by the Florida Wildlife Federation. A variety of experts from several organizations attended including FWC, FWS, USGS and the NGO sector.

Two workshops were organized. The first took place in St. Petersburg, Florida at the Fish & Wildlife Research Institute (FWRI) on the 25th and 26th of January, 2011. The goal of this workshop was to review the existing habitat models and initial overlay model impacts for each of the six species, and to jointly scope potential refinements and enhancements. This was accomplished using species-specific break out sessions, in which the following four topics were covered:

1. Verification of existing habitat models, and review of initial SEVA overlays maps.
2. Assessment of the availability of alternative data sources or habitat models.
3. Identification of “existing and available” research or data suitable for incorporation within the pilot study
4. Discussion and identification of knowledge gaps and areas requiring future research over short, medium and longer-term

In addition to these four common tasks, we undertook additional work for two of the species, the American Crocodile and Salt Marsh Snake. In these cases, our experts were able to identify a series of spatial rules to estimate habitat quality and/or potential future habitat under climate change. We used these



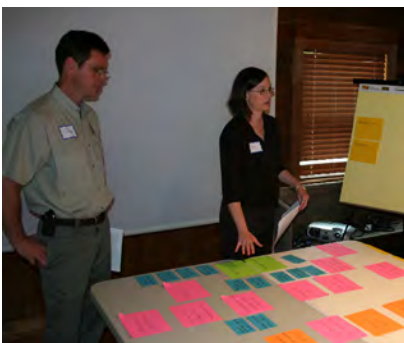
“proxy habitat” models to refine second round impact assessments. The second workshop took place in Orlando Florida, at the Orlando Science Center, from the April 28-29, 2011. The objective of this workshop was to identify potential climate adaptation management actions in conceptual, as well as geographically-explicit forms. This workshop was designed for professional land managers, wildlife biologists and wildlife researchers who work with native Florida species.



The first set of activities in this workshop was developed in partnership with Defenders of Wildlife and was undertaken was done in species-level breakout groups. Each group was asked to develop a conceptual model of climate change impacts on a single species. They were asked to identify stressors, potential management actions, and the relationships between them. While they were requested to focus most attention on climate and sea level rise stressors, they were free to consider any important impact effecting the species, regardless of source. Participants were given a base set of colored index cards, containing stressors & management actions identified in prior Wildlife Action Planning for the species. They were also given blank cards, so that they could add stressors or management actions not previously considered. This format and mechanism was designed to make use of prior planning work, while expanding potential stressors and adaptation mechanisms considered. It was also intended as a mechanism to capture all potential adaptation management actions, not only spatial ones.



The second activity of the management actions workshop was what we have described above as SEAP, or spatially-explicit adaptation planning. Rather than being conducted in a species-specific fashion, this work was organized according the three major management context types identified in this study. Each group of participants was responsible for one type and its corresponding geography, and for two species. The intent of this activity was to begin to plot out where particular actions might be undertaken, and to do so in a manner which recognized the actual land management context within which those actions would need to function. For example, inventory and monitoring is a management activity recommended by most groups. However, this activity must be undertaken in very different ways when private land, or multiple agency jurisdictions are involved.



4.0 Spatially-Explicit Species Vulnerability Assessment

This chapter presents the results of the spatially-explicit vulnerability assessment (SEVA), the first of the two components of the spatial resilience planning method. As was discussed previously in the methods section, the goal of this component is to identify species habitat vulnerable to climate and other changes.

It was not at the outset clear how to best represent this information. We sought a general method which could be applied to any number of species consistently. In the end, we used multiple forms of representation, including maps, tables and pie charts. The initial “habitat impacts and drivers” classification can be seen below in Figure 14. We chose to stress the two most common drivers - sea level rise inundation and urbanization. For cartographic and reporting simplicity, we aggregated all other change drivers.

This information was first presented in workshop format. At that time, species experts reviewed the results and provided feedback about the spatial patterns identified, as well as the data used. They also provided a series of spatial analysis rules to improve the vulnerability analysis for further phases.

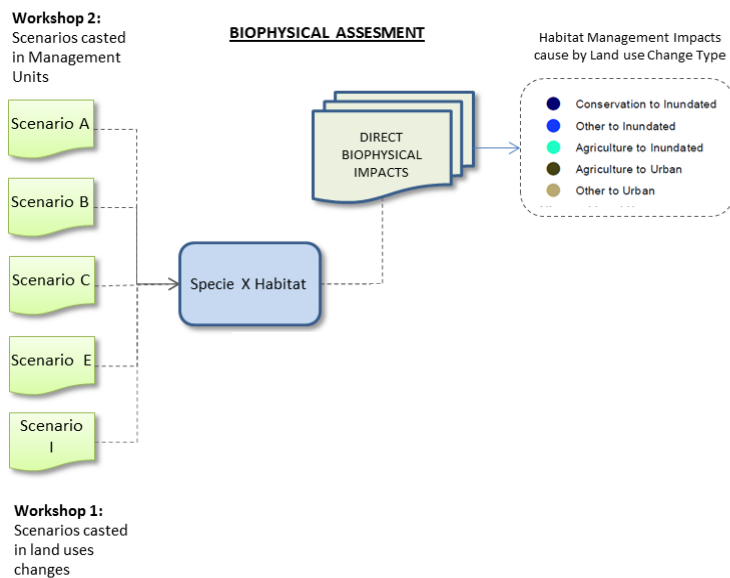


Figure 14: Spatially-explicit Scenario Vulnerability Assessment

American Crocodile

(Crocodylus acutus)

Habitat Description

'American crocodiles (*Crocodylus acutus*) are a shy and reclusive species. They live in coastal areas throughout the Caribbean, and occur at the northern end of their range in south Florida. They live in brackish or saltwater areas, and can be found in ponds, coves, and creeks in mangrove swamps. They are occasionally being encountered inland in freshwater areas of the SE Florida coast as a result of the extensive canal system.

Crocodiles are ectothermic, meaning they rely on external sources of heat to regulate their body temperature. Crocodiles control their body temperature by basking in the sun, or moving to areas with warmer or cooler air or water temperatures.'

Florida Fish and Wildlife Commission 2011



Figure 15: American Crocodile

American Crocodile Habitat

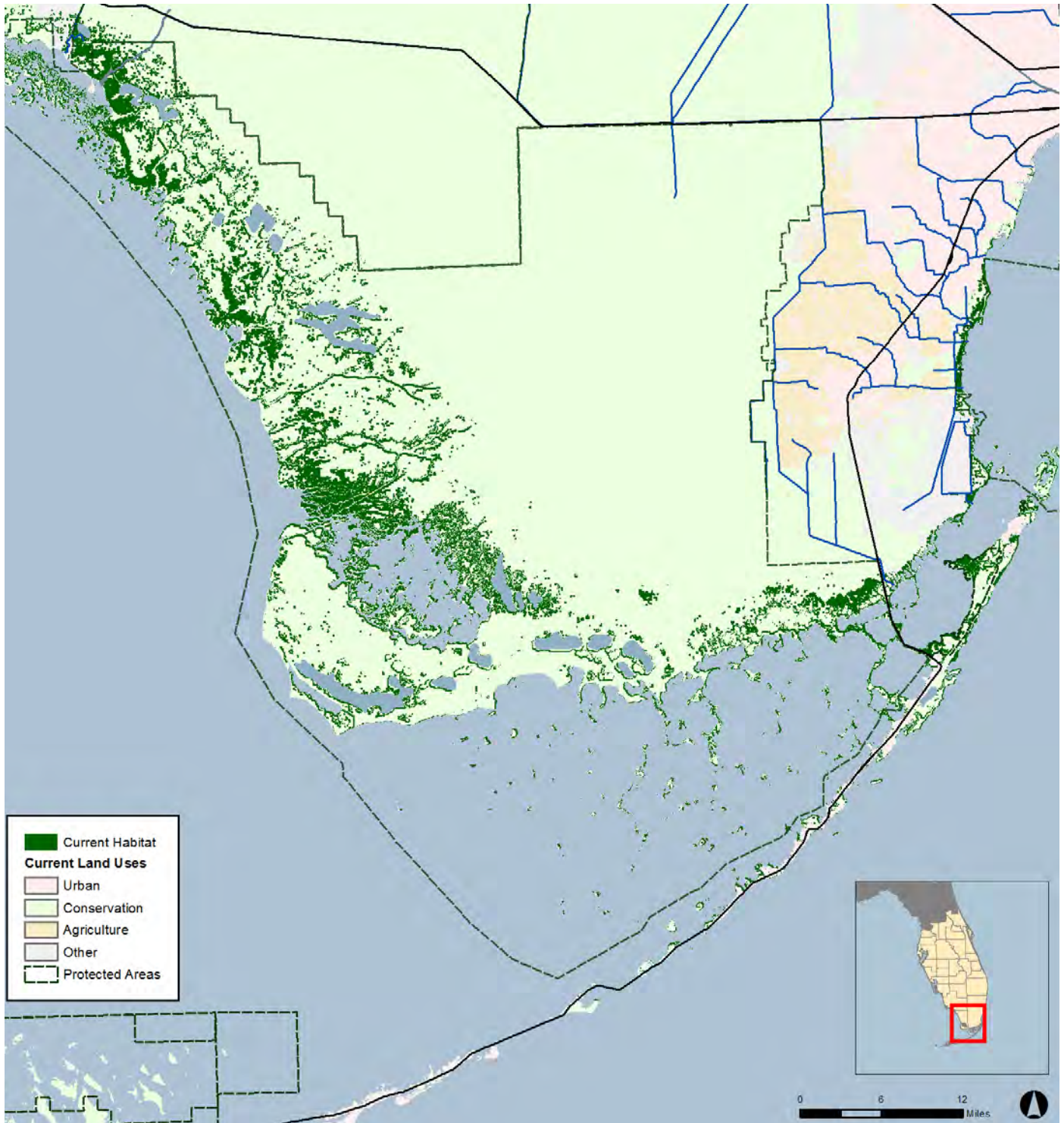
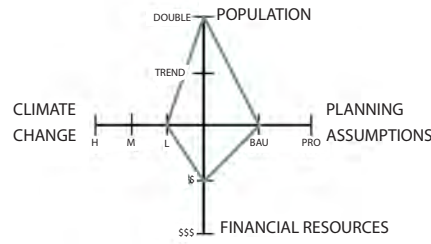


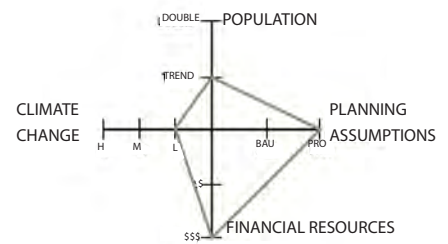
Figure 16: American Crocodile: Habitat

American Crocodile Spatial Vulnerability Under MIT Scenarios

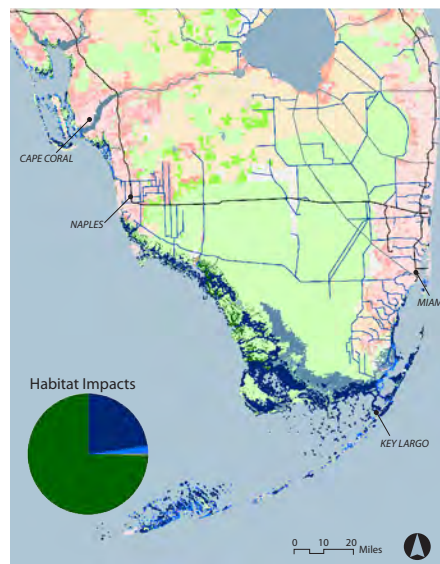
Scenario A



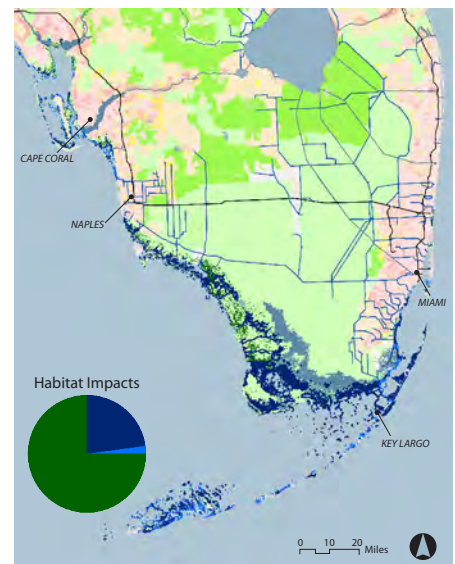
Scenario B



Scenario A Land Cover 2060



Scenario B Land Cover 2060



Map Legend

Habitat Impacts & Drivers	
●	Agriculture Inundated
●	Agriculture Urbanized
●	Conservation Inundated
●	Other Uses Inundated
●	Other Uses Urbanized
●	No Habitat Conflict

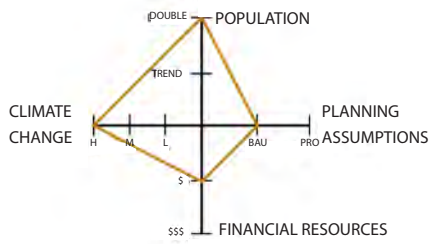
Current Land Use	Projected Land Use
■ Agriculture	■ Agriculture
■ Conservation	■ Conservation
■ Urban	■ Urban

Habitat Impacts By Land Use Type	2060	
	%	Acres
● Agriculture Inundated	0.01%	26
● Agriculture Urbanized	0.01%	28
● Conservation Inundated	22.84%	55,686
● Other Uses Inundated	2.00%	4,875
● Other Uses Urbanized	0.43%	1,048
● No Habitat Conflict	74.71%	182,177
Total Habitat Conflict	25.29%	61,664

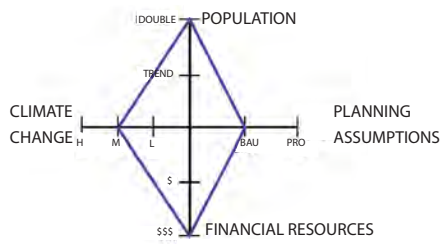
Habitat Impacts By Land Use Type	2060	
	%	Acres
● Agriculture Inundated	0.01%	26
● Agriculture Urbanized	0.00%	0
● Conservation Inundated	22.84%	55,68
● Other Uses Inundated	2.00%	4,875
● Other Uses Urbanized	0.03%	76
● No Habitat Conflict	75.12%	183,177
Total Habitat Conflict	24.88%	60,664

Figure 17: American Crocodile Spatial Vulnerability Under MIT Scenarios

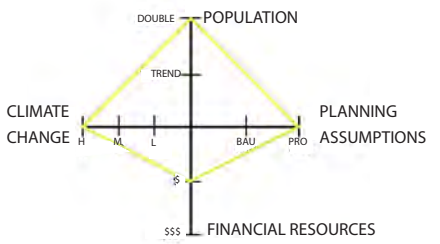
Scenario C



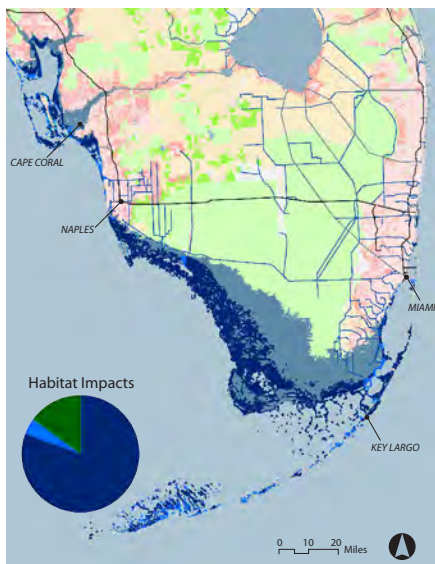
Scenario E



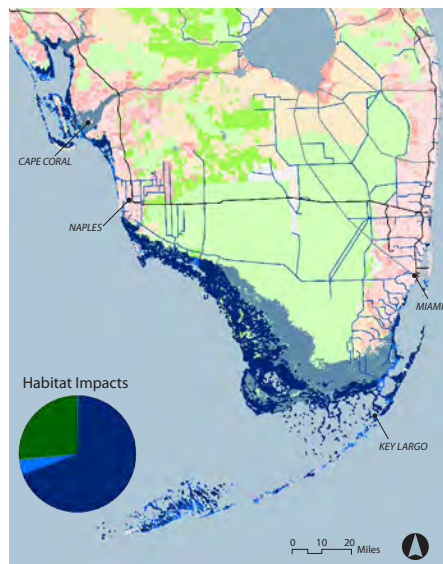
Scenario I



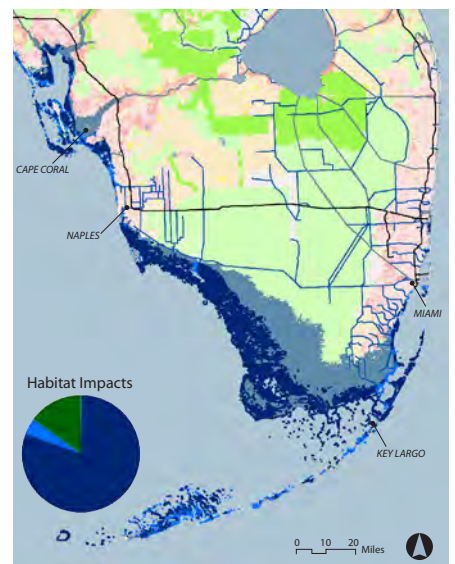
Scenario C Land Cover 2060



Scenario E Land Cover 2060



Scenario I Land Cover 2060

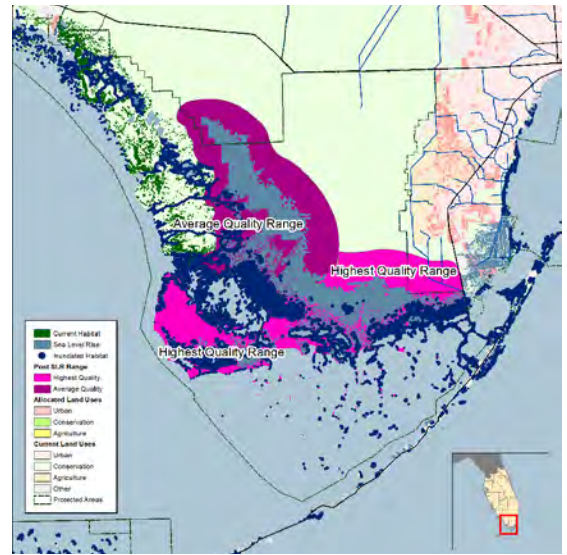


Habitat Impacts By Land Use Type	2060	
	%	Acres
Agriculture Inundated	0.08%	192
Agriculture Urbanized	0.01%	12
Conservation Inundated	80.49%	196,270
Other Uses Inundated	4.48%	10,923
Other Uses Urbanized	0.05%	122
No Habitat Conflict	14.90%	36,322
Total Habitat Conflict	85.10%	207,579

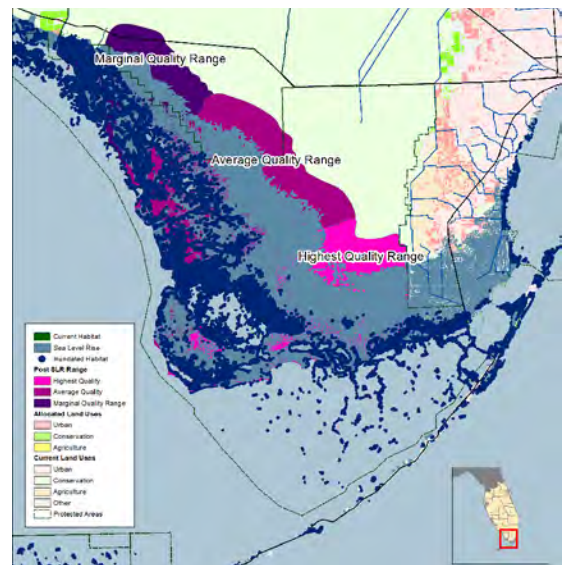
Habitat Impacts By Land Use Type	2060	
	%	Acres
Agriculture Inundated	0.05%	128
Agriculture Urbanized	0.01%	27
Conservation Inundated	69.20%	168,746
Other Uses Inundated	4.08%	9,942
Other Uses Urbanized	0.17%	416
No Habitat Conflict	26.49%	64,582
Total Habitat Conflict	73.51%	179,259

Habitat Impacts By Land Use Type	2060	
	%	Acres
Agriculture Inundated	0.08%	192
Agriculture Urbanized	0.00%	4
Conservation Inundated	80.49%	196,270
Other Uses Inundated	4.48%	10,923
Other Uses Urbanized	0.02%	51
No Habitat Conflict	14.93%	36,396
Total Habitat Conflict	85.07%	207,446

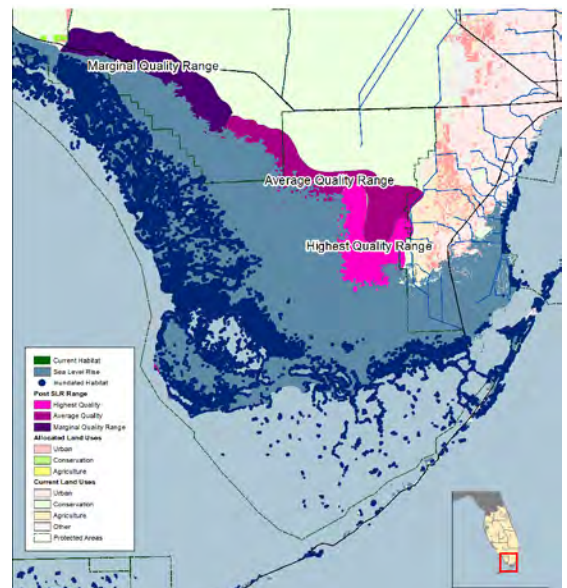
Potential Habitat 2060



Potential Habitat Under Low Sea-level Rise



Potential Habitat Under Medium Sea-level Rise



Potential Habitat Under High Sea-level Rise

Figure 18: American Crocodile : Potential Habitat 2060

American Crocodile Habitat Impacts by Scenario and Current Management

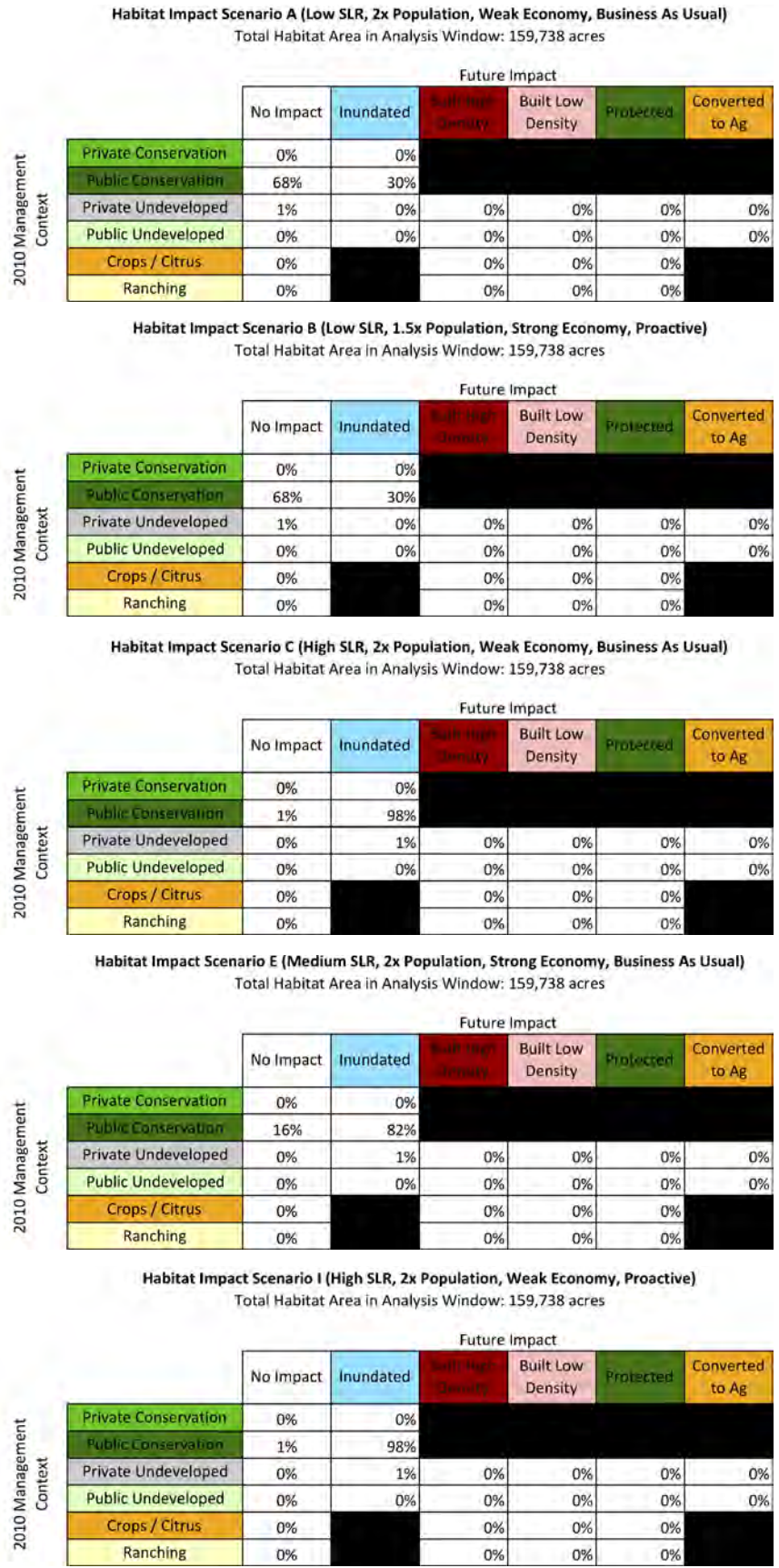


Figure 19: American Crocodile: Habitat Impacts Chart by Scenario

Habitat Impact : Scenario A
(Low SLR, 2x Population, Weak Economy, Business and Usual)

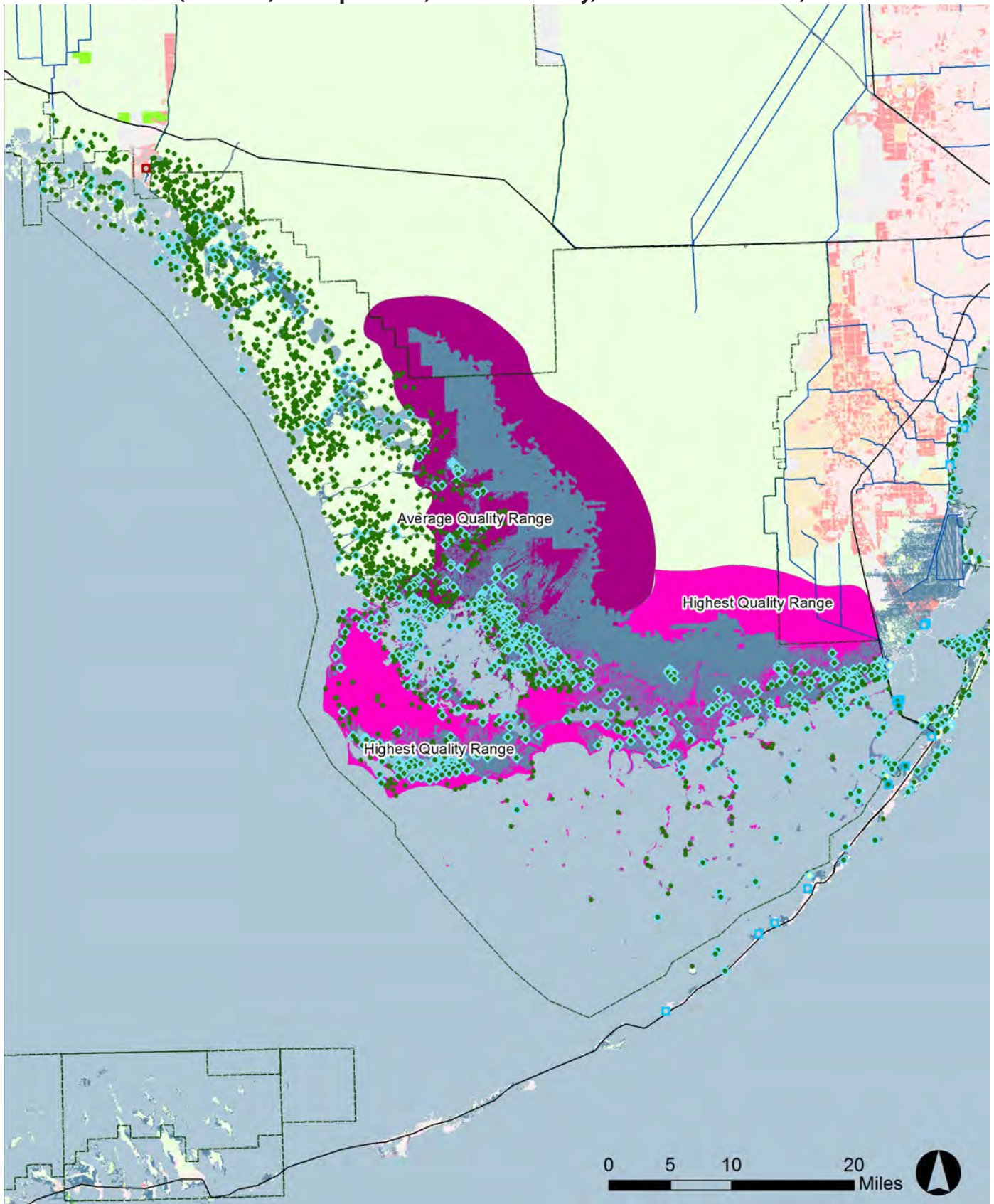
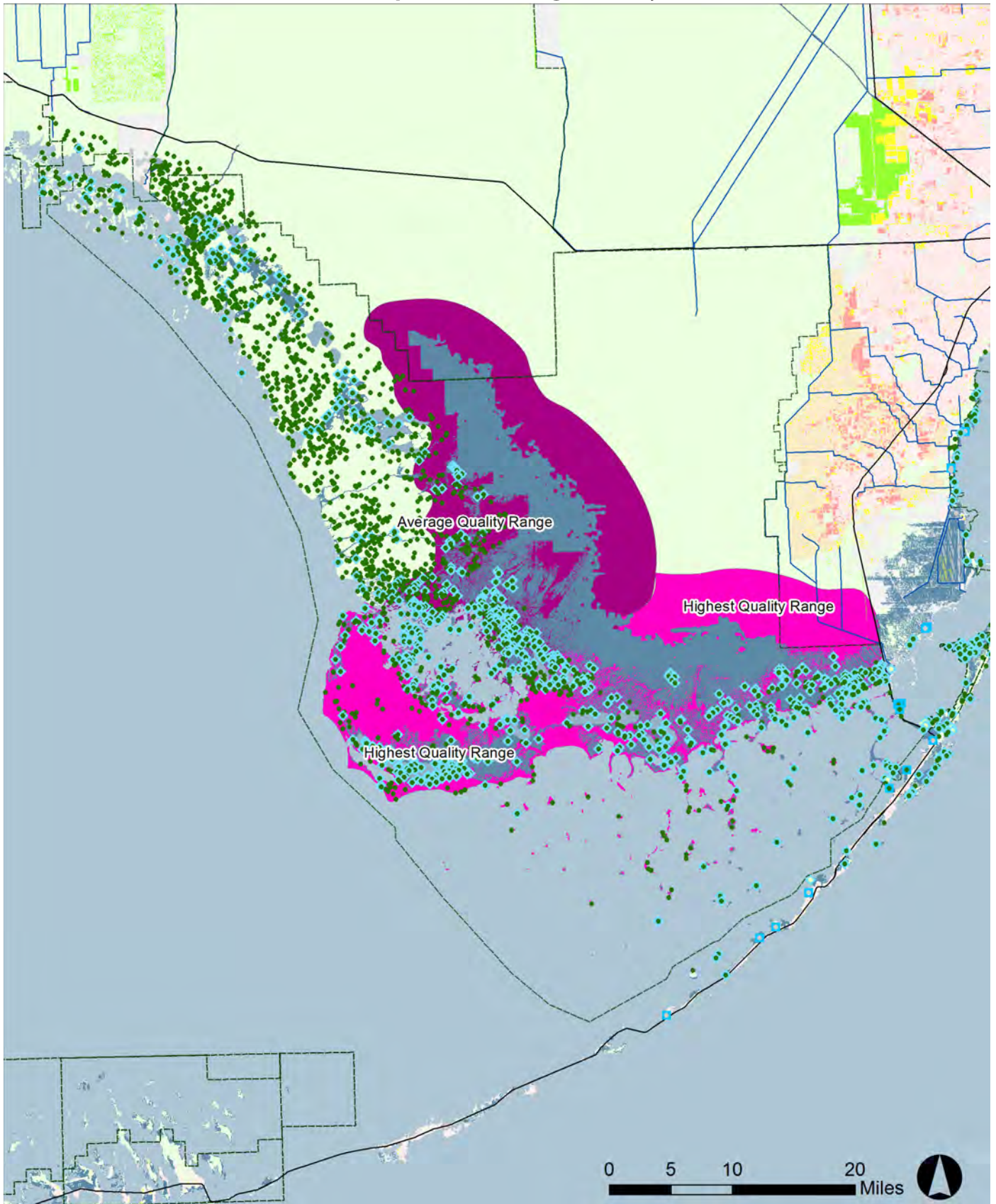
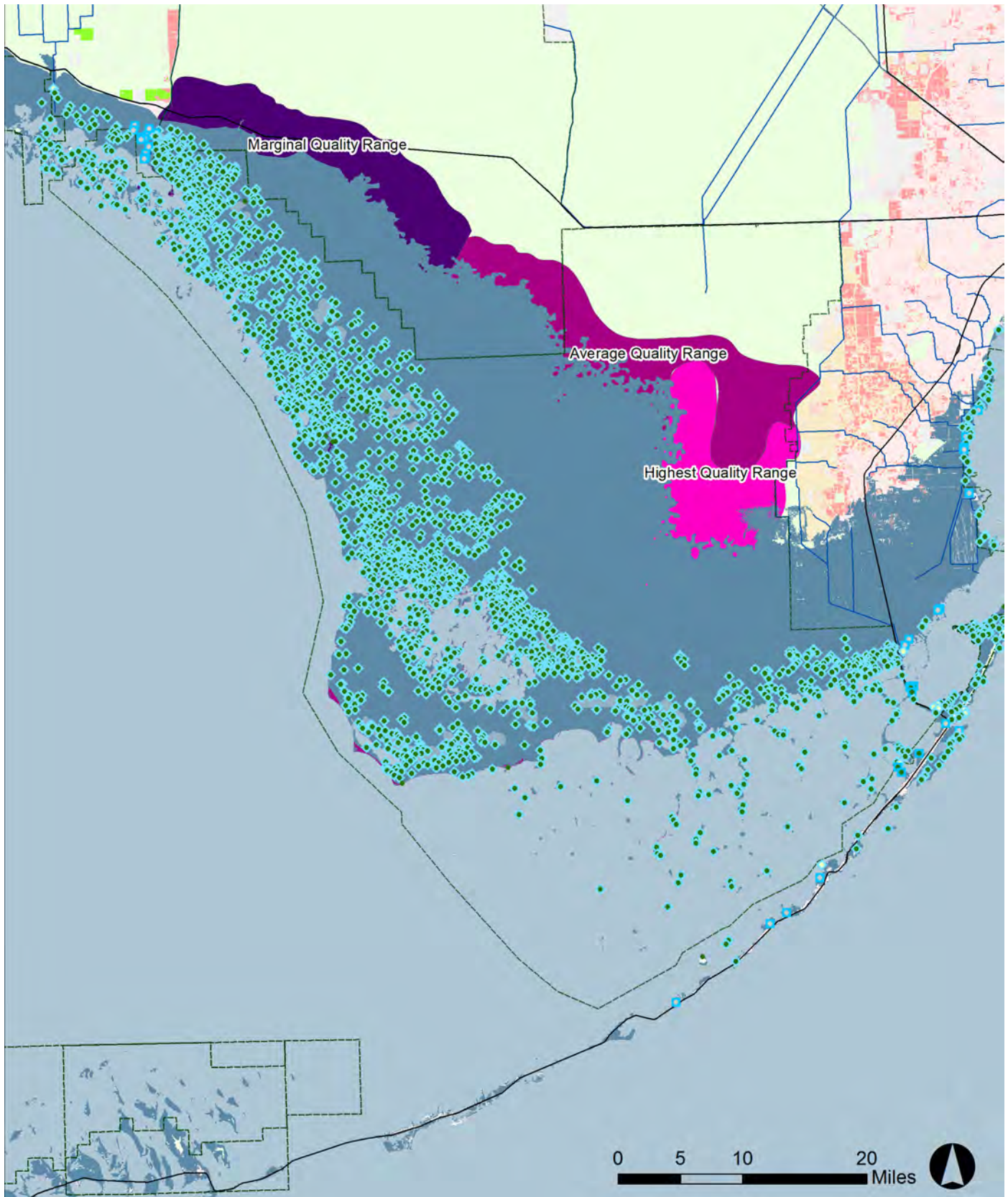


Figure 20: American Crocodile: Habitat Impacts Maps by Scenario

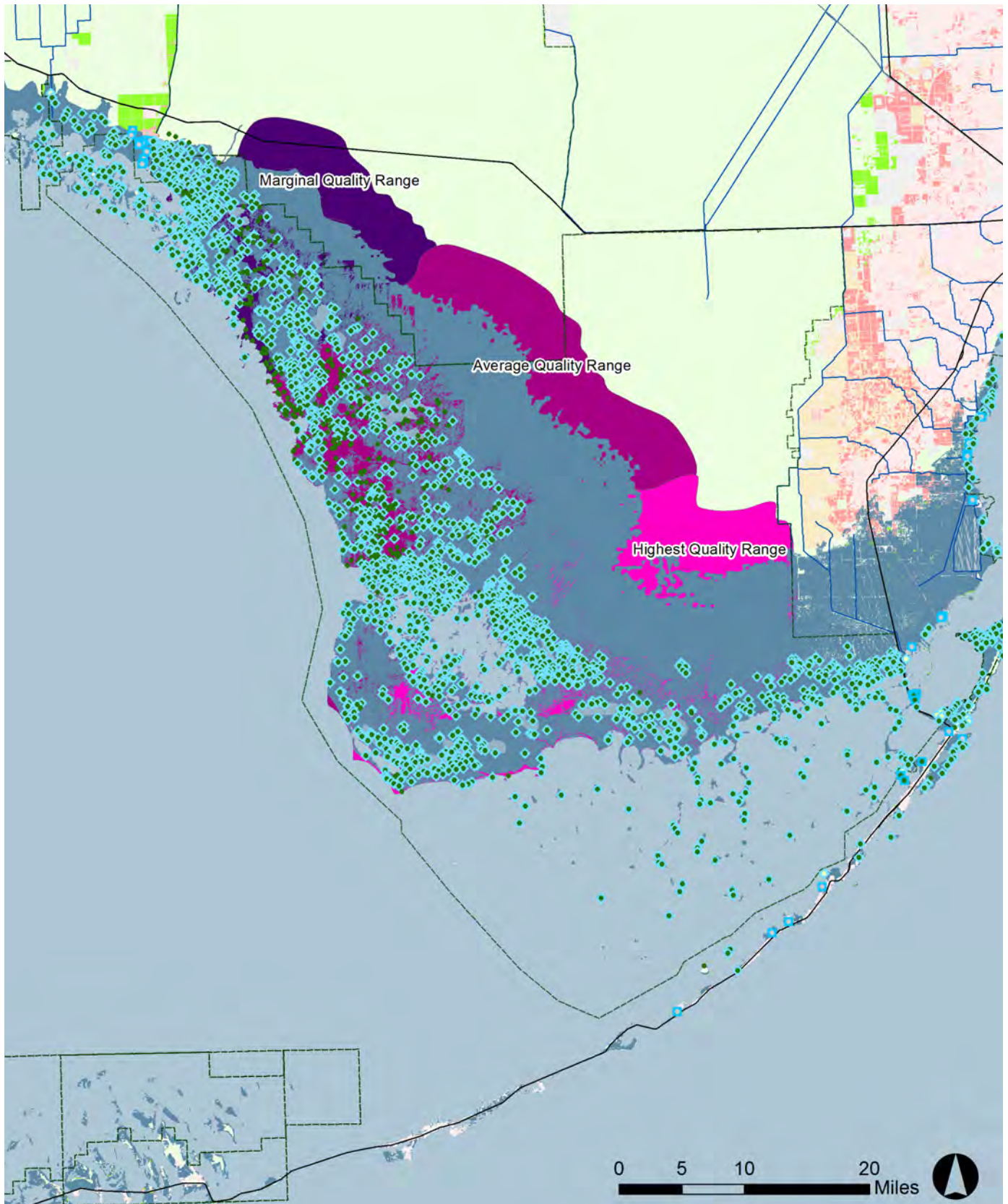
Habitat Impact : Scenario B
(Low SLR, 1.5x Population, Strong Economy, Proactive)



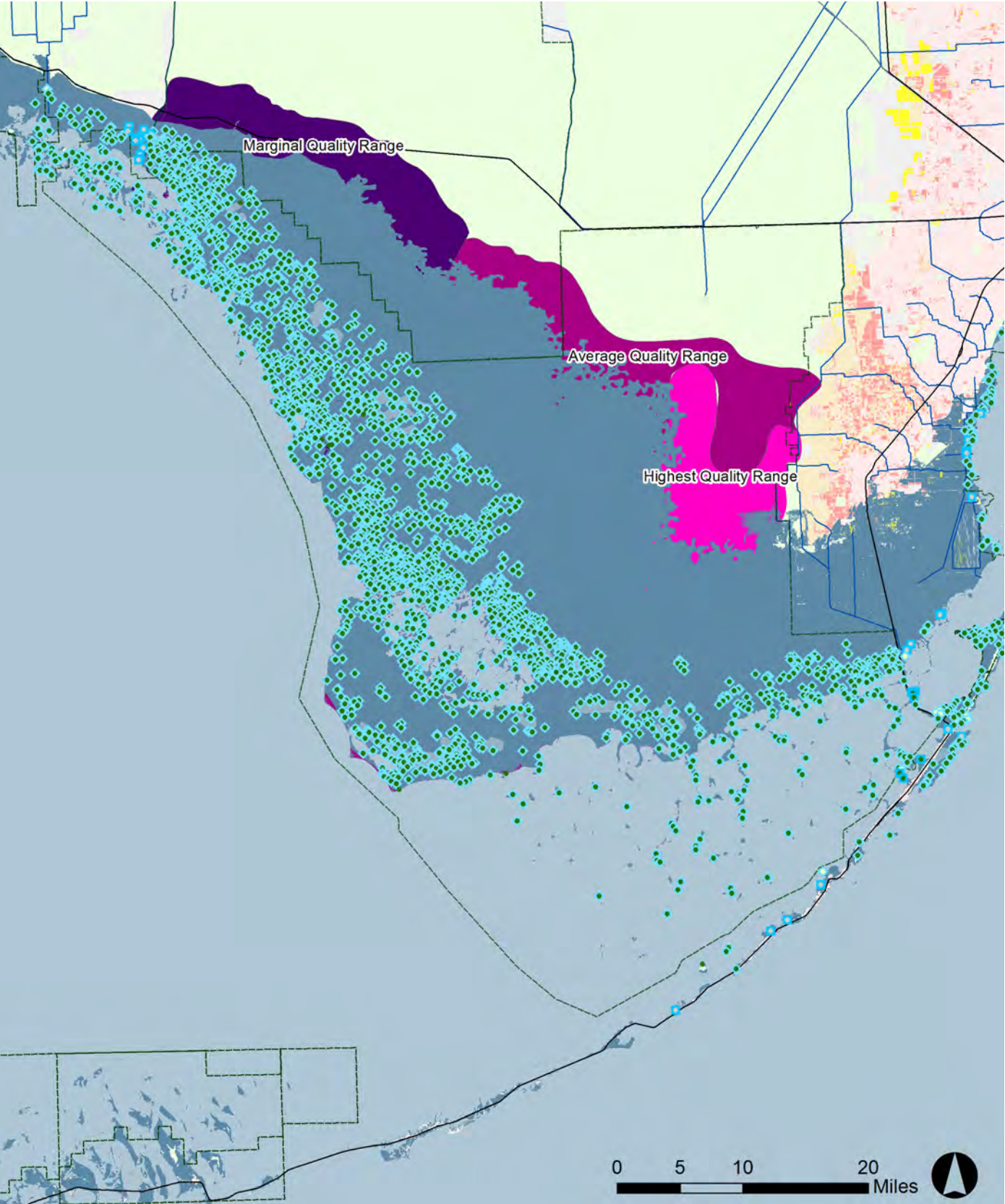
Habitat Impact : Scenario C
(High SLR, 2x Population, Weak Economy, Business and Usual)



Habitat Impact : Scenario E
(Medium SLR, 2x Population, Strong Economy, Business and Usual)



Habitat Impact : Scenario I
(High SLR, 2x Population, Weak Economy, Proactive)



Conclusions Spatial Vulnerability: American Crocodile

The spatial-explicit vulnerability assessment (SEVA) for the American Crocodile was developed through a process that included a series of spatial analysis conducted at MIT and a process of peer consultation and validation during the first vulnerability and adaptation workshop. Three experts participated in the session.

The experts were presented with three inundation scenarios including a low SLR estimate of +3.6", a medium estimate of +18.4 and a high SLR estimate of 39.1". The habitat data used was created originally with the purpose to provide landscape-scale guidance to decision makers involved in public land acquisition, land use planning and other land conservation efforts at regional scales. Data were primarily based on medium-scale (30m) land cover data classified from Landsat 7 ETM+ imagery, therefore restricting its use only at 1:100000 or smaller scales. Data included mangrove-lined creeks, bays, and ponds, with a factor for known nesting locations.

General Findings

The initial habitat assessment include all areas indicated in the FWC crocodile model which take account of areas along the west coast of South Florida. The initial advice by the experts was to focus only in the south area of Everglades National Park (ENP) given that the region represents the most critical area for this species. It also represents the area where all primary nesting and sighting. This area expands along Flamingo, Cape Sable, and Key Largo regions. Furthermore, experts agreed that there are few occurrences in northwest of the areas indicated, but genetic studies have shown they are not the same population. Therefore, as suggested further analysis was confined to the indicated area.

Once the area was determined, a series of conclusions were reached by a process in which the experts reviewed the mapping analysis:

1. Given the low lying elevation on the South shore of ENP (areas indicated for analysis), the habitat will be substantially inundated under all SLR estimates (see table for details); this in effect will shift the crocodile habitat inland through progressive processes. The crocodile is expected to adapt to the SLR conditions projected given its ability to migrate north and the fact that the ENP provides space to move North without obstructions.
2. Despite the habitat shift represented on the vulnerability map, the availability of nesting habitat will remain stable under all scenarios presented.
3. Under all SLR scenarios there will be fresh water head and ponds, for which the crocodile can find micro habitats to survive.

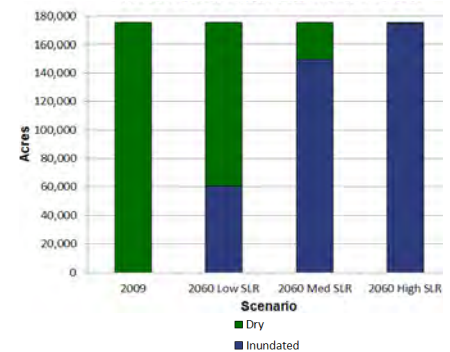


Figure 21: SLR habitat inundation for the American Crocodile

4. Generally speaking temperature is not expected to be an inhibiting factor for this species. Monitoring will be important to track potential changes to track behavior and juvenile survival, among others factors.
5. With the North-shifting habitat, it is expected the this species will have a higher mortality rate due to road crossing alone US 41 (Tamiami Trail). This will vary depending on the SLR scenario.
6. The ability of this species to move and adapt is restricted by the US 41 since the road will impede mangroves for migrating north even if salinity levels are suitable.

Summary of Habitat Inundation/Loss under SLR scenarios			
American Crocodile	Low	Medium	High
Habitat Inundated	30%	82%	98%
Other habitat impacts	0%	1%	1%
Current habitat un- changed	70%	7%	1%

Figure 22: Summary of Habitat Inundation/lost under SLR scenarios

Potential Habitat: Spatial Rules

Crocodile experts provided a series of “rules” to investigate and visualize what the potential habitat for the crocodile might be under a set of SLR estimations by 2060.

The spatial rules provided by experts were:

1. Shift the habitat north into ENP by an average of 10km inland (adjusted offset distance under each scenario).
2. All fully-inundated areas of current habitat should be eliminated as potential habitat.
3. Differentiate the future potential habitat into 3 categories: highest quality, average quality and marginal quality range. This differentiation was based on expert’s experience which indicates that there is a east-west decrease in terms of the quality.
4. The new islands created by higher sea levels on Florida Bay should be tagged as highest habitat quality. The same categorization should be designated to remaining islands on Florida Bay, and non-inundated areas on Key Largo.

Data Improvements Recommended for Future Assessments

1. Improve input distribution data, and models to incorporate better presentation of the spatial relationships of the habitat.
2. The scenarios will need to provide more biologically-relevant information such as vegetation change that gets triggered in each scenario as well as some indication of disturbance regimes.
3. Incorporation of hydrological features such as creeks should be incorporated in the scenario data.
4. Develop SLR scenarios that represent tidal fluctuations (current models only represent mean tide height).
5. Given how critical SLR is to crocodile habitat, future research should model highest tide (October) and re-asses habitat vulnerability with a series of adjusted “bath tub” inundation simulations using the latest LIDAR/NOAA SLR quadratic interpolation methods (officially used by the SE Florida 4-county climate compact).
6. Given the geographic mismatch of crocodile habitat geographic conditions and nesting condition, future assessments should consider developing vulnerability studies for both categories (this study focused only on the overall habitat).
7. Future research should study changes in freshwater flows, as salinity is an important factor for juvenile survival, and ultimately affecting distribution.
8. Future baseline scenarios should incorporate hydrology projections into its architecture (including salinity) given how relevant is this factor for this species.

Conclusions American Crocodile

The American crocodile habitat will be significantly impacted with SLR. Given the geographic distributions of its primary habitat and nesting areas on conservation lands, other threats such as land use change will represent direct stressors only in the future. Although nesting sites can take a limited amount of flooding and this makes medium to high SLR estimations of particular concern. Under all SRL modeled scenarios the geographic configuration of the habitat will change significantly. Primarily, most of the habitat located on the Florida Bay keys will disappear given its low elevation; the western section of the habitat by Cape Sable will be affected less significantly but in the high SLR projection given the presence of higher topographic lines. Conversely, most of the Cape Sable habitat extends will disappear.

New habitat is expected to take place along the south shore of the ENP. Experts also considered that the behavior of the western species may be a good indicator of what to expect with sea level rise. Finally, temperature variations will play an important role in determining adaptation as vegetation, and temperature variance is tightly linked.

Atlantic Salt Marsh Snake (*Nerodia clarkii taeniata*)

Habitat Description

The Atlantic salt marsh snake inhabits coastal salt marshes and mangrove swamps. Specifically, it occurs along shallow tidal creeks and pools, in a saline environment ranging from brackish to full strength. It is often associated with fiddler crab burrows.

The Atlantic salt marsh snake (*N. c. taeniata*) is one of three salt marsh snakes occurring in Florida. *Nerodia c. taeniata* occurs only on the east coast of Florida and is likely to be restricted to the salt marshes of Volusia County (Kochman, 1992a; USFWS, 1993). South of Volusia County this species intergrades with the more common mangrove salt marsh snake (*N. c. compressicauda*) in the marshes of Brevard and Indian River counties. Development pressure resulting in habitat loss and salt-marsh alteration caused by draining, diking, and impoundments, precipitates hybridization with freshwater snakes. These are the primary reasons the Atlantic salt marsh snake is listed as threatened

Kochman, 1992a; USFWS, 1993.

Extensive drainage and development within the coastal zone has reduced the available habitat of this species. Continued filling of coastal wetlands will further limit the range of this already restricted reptile. Additionally, creating impoundments in marshlands for mosquito control may eliminate habitat by changing water salinity. There is also a concern that habitat disturbance within these regions may have broken down natural isolating mechanisms between the Atlantic salt marsh snake and the adjacent freshwater snake (*Nerodia fasciata pictiventris*). This breakdown may be responsible for hybridization between these species.



Figure 23: Atlantic Salt-Marsh Snake

(source: <http://www.fws.gov/FWRITechnicalReportTR-15>)

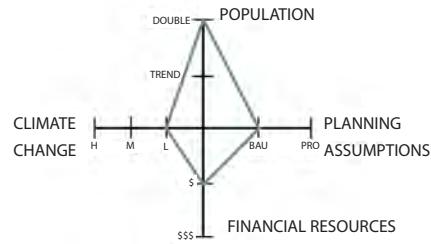
Atlantic Salt Marsh Snake Habitat



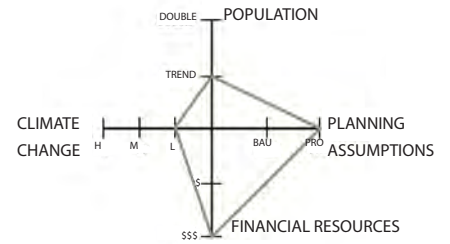
Figure 24: Atlantic Salt-Marsh Snake; Habitat

Atlantic Salt Marsh Snake Spatial Vulnerability Under MIT Scenarios

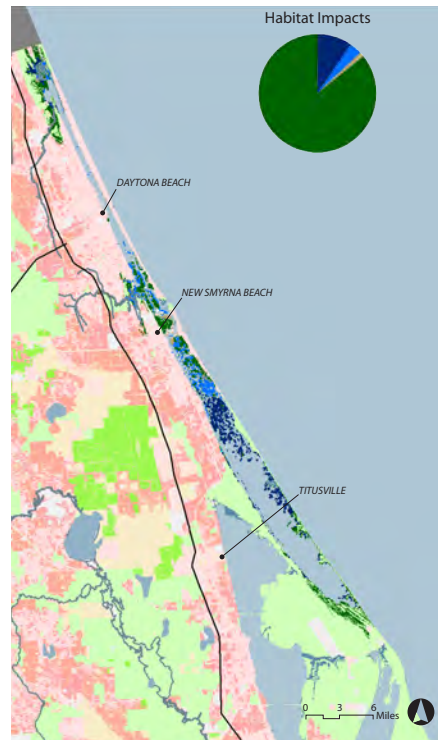
Scenario A



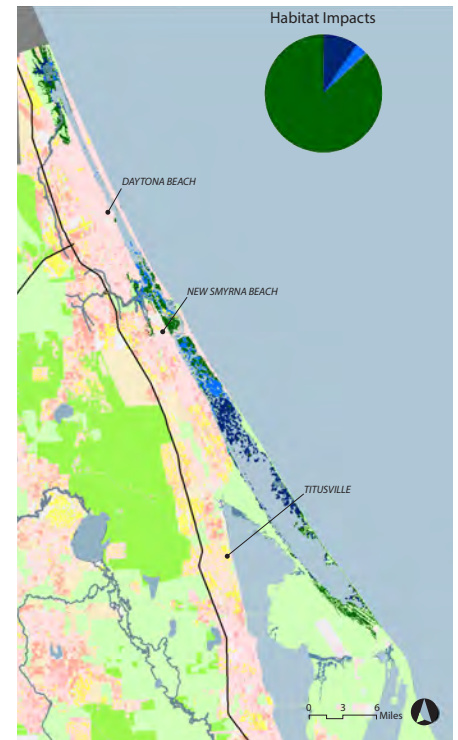
Scenario B



Scenario A Land Cover 2060



Scenario B Land Cover 2060



Map Legend

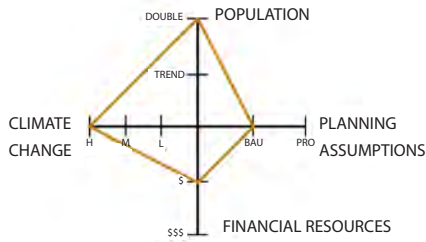
Habitat Conflict	
●	Agriculture Inundated
●	Agriculture Urbanized
●	Conservation Inundated
●	Other Uses Inundated
●	Other Uses Urbanized
●	No Habitat Conflict

Habitat Impacts By Land Use Type	2060	
	%	Acres
● Agriculture Inundated	0.02%	3
● Agriculture Urbanized	0.09%	19
● Conservation Inundated	9.53%	1,916
● Other Uses Inundated	3.33%	670
● Other Uses Urbanized	1.29%	259
● No Habitat Conflict	85.74%	17,240
Total Habitat Conflict	14.26%	2,868

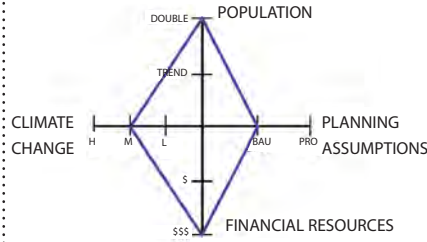
Habitat Impacts By Land Use Type	2060	
	%	Acres
● Agriculture Inundated	0.02%	3
● Agriculture Urbanized	0.07%	14
● Conservation Inundated	9.53%	1,916
● Other Uses Inundated	3.33%	670
● Other Uses Urbanized	0.23%	46
● No Habitat Conflict	86.82%	17,458
Total Habitat Conflict	13.18%	2,650

Figure 25: Atlantic Salt Marsh Snake: Spatial Vulnerability Under MIT Scenarios

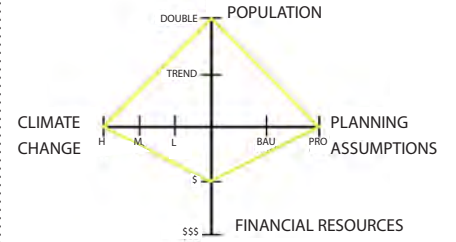
Scenario C



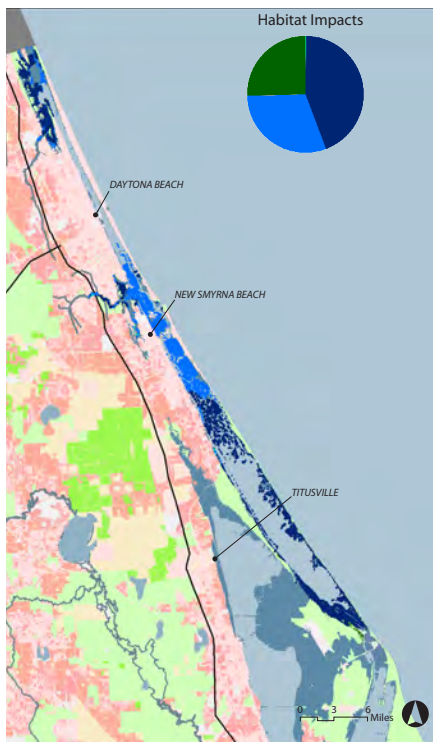
Scenario E



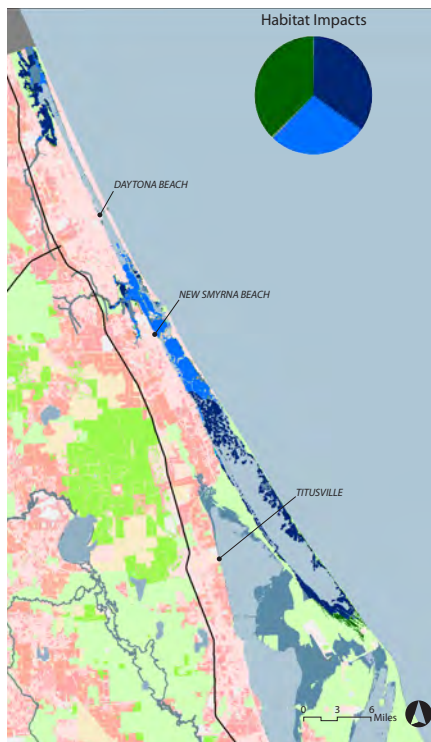
Scenario I



Scenario C Land Cover 2060



Scenario E Land Cover 2060



Scenario I Land Cover 2060



Habitat Impacts By Land Use Type	2060	
	%	Acres
Agriculture Inundated	0.16%	32
Agriculture Urbanized	0.01%	1
Conservation Inundated	44.10%	8,867
Other Uses Inundated	30.30%	6,092
Other Uses Urbanized	0.10%	20
No Habitat Conflict	25.34%	5,095
Total Habitat Conflict	74.66%	15,013

Habitat Impacts By Land Use Type	2060	
	%	Acres
Agriculture Inundated	0.07%	14
Agriculture Urbanized	0.05%	11
Conservation Inundated	34.70%	6,978
Other Uses Inundated	27.38%	5,506
Other Uses Urbanized	0.45%	90
No Habitat Conflict	37.35%	7,510
Total Habitat Conflict	62.65%	12,597

Habitat Impacts By Land Use Type	2060	
	%	Acres
Agriculture Inundated	0.16%	32
Agriculture Urbanized	0.01%	1
Conservation Inundated	44.10%	8,867
Other Uses Inundated	30.30%	6,092
Other Uses Urbanized	0.10%	19
No Habitat Conflict	25.34%	5,096
Total Habitat Conflict	74.66%	15,012

Potential Habitat / 2060

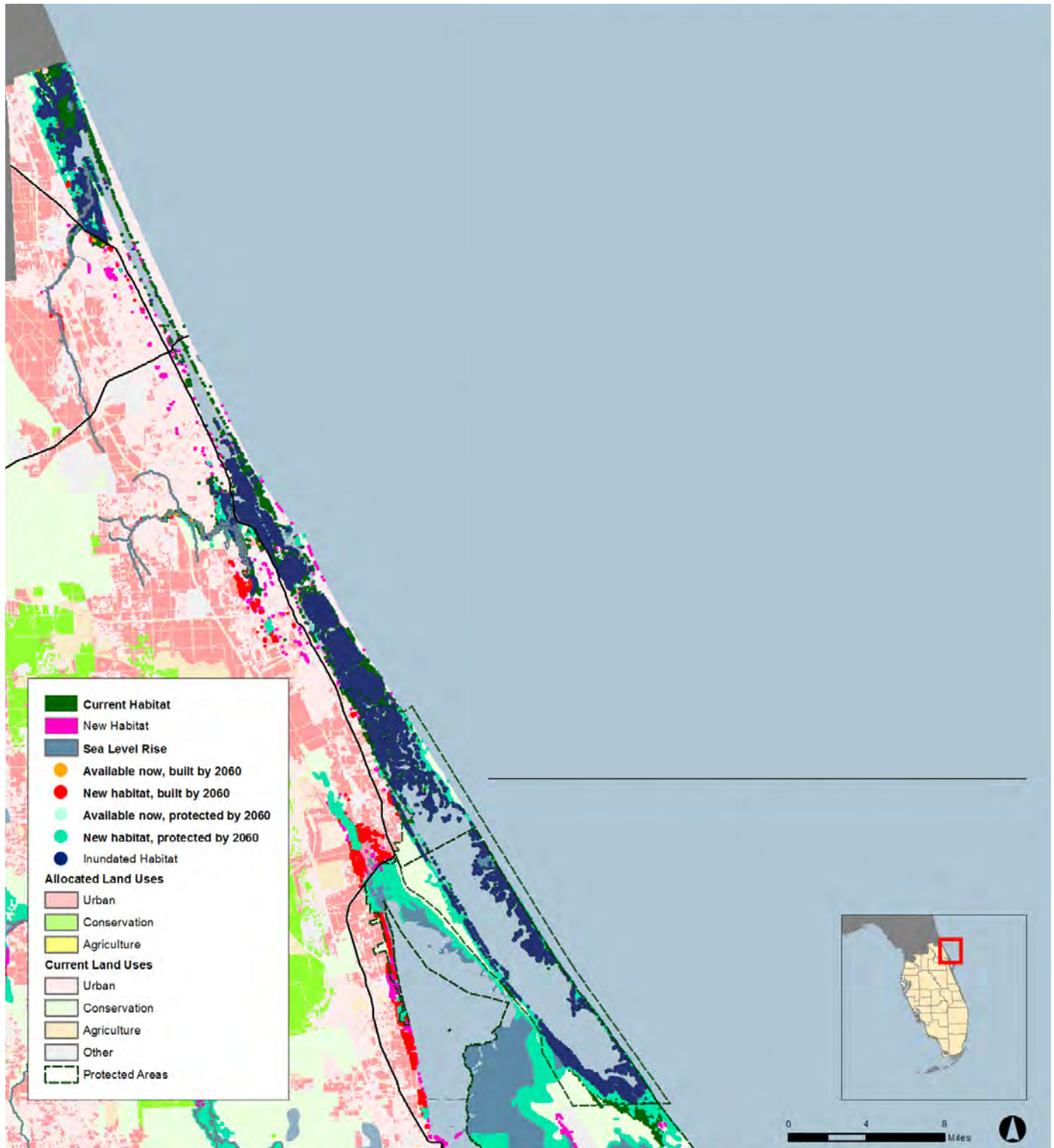


Figure 26: Atlantic Salt Marsh Snake: Potential Habitat 2060

Atlantic Salt Marsh Snake Habitats Impacts by Scenario and Current Management

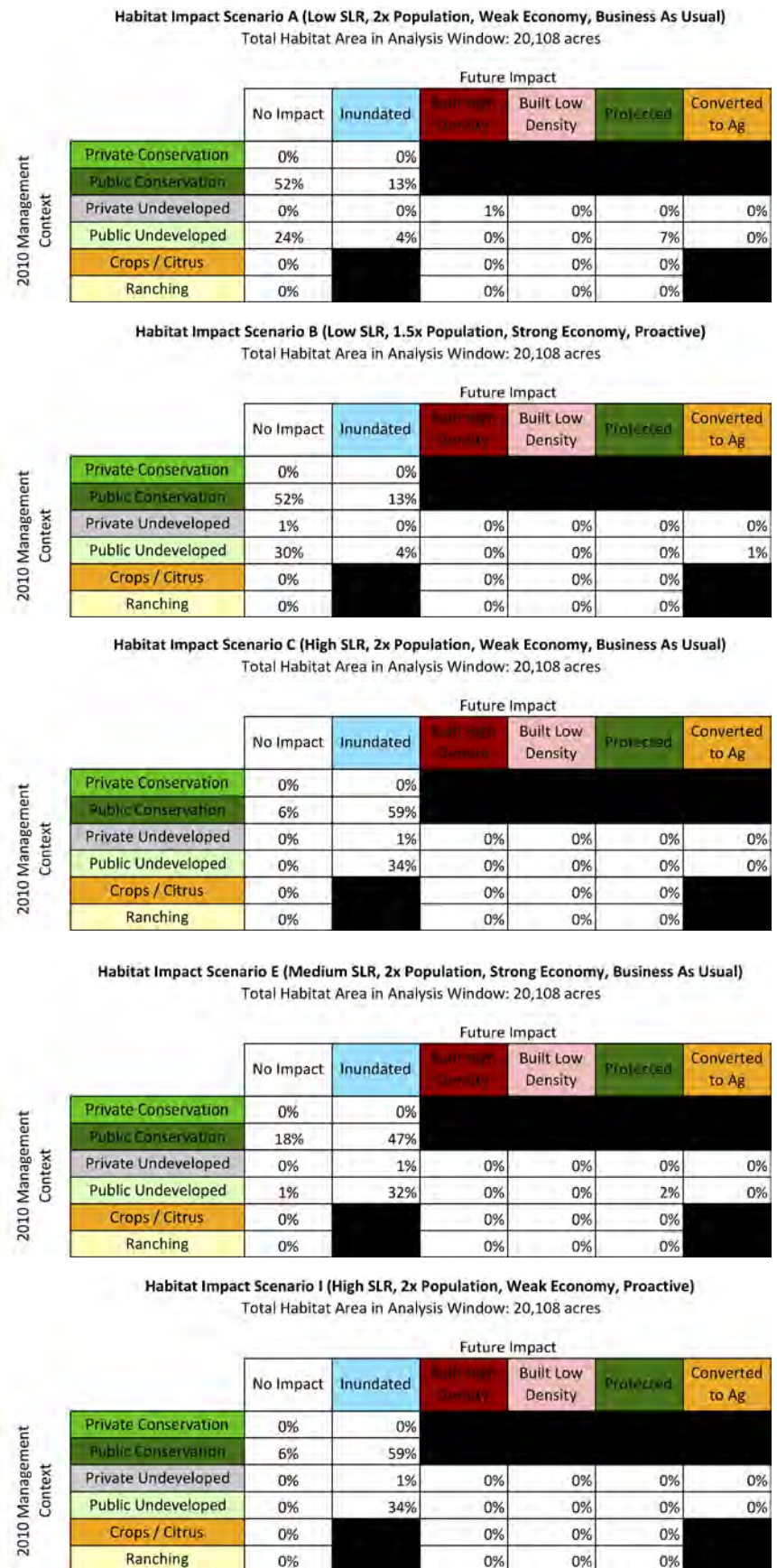


Figure 27: Atlantic Salt Marsh Snake Habitat Charts by Scenario

Habitat Impact : Scenario A
(Low SLR, 2x Population, Weak Economy, Business As Usual)

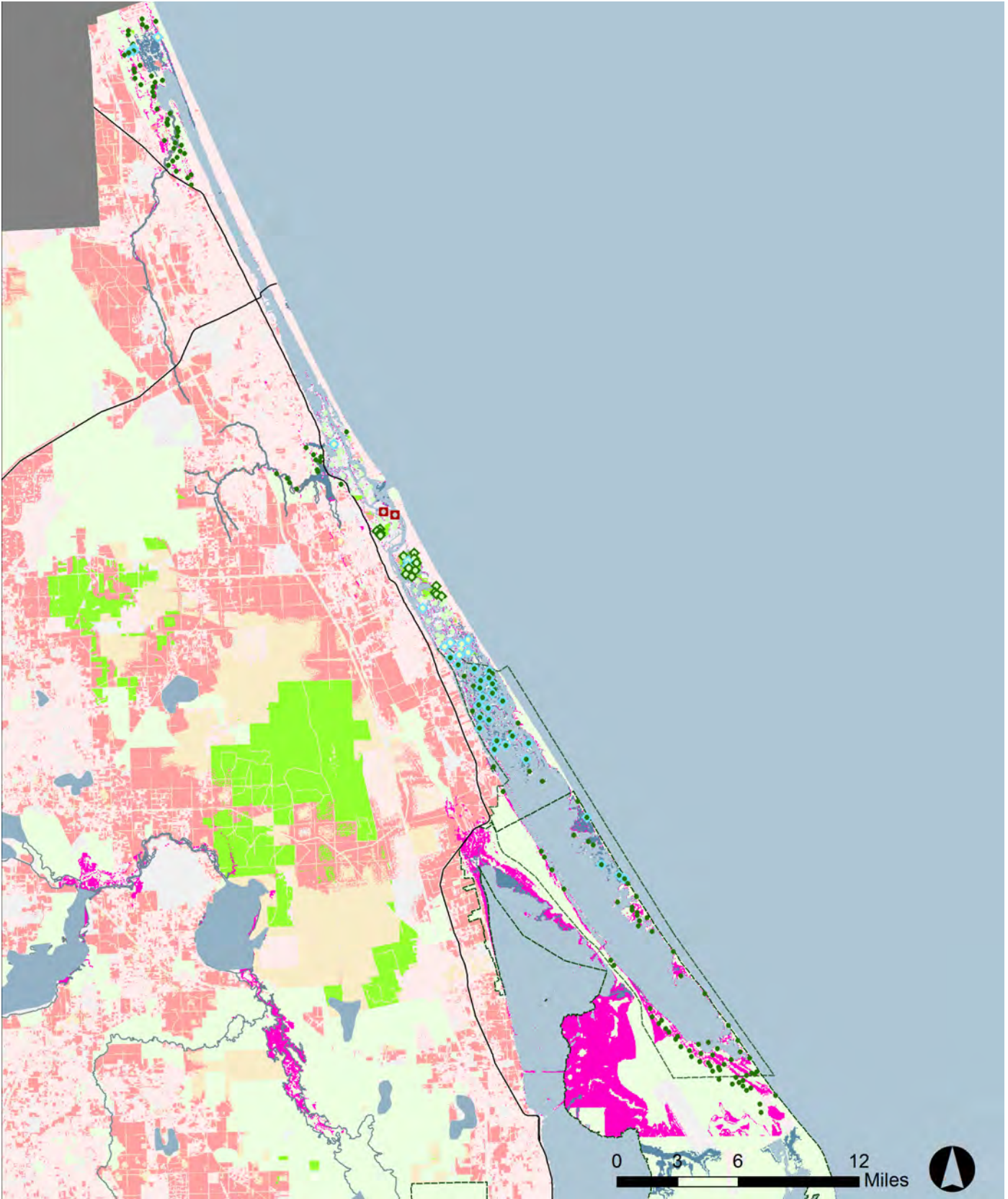
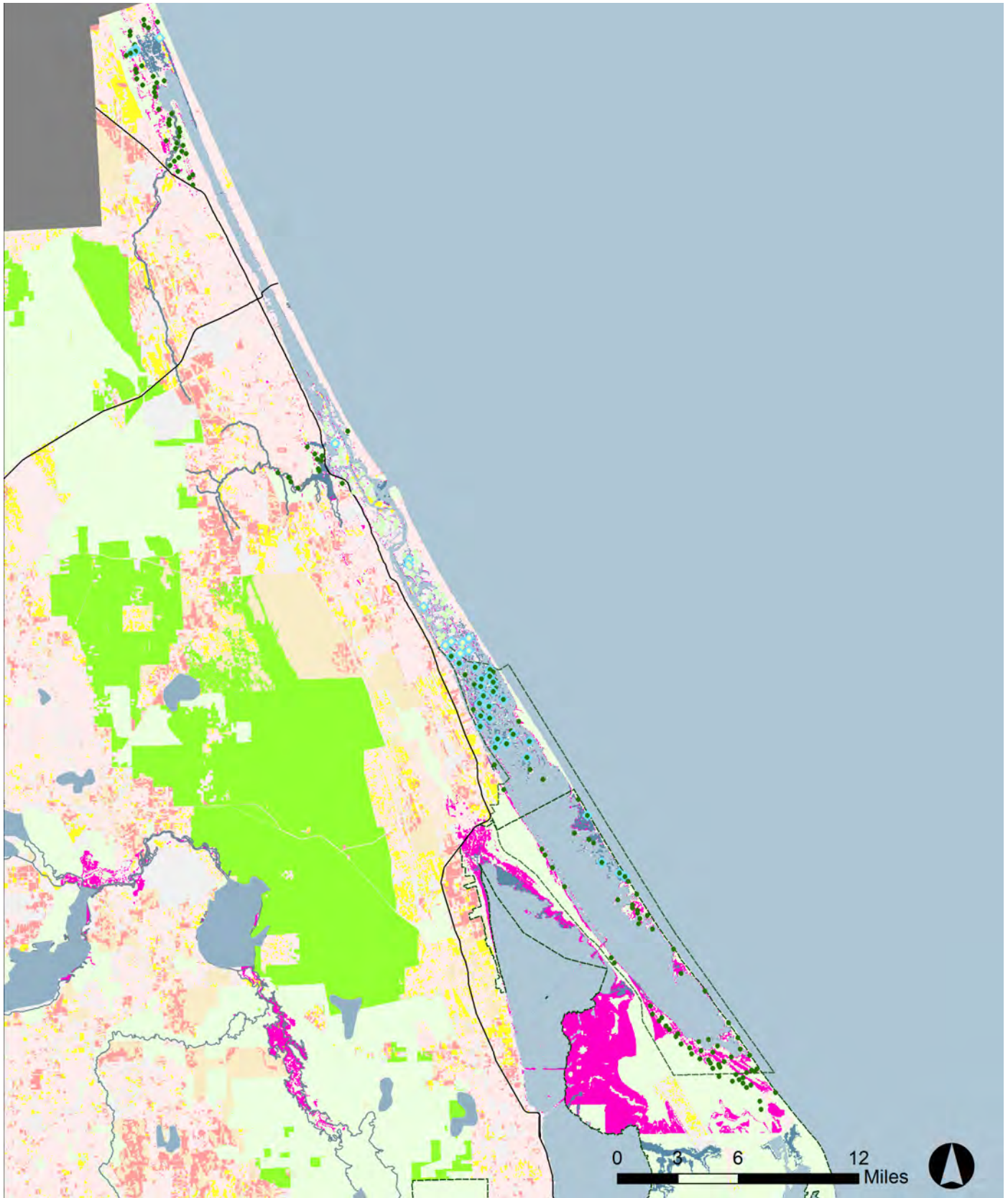
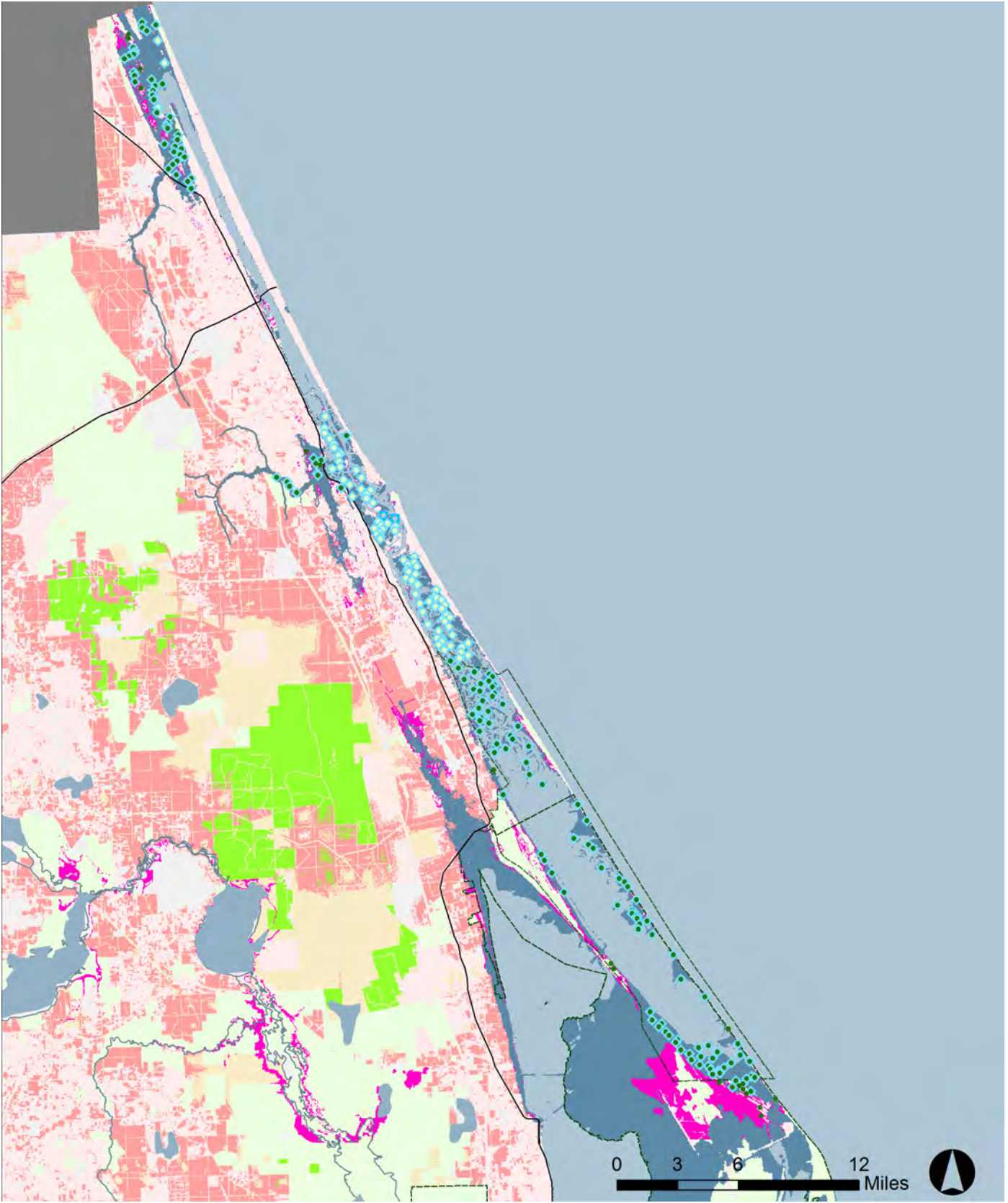


Figure 28: Atlantic Salt Marsh Snake: Habitat Impact Maps by Scenario

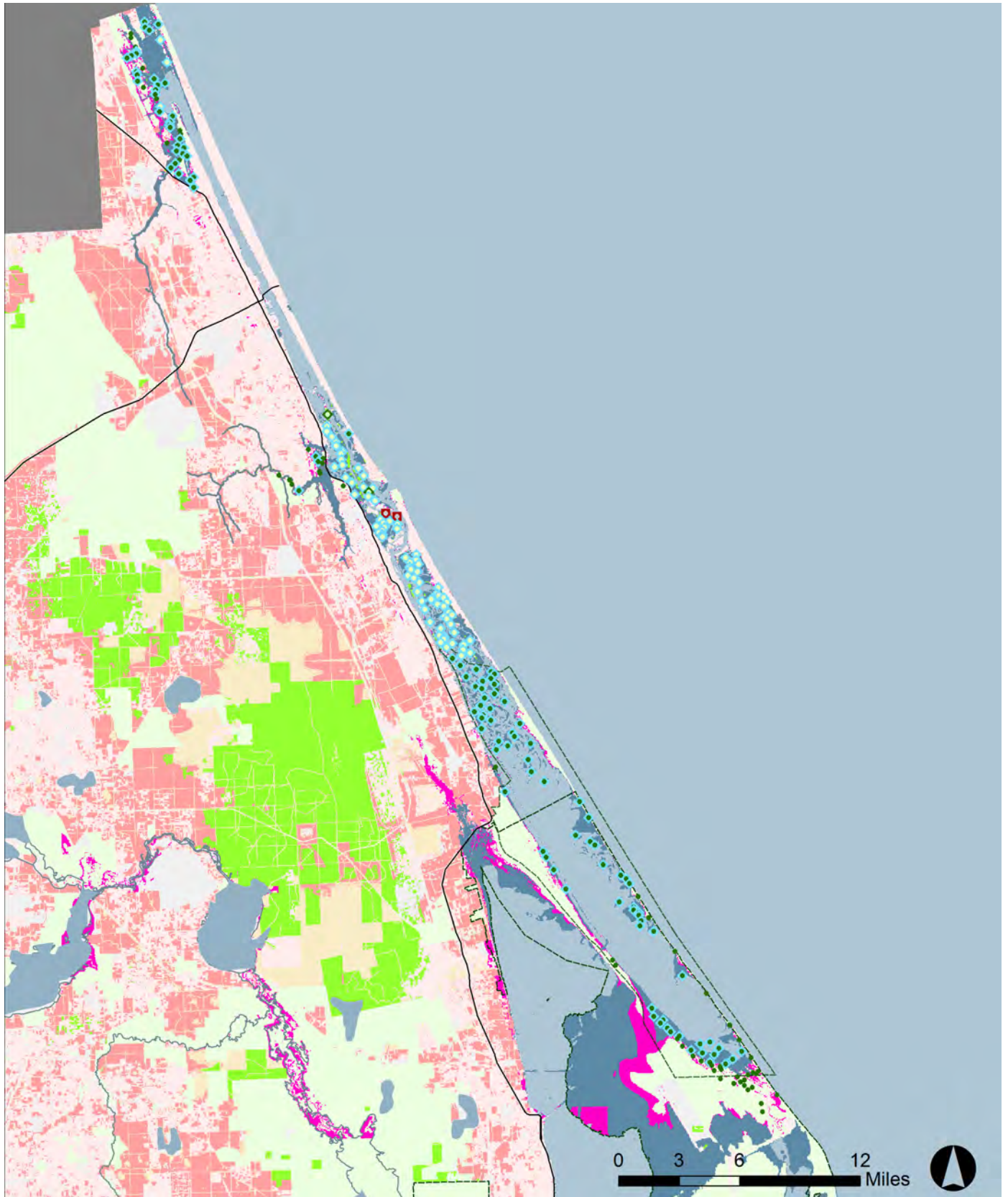
Habitat Impact : Scenario B
(Low SLR, 1.5x Population, Strong Economy, Proactive)



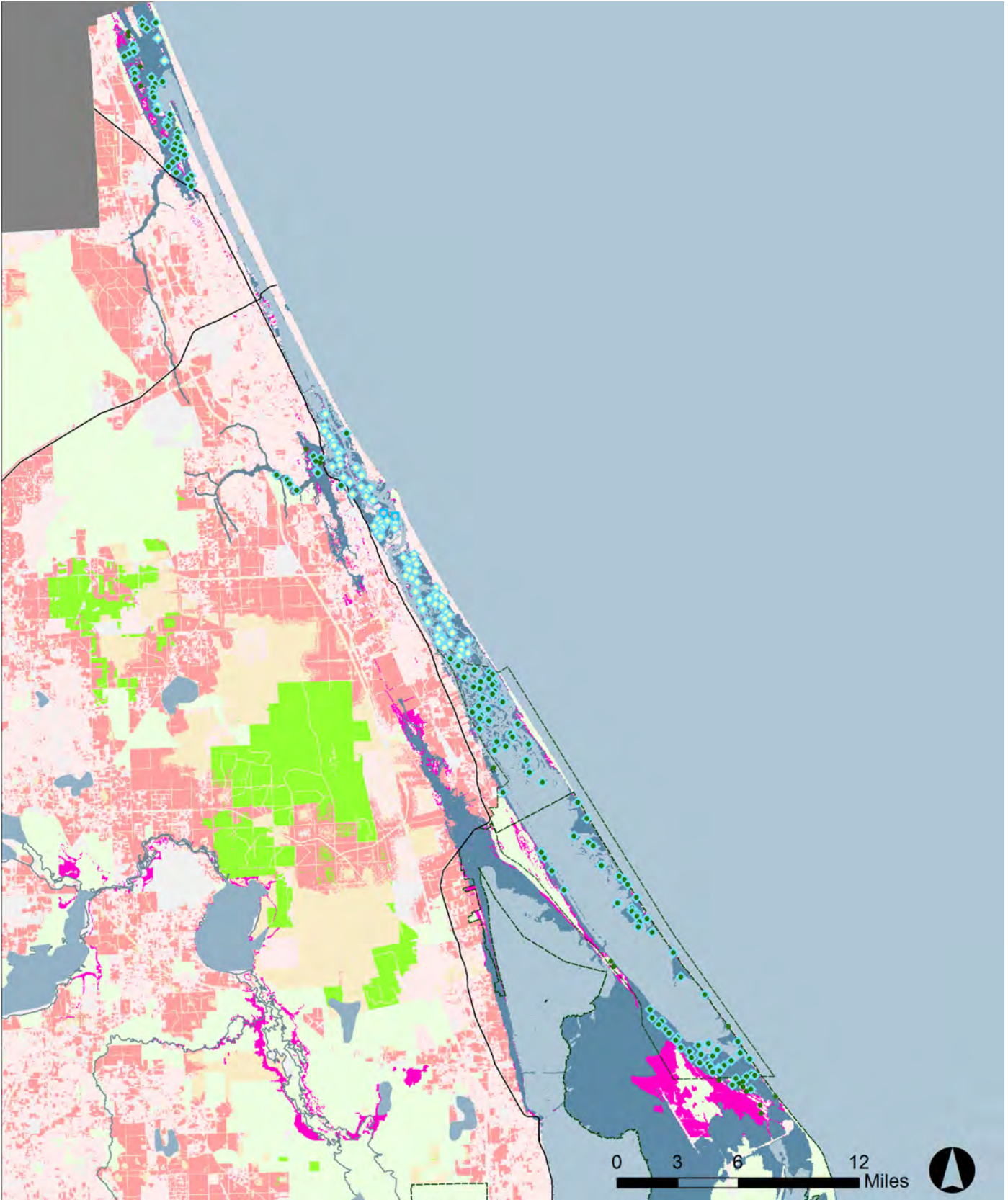
Habitat Impact : Scenario C
(High SLR, 2x Population, Weak Economy, Business As Usual)



Habitat Impact : Scenario E
(Medium SLR, 2x Population, Strong Economy, Business As Usual)



Habitat Impact : Scenariol
(High SLR, 2x Population, Weak Economy, Business As Usual)



Conclusions Spatial Vulnerability: Atlantic Salt Marsh Snake

General Findings

Changes in habitat due to sea level rise

A salt marsh — the primary habitat for the salt-marsh snake — is an environment in the upper coastal intertidal zone between land and salt water dominated by dense salt-tolerant plants. The salt marsh is a dynamic system which can adapt by expanding seaward or landward over time. Furthermore, as the height of the sea gradually increases, so does the reach of tidal waters—providing growth conditions that favor salt-marsh plants over terrestrial vegetation and allowing the marsh to expand. Unfortunately, in this case coastal development at a marsh’s edge prohibits its landward movement. In terms of the SLR effects on the salt marsh as noted by Phippen and Donovan (2011) , as sea level rise rates accelerate, the marsh system becomes destabilized. The inundated plants will no longer be provided with optimal growing conditions, making the marsh susceptible to greater levels of erosion and flooding. The cycle of destabilization increases over time.

The spatial vulnerability analysis indicates that the ASMS will lose anywhere between 17% and 94% of its habitat due to SLR (see table below), and that while other factors such as costal development and other land uses will not change its current habitat significantly, it will preclude the salt marsh to migrate inland, therefore prohibiting viable adaptation options.

Summary of Habitat Inundation/Loss Under SLR Scenarios			
Atlantic Salt-Mash Snake	Low	Medium	High
Habitat Inundated	17%	80%	94%
Other habitat impacts	1%	1%	2%
Current habitat unchanged	82%	19%	6%

Figure 29: Summary of Salt Marsh Snake Habitat Inundation/loss Under SLR Scenarios

Other climate factors

Besides the destabilization or disappearance of salt marsh due to SLR, other climate change factors are expected to impact the Atlantic salt marsh snake. Temperatures will not directly affect the creatures as they will find thermal refuge for cold weather events. However, winter freezes are likely to transform the vegetation in this area, and this is a source of climate impact not directly measurable here.

Urbanization: Coastal development conditions determine another important challenge for the Atlantic salt marsh snake. Because the MIT scenarios simulate current and future urban growth it was relatively simple for the experts to determine that current levels of coastal development represent a profound impediment for the potential displacement of salt marshes in this area towards the inland. The habitat of this species is largely in areas adjacent to existing development. However, it was possible to identify a set of small suitable areas that would serve as potential habitat in the future. Those can be seen in the final maps as identified as “potential habitat.” Nonetheless, the challenge for the conservation of this species is not so much future coastal development as it is existing development which already precludes most potential adaptation areas

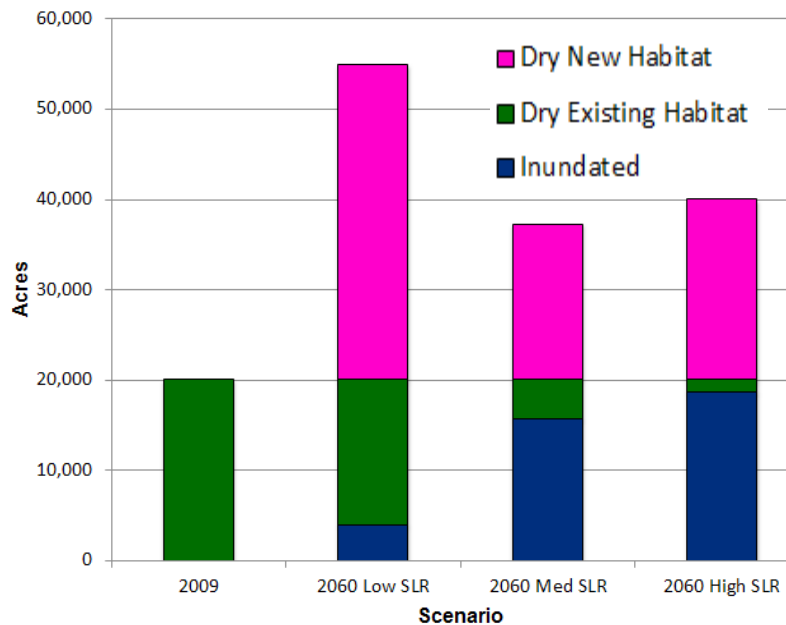


Figure 30: Salt Marsh Snake Inundation and New Potential Habitat

Future Habitat Under Scenarios and Associated Vulnerabilities:

The experts consulted provided a series of rules to determine what could be the potential habitat for the Atlantic Salt-Marsh Snake under the set of projected future scenarios.

The spatial rules were:

1. Identify areas west (inland) of current habitat patches with no development in future land use projections. Such undeveloped areas must be adjacent to salt or brackish water in order to provide suitable conditions for salt marsh inland migration.
2. Areas adjacent to streams and channels in close proximity to brackish or areas inundated may become suitable in the future.

** There is currently not enough ecological information available to create meaningful depictions of habitat quality, so simple presence/absence mapping is sufficient.*

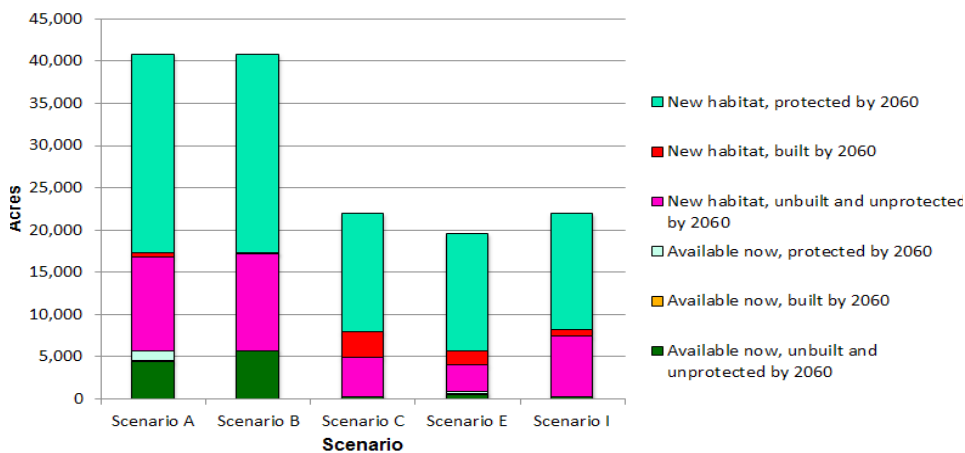


Figure 31: Development Conflict and Potential New Habitat for Areas Outside Primary Habitat

Data Improvements and Recommended Future Research

A series of research needs were identified in discussion with the experts. This list outlines the most important voids which should be researched in order to improve future efforts in the detection of the ASMS habitat vulnerability.

1. Future vulnerability analysis efforts should incorporate vegetation change conditions for each scenario to determine the effects on habitat. This is particularly relevant for mangroves, which may encroach on salt marsh habitats.
2. Studies on salinity dynamics on channels and streams will be useful to determine future potential habitat.
3. Future research should model highest tide (October) and re-evaluate the habitat vulnerability with a series of SLR projections using the latest LIDAR/ NOAA SLR quadratic interpolation methods.
4. Future work should integrate temperature as it represents the most relevant factor determining the arrival of mangroves to this area.

Conclusions Atlantic Salt Marsh Snake

The Atlantic Salt Marsh Snake will be significantly impacted under most simulated scenarios. The ASMS presents three areas of primary habitat in the north east of Peninsular Florida: the south section expanding Cape Canaveral/ Kennedy Space Center and the Canaveral Seashore areas, the central area composed by Port Orange and the Ponce Inlet and lastly a northern section Daytona Beach and Ormond Beach (see habitat map). Given geomorphology and the levels of current and future coastal development each of these areas will be impacted differently.

Low SLR affects primarily the central section by inundating current conservation habitat (9.53 Medium to high SLR SLR adds impacts on both northern and southern ranges. The substantial difference between the lower and the higher SLR projections in terms of the habitat impacts is the amount of non-protected areas that get inundated. Non-protected areas in ASMS habitat grow from 4.7% to 28% to 31% under low, medium and high SLR. This is a clear indicator that with higher SLR projections a significant percent of the available habitat areas will be inundated. Conversely almost half of the habitat on protected areas will disappear due to inundation. Furthermore, this does not account for tidal conditions or storm surges on barriers beaches, which may further diminish available habitat.

Salt Marsh Snake Habitat Impacted Under SLR			
Conservation Status	Low	Medium	High
Protected Areas inundated	10%	35%	44%
Non-protected areas inundated	5%	28%	31%

Figure 32: Salt Marsh Snake Habitat Impacts Under SLR

Managed appropriately, the Cape Canaveral and the Kennedy Space Center Canaveral Sea Shore presents clusters with the highest adaptation potential. Unfortunately, outside of that area and given reduced space to move, the species may not have many options in terms of adaptation as it may seem trapped between SLR and coastal development. Despite some scenarios showing substantial additional coastal development, SLR remains the primary cause of habitat loss.

Key Deer *(Odocoileus virginianus clavium)*

Habitat Description

The Key Deer is a subspecies of the white-tailed deer and is only found in the Florida Keys.

The Key Deer's historical range probably extended from Key Vaca to Key West. Their current range includes approximately 26 islands from Big Pine Key to Sugarloaf Key. Due to uncontrolled hunting and habitat destruction, their numbers were estimated at less than 50 animals in the 1940's. With the establishment of National Key Deer Refuge in 1957 and intensive law enforcement efforts, the population has since increased and has now stabilized. A research study completed in 2000 estimated the population between 700 and 800 deer with two-thirds of this population located on Big Pine Key.

Key Deer use all habitat types within their range, including pine rocklands, hardwood hammocks, mangroves, and freshwater wetlands. Pine rocklands are of particular importance because they contain permanent freshwater sources, which are essential for their survival. Key Deer feed on over 160 species of plants including the native red, black and white mangroves and thatch palm berries. As human development has increased within the range of the Key deer they have increased their use of residential and commercial areas where they feed on ornamental plants.

(Source: Florida Fish and Wildlife Commission)



Figure 33: Key Deer

Key Deer Habitat

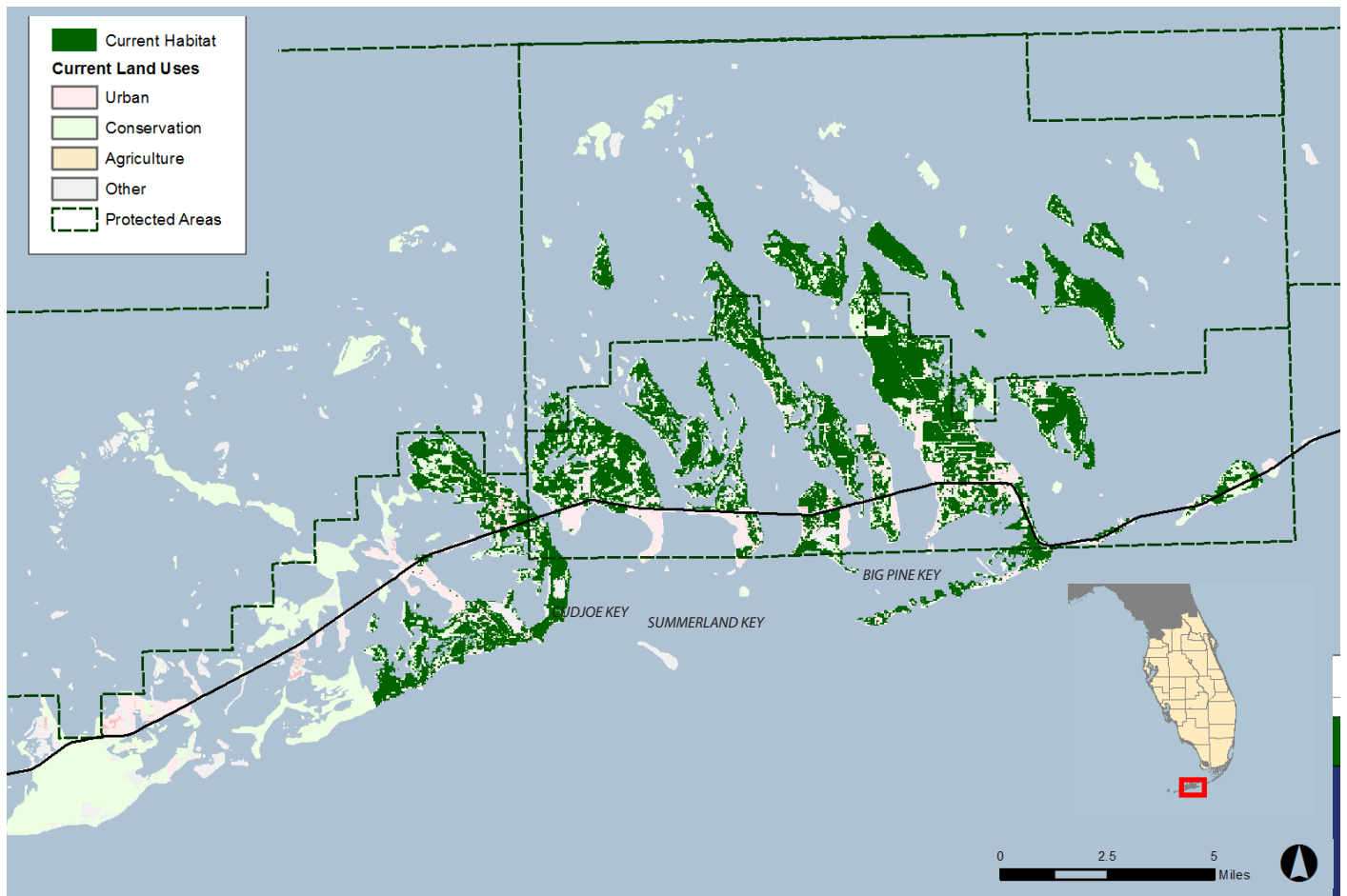


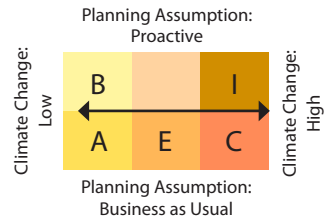
Figure 34: Key Deer: habitat

Key Deer Spatial Vulnerability Under MIT Scenarios

Scenario Dimensions Table

Climate Change	Population (millions)	Planning Assumptions	Financial Resources
Low (+3.6" SLR)	Trend (25)	Business as Usual (BAU)	Low (\$)
Med. (+18.4" SLR)	Double (29)	Proactive (PRO)	High (\$\$\$)
High (+39.1" SLR)			

Scenario Organization

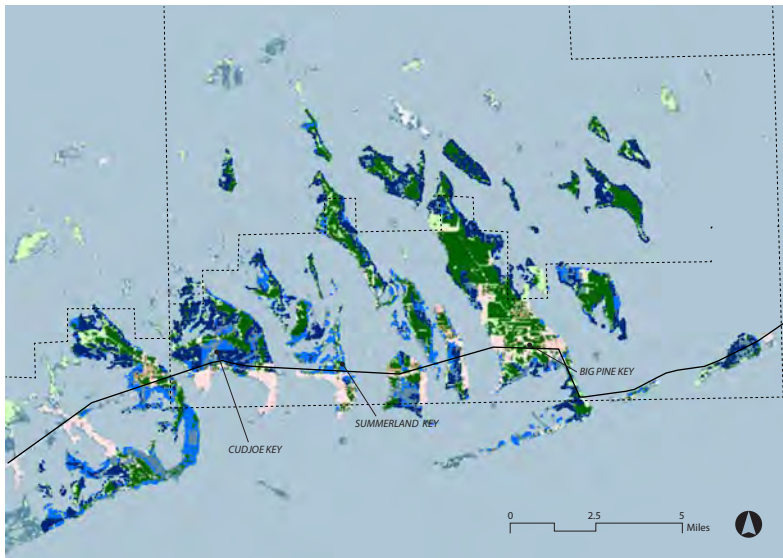


Map Legend

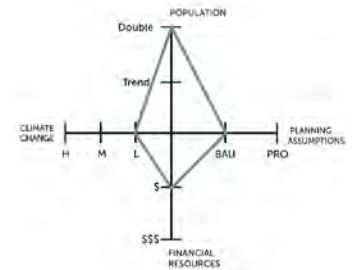
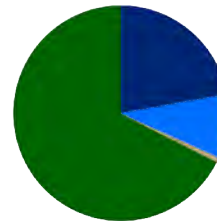
Current Land Use	Projected Land Use
Agriculture	Agriculture
Conservation	Conservation
Urban	Urban

Habitat Conflict
Agriculture Inundated
Agriculture Urbanized
Conservation Inundated
Other Uses Inundated
Other Uses Urbanized
No Habitat Conflict

Scenario A Land Cover 2060

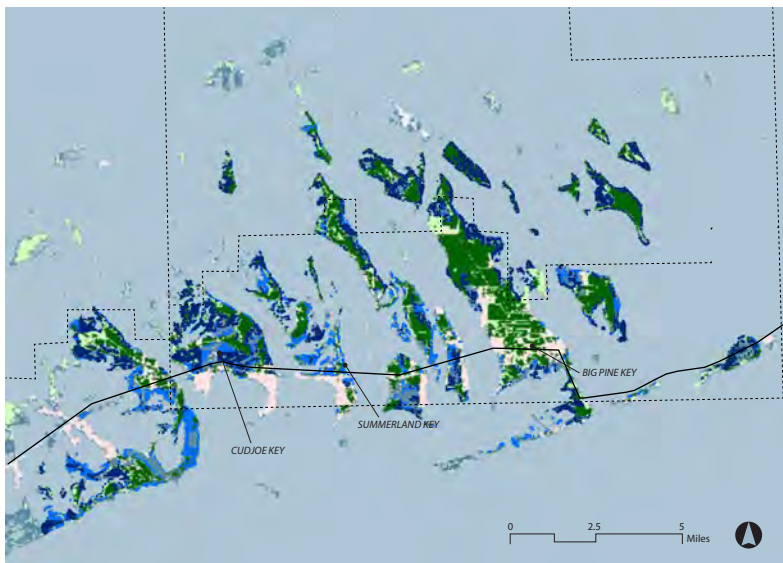


Habitat Impacts

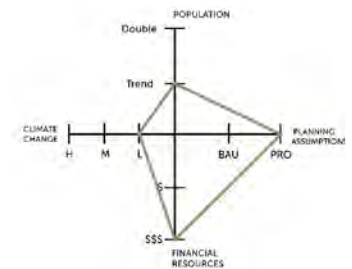
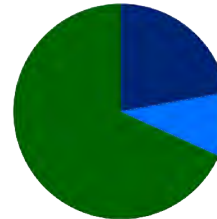


Habitat Impacts	2060	
	%	Acres
By Land Use Type		
Conservation Inundated	22.19%	4,178
Other Uses Inundated	9.53%	1,795
Other Uses Urbanized	0.73%	137
No Habitat Conflict	65.56%	12,721
Total Habitat Conflict	32.44%	6,109

Scenario B Land Cover 2060



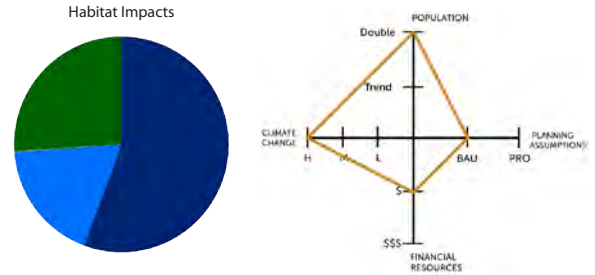
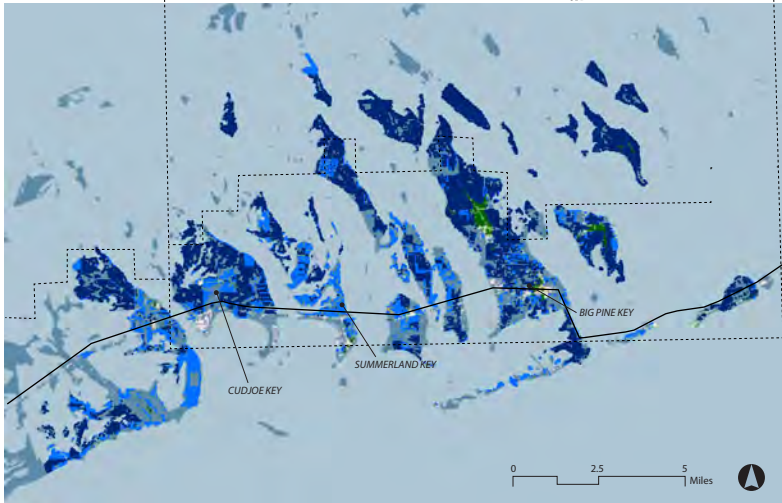
Habitat Impacts



Habitat Impacts	2060	
	%	Acres
By Land Use Type		
Conservation Inundated	9.53%	1,795
Other Uses Inundated	68.28%	12,858
No Habitat Conflict	31.72%	5,973
Total Habitat Conflict	31.72%	5,973

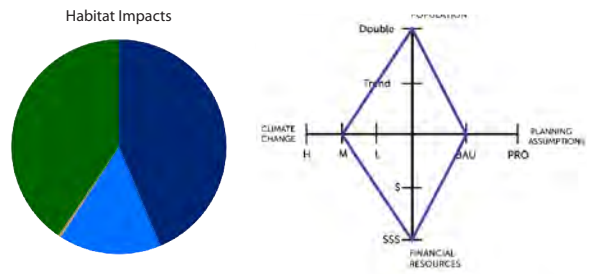
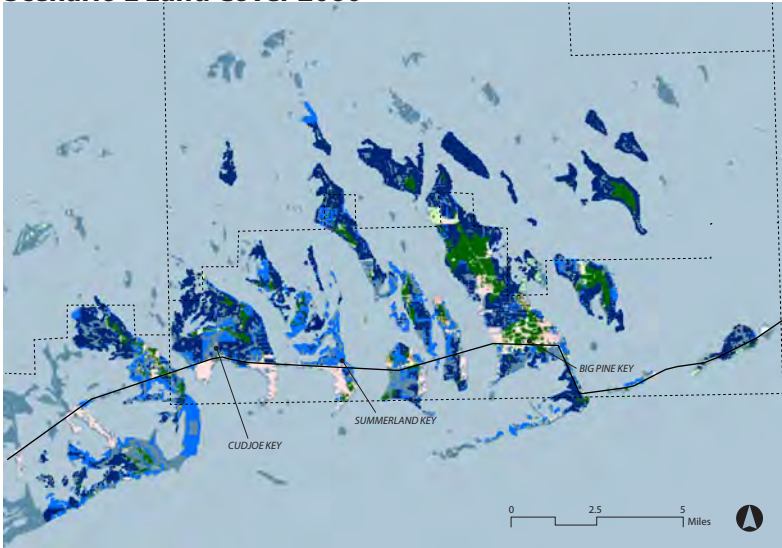
Figure 35: Key Deer Spatial Vulnerability Under MIT Scenarios

Scenario C Land Cover 2060



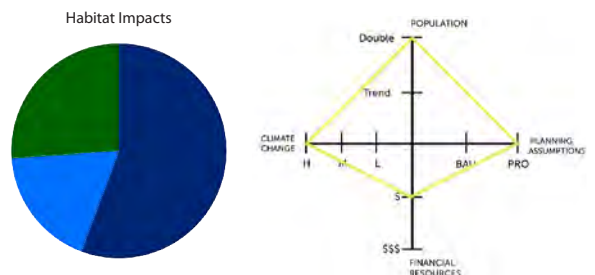
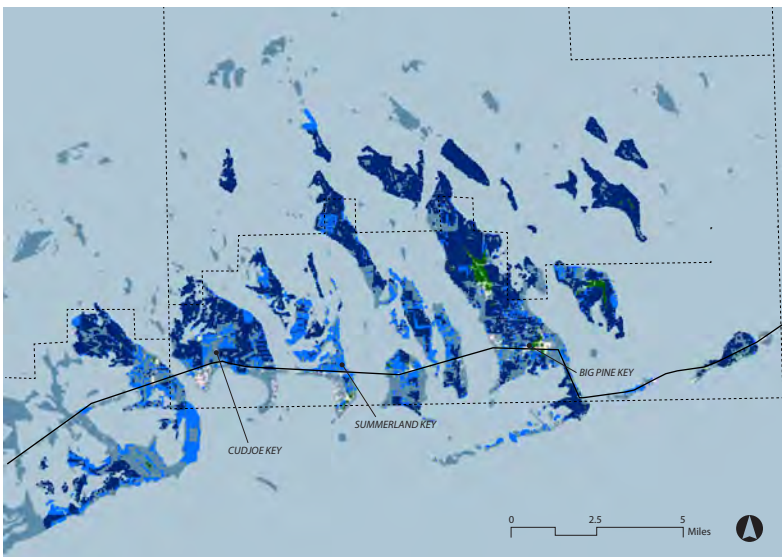
Habitat Conflict By Land Use Type	2060	
	%	Acres
● Conservation Inundated	55.69%	10,486
● Other Uses Inundated	18.27%	3,440
● Other Uses Urbanized	0.09%	17
● No Habitat Conflict	25.95%	4,887
Total Habitat Conflict	74.05%	13,943

Scenario E Land Cover 2060



Habitat Conflict By Land Use Type	2060	
	%	Acres
● Conservation Inundated	43.71%	8,230
● Other Uses Inundated	15.40%	2,900
● Other Uses Urbanized	0.41%	78
● No Habitat Conflict	40.48%	7,622
Total Habitat Conflict	59.52%	11,208

Scenario I Land Cover 2060-



Habitat Conflict By Land Use Type	2060	
	%	Acres
● Conservation Inundated	55.69%	10,486
● Other Uses Inundated	18.27%	3,440
● Other Uses Urbanized	0.01%	1
● No Habitat Conflict	26.04%	4,903
Total Habitat Conflict	73.96%	13,927

Key Deer Habitat Impacts by Scenario and Current Management

Habitat Impact Scenario A (Low SLR, 2x Population, Weak Economy, Business As Usual)
Total Habitat Area in Analysis Window: 18,830 acres

2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	1%	1%				
Public Conservation	50%	31%				
Private Undeveloped	2%	5%	0%	0%	1%	0%
Public Undeveloped	6%	4%	0%	0%	0%	0%
Crops / Citrus	0%		0%	0%	0%	
Ranching	0%		0%	0%	0%	

Habitat Impact Scenario B (Low SLR, 1.5x Population, Strong Economy, Proactive)
Total Habitat Area in Analysis Window: 18,830 acres

2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	1%	1%				
Public Conservation	50%	31%				
Private Undeveloped	3%	5%	0%	0%	0%	0%
Public Undeveloped	5%	4%	0%	0%	0%	0%
Crops / Citrus	0%		0%	0%	0%	
Ranching	0%		0%	0%	0%	

Habitat Impact Scenario C (High SLR, 2x Population, Weak Economy, Business As Usual)
Total Habitat Area in Analysis Window: 18,830 acres

2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	0%	1%				
Public Conservation	4%	77%				
Private Undeveloped	0%	8%	0%	0%	0%	0%
Public Undeveloped	0%	10%	0%	0%	0%	0%
Crops / Citrus	0%		0%	0%	0%	
Ranching	0%		0%	0%	0%	

Habitat Impact Scenario E (Medium SLR, 2x Population, Strong Economy, Business As Usual)
Total Habitat Area in Analysis Window: 18,830 acres

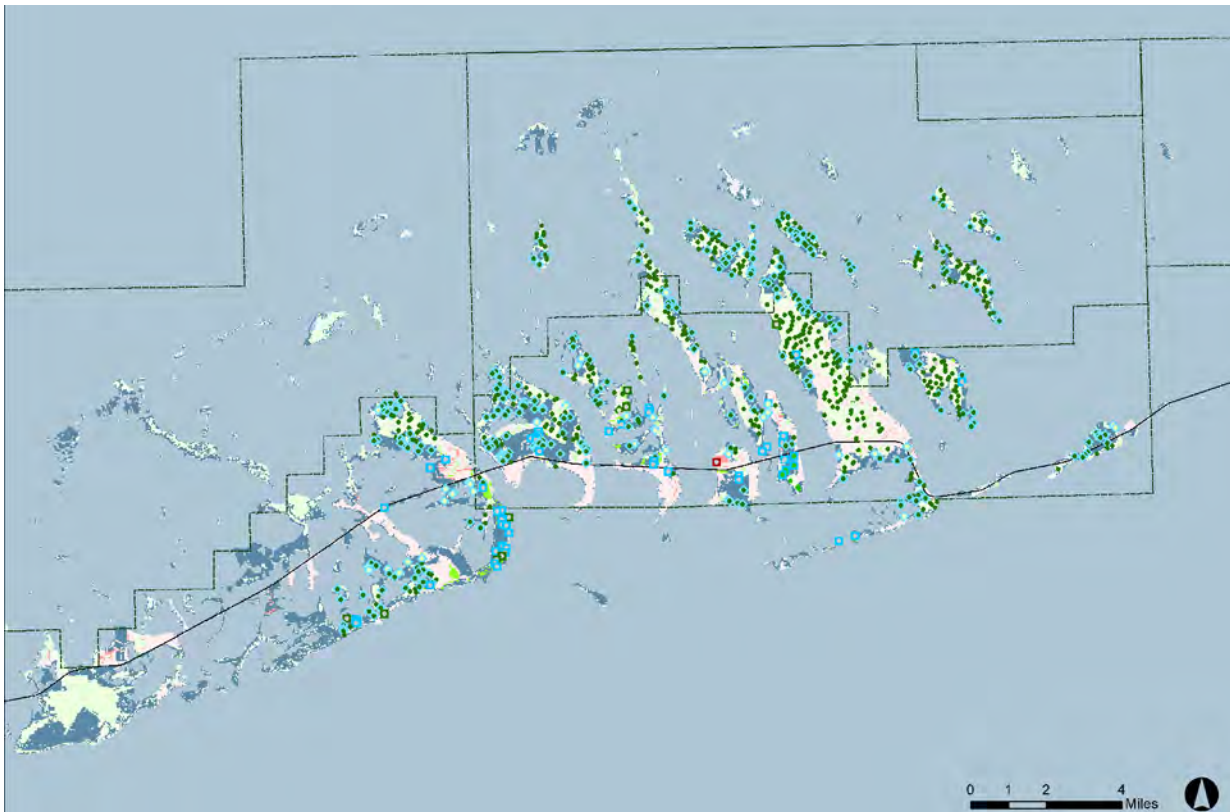
2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	0%	1%				
Public Conservation	20%	60%				
Private Undeveloped	0%	7%	0%	0%	0%	0%
Public Undeveloped	2%	8%	0%	0%	0%	0%
Crops / Citrus	0%		0%	0%	0%	
Ranching	0%		0%	0%	0%	

Habitat Impact Scenario I (High SLR, 2x Population, Weak Economy, Proactive)
Total Habitat Area in Analysis Window: 18,830 acres

2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	0%	1%				
Public Conservation	4%	77%				
Private Undeveloped	0%	8%	0%	0%	0%	0%
Public Undeveloped	0%	10%	0%	0%	0%	0%
Crops / Citrus	0%		0%	0%	0%	
Ranching	0%		0%	0%	0%	

Figure 36: Key Deer Habitat Impact Charts by Scenario

Habitat Impact : Scenario A
(Low SLR, 2x Population, Weak Economy, Business As Usual)



Habitat Impact : Scenario B
(Low SLR, 1.5x Population, Strong Economy, Proactive)

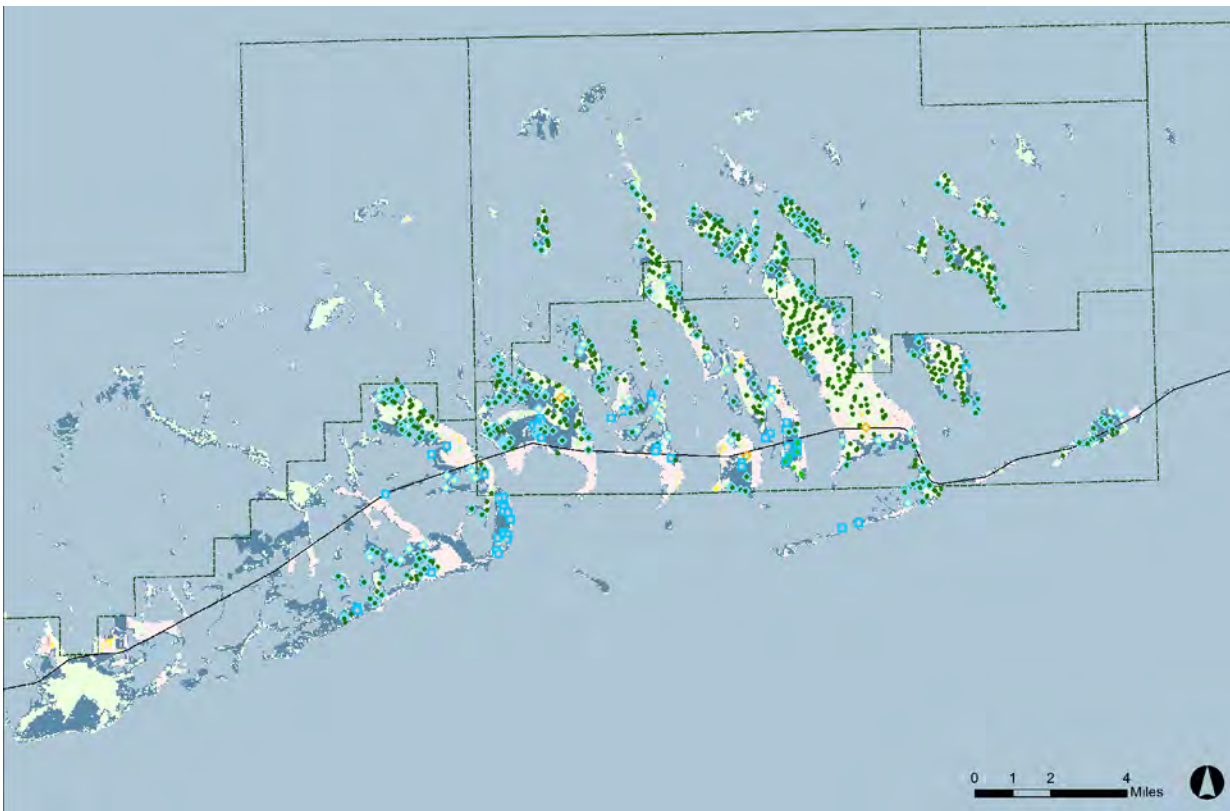
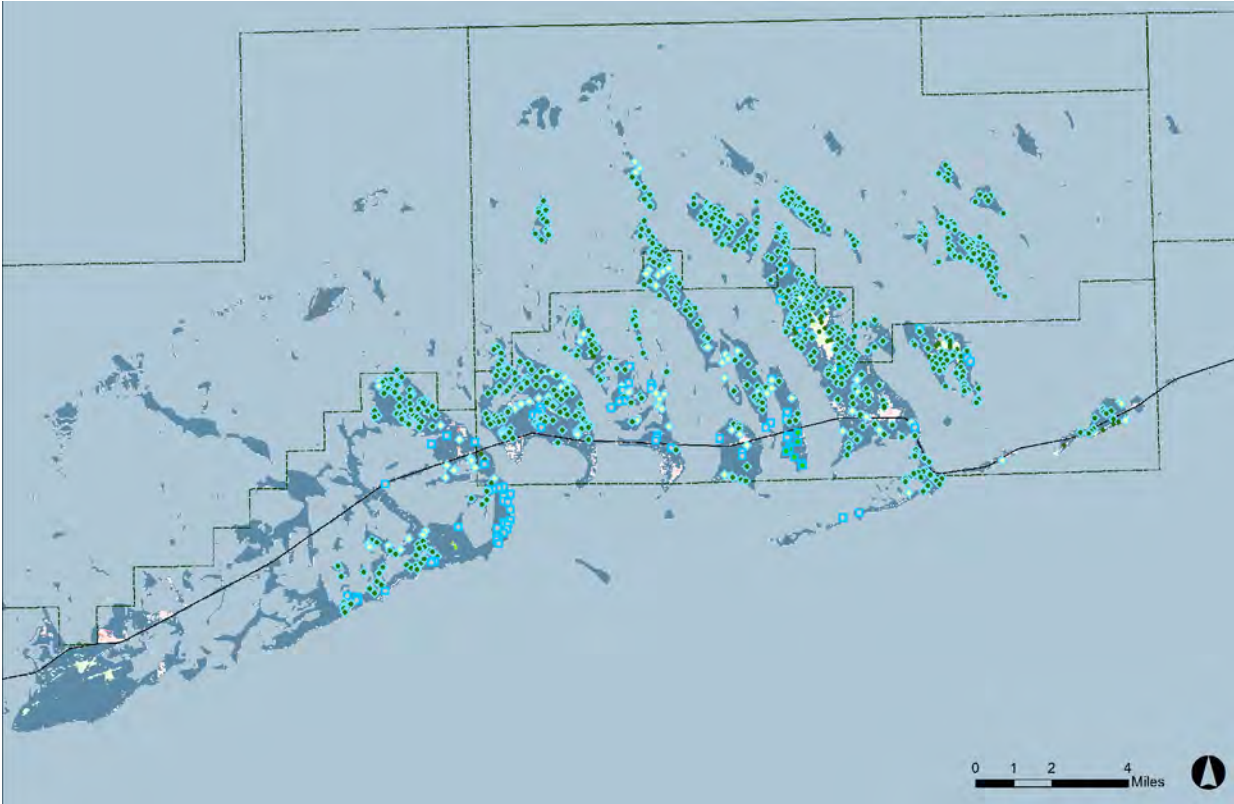
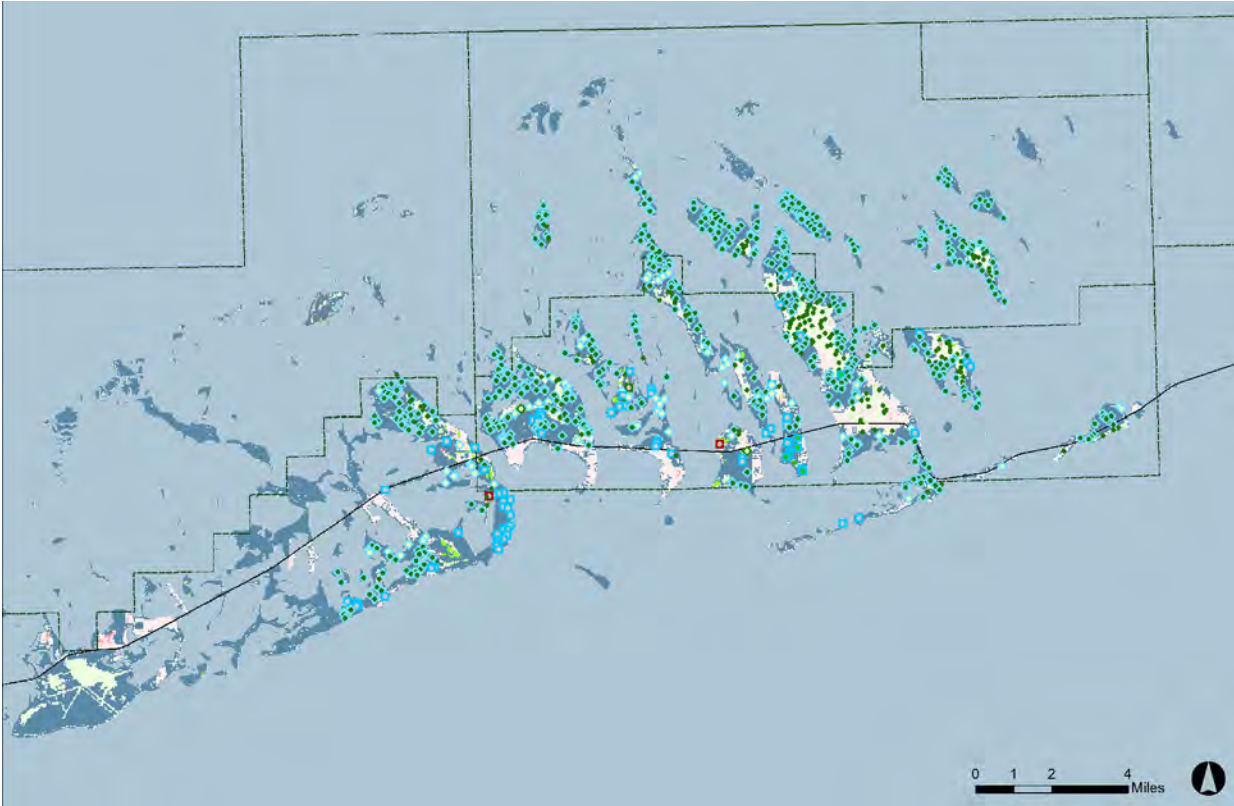


Figure 37: Key Deer Habitat Impact Maps by Scenario

Habitat Impact : Scenario C
(High SLR, 2x Population, Weak Economy, Business As Usual)



Habitat Impact : Scenario E
(Med SLR, 2x Population, Strong Economy, Business As Usual)



**Habitat Impact : Scenario I
(High SLR, 2x Population, Weak Economy, Proactive)**

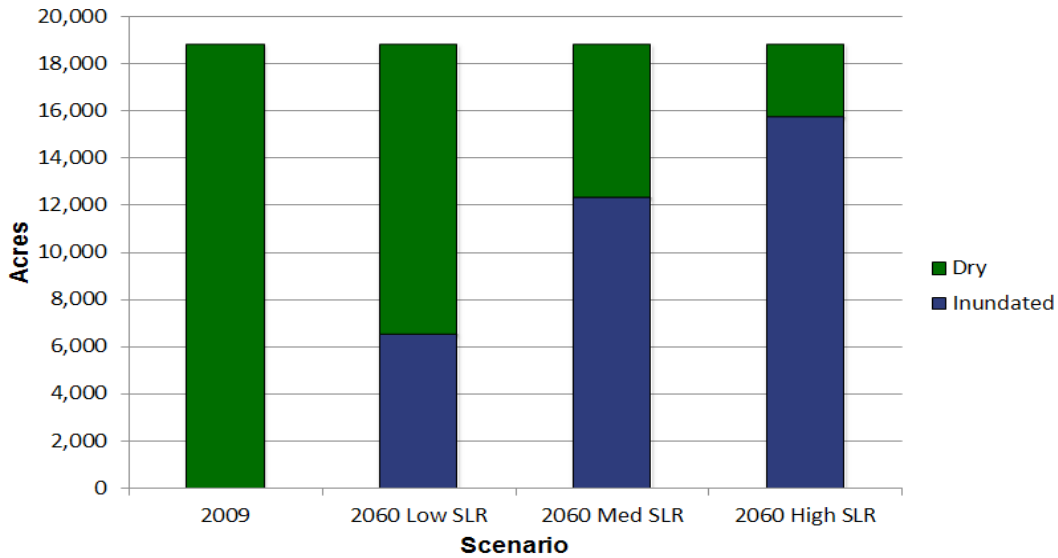
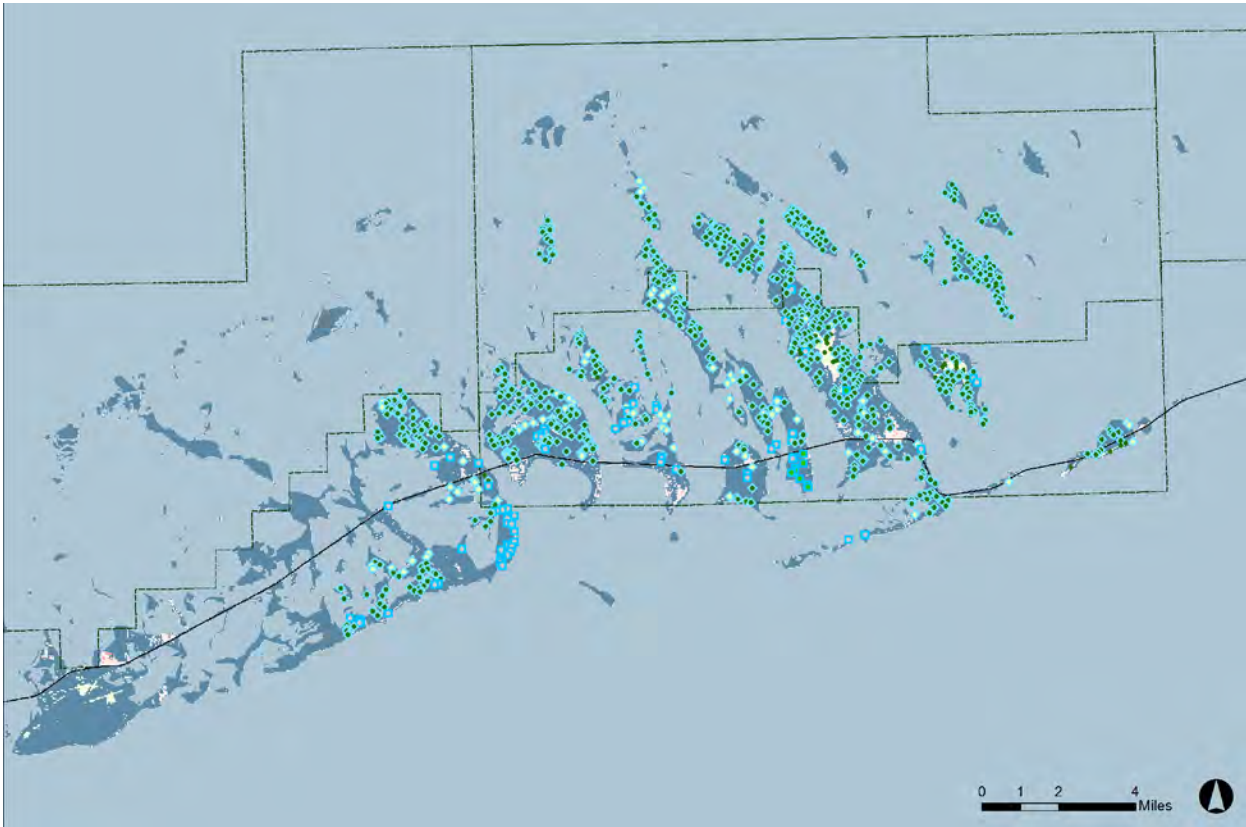


Figure 38: Summary of Inundation Impacts to Key Deer Habitat Under Different Scenarios

Conclusions Spatial Vulnerability: Key Deer

Process

In contrast to the extensive habitat mapping changes suggested for many other species, our experts were generally satisfied with the existing 2009 FFWC model for the Key deer. For this reason, those data were used without modification. In this case, the area surrounding Key deer habitat is mostly “built out” and so there were not many projected changes relative to development pressure.

General Results

Sea-level rise and land use change impacts on key deer habitat vary from 32% of the total habitat (5,972 acres) under a the low SLR scenario with trend population growth and proactive urbanization and land policies to 74.6% (13,942 acres) in a high SLR scenario with double population and ‘business as usual’ urbanization and land policies.

Summary of Habitat Inundation/Loss Under SLR Scenarios			
Key Deer	Low	Medium	High
Habitat Inundated	32%	60%	74%
Other habitat impacts	1%	1%	<1%
Current habitat not change	66%	40%	26%

Figure 39: Key Deer Habitat Inundation/Loss Under SLR Scenarios

Besides the expected displacement of the Key Deer habitat due to Sea level rise, there are additional challenges associated with SLR. Sea level rise would cause the salinity to increase in fresh water areas that the key deer use as drinking water. Unfortunately currently salinity recordings are so variable that few conclusions can be made from the studies. Therefore is the need to standardize methods to measure and register these conditions due to their importance to the survival of the key deer. However, experts agreed that salinity for deer drinking water should not exceed 15 parts per thousand. Given these critical conditions for the survival of this species, future research should add a variable for drinking water to the vulnerability model.

Changes in precipitation will also affect hydrological conditions and treating to change the watering holes conditions. Unfortunately the data on the water holes is old and not in a GIS format making not possible to be incorporated into a spatial vulnerability model and relate it to the metapopulations. In addition to changes to the precipitation and storm water surge can impact a water hole for months/

Additional Rules and Future Research

Experts thought that the single most important methodological improvement for this species would be to include estimates of important seasonal events impacting the availability of fresh water for this species. In particular, storm surge is known to salinate some coastal areas, significantly reducing the availability of this limiting resource to the deer. As with several other species, adoption of the latest NOAA methods and data sources would improve baselines representations of sea level, and October high tides are a particular period of concern. Because Monroe county falls within the “4 county climate compact” area, this could be accomplished with a relatively minor update to the MIT scenarios.

In addition, it was noted that death due to highway mortality is a significant factor for this species. However no data sources or literature was identified which would currently allow the quantification of this effect, or of potential design mitigation measures such as fencing.

Florida Panther *(Puma concolor coryi)*

Habitat Description

“The home range of male panthers is about 520 square km (200 square miles or 128,494 acres) and the home range of female panthers is about 195 square km (75 square miles or 48,185 acres). Young males are often without a home range of their own. Young females usually remain close to where they were born (less than 13 km; 8 mi.) and frequently continue to share a portion of their mother’s home range. Males disperse greater distances. Dispersal of young panthers, particularly males, has been greatly reduced in south Florida by human development.

Within the panther’s range are a number of distinctive natural communities as well as areas disturbed to varying degrees by human activities. Scientists usually define the natural communities on the basis of vegetation. Most animals, including the panther, use a variety of natural communities to meet their needs. Panthers, especially young males, may travel through disturbed areas but their needs for adequate food and cover can only be met by the natural communities within their range.”

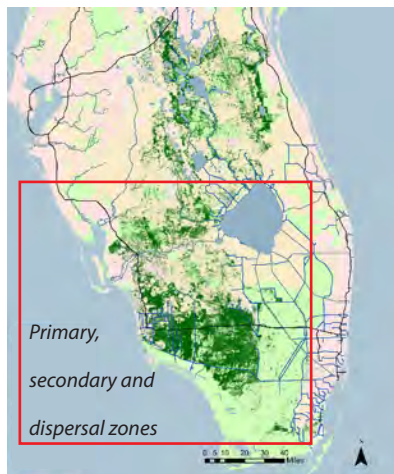


Figure 40: FWC Panther Potential Habitat, 2009

(Florida Fish and Wildlife Commission 2011)



Figure 41: Florida Panther

Florida Panther Habitat

The Florida Panther's primary, dispersal and secondary habitat zones (based on Kautz et al 2006)

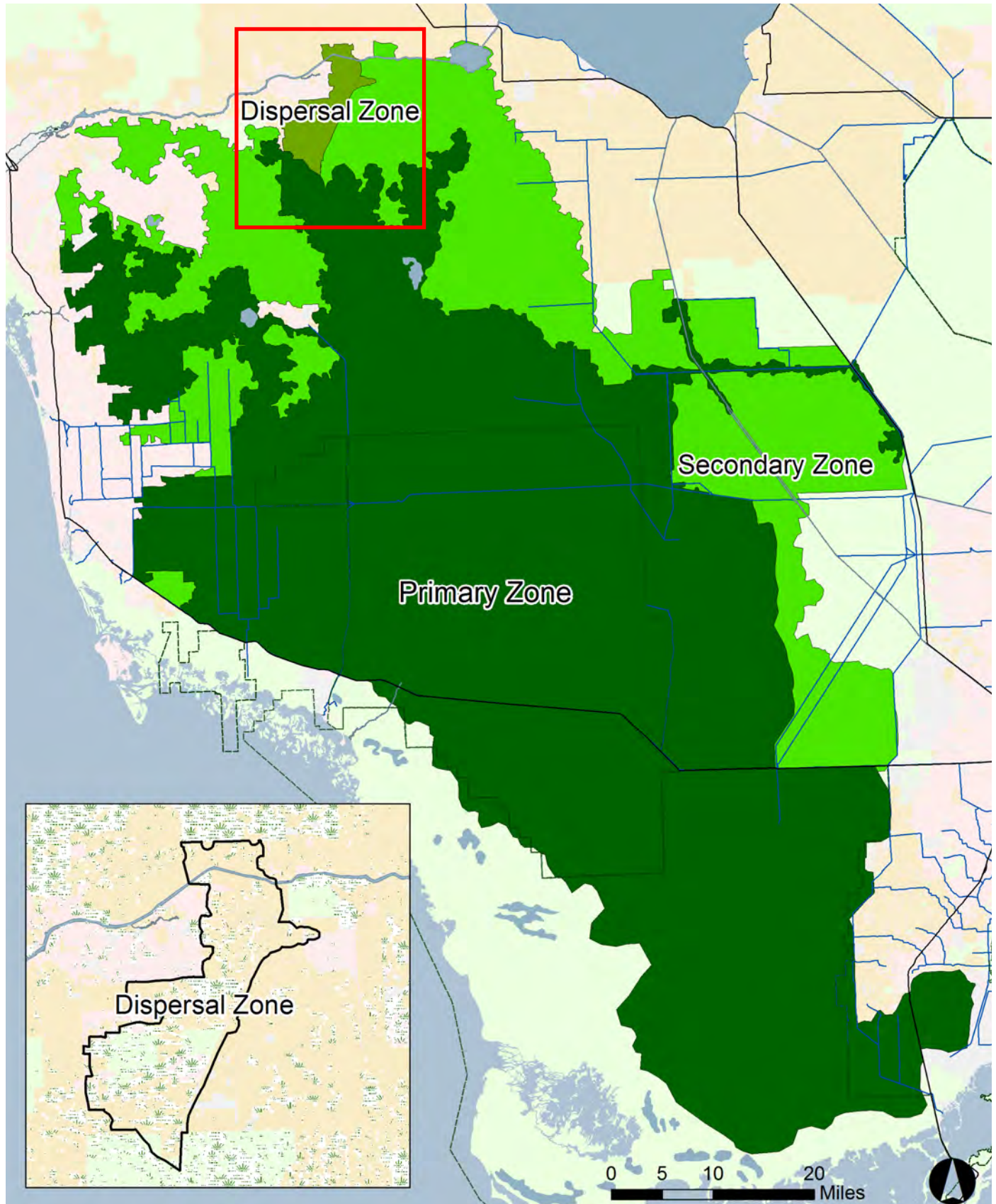
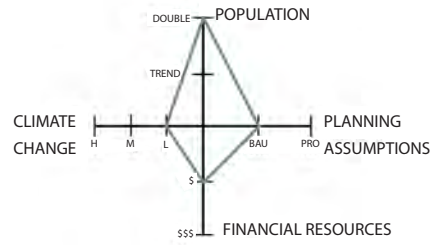


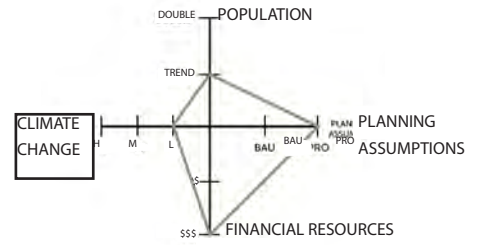
Figure 42: Florida Panther: Habitat

Florida Panther Spatial Vulnerability Under MIT Scenarios

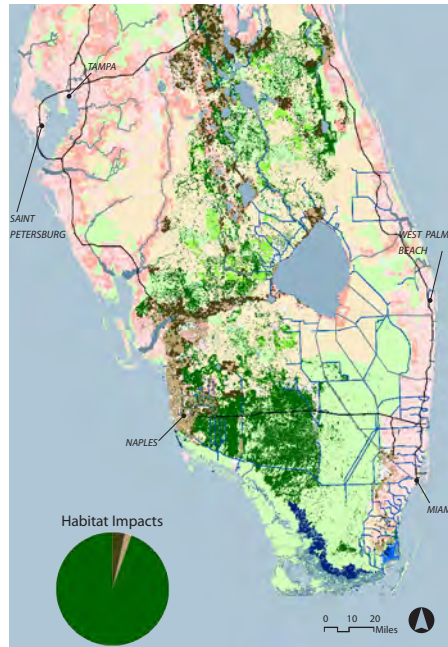
Scenario A



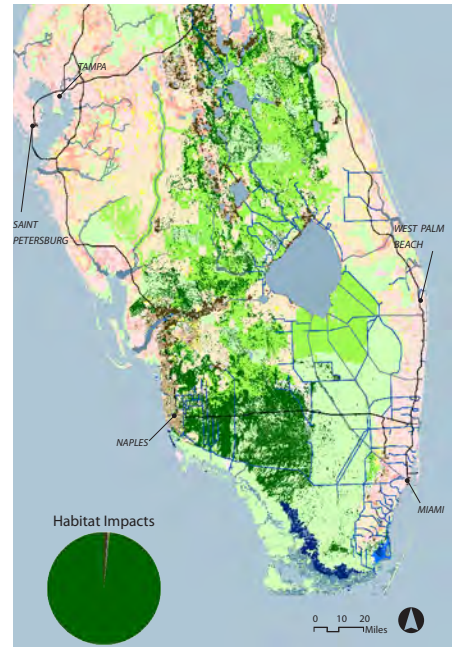
Scenario B



Scenario A Land Cover 2060



Scenario B Land Cover 2060



Map Legend

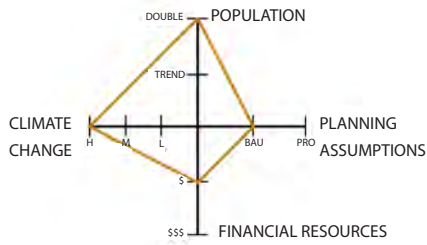
- Habitat Conflict
- Agriculture Inundated
- Agriculture Urbanized
- Conservation Inundated
- Other Uses Inundated
- Other Uses Urbanized
- No Habitat Conflict

Figure 43: Florida Panther: Spatial Vulnerability Under MIT Scenarios

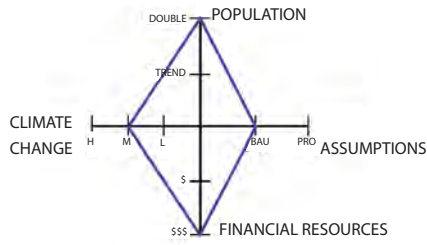
Habitat Impacts By Land Use Type	2060	
	%	Acres
Agriculture Inundated	0.00%	2
Agriculture Urbanized	3.26%	69,622
Conservation Inundated	0.18%	3,931
Other Uses Inundated	0.03%	593
Other Uses Urbanized	1.97%	42,170
No Habitat Conflict	94.56%	2,022,412
Total Habitat Conflict	5.44%	116,318

Habitat Impacts By Land Use Type	2060	
	%	Acres
Agriculture Inundated	0.00%	2
Agriculture Urbanized	0.88%	18,814
Conservation Inundated	0.18%	3,931
Other Uses Inundated	0.03%	593
Other Uses Urbanized	0.44%	9,442
No Habitat Conflict	98.47%	2,105,948
Total Habitat Conflict	1.53%	32,782

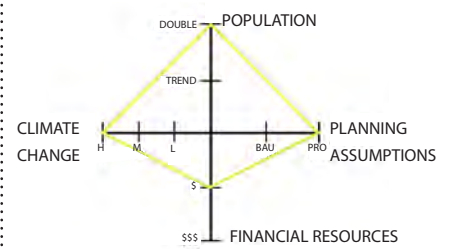
Scenario C



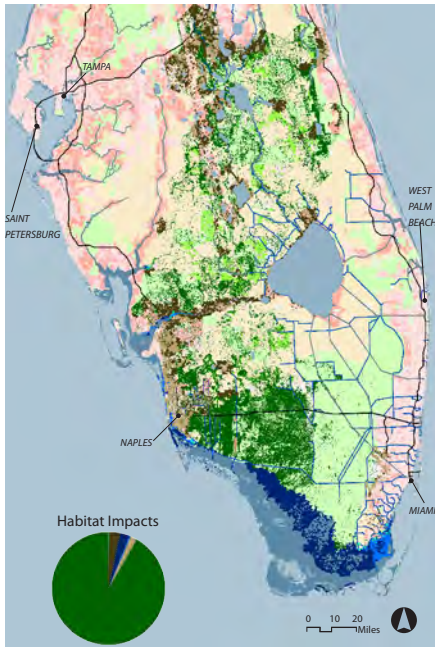
Scenario E



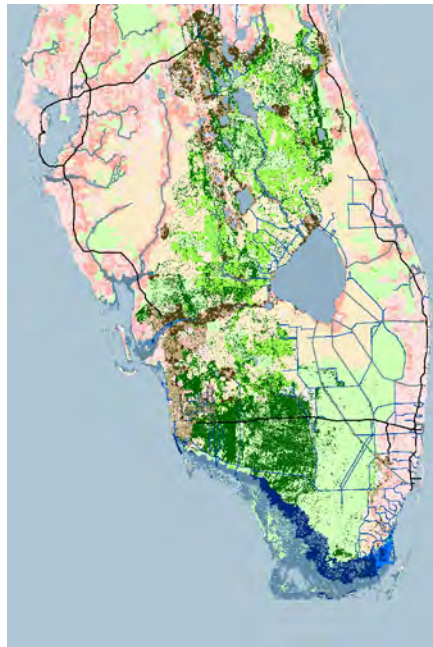
Scenario I



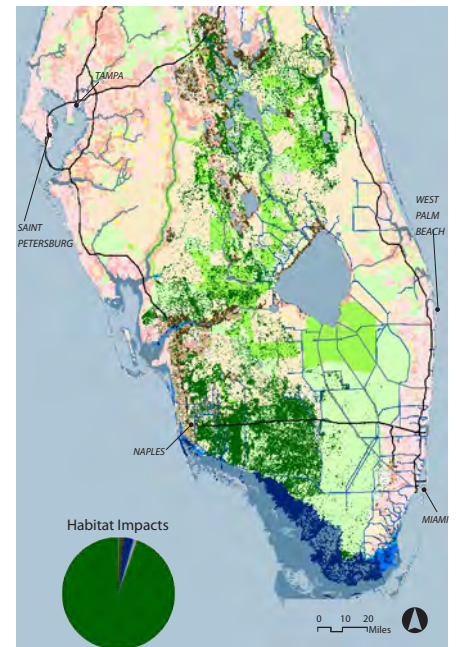
Scenario C Land Cover 2060



Scenario E Land Cover 2060



Scenario I Land Cover 2060



Habitat Impacts	2060	
By Land Use Type	%	Acres
● Agriculture Inundated	0.06%	1,177
● Agriculture Urbanized	3.29%	70,301
● Conservation Inundated	2.76%	59,087
● Other Uses Inundated	0.32%	6,907
● Other Uses Urbanized	1.90%	40,573
● No Habitat Conflict	91.68%	1,960,685
Total Habitat Conflict	8.32%	178,046

Habitat Impacts	2060	
By Land Use Type	%	Acres
● Agriculture Inundated	0.02%	436
● Agriculture Urbanized	2.88%	61,579
● Conservation Inundated	1.36%	29,118
● Other Uses Inundated	0.20%	4,324
● Other Uses Urbanized	1.78%	38,004
● No Habitat Conflict	93.76%	2,005,269
Total Habitat Conflict	6.24%	133,461

Habitat Impacts	2060	
By Land Use Type	%	Acres
● Agriculture Inundated	0.06%	1,177
● Agriculture Urbanized	1.41%	30,138
● Conservation Inundated	2.76%	59,087
● Other Uses Inundated	0.32%	6,907
● Other Uses Urbanized	0.79%	16,832
● No Habitat Conflict	94.66%	2,024,589
Total Habitat Conflict	5.34%	114,142

Florida Panther Habitat Impacts by Scenario and Current Management

Habitat Impact Scenario A (Low SLR, 2x Population, Weak Economy, Business As Usual)
Total Habitat Area in Analysis Window: 2,890,867 acres

2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	0%	0%				
Public Conservation	68%	4%				
Private Undeveloped	1%	0%	0%	0%	0%	0%
Public Undeveloped	3%	0%	0%	0%	0%	0%
Crops / Citrus	11%		1%	0%	1%	
Ranching	6%		1%	0%	3%	

Habitat Impact Scenario B (Low SLR, 1.5x Population, Strong Economy, Proactive)
Total Habitat Area in Analysis Window: 2,890,867 acres

2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	0%	0%				
Public Conservation	68%	4%				
Private Undeveloped	1%	0%	0%	0%	1%	0%
Public Undeveloped	2%	0%	0%	0%	1%	0%
Crops / Citrus	7%		0%	0%	5%	
Ranching	2%		0%	0%	9%	

Habitat Impact Scenario C (High SLR, 2x Population, Weak Economy, Business As Usual)
Total Habitat Area in Analysis Window: 2,890,867 acres

2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	0%	0%				
Public Conservation	58%	14%				
Private Undeveloped	1%	0%	0%	0%	0%	0%
Public Undeveloped	3%	0%	0%	0%	0%	0%
Crops / Citrus	11%		1%	0%	1%	
Ranching	6%		1%	0%	3%	

Habitat Impact Scenario E (Medium SLR, 2x Population, Strong Economy, Business As Usual)
Total Habitat Area in Analysis Window: 2,890,867 acres

2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	0%	0%				
Public Conservation	63%	10%				
Private Undeveloped	0%	0%	0%	0%	1%	0%
Public Undeveloped	2%	0%	0%	0%	0%	0%
Crops / Citrus	9%		0%	0%	2%	
Ranching	3%		0%	0%	7%	

Habitat Impact Scenario I (High SLR, 2x Population, Weak Economy, Proactive)
Total Habitat Area in Analysis Window: 2,890,867 acres

2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	0%	0%				
Public Conservation	58%	14%				
Private Undeveloped	1%	0%	0%	0%	0%	0%
Public Undeveloped	3%	0%	0%	0%	0%	0%
Crops / Citrus	11%		0%	0%	1%	
Ranching	7%		0%	0%	3%	

NOTE: Impacts were evaluated only on the panther habitat's primary, dispersal and secondary zones according to Kautz et al, 2006

Figure 44: Florida Panther: Habitat Impacts Chart per Scenario

Habitat Impact : Scenario A
(Low SLR, 2x Population, Weak Economy, Business As Usual)

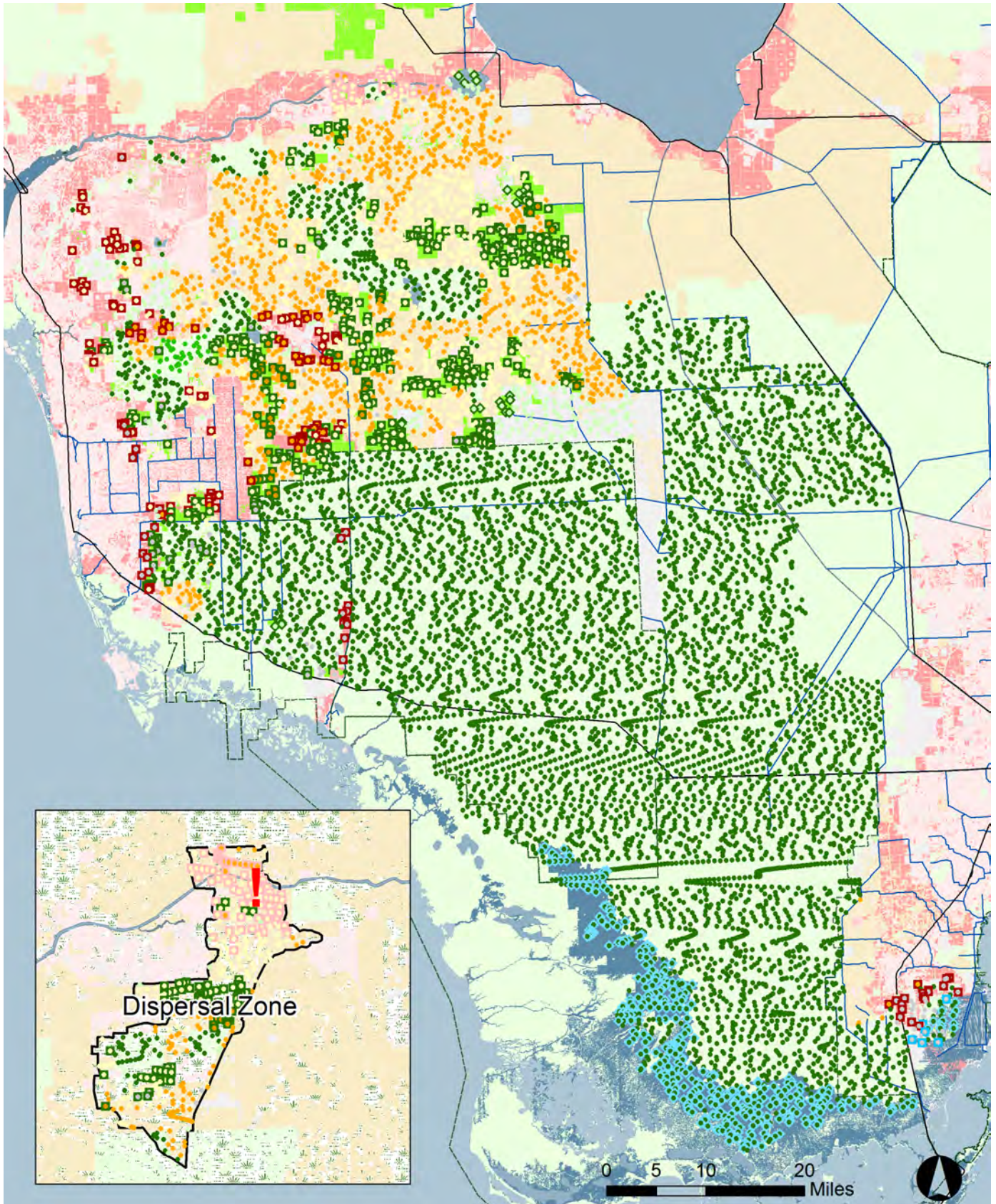
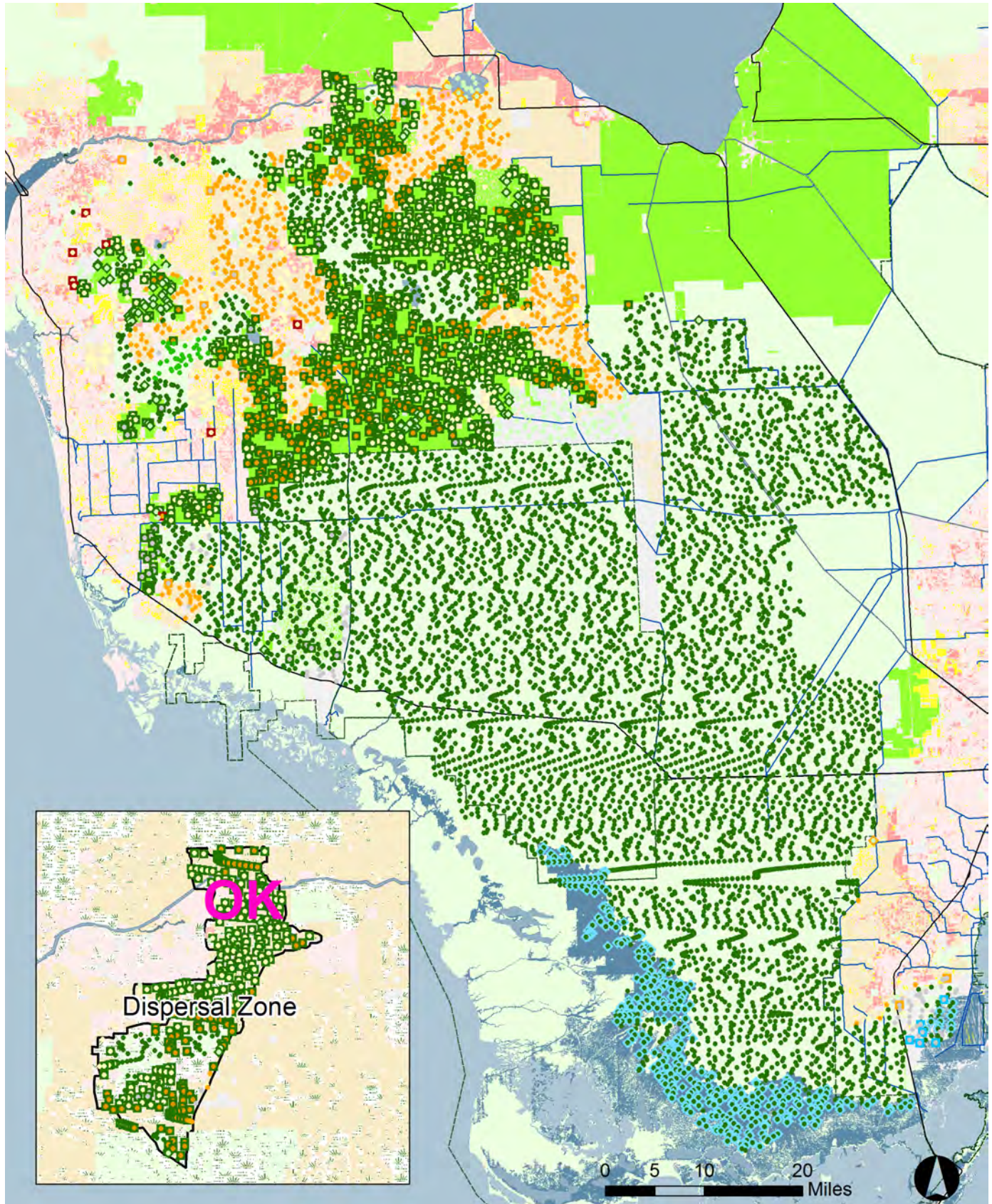
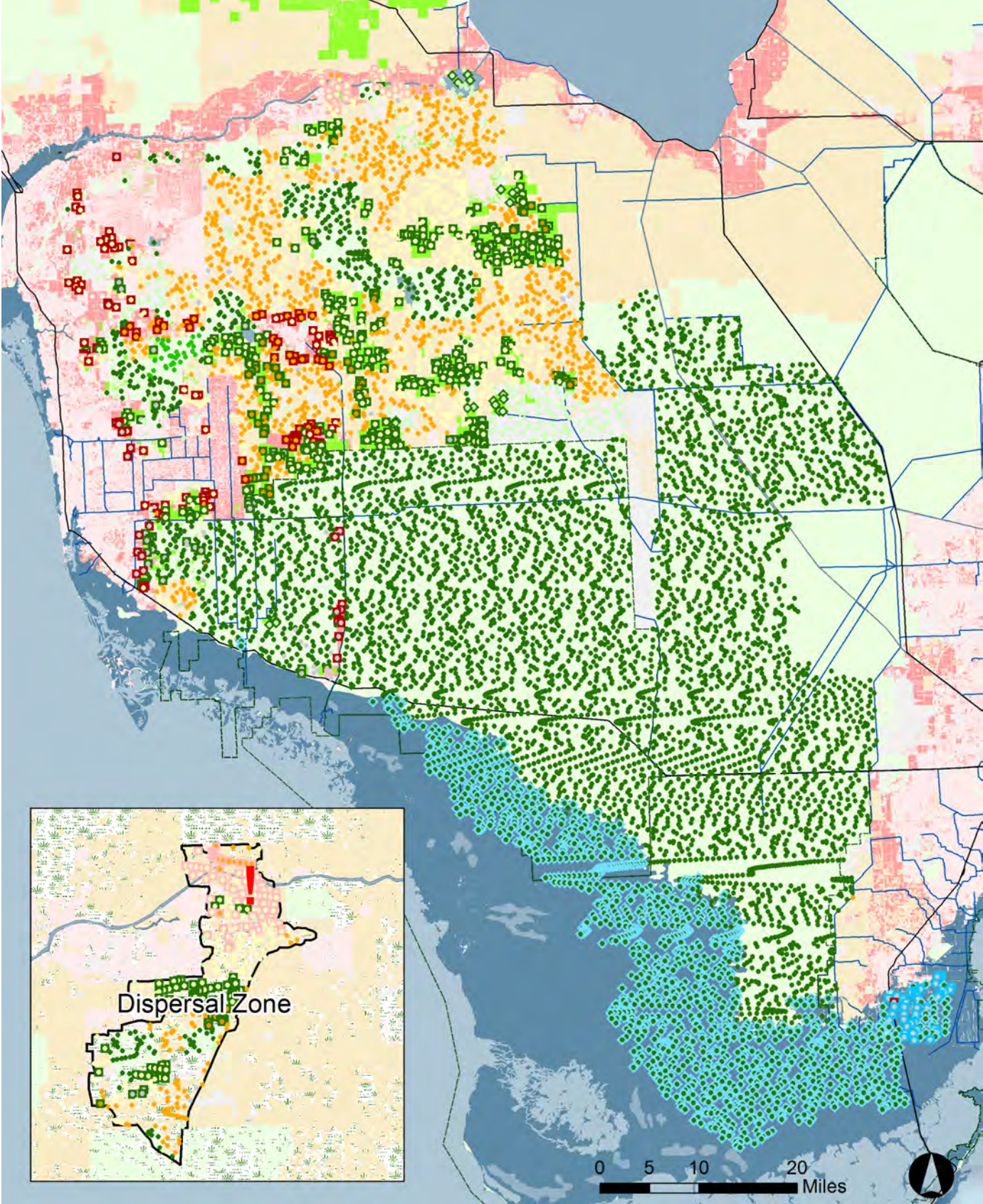


Figure 45: Florida Panther: Habitat Impacts Maps per Scenario

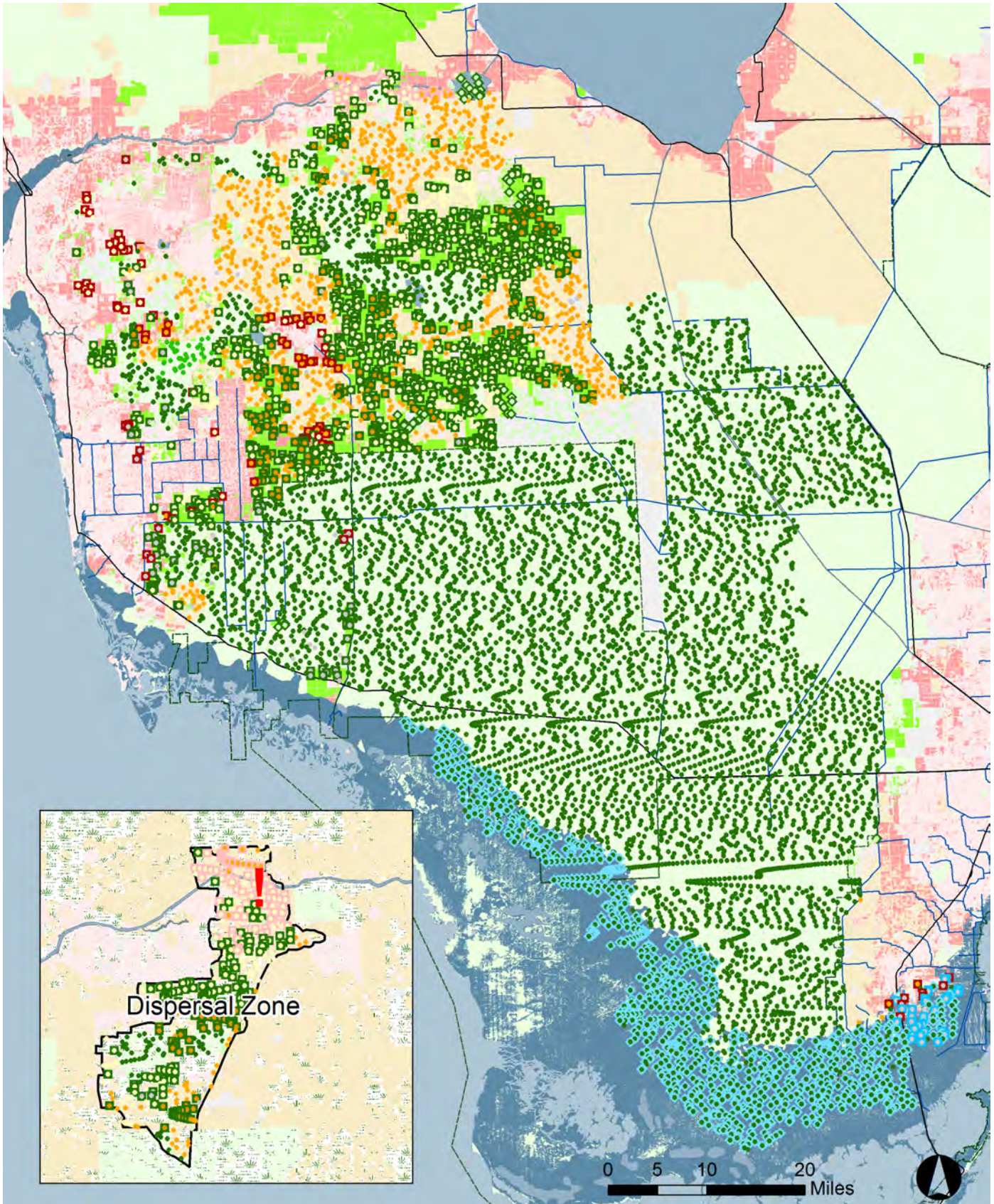
Habitat Impact : Scenario B
(Low SLR, 1.5x Population, Strong Economy, Proactive)



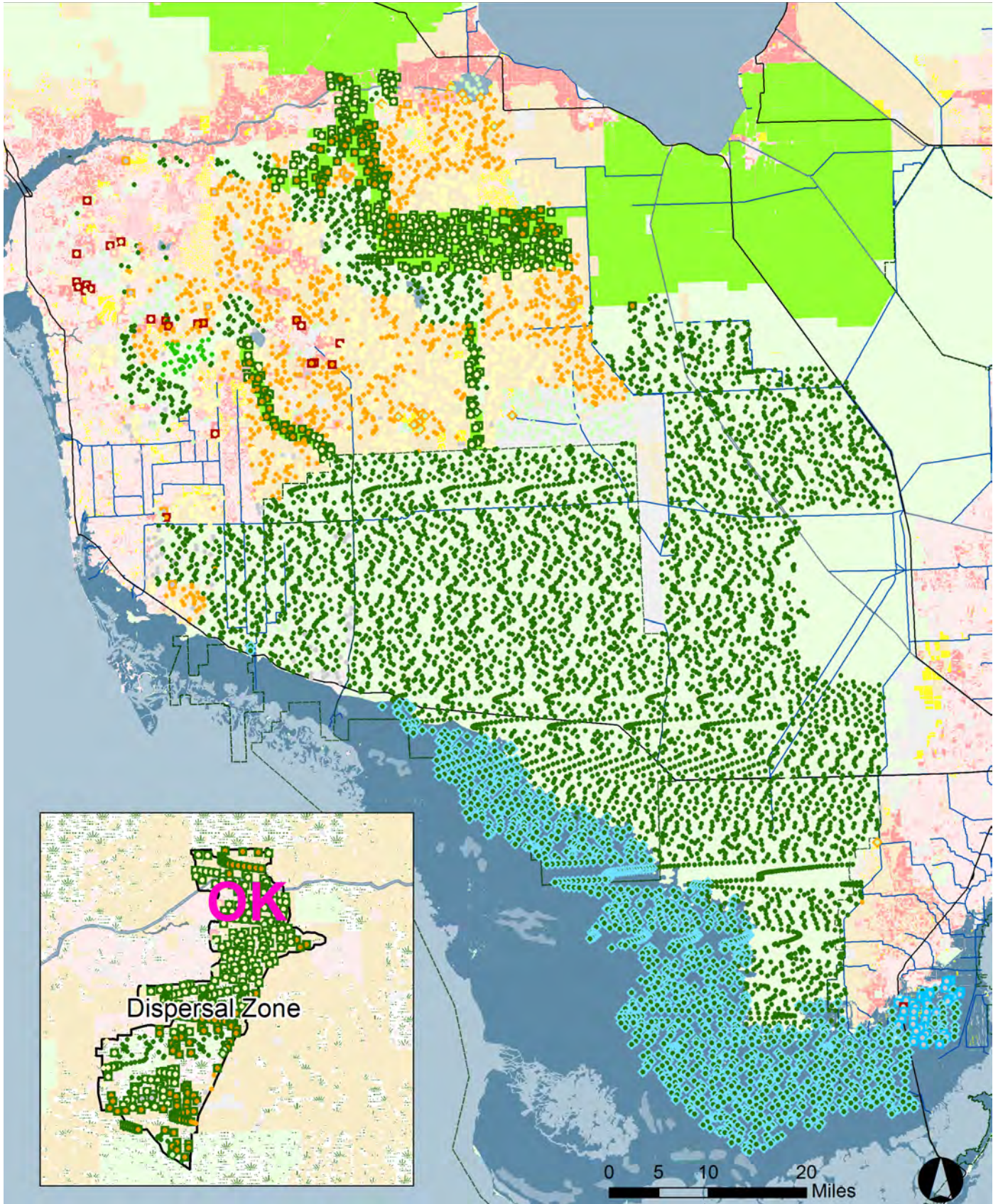
Habitat Impact : Scenario C
(High SLR, 2x Population, Weak Economy, Business As Usual)



Habitat Impact : Scenario E
(Medium SLR, 2x Population, Strong Economy, Business As Usual)



Habitat Impact : Scenario I
(High SLR, 2x Population, Weak Economy, Proactive)



Conclusions Spatial Vulnerability: Florida Panther

The spatial-explicit vulnerability assessment (SEVA) for the Florida Panther habitat was developed using spatial analysis conducted at MIT and a workshop-based expert consultation and validation process.

Analysis and Data:

The participating experts were presented with the panther spatial vulnerabilities (impacted habitat) under five MIT scenarios (see background section for a description of the scenarios) which simulated changes in SLR, urbanization policies, availability of financial resources and future population. SLR inundation scenarios included a low SLR estimate of +3.6", a medium estimate of +18.4 and a high SLR estimate of 39.1".

The initial vulnerability assessment employed the FWC habitat suitability map (2009). However, when presented to the experts, they recommended instead to focus the analysis on the primary, secondary, and dispersal zones indicated and documented in the paper authored by Kautz et al., (2009) All spatial analysis developed after the January workshop reflects this change. In order to retain methodological consistency across species, our analysis of the vulnerability and impacts was calculated across the three zones. In future studies, experts agrees that for this species it would be ideal to isolate the individual impacts on primary, secondary, and dispersal. Experts also suggested that the impacts should be described by time period (identifying immediate, mid and long-term impacts). Finally, the group suggested a study of potential sites for Florida Panther introduction north of the Caloosahatchee, as the research from Thatcher et al (2009) indicates discreet patches north of the river suitable for reintroduction. An attempt was made to acquire that data as GIS files, but was not possible to acquire such data in the time frame of the project.

General Findings

Most panther habitat takes place inland in ranch and open space areas; therefore no major direct impacts due to inundation are experienced for this species. Nonetheless, indirect effects of inundation have important potential consequences on panther habitat. The primary likely mechanism for this as shown in the MIT scenario impact modeling would be via increased inland development and associated habitat fragmentation. Under moderate to severe climate change, coastal residential options become both riskier and more expensive, promoting a shift of development pattern inland and into panther habitats. Given the broad extent and heterogeneity of panther habitat, experts suggested focusing this pilot’s vulnerability assessment efforts on a set of case study areas. For this reason, further analysis and adaptation modeling was confined to the area indicated in the maps which follow.

Experts provided a list of the areas of concern that could serve for future search as case study areas. These areas are:

1. Corkscrew Road Crossing (should be same as Caloosahatchee Ecoscape)
2. Area immediately north of Caloosahatchee.
3. Bottom of the Everglades National Park

Summary of Habitat Inundation/Loss Relative to SLR			
Florida Panther Habitat	Low	Medium	High
Habitat Inundated	4%	10%	14%
Other Habitat Impacts	16%	10%	6%
Current Habitat Unchanged	70%	80%	80%

Figure 46: Florida Panther Habitat Inundation/Loss under SLR Scenarios

Data Improvements Recommended for Future Assessments

1. Vegetation and land production intensity are important factors for the Florida Panther habitat. Future research should incorporate vegetation and more desegregated land use types (particularly of agriculture lands to reflect which types of agriculture use and what kind of vegetation takes place in those properties).
2. Future data will need to indicate differences between conservation and active agriculture vs decommissioned agriculture areas.

Future research

A series of research needs were identified in discussion with the experts.

1. Given the increasing issues of landscape fragmentation and shrinking habitat conditions, there is the need to study Florida Panther vulnerability by created highly detailed context areas zooms accounts identifying key parcels to manage.
2. Given that not all habitat is equal, there is the need to created polygons of primary, secondary and dispersal areas and identify the relative vulnerability and associated acreage lost in each of those. The first part of this process was done within this pilot. However future work should break out analytic results relative to habitat priority.
3. Derive landscape ecology criteria for habitat to extend understanding of impacts beyond simple overlay. Of the species considered in the pilot, the Florida Panther is amongst the widest ranging, and is the most sensitive to broad scale landscape pattern. The input data required for such a spatial analysis was generated within this pilot. However the spatial analysis rules required to conduct a landscape ecology habitat assessment go beyond overlay, to include "minimum patch area" and "interpatch distance" analyses.
4. Given limited resources there is the need to organize impacts characterizing their different time intervals: staging/timing is important. This could be done at one time scale using the existing MIT scenarios. While not attempted in this pilot, these are available for 2020 and 2040 as well as for the 2060 tested here.

Least Tern *(Sternula antillarum)*

Habitat Description

“Not only are the terns extremely susceptible to nest disturbance, they have lost extensive nesting habitat to beach development and increased human activity there. Least terns are colony nesters, meaning they nest in a group, which allows them to exchange information about food sources, as well as to detect and mob predators. An entire colony can be easily destroyed by predation by red foxes, raccoons, dogs and house cats, by human trampling, or by catastrophic storms.

In the past couple of decades, due to habitat loss, least terns have taken to nesting on flat roofs, especially gravel ones. The Florida Fish and Wildlife Conservation Commission has developed an educational pilot program being implemented in Pinellas county. The program is to help business (or home) owners educate their customers about having tolerance for least terns that are ‘squatting’ on their flat, gravel roofs. A poster was developed to promote the public educational project.

Least terns do respond quickly to improved habitat, such as the removal of beach vegetation or the dumping of dredged sand. Least tern populations seem to be slowly rising, although they are still listed as ‘threatened’ by the state. At many nesting areas, signs warn people against entering colonies, many of which are roped off during breeding season.”



Figure 47: Least Tern

(Source: Florida Fish and Wildlife Commission 2011)

Least Tern Habitat

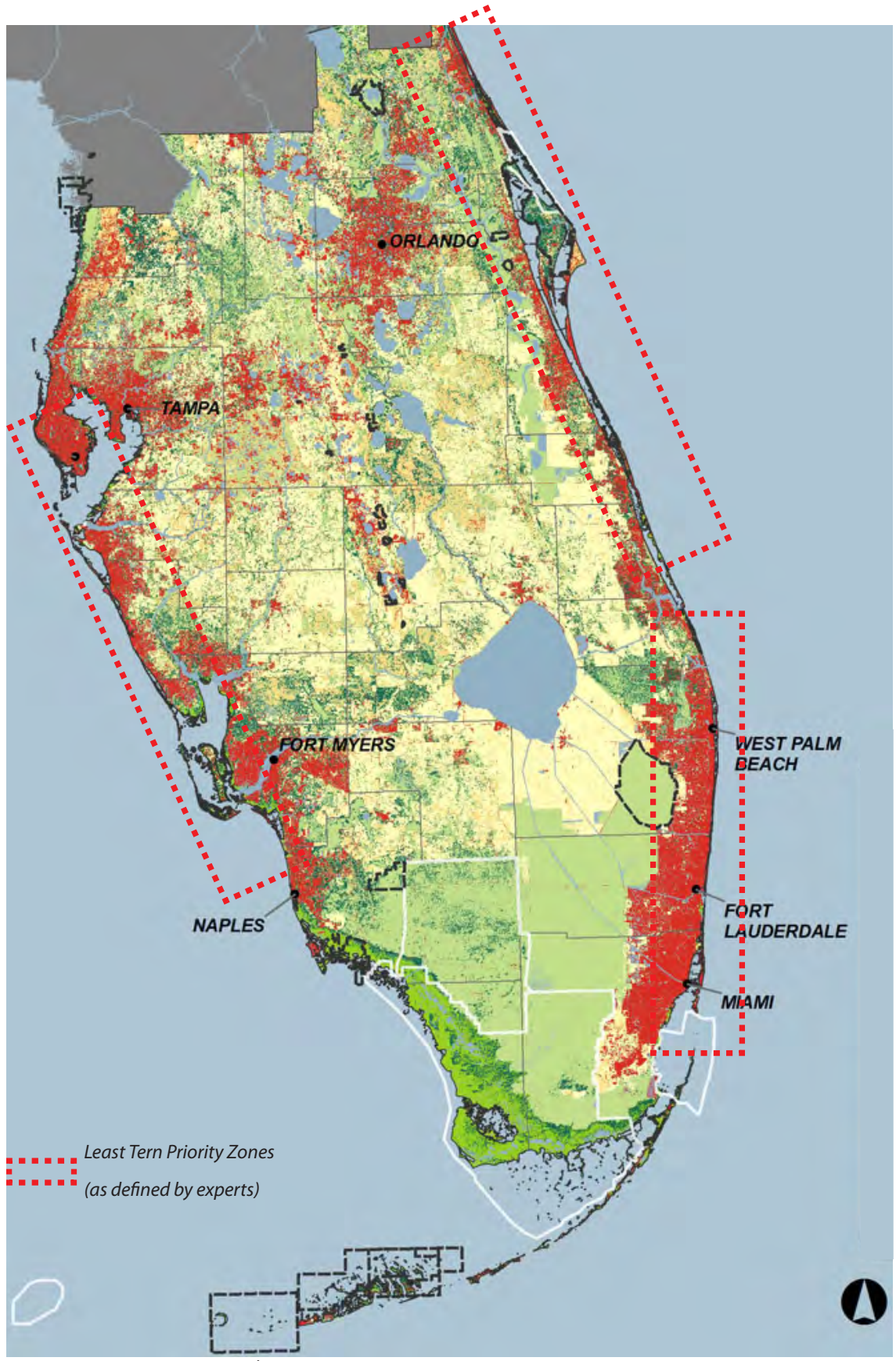
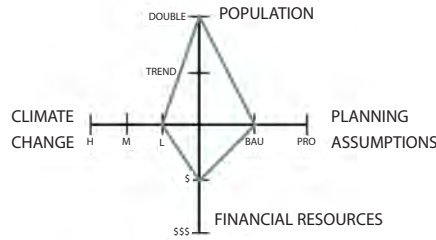


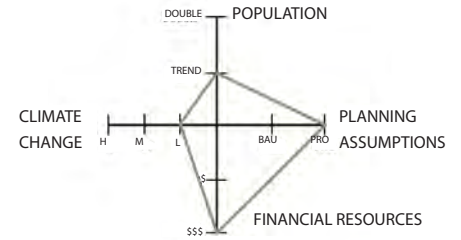
Figure 48: Least Tern: Habitat

Least Tern Spatial Vulnerability Under MIT Scenarios

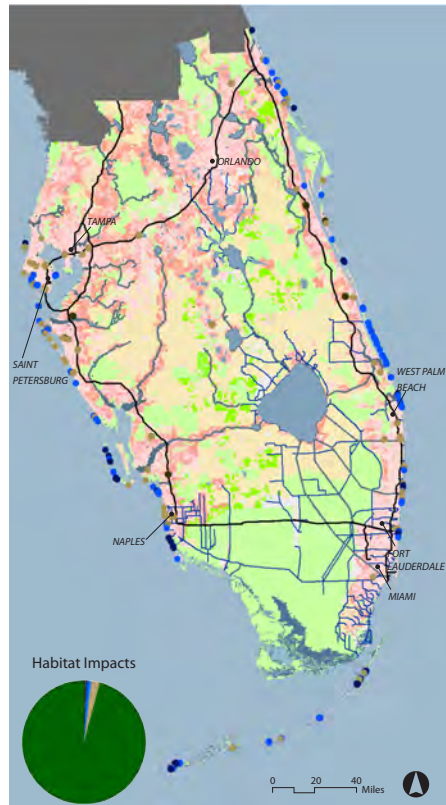
Scenario A



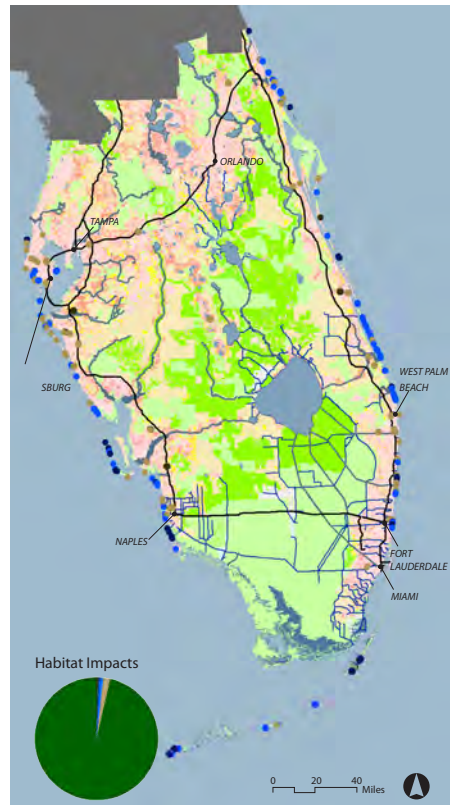
Scenario B



Scenario A Land Cover 2060



Scenario B Land Cover 2060



Map Legend

Habitat Conflict	
●	Agriculture Inundated
●	Agriculture Urbanized
●	Conservation Inundated
●	Other Uses Inundated
●	Other Uses Urbanized
●	No Habitat Conflict

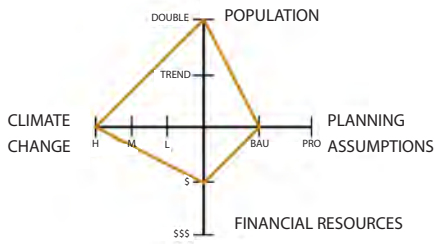
Current Land Use	Projected Land Use
■ Agriculture	■ Agriculture
■ Conservation	■ Conservation
■ Urban	■ Urban

Habitat Impacts	2060	
By Land Use Type	%	Acres
● Agriculture Inundated	0.00%	0
● Agriculture Urbanized	0.43%	96
● Conservation Inundated	0.48%	108
● Other Uses Inundated	0.99%	224
● Other Uses Urbanized	2.26%	512
● No Habitat Conflict	95.85%	21,729
Total Habitat Conflict	4.15%	940

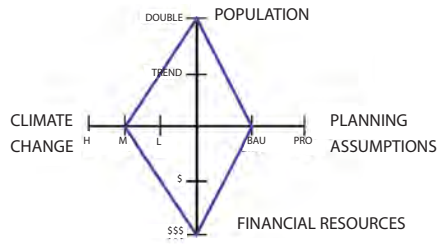
Habitat Impacts	2060	
By Land Use Type	%	Acres
● Agriculture Inundated	0.00%	0
● Agriculture Urbanized	0.33%	75
● Conservation Inundated	0.48%	108
● Other Uses Inundated	0.99%	224
● Other Uses Urbanized	1.81%	410
● No Habitat Conflict	96.39%	21,852
Total Habitat Conflict	3.61%	817

Figure 49: Least Tern: Spatial Vulnerability Under MIT Scenarios

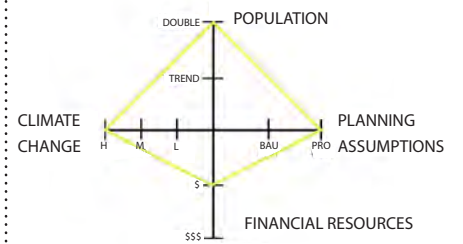
Scenario C



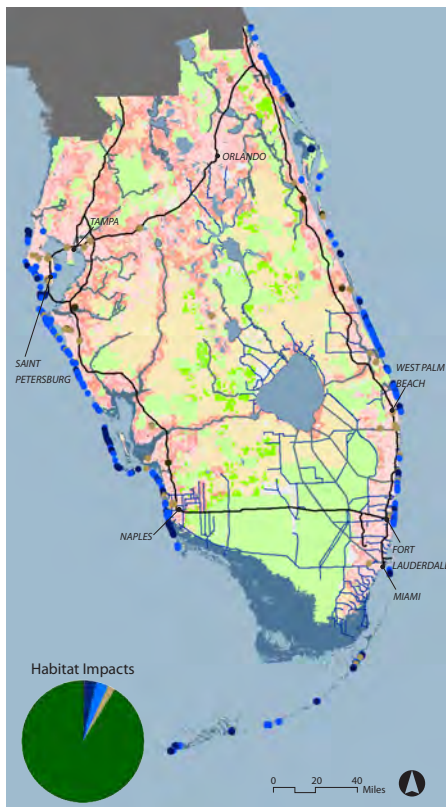
Scenario E



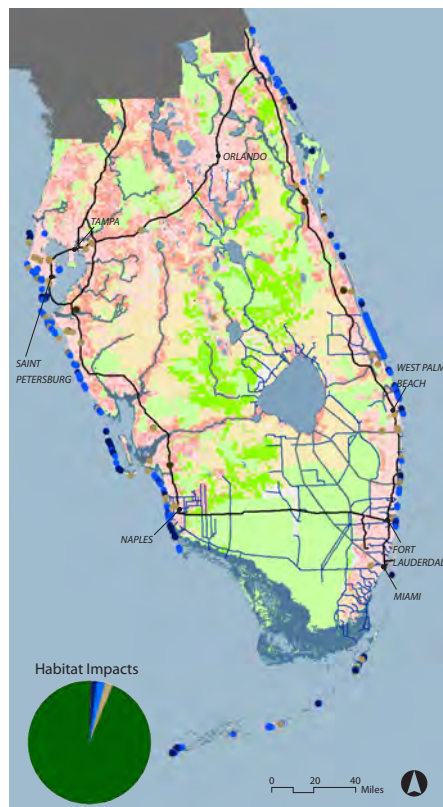
Scenario I



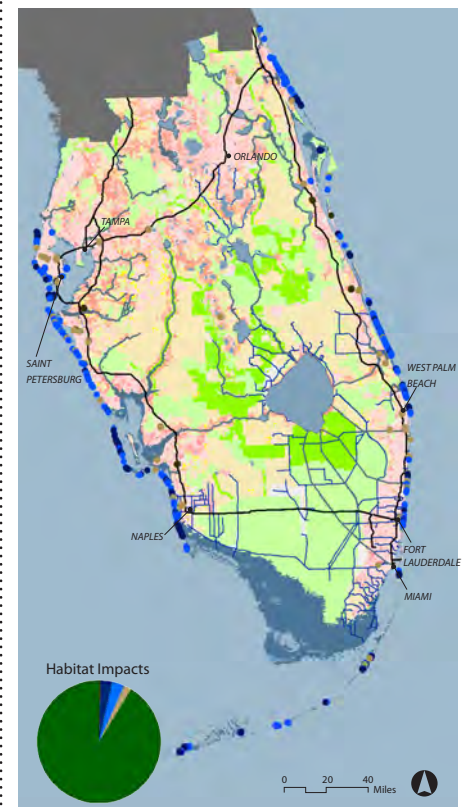
Scenario C Land Cover 2060



Scenario E Land Cover 2060



Scenario I Land Cover 2060



Habitat Impacts	2060	
By Land Use Type	%	Acres
Agriculture Inundated	0.02%	5
Agriculture Urbanized	0.40%	91
Conservation Inundated	3.07%	695
Other Uses Inundated	3.22%	730
Other Uses Urbanized	1.99%	452
No Habitat Conflict	91.30%	20,696
Total Habitat Conflict	8.70%	1,973

Habitat Impacts	2060	
By Land Use Type	%	Acres
Agriculture Inundated	0.01%	2
Agriculture Urbanized	0.41%	94
Conservation Inundated	1.60%	362
Other Uses Inundated	2.05%	465
Other Uses Urbanized	2.11%	479
No Habitat Conflict	93.82%	21,267
Total Habitat Conflict	6.19%	1,402

Habitat Impacts	2060	
By Land Use Type	%	Acres
Agriculture Inundated	0.02%	5
Agriculture Urbanized	0.38%	85
Conservation Inundated	3.07%	695
Other Uses Inundated	3.22%	730
Other Uses Urbanized	2.00%	453
No Habitat Conflict	91.32%	20,701
Total Habitat Conflict	8.68%	1,968

Conclusions Spatial Vulnerability: Least Tern

Unlike the other species studies, the research team was unable to obtain habitat suitability data for the least tern. This made it impossible to implement the same form of spatially explicit vulnerability assessment used for other species in the pilot, with consequences which will be discussed below.

Given the absence of habitat suitability modeling for this species, participating experts were presented with the representation of the proxy habitat developed for the workshop by MIT and derived from roof and beach data (see below). A basic overlay analysis of the MIT scenarios against this proxy habitat was conducted and presented to the experts for discussion.

The “ad hoc” habitat representation developed by MIT had as a goal to provide some representation of the spatial distribution of the least tern for the basis of discussion. The proxy habitat was done by combining roof top data occurrence points as well as all areas categorized as sand beaches according to NOAA data sources.

The available data was not of sufficient spatial resolution to allow reliable SEVA estimates. However, the depiction of the habitat based on the proxy variables was sufficient to permit experts to discuss and identify a series of spatial patterns and areas of interest. In particular, experts identified three different areas of diverse priority which they suggested should be studied more carefully and at higher resolutions. These areas are depicted as the three priority maps for the least tern in the previous pages.

In addition to the identification of the priority areas, the experts suggested removing the roofs as indicators of habitat and from the analysis. Experts suggested that beyond the direct impacts on beach habitat, the indirect impacts of human use of beaches should be considered as a critical factor in determining least tern habitat vulnerabilities. They furthermore suggested that an analysis that could identify beaches with higher human use should be considered highly vulnerable. Some basic criteria were designed to express potential conditions such as urban encroachment and likelihood of human disturbance.

Because the primary nesting habitat for the least tern occurs on beaches, this species is very susceptible to disturbances from development on or near the beach as well as other related human activity in these areas.

In order to detect the impacts on this habitat, two different approaches were taken within the pilot workshop phase: a direct beach impact analysis (in which beaches got developed or inundated) and an indirect impact analysis (human use of beach visitation and adjacent development). The first level of analysis was conducted against each MIT scenario for the geographic extent of the habitat impacts. The quantification of these impacts from inundation and land use change presented on prior pages is for the entire habitat area, not just the detail views..

The indirect analysis was specified by experts during the first workshop as a function of distance to development. This was assumed to represent a reasonable proxy to beach visitation and human disturbance. In order to carry out this analysis a threshold of development density had to be defined. By inves-

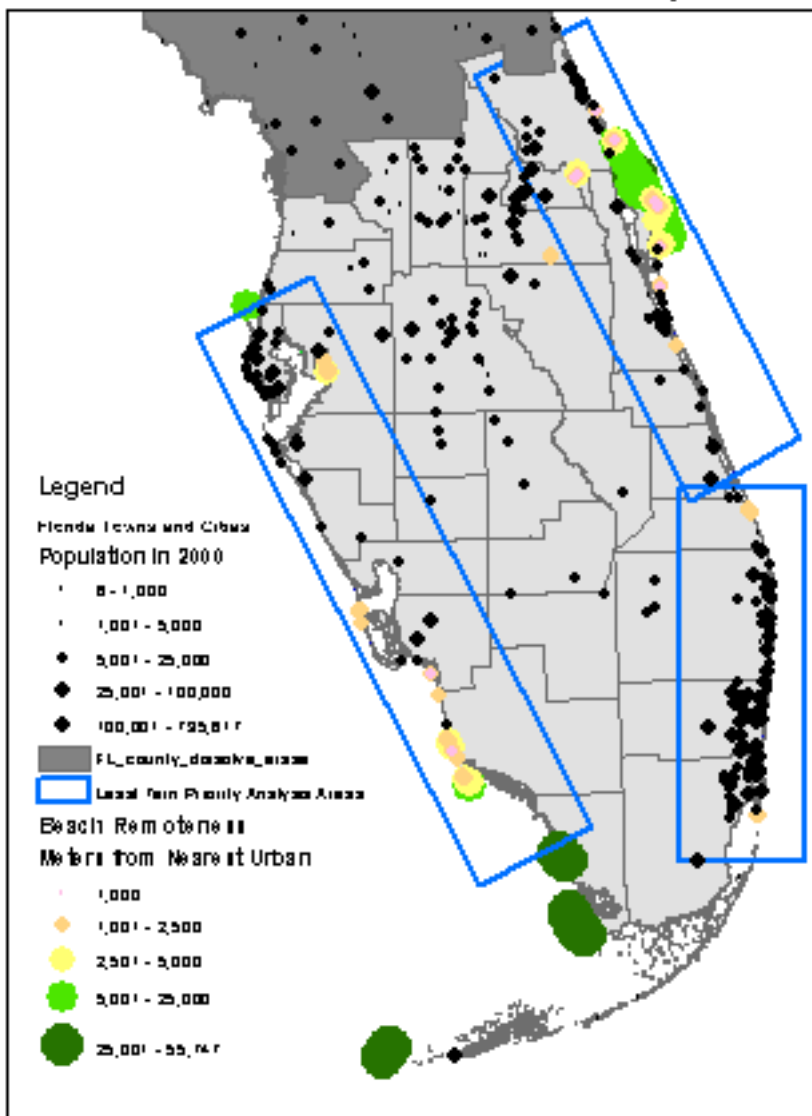


Figure 50: Beach Remoteness and Least Tern Priority Areas

Identifying pre-development and post-development habitat areas a threshold of 2.5 people per acre was defined (represented in the figure below). A GIS accessibility analysis was then performed to compute travel time in minutes from all beaches over the roads networks. The furthest areas considered were 1 hour drive to beaches. Those areas in closer proximity to the beaches and within areas of dense human population represented the most impacted habitats.

Data, Process and Future Research

Much data and model development is needed to be able to develop a spatially-explicit vulnerability analysis and determine the necessary management and adaptation measures for survival of the least tern under climate change. Given how extremely susceptible to nest disturbance this species is, it is important

Development Density Near Least Tern Nests

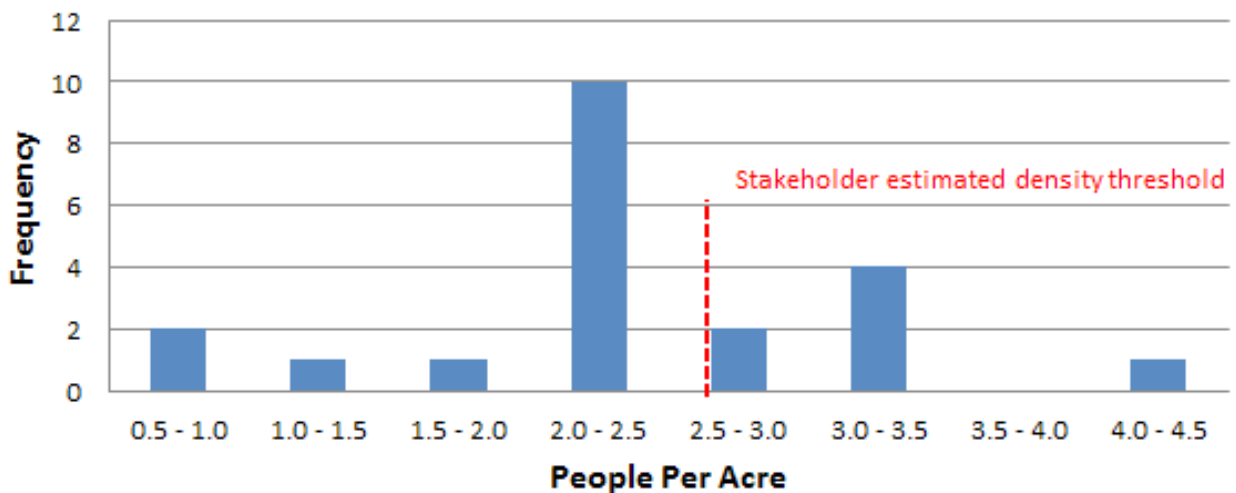


Figure 51: Human population density threshold used to simulate human impacts on Least Tern Nesting habitat.

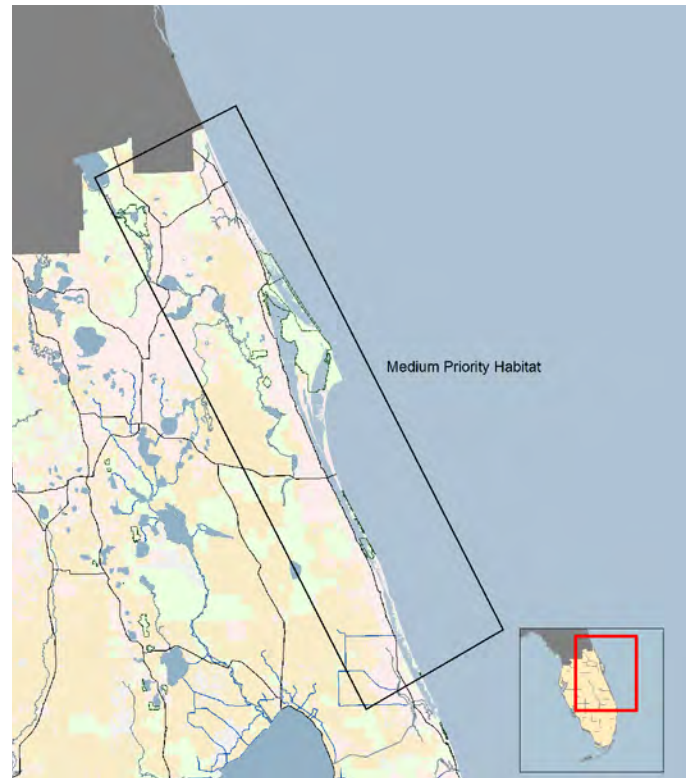
to conduct adequate monitoring and investigations that can determine the tolerance threshold of the nesting habitats due to beach development and increased human activity. These investigations should be included in the habitat suitability models which are needed to be able to develop the vulnerability assessments. In addition, it is important to recognize the increased occurrence and nesting on flat roofs, especially gravel ones. While this does not represent an ideal habitat given the possible human tolerance issues and lack of other wildlife activity, these structures are actively used by these birds as nesting sites.

The least tern beach habitat is very sensitive to other climate related stressors. SLR and increased storm events will provoke erosion which will pose impor-

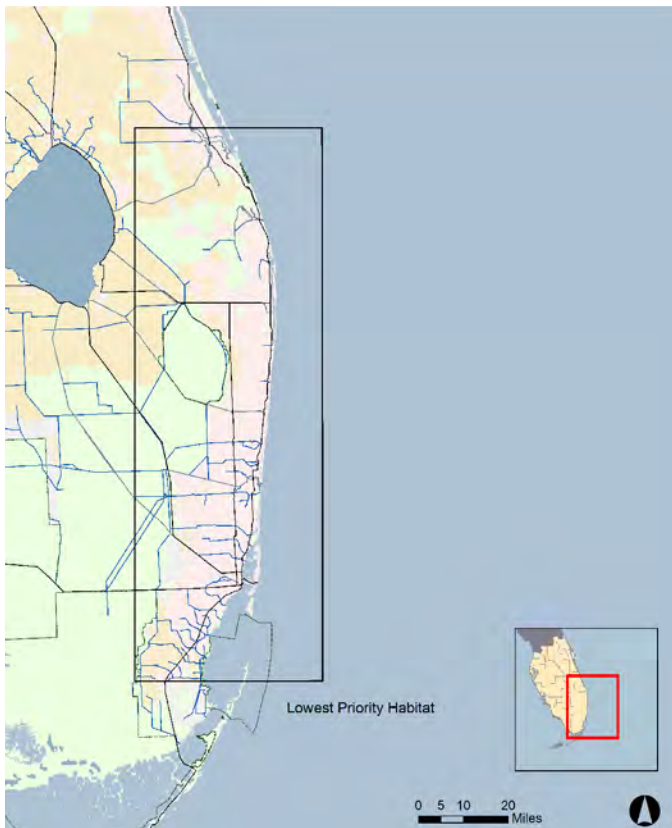
tant challenges on barrier islands and other unprotected beach areas. Increasing SLR will result in shoreline retreat due to inundation, and will eliminate suitable beach habitat for nesting when development occurs in areas immediately adjacent to the beach.

Overwash (“the natural response of undeveloped barrier islands to sea level rise”) will represent another problem to the least tern as it will change the geomorphology and induce vegetation changes in this habitat. This is of particular concern for coastal barrier islands (such as the priority areas indicated by experts in the northeast of the study area) where wave erosion may transport sand in a landward as well as a seaward direction. By gradually transporting it landward, overwash can enable a barrier island to rise with sea level, in a fashion similar to rolling up a rug (Titus, 1998).

Least Tern Medium Priority Habitat



Least Tern Lowest Priority Habitat



Least Tern Highest Priority Habitat

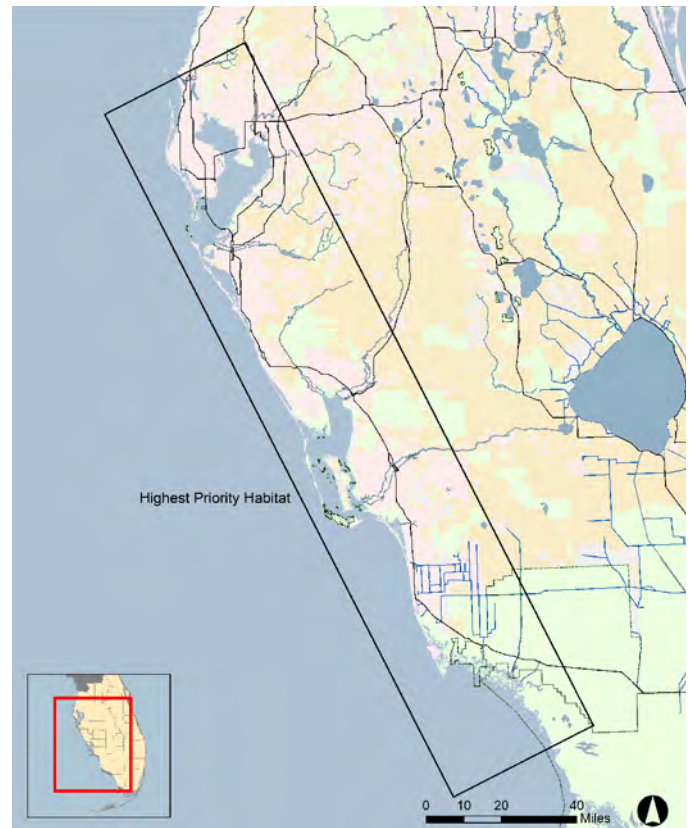


Figure 52: Least Tern Primary Zones

The Least Tern proved to be an exceptionally challenging species in terms of geographic modeling. As mentioned above, there was no prior wildlife habitat modeling data available for this species, and the initial impact modeling here was based on a “proxy habitat” model.

In constructing this model, it became apparent that spatial scale of base datasets make it difficult to generate an appropriate model for this species at the analysis scales supported by the regional scenarios. The MIT scenarios were generated at a 50 meter resolution from a variety of datasets. The base land cover datasets used were the National Land Cover Dataset or NLCD from

2011			Low SLR			High SLR		
Landsat	Photointerp	% Diff	Landsat Acres	Photo Acres	% Diff	Landsat Acres	Photo Acres	% Diff
22,669	12,735	78%	817	986	-17%	1,973	4,133	-52%

Figure 53: Scale and Data Sensitivity of Inundation Modeling

USGS, and its coastal equivalent from NOAA’s Coastal Change Analysis Program, known as C-CAP. Both are derived from Landsat 7 imagery, and have a 30m pixel size. Depending on the classification methods used, this generates a hypothetical minimum mapping unit of 1/4 acre, and recommended minimum map scale of 1:100,000. In practice, two other subtle issues were discovered which lowered the effective resolution of these data.

The first issue is a technical subtlety of raster image processing which normally can be ignored, but here became significant. That is that the default cell reclassification methods of ESRI ArcGIS software use either “cell center” or “majority presence” rules to determine which of several grid cell values dominate. When we originally created the MIT scenarios, we reclassified the imagery from 30m to 50m in a way which gave no special priority to beaches. Because this feature type is frequently narrower than 50m, it was often dominated by surrounding land cover from water and land.

We revisited this issue after the workshops, using a different, higher-resolution source of beach land cover. We obtained and merged the most recently available land use / land cover datasets from all of the regional water management districts. These data were obtained using very different methods than NLCD/C-CAP, namely hand interpretation of ortho-imagery of approximately 1m resolution. This imagery source has 900 times better spatial resolution than Landsat 7 (30 x 30), and the classification technique applied also was significantly more accurate.

We found that the later data sources and methods led to very large and inconsistent differences in detected beach area. These results can be seen in the table below. Note that under 2011 conditions, estimated habitat detected by Landsat is almost twice that detected by photointerpretation, but that under either low or high sea level rise impact computations, the differences run the opposite direction (photointerpretation shows higher impacts than Landsat). Based on this analysis, we must conclude that the proxy habitat used in the first stakeholder workshop very poorly characterized the habitat type most important for this species.

When we further investigated this issue, we found that impacts calculated based on the photointerpreted data were also significantly different than initial impact calculations.

Direct Beach Inundation	2011	Low SLR		High SLR	
	Photo Acres	Photo Acres	% Current	Photo Acres	% Current
Swimming Beach	10,723	792	6%	3,566	33%
Non-swimming Beaches	2,012	194	2%	567	28%
Total	12,735	986	8%	4,133	32%

Figure 54: Least Tern : Direct Beach Inundation

Indirect Beach Inundation	2011	High SLR		Within 50m of High SLR	
	Photo Acres	Photo Acres	% Current	Photo Acres	% Current
Swimming Beach	10,723	3,566	33%	6,852	64%
Non-swimming Beaches	2,012	567	28%	1,155	11%
Total	12,735	4,133	32%	8,007	75%

Figure 55: Least Tern: Indirect Beach Inundation

Terrain Scale Issues

Finally, there is a second major scale issue which became apparent upon close examination of the impact modeling. We found it curious and suspect that even with photointerpreted data and high sea level rise only approximately 1/3 of beaches were being shown as vulnerable. Therefore, we conducted a second form of sensitivity test, looking at cells immediately adjacent to those inundated under high SLR. We found that adjusting our definition of "impact" from direct inundation to indirect led to a doubling of estimated vulnerabilities. (See table above).

In reality, these locations would be potentially vulnerable, at least to seasonal high tides and storm surge, if not to annualized mean high tide. This issue was further investigated using higher resolution terrain elevation data from 10 foot resolution LIDAR. This data is not yet uniformly available for the full

study area, but was available for the “4 county compact” area including Palm Beach, Broward, Miami-Dade and Monroe counties.

Spot checking in these areas made it clear that the 50m horizontal grid cell size of the MIT scenarios and the 30m base elevation data from USGS included within them causes elevation averaging which is important for beach inundation analyses. Terrain elevations within 50m cells appear to “average in” beach foredunes, causing them to appear higher than under LIDAR data (and thus less-sensitive to impacts)

Post-workshop Least Tern SEVA Conclusions

Unfortunately, the pilot nature of this study did not allow the creation of new calibrated and validated habitat suitability models for this species. It is apparent from the post-workshop sensitivity analyses discussed here that this can and should be done.

For this reason, we do not make further inference from the initial impact estimates in our conclusions, except to identify this issue.

Short-Tailed Hawk *(Buteo brachyurus)*

Habitat Description

The Short-tailed Hawk is one of the rarest and least-studied birds in the United States. The Short-tailed Hawk's immediate nesting habitat usually consists of tall, dense, often wet forest. However, year-round foraging habitats span a broad range of plant communities and physical landscapes. These include swamp forest, mixed forest-prairie landscapes, pine savannas, mangroves, coastal marshes and prairies, and pastures and suburban settings with scattered trees and shrubs.

(Source: Miller, Karl E. and Kenneth D. Meyer. 2002)



Figure 56: Short-Tailed Hawk

Short-Tailed Hawk Habitat

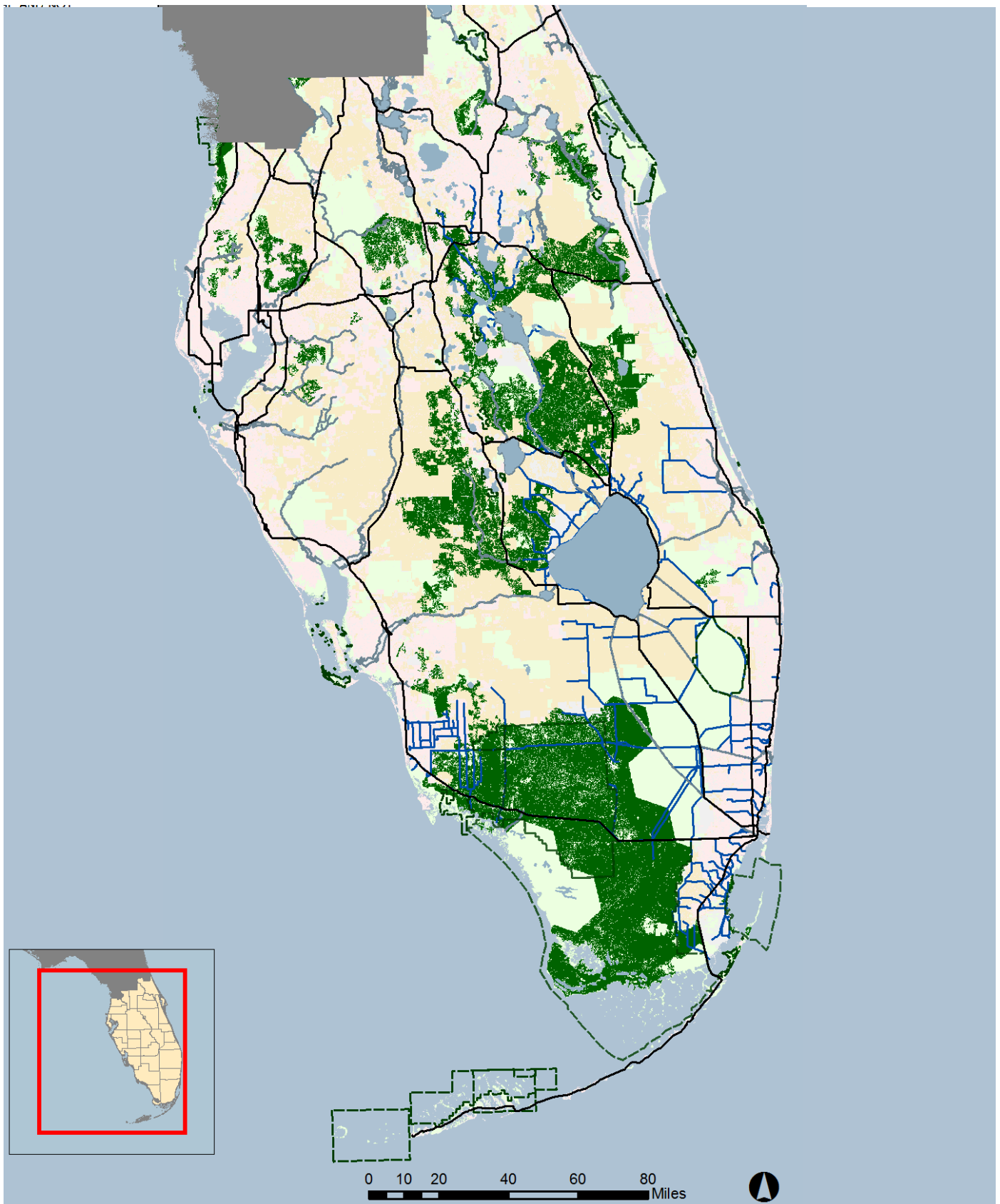
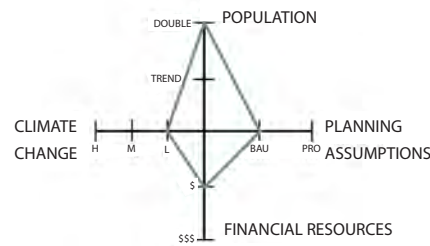


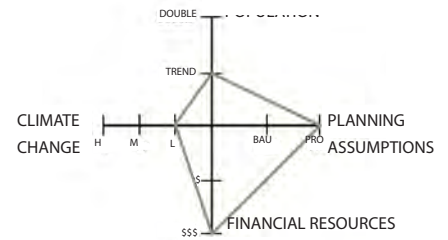
Figure 57: Short-Tailed Hawk: Habitat

Short-Tailed Hawk Spatial Vulnerability Under MIT Scenarios

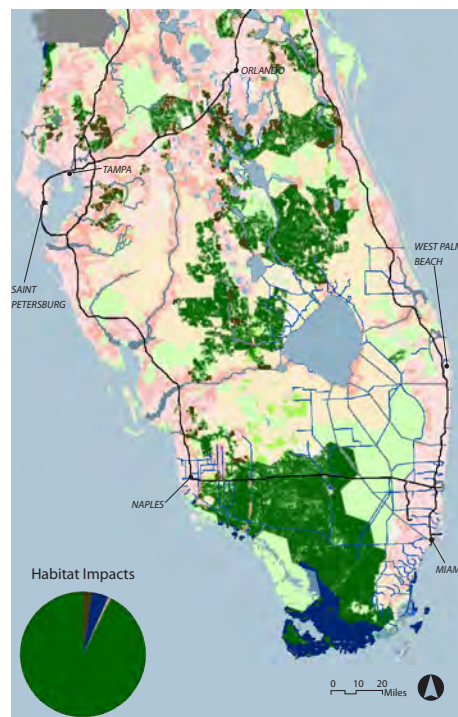
Scenario A



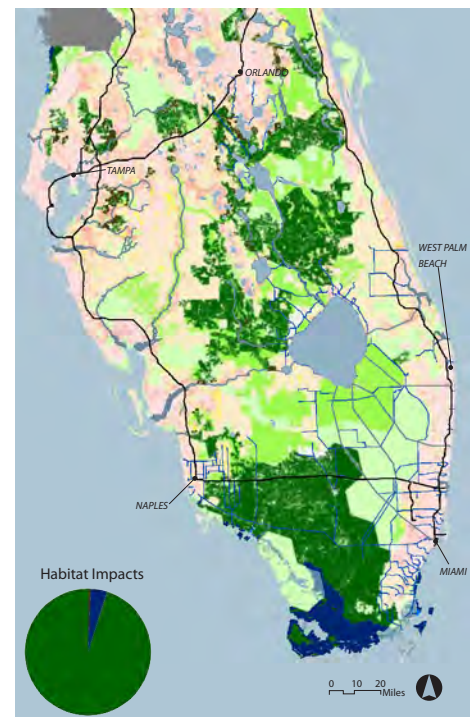
Scenario B



Scenario A Land Cover 2060



Scenario B Land Cover 2060



Map Legend

Habitat Conflict	
●	Agriculture Inundated
●	Agriculture Urbanized
●	Conservation Inundated
●	Other Uses Inundated
●	Other Uses Urbanized
●	No Habitat Conflict

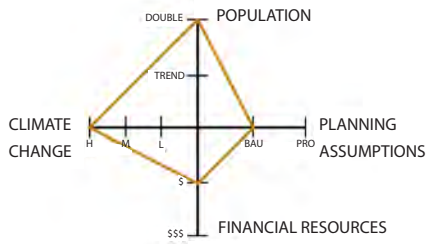
Current Land Use	Projected Land Use
■ Agriculture	■ Agriculture
■ Conservation	■ Conservation
■ Urban	■ Urban

Habitat Impacts By Land Use Type	2060	
	%	Acres
● Agriculture Urbanized	2.37%	91,111
● Conservation Inundated	4.25%	165,522
● Other Uses Inundated	0.02%	644
● Other Uses Urbanized	0.71%	27,466
● No Habitat Conflict	92.66%	3,665,272
Total Habitat Conflict	7.34%	285,763

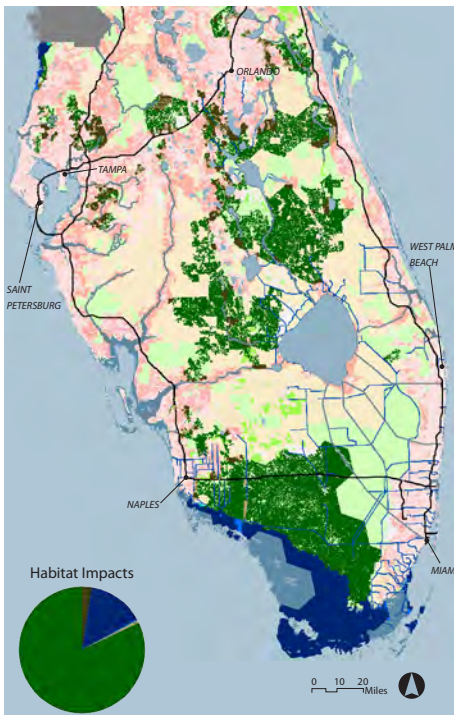
Habitat Impacts By Land Use Type	2060	
	%	Acres
● Agriculture Urbanized	0.69%	26,673
● Conservation Inundated	4.25%	165,522
● Other Uses Inundated	0.02%	644
● Other Uses Urbanized	0.10%	3,853
● No Habitat Conflict	94.94%	3,694,324
Total Habitat Conflict	5.06%	196,711

Figure 58: Short Tailed hawk: Spatial Vulnerability Under MIT Scenarios

Scenario C

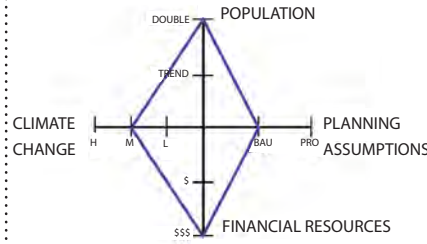


Scenario C Land Cover 2060

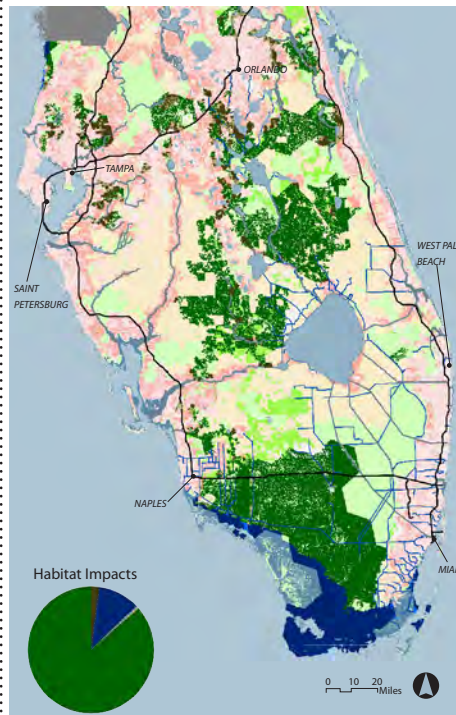


Habitat Impacts	2060	
By Land Use Type	%	Acres
● Agriculture Inundated	0.03%	1,150
● Agriculture Urbanized	2.40%	93,314
● Conservation Inundated	14.55%	566,206
● Other Uses Inundated	0.26%	9,996
● Other Uses Urbanized	0.66%	25,855
● No Habitat Conflict	82.10%	3,194,515
Total Habitat Conflict	17.90%	696,521

Scenario E

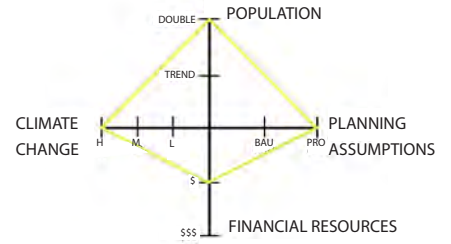


Scenario E Land Cover 2060

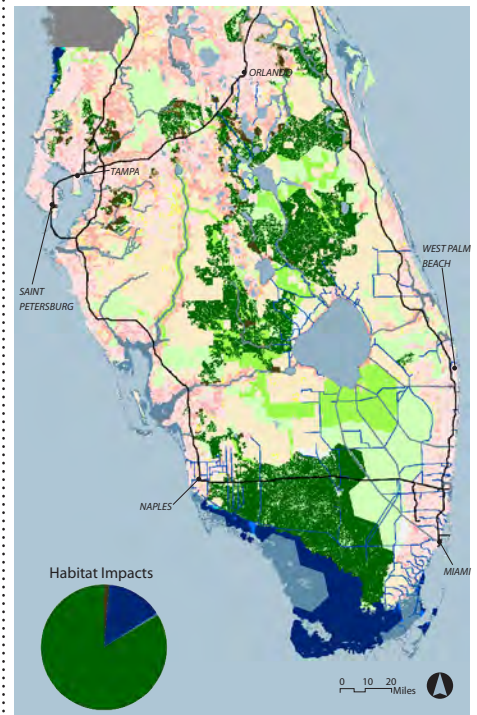


Habitat Impacts	2060	
By Land Use Type	%	Acres
● Agriculture Inundated	0.00%	5
● Agriculture Urbanized	2.12%	82,668
● Conservation Inundated	10.70%	416,301
● Other Uses Inundated	0.14%	5,586
● Other Uses Urbanized	0.60%	23,308
● No Habitat Conflict	86.43%	3,363,168
Total Habitat Conflict	13.57%	527,867

Scenario I



Scenario I Land Cover 2060



Habitat Impacts	2060	
By Land Use Type	%	Acres
● Agriculture Inundated	0.03%	1,150
● Agriculture Urbanized	1.25%	48,707
● Conservation Inundated	14.55%	566,206
● Other Uses Inundated	0.26%	9,996
● Other Uses Urbanized	0.23%	8,796
● No Habitat Conflict	83.68%	3,256,180
Total Habitat Conflict	16.32%	634,855

Short Tailed Hawk

Habitat Impacts by Scenario and Land Management Type

Habitat Impact Scenario A (Low SLR, 2x Population, Weak Economy, Business As Usual)
Total Habitat Area in Analysis Window: 3,891,036 acres

2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	2%	0%				
Public Conservation	63%	5%				
Private Undeveloped	1%	0%	0%	0%	0%	0%
Public Undeveloped	1%	0%	0%	0%	0%	0%
Crops / Citrus	1%		0%	0%	0%	
Ranching	16%		2%	1%	6%	

Habitat Impact Scenario B (Low SLR, 1.5x Population, Strong Economy, Proactive)
Total Habitat Area in Analysis Window: 3,891,036 acres

2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	2%	0%				
Public Conservation	63%	5%				
Private Undeveloped	1%	0%	0%	0%	1%	0%
Public Undeveloped	1%	0%	0%	0%	0%	0%
Crops / Citrus	0%		0%	0%	1%	
Ranching	5%		0%	1%	18%	

Habitat Impact Scenario C (High SLR, 2x Population, Weak Economy, Business As Usual)
Total Habitat Area in Analysis Window: 3,891,036 acres

2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	2%	0%				
Public Conservation	51%	17%				
Private Undeveloped	1%	0%	0%	0%	0%	0%
Public Undeveloped	1%	0%	0%	0%	0%	0%
Crops / Citrus	1%		0%	0%	0%	
Ranching	16%		2%	2%	6%	

Habitat Impact Scenario E (Medium SLR, 2x Population, Strong Economy, Business As Usual)
Total Habitat Area in Analysis Window: 3,891,036 acres

2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	2%	0%				
Public Conservation	55%	12%				
Private Undeveloped	1%	0%	0%	0%	1%	0%
Public Undeveloped	1%	0%	0%	0%	0%	0%
Crops / Citrus	1%		0%	0%	1%	
Ranching	6%		1%	1%	16%	

Habitat Impact Scenario I (High SLR, 2x Population, Weak Economy, Proactive)
Total Habitat Area in Analysis Window: 3,891,036 acres

2010 Management Context	Future Impact					
	No Impact	Inundated	Built High Density	Built Low Density	Protected	Converted to Ag
Private Conservation	2%	0%				
Public Conservation	51%	17%				
Private Undeveloped	2%	0%	0%	0%	1%	0%
Public Undeveloped	1%	0%	0%	0%	0%	0%
Crops / Citrus	1%		0%	0%	0%	
Ranching	14%		0%	2%	9%	

Figure 59: Short-Tailed Hawk: Habitat Impacts Chart per Scenario

Habitat Impact : Scenario A
(Low SLR, 2x Population, Weak Economy, Business As Usual)

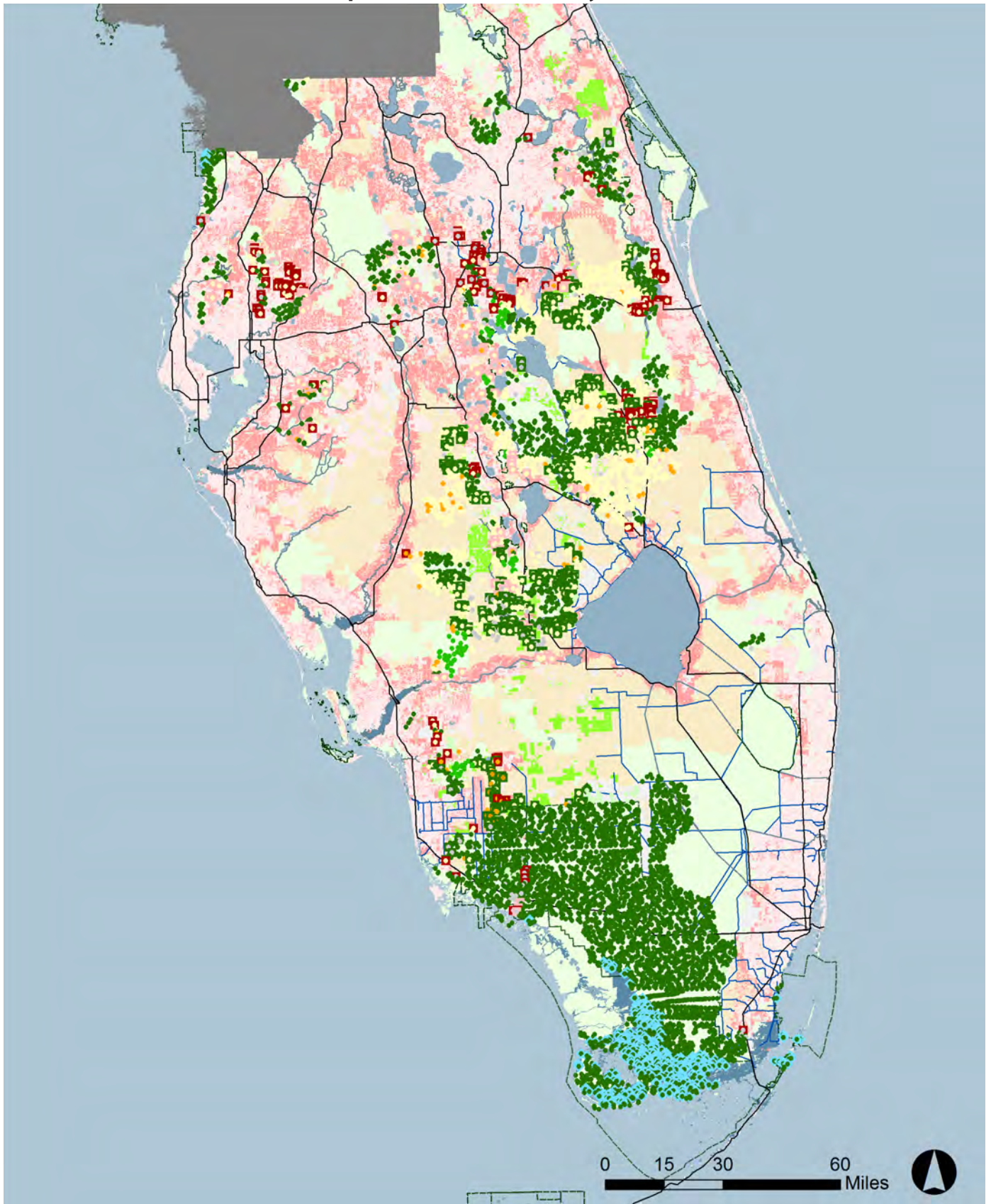
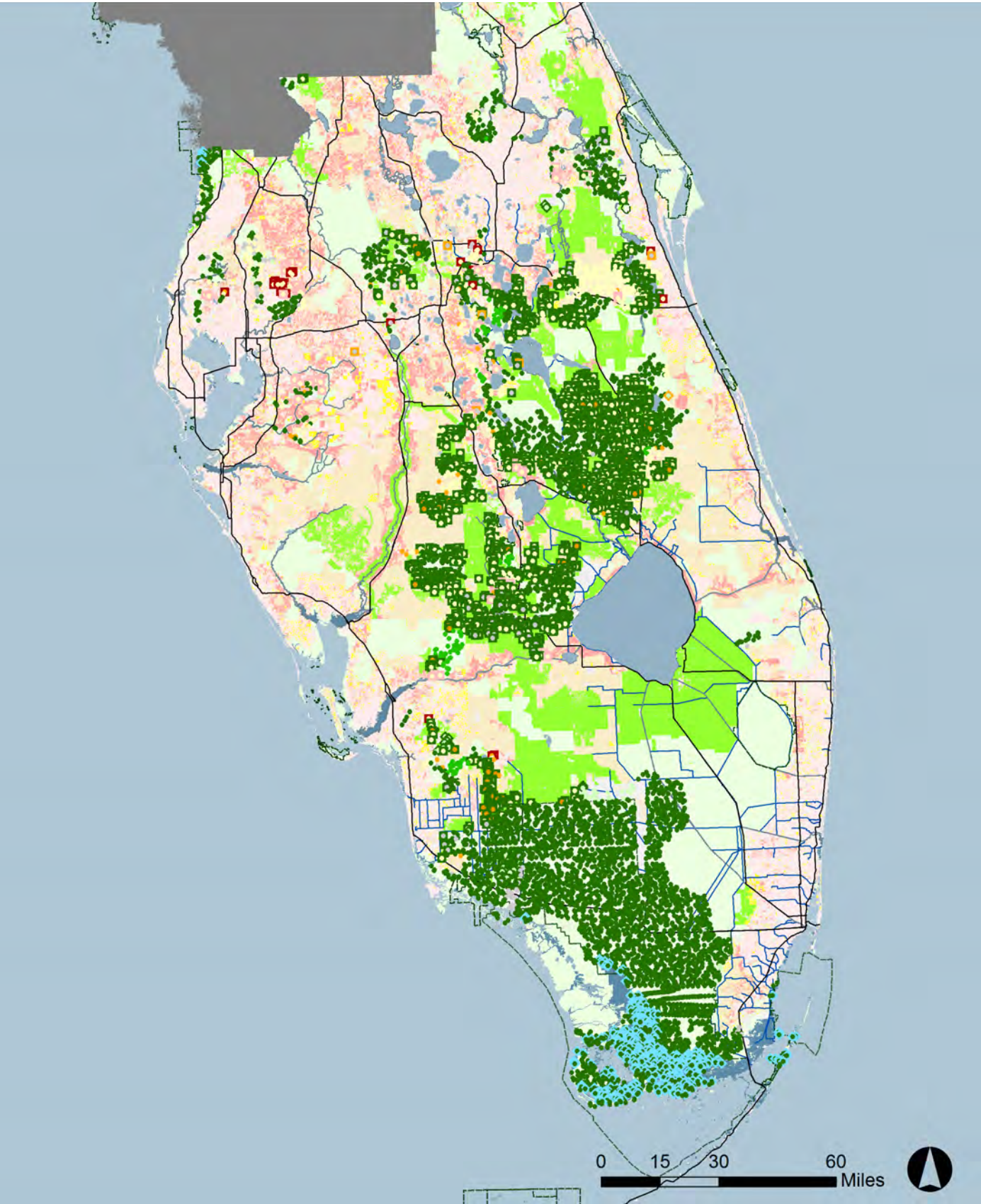
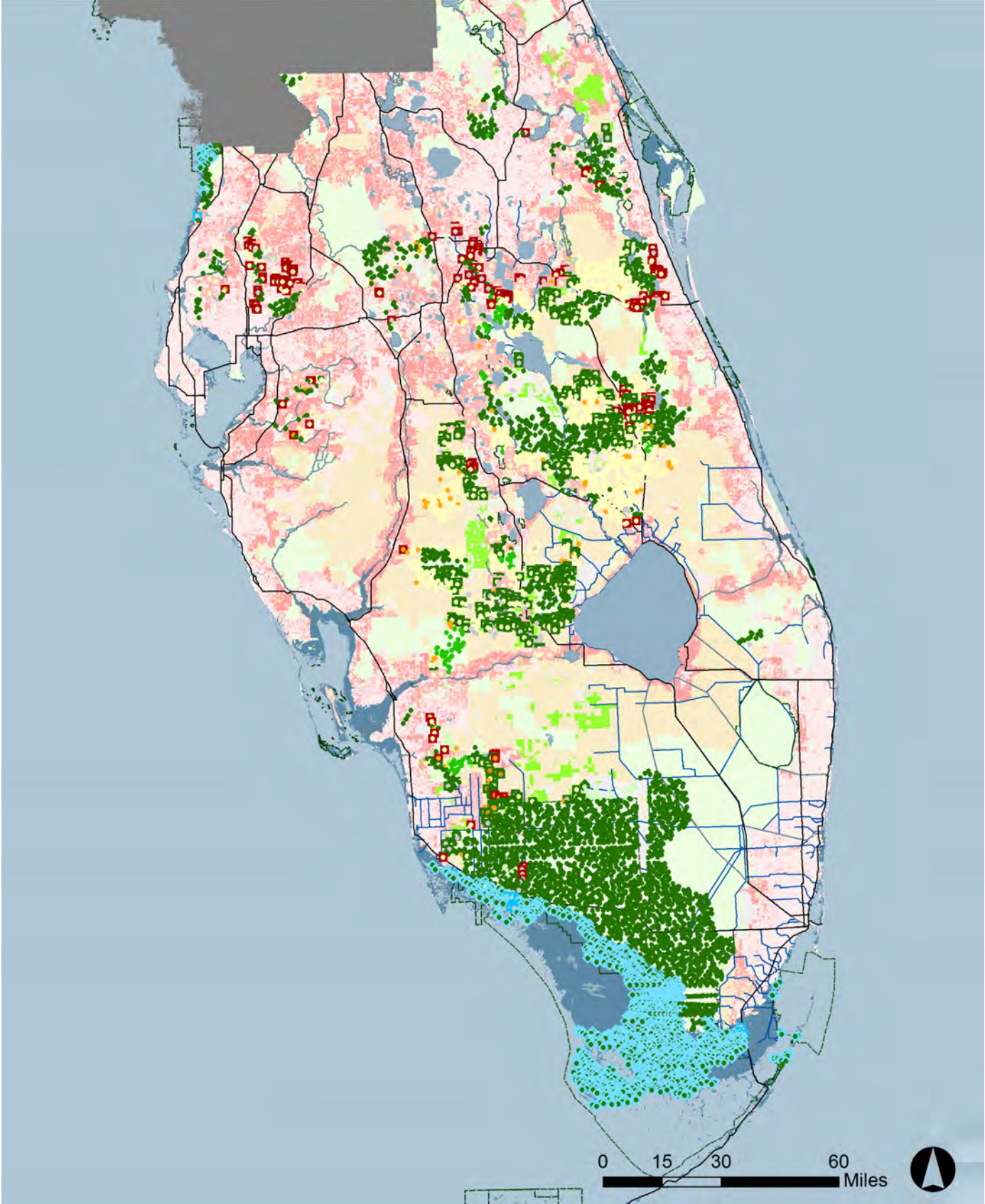


Figure 60: Short-Tailed Hawk: Habitat Impacts Maps per Scenario

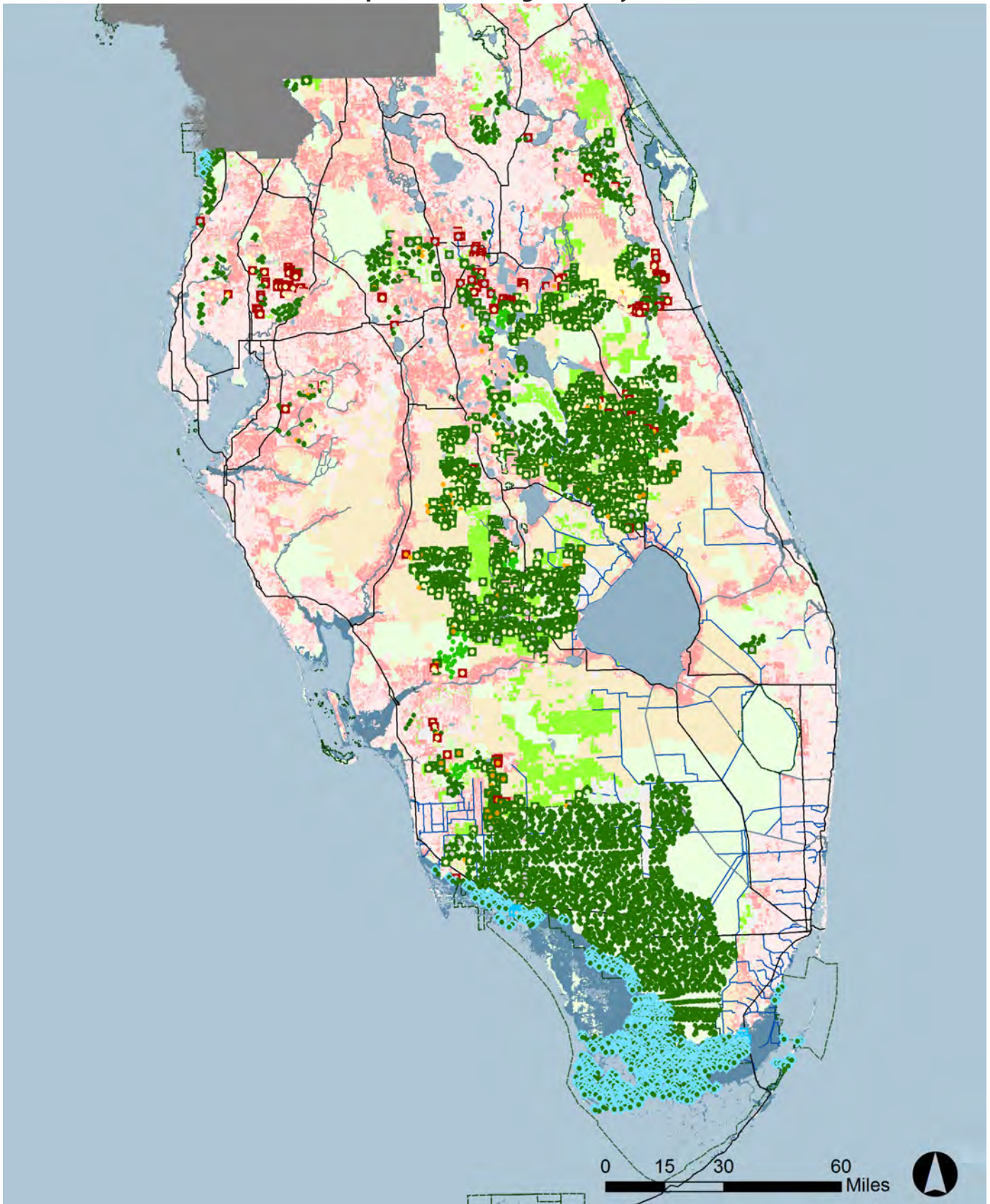
Habitat Impact : Scenario B
(Low SLR, 1.5x Population, Strong Economy, Proactive)



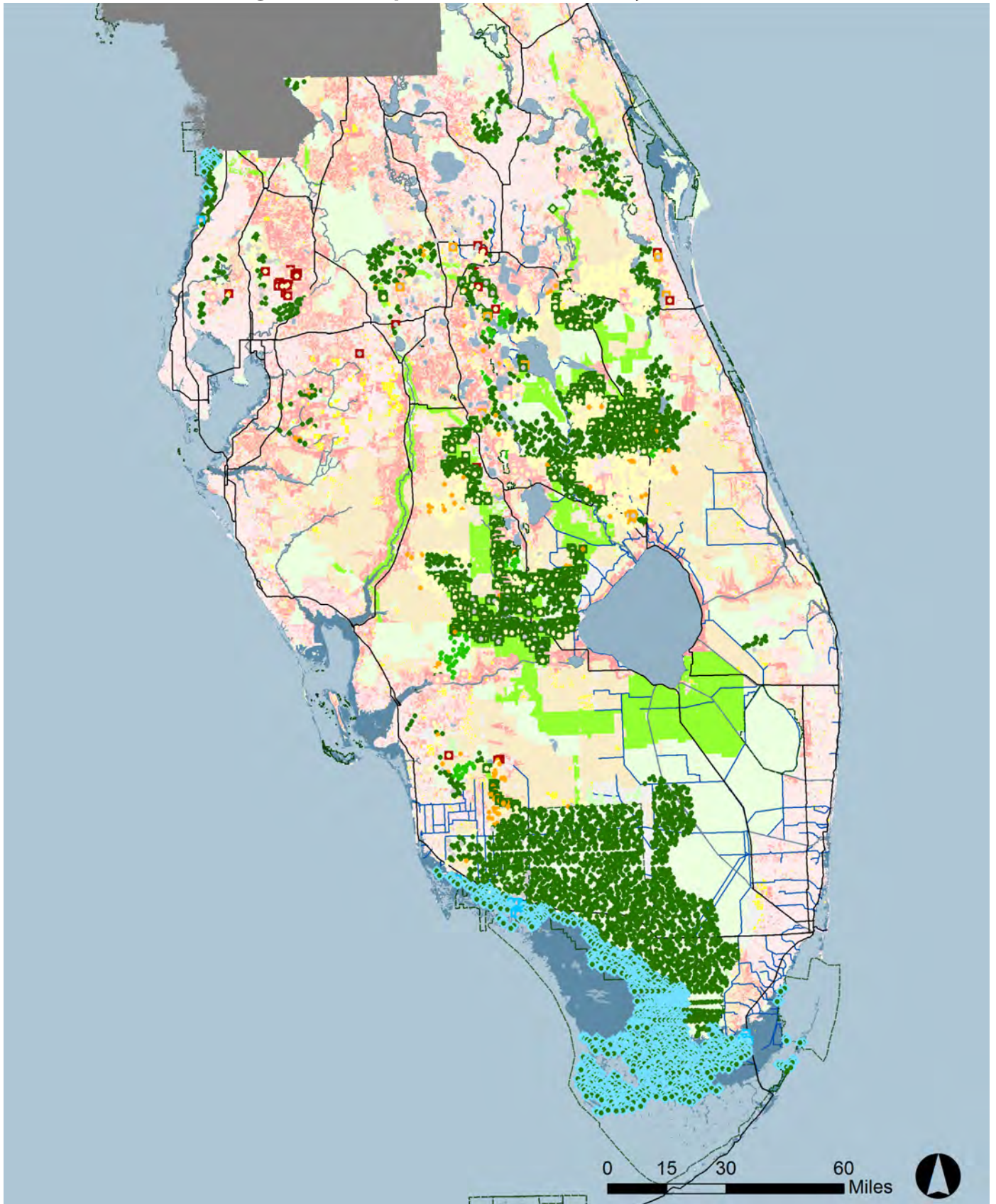
Habitat Impact : Scenario C
(High SLR, 2x Population, Weak Economy, Business As Usual)



Habitat Impact : Scenario E
(Medium SLR, 2x Population, Strong Economy, Business As Usual)



Habitat Impact : Scenario I
(High SLR, 2x Population, Weak Economy, Proactive)



Conclusions Spatial Vulnerability: Short-Tailed Hawk

Sea-level rise and land use change impacts on short-tailed hawk habitat vary under each scenario. The least impacting scenario presents loss by 2060 of approximately 5% of the habitat or 196 acres. Conditions under this scenario are: low sea-level rise (+3.6" SLR), trend population growth and proactive urban and land use policies. The most impacting scenario results in a loss of 18% of the habitat by 2060 or equivalent to 197 acres. This scenario simulates conditions of high sea-level rise double the human population and business as usual for urban and land use policies.

Summary of Habitat Inundation/Loss Under SLR Scenarios			
Short-Tailed Hawk	Low	Medium	High
Habitat inundated	4%	11%	15%
Other habitat impacts	3%	3%	3%
Current habitat unchanged	93%	86%	82%

Figure 61: Short-Tailed Hawk Habitat Inundation/Loss under SLR Scenarios

General Findings

Our experts noted significant errors of omission in the FWC 2009 habitat model outputs. These were traced to the decision in that modeling effort to count as habitat only suitable areas within a given distance of known occurrence observations. Because this bird is secretive and relatively poorly studied, and also because the state experts currently have access to more and better observation data, they uniformly agreed that a better model is needed. This could be created by dropping the occurrence criteria from the original model, or by supplementing the original model with additional occurrence data. However due to staffing at FWC and resource limitations within this pilot, it was not possible to revise this habitat model. This means that the impacts computed above are likely underestimates.

The second issue raised about habitat is that for this species, there is a large variation between nesting and wintering habitat, and this is not reflected in the available modeling outputs. Experts wanted to see the habitat modeling revised to reflect these important seasonal differences.

A third issue raised was one common to many other pilot species: the scenarios given did not reflect vegetation sensitivity to climate change. In particular, wooded wetlands in this region were considered by our experts as likely to migrate, in the case of mangroves, or to disappear, in the case of interior wooded wetlands under drying scenarios. Furthermore, under drying scenarios, our experts felt that a variety of other human uses were likely to replace wooded wetlands. This dynamic was not modeled in the existing AttConn simulation runs.

These concerns led directly to short, medium and long term research recommendations for this species. In the short term, existing habitat models should be revised to reflect better occurrence information, and to split wintering and nesting seasonal habitats. In the medium term, the relationship between wooded wetlands and climate change scenarios should be more carefully explored, and this component should be added to vegetation succession modeling efforts. In the longer term, scenarios should be re-run on the basis of these upgraded inputs, including human responses to the “buildability” or “ranchability” of areas currently too wet to be subject to conversion pressures.

5.0 Adaptation planning process (SEAP)

The Spatially-explicit adaptation planning process (SEAP) is the second structural component of the Spatial Resilience Methodology. This component of the process is developed after the initial spatially-explicit vulnerability assessment (SEVA) and has as an objective to define and apply the necessary management strategies (adaptation policies and management practices) to the geographic extent of the studied species' habitat seeking to reduce the identified vulnerability and associated challenges.

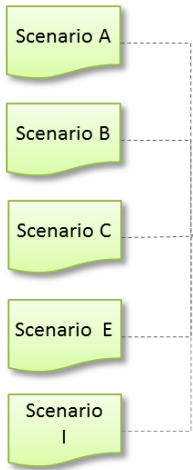
The spatially-explicit adaptation planning process was developed during the second FWC workshop. This took place in the Orlando Science Center, Orlando, Florida on April 28-29, 2011. It included most of the same species experts as the first workshop, but in addition a number of land and wildlife managers were invited. In this session, we reviewed the revised models, and then in partnership with Defenders of Wildlife performed a "conceptual modeling" exercise focused on the development of species management actions appropriate under climate change. A final session concentrated on potential spatial planning options for each species.

During the development of the workshop a list of management strategies for each of the six species was obtained from a process led by Defenders of Wildlife through a Conceptual Modeling Exercise (see Defenders of Wildlife for details on the process and details of the conceptual model - Dubois et al, 2011). Then using "geodesign" techniques, participants "sketched" those and other management actions on top of base or impact maps under different scenarios. In this way, we were able to identify not only "which" actions might be required, but "how much" and "where."

In order to operationalize the spatially-explicit adaptation planning process we selected case study areas within each of the species habitat where the vulnerabilities identified were critical. In addition the selected case study areas represented clearly one of the three vulnerability geographic conditions: first, species with narrow habitat ranges whose habitat is under severe threat from

Workshop 2 Process

Workshop 2:
Scenarios casted
in Management
Units



Workshop 1:
Scenarios casted
in land uses
changes

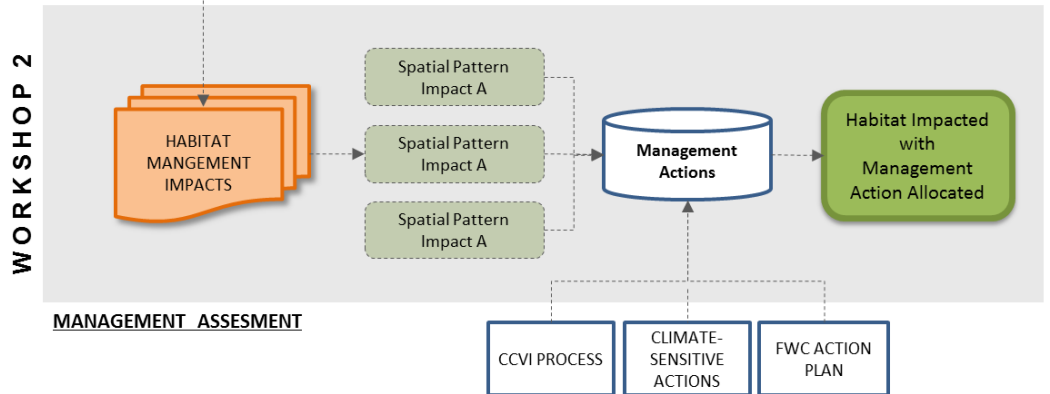
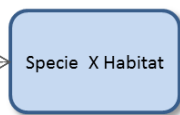


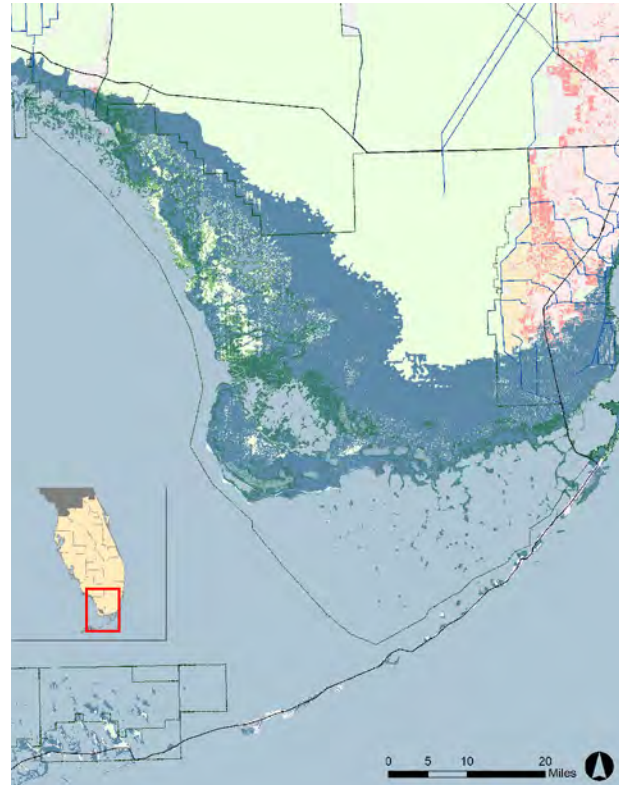
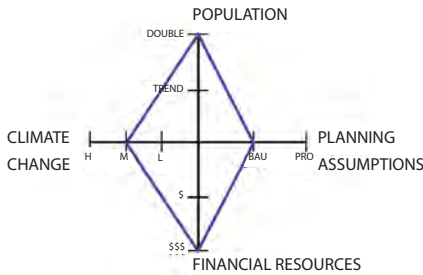
Figure 62: Framework - Adaptation Planning Process (SEAP)

sea level rise, urbanization, or the combination of both. Second were a set of species persisting mostly within Florida’s extensive large conservation areas, such as Everglades National Park; and third were a set of species whose remaining habitat is reliant on private lands.

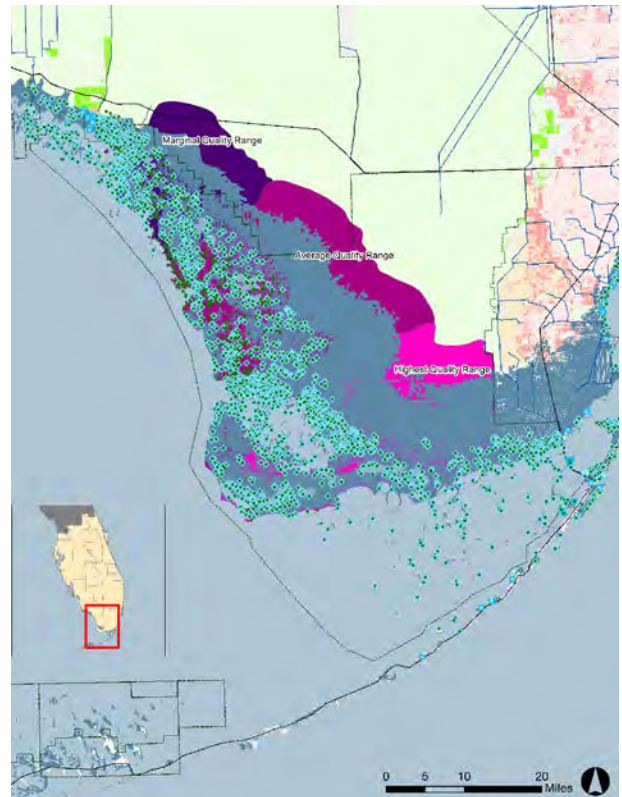
Case Study Areas

5.1.1 “Room to Move” Case Study

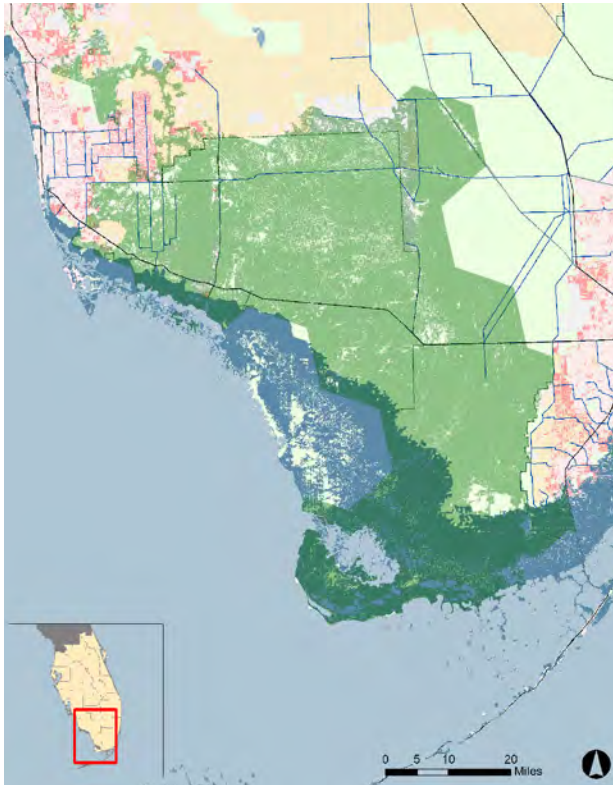
Impact maps show scenario E: medium SLR, Double Population, High Financial Resources and Business as Usual Planning



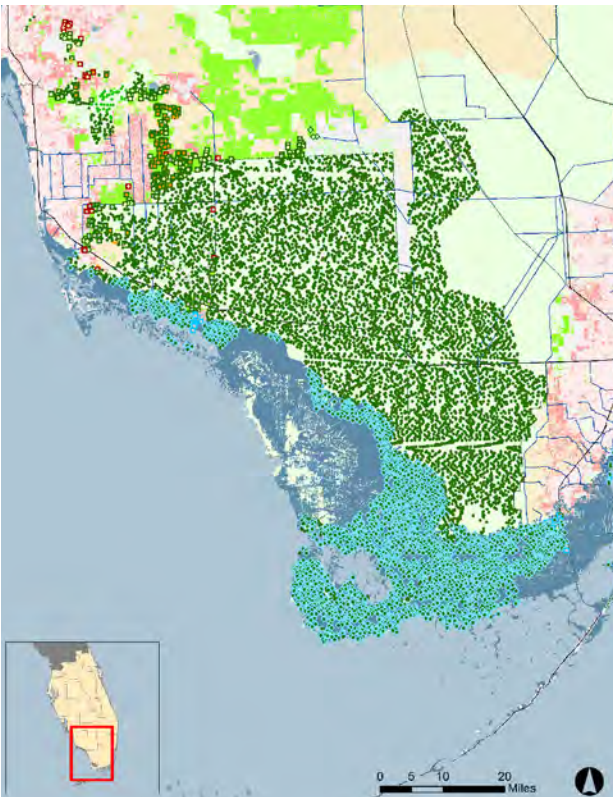
American Crocodile Current Habitat



American Crocodile Impact by 2060



Short-Tailed Hawk Current Habitat



Short-Tailed Hawk Habitat Impact by 2060

LEGEND

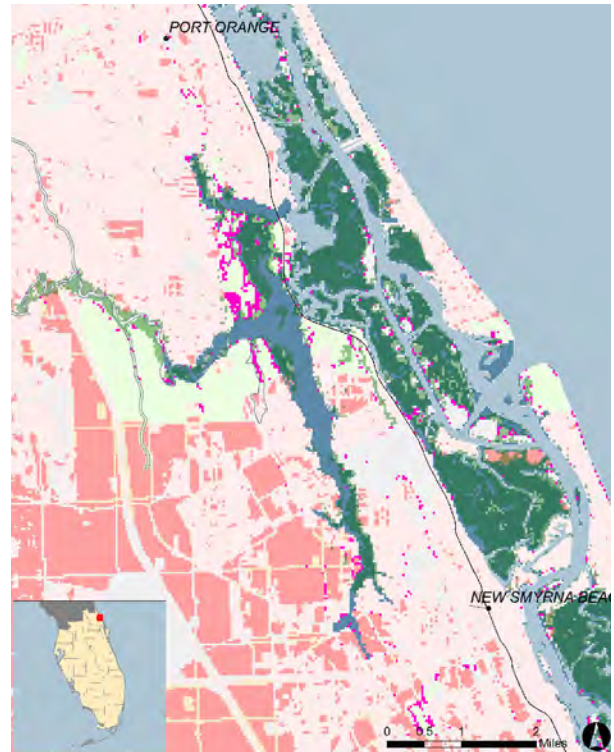
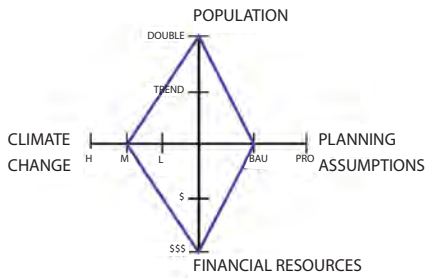
- Current Habitat
- Sea Level Rise
- Habitat Impacts**
- Impacts on Public Land**
 - Public Conservation No Impact
 - Public Conservation To Inundated
 - Public Undeveloped No Impact
 - Public Undeveloped To Inundated
 - Public Undeveloped To High Impact Urban
 - Public Undeveloped To Low Impact Urban
 - Public Undeveloped To New Conservation
 - Public Undeveloped To New Agriculture
- Impacts on Private Land**
 - Private Conservation No Impact
 - Private Conservation To Inundated
 - Private Crops/Citrus No Impact
 - Private Crops/Citrus To High Impact Urban
 - Private Crops/Citrus To Low Impact Urban
 - Private Crops/Citrus To New Conservation
 - Private Ranching No Impact
 - Private Ranching To High Impact Urban
 - Private Ranching To Low Impact Urban
 - Private Ranching To New Conservation
 - Private Undeveloped No Impact
 - Private Undeveloped To Inundated
 - Private Undeveloped To High Impact Urban
 - Private Undeveloped To Low Impact Urban
 - Private Undeveloped To New Conservation
 - Private Undeveloped To New Agriculture
- New Potential Habitat**
 - Highest Quality
 - Average Quality
 - Marginal Quality
- Allocated Land Uses**
 - Urban
 - Conservation
 - Agriculture
- Current Land Uses**
 - Urban
 - Conservation
 - Agriculture
 - Other
 - Protected Areas

Figure 63: Case Study "Room to Move"

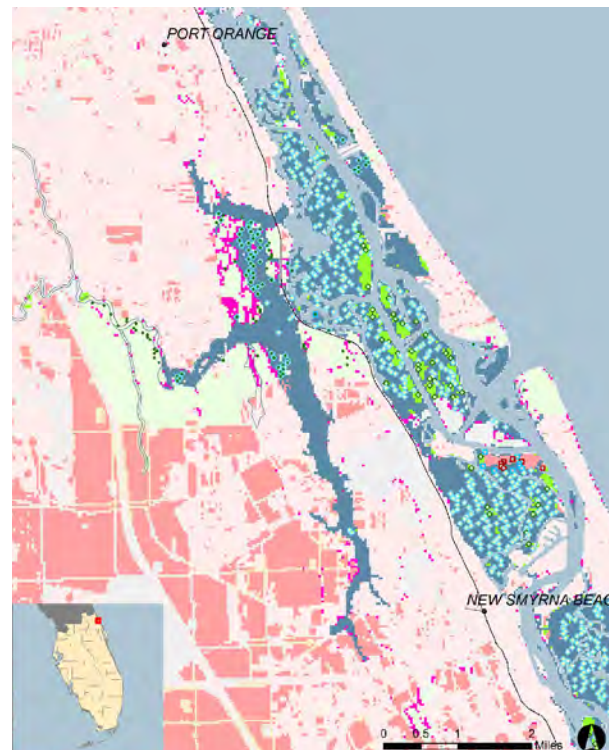
Case Study Areas

5.1.2 "Surrounded on all Sides" Case Study

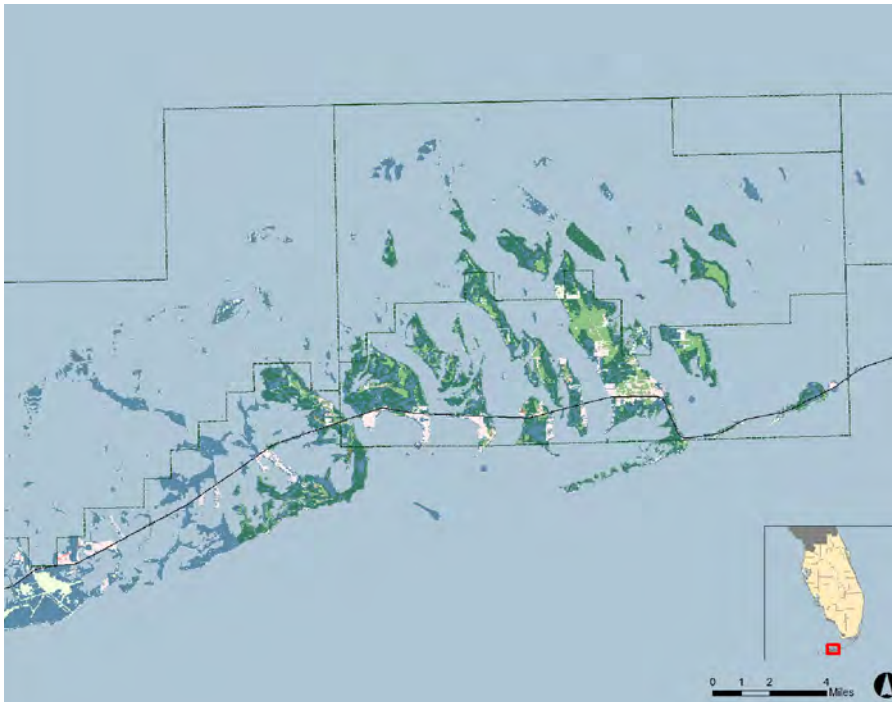
Impact maps show scenario E: medium SLR, Double Population, High Financial Resources and Business as Usual Planning



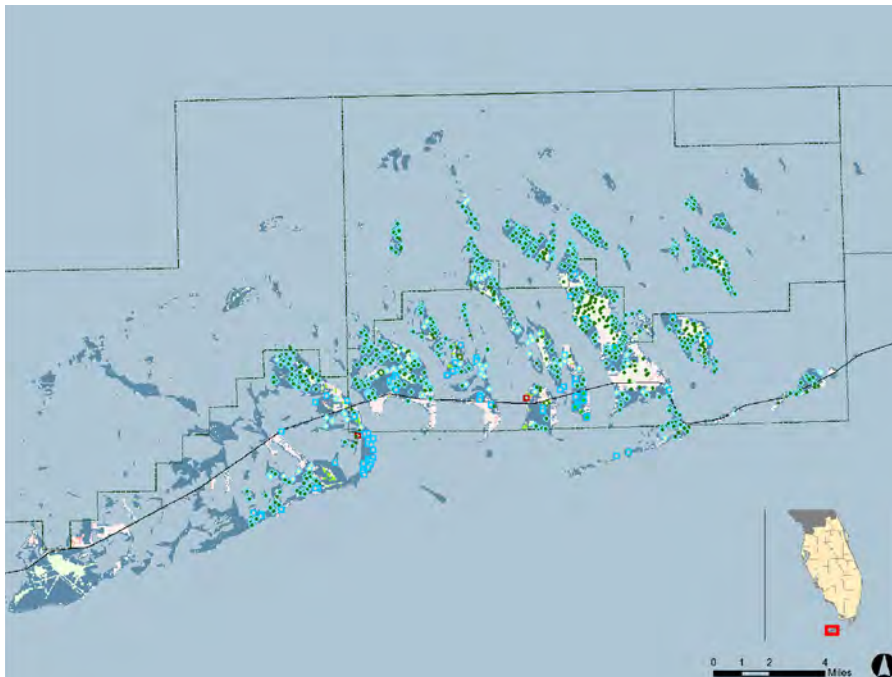
Atlantic Salt-Marsh Snake Current Habitat



Atlantic Salt-Marsh Snake Habitat Impacts by 2060



Key Deer Current Habitat



Key Deer Habitat Impacts by 2060

LEGEND

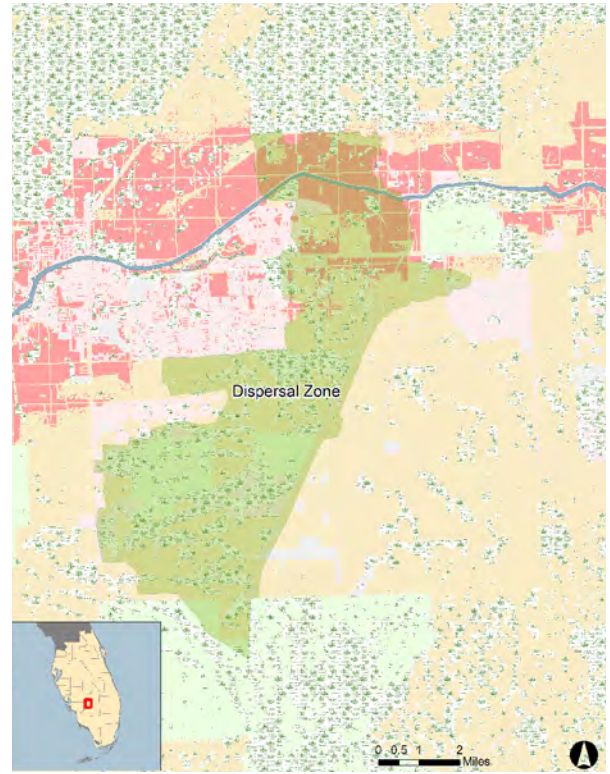
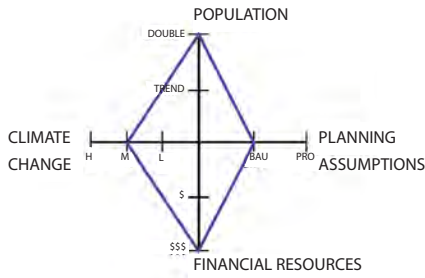
- Current Habitat
- Sea Level Rise
- Habitat Impacts**
- Impacts on Public Land**
- Public Conservation No Impact
- Public Conservation To Inundated
- Public Undeveloped No Impact
- Public Undeveloped To Inundated
- Public Undeveloped To High Impact Urban
- Public Undeveloped To Low Impact Urban
- Public Undeveloped To New Conservation
- Public Undeveloped To New Agriculture
- Impacts on Private Land**
- Private Conservation No Impact
- Private Conservation To Inundated
- Private Crops/Citrus No Impact
- Private Crops/Citrus To High Impact Urban
- Private Crops/Citrus To Low Impact Urban
- Private Crops/Citrus To New Conservation
- Private Ranching No Impact
- Private Ranching To High Impact Urban
- Private Ranching To Low Impact Urban
- Private Ranching To New Conservation
- Private Undeveloped No Impact
- Private Undeveloped To Inundated
- Private Undeveloped To High Impact Urban
- Private Undeveloped To Low Impact Urban
- Private Undeveloped To New Conservation
- Private Undeveloped To New Agriculture
- New Potential Habitat**
- Highest Quality
- Average Quality
- Marginal Quality
- Allocated Land Uses**
- Urban
- Conservation
- Agriculture
- Current Land Uses**
- Urban
- Conservation
- Agriculture
- Other
- Protected Areas

Figure 64: Case Study "Surrounded on all Sides"

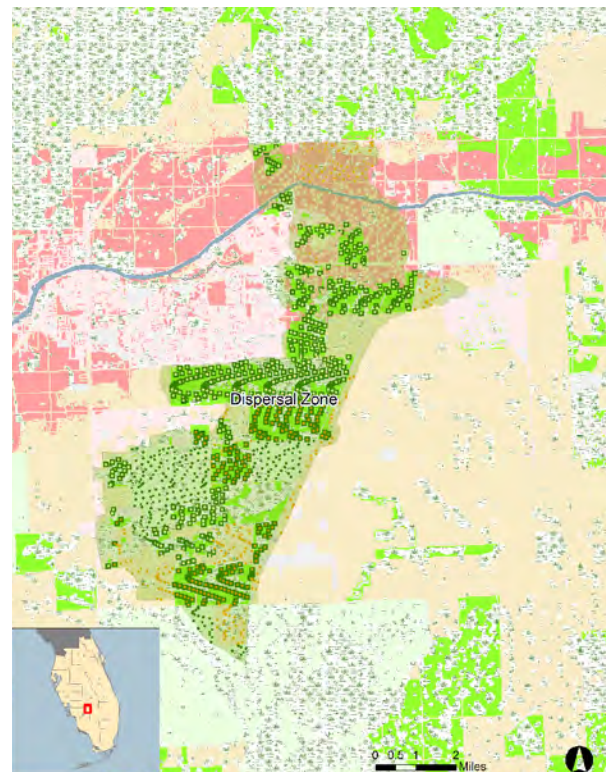
Case Study Areas

5.1.3 “Dealing with the Neighbors” Case Study

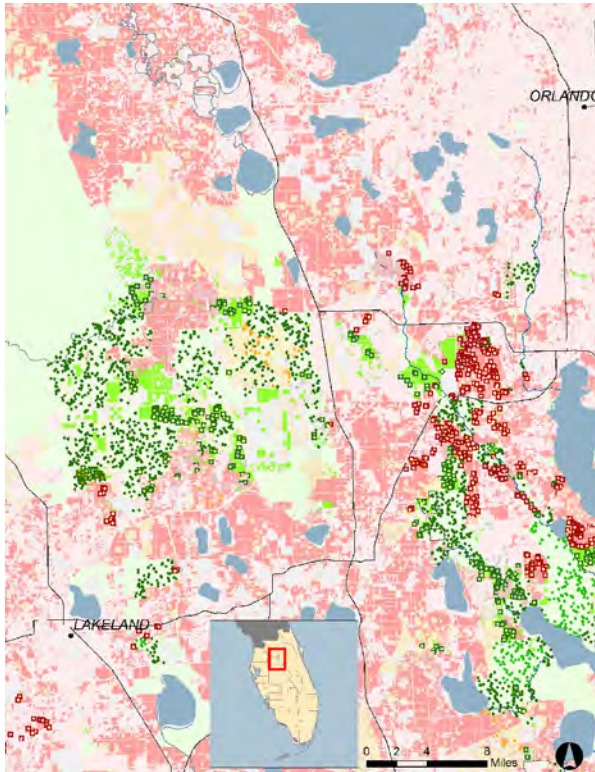
Impact maps show scenario E: medium SLR, Double Population, High Financial Resources and Business as Usual Planning



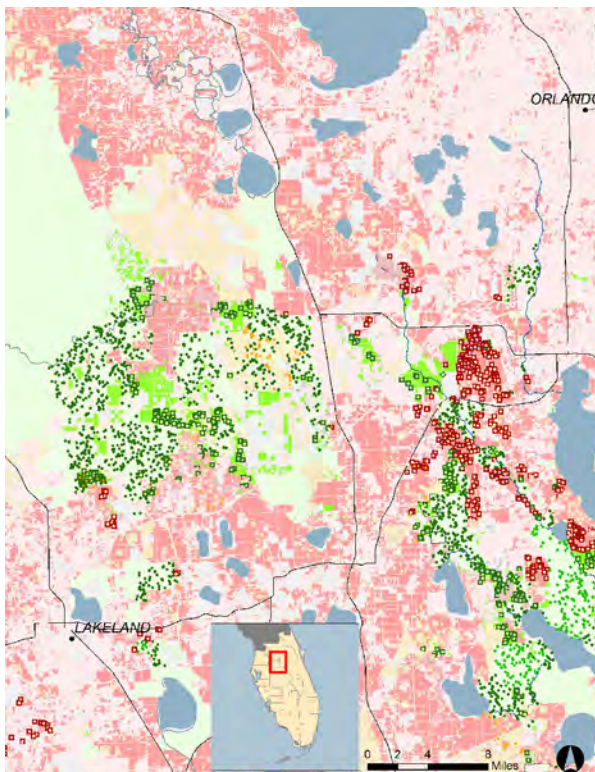
Florida Panther Current Habitat



Florida Panther Habitat Impacts by 2060



Short-Tailed Hawk Current Habitat



Short-Tailed Hawk Habitat Impact by 2060

LEGEND

- Current Habitat
- Sea Level Rise
- Habitat Impacts**
- Impacts on Public Land**
 - Public Conservation No Impact
 - Public Conservation To Inundated
 - Public Undeveloped No Impact
 - Public Undeveloped To Inundated
 - Public Undeveloped To High Impact Urban
 - Public Undeveloped To Low Impact Urban
 - Public Undeveloped To New Conservation
 - Public Undeveloped To New Agriculture
- Impacts on Private Land**
 - Private Conservation No Impact
 - Private Conservation To Inundated
 - Private Crops/Citrus No Impact
 - Private Crops/Citrus To High Impact Urban
 - Private Crops/Citrus To Low Impact Urban
 - Private Crops/Citrus To New Conservation
 - Private Ranching No Impact
 - Private Ranching To High Impact Urban
 - Private Ranching To Low Impact Urban
 - Private Ranching To New Conservation
 - Private Undeveloped No Impact
 - Private Undeveloped To Inundated
 - Private Undeveloped To High Impact Urban
 - Private Undeveloped To Low Impact Urban
 - Private Undeveloped To New Conservation
 - Private Undeveloped To New Agriculture
- New Potential Habitat**
 - Highest Quality
 - Average Quality
 - Marginal Quality
- Allocated Land Uses**
 - Urban
 - Conservation
 - Agriculture
- Current Land Uses**
 - Urban
 - Conservation
 - Agriculture
 - Other
 - Protected Areas

Figure 65: Case Study "Dealing with the Neighbors"

Adaptation Strategies and GeoDesigns:

5.2.1 “Room to Move”

This particular management context is the simplest in management terms in that there are large blocks of public ownership dedicated to conservation. There are a few absolute restrictions on research and conservation-oriented management actions on national parks and refuges. There are procedural requirements for undertaking particular actions, but in the context of long-term climate change research, few of these pose barriers to the actions recommended by our experts. In areas with significant tourism and recreational use there may be some practical challenges, for example in maintaining the security of expensive field-monitoring equipment, but these can be worked out within existing management regimes.

The most significant constraints are likely to revolve around the issue of endangered species and adaptive management experiments. In the case of South-central Florida, the two most likely sources of similar conflict would likely revolve around attempts to re-establish historic disturbance regimes for fire and flooding. These are somewhat less of a concern within very large protected areas, but they do remain, since these areas do have private neighboring lands as well as some competing uses.

Identified Adaptation Strategies Deployed

Strategy 1: Monitoring SLR Impacts in Identified Priority Areas

The group recommended funding monitoring efforts in regions mapped below using existing protocols. The spatial monitoring strategy anticipates future treatment areas and would conduct monitoring in those areas so as to establish a pre-treatment baseline.

Strategy 2: SLR Species and Habitat Research.

The major research gap identified by our experts is the lack of detailed understanding of SLR impacts on habitats and species of concern. In particular, research on nesting habitat disruption by SLR and related habitat changes was considered to be of high priority and feasibility. Of specific relevance to the species considered in this project, this type of research could feed directly into refined versions of future climate-sensitive wildlife habitat models for the American Crocodile and Short-tailed Hawk. More broadly, the mechanisms at work in SLR-driven habitat change within Mangrove and Salt Marsh habitats are high priorities, since they affect many species of concern.

A major complication in this research is the interaction with ground water systems and with CERP restoration efforts. It is unlikely that systematic adaptive management experiments with replicates could be designed in such a large and human-coupled water system. Therefore, “natural experiments” will be needed which take advantage of spatial and temporal variations occurring within this region. In order for these to be accomplished, it is important that baseline monitoring systems be established and extended with stratified sampling that captures a range of biotic and human-influenced variations.

Strategy 3: Preparing for Potential Northward, Upland Habitat Shifts

It is clear from the SLR simulations within the scenarios that habitat losses are likely to start and to be concentrated in the South and Southwest of this region. In order to maintain existing species populations, this will place increasing pressure Northward following the climate gradient, and up-hill, following microterrain and hydrological gradients. In broad geographic terms, this means that the coastal ridge and Everglades Agricultural Area will become important in maintaining “room to move” for conservation. Habitat occupancy surveys are particularly important in these regions, so that managers can understand which potential habitat areas are functionally connected and could provide appropriate climate change mitigation through conservation acquisition.

Strategy 4: Habitat Quality Improvement

The second recommended action is to undertake habitat quality improvement projects within this region. These will vary somewhat by species, but are facilitated by the existence in most cases of a single-agency management regime with conservation mandate. Many of these are covered within existing management plans. Our experts advocated revisiting and prioritizing these actions based in part on the new information obtained from high-resolution LIDAR mapping of terrain and likely SLR inundation areas. For example, those areas inland and North of the existing primary mainland American Crocodile habitat should receive particular attention given the finding of this pilot that most of the Florida Keys habitat for this species is under grave threat.



Figure 66: "Room to move" - Initial Sketch

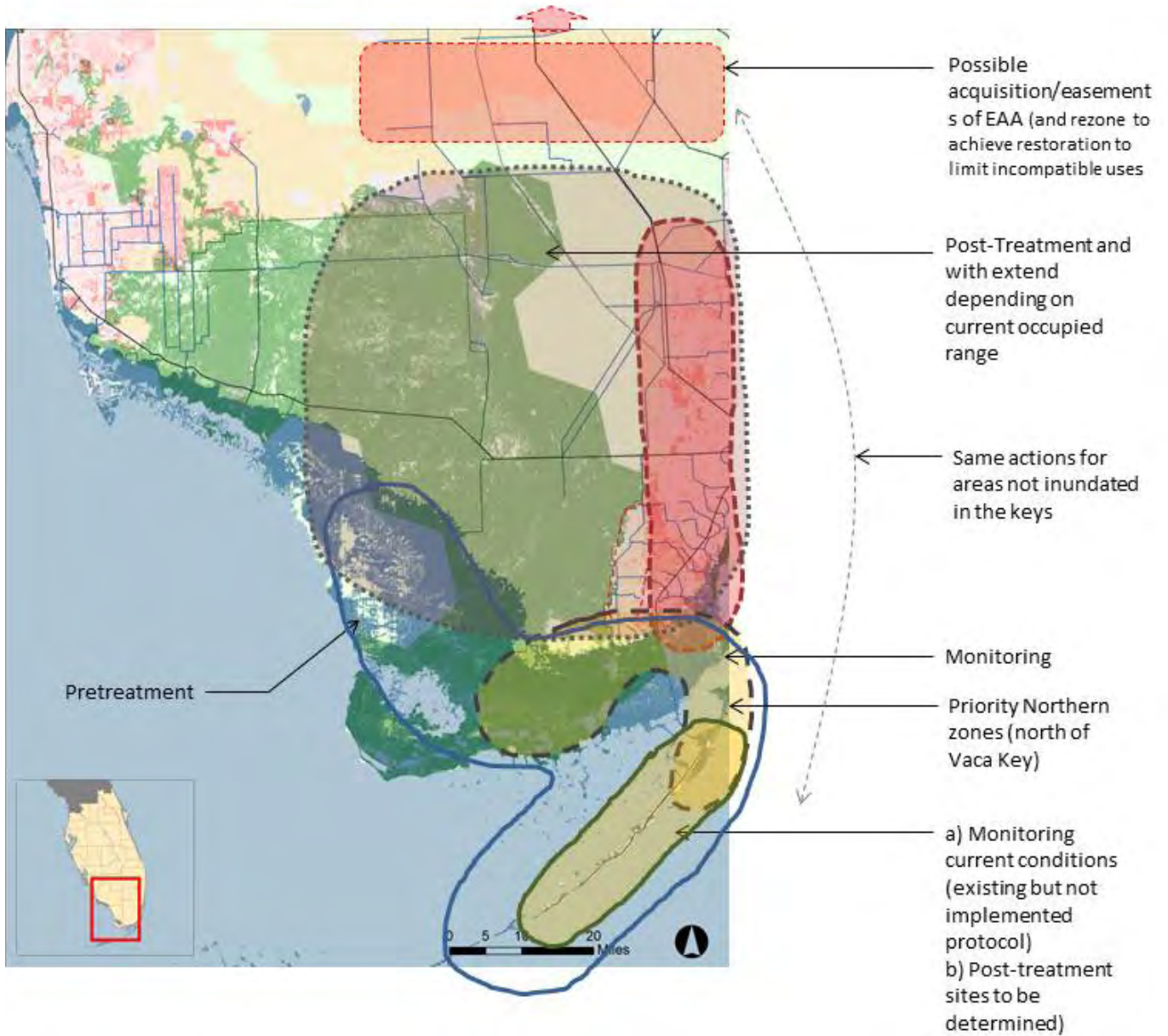


Figure 67: "Room to move" - Diagram

Adaptation Strategies and GeoDesigns

5.2.2 “Surrounded on All Sides”

The final management context areas we considered are in many ways the most challenging. These are areas which are either nearly or completely surrounded by incompatible habitats or uses. In our pilot, these areas were represented by the Atlantic Salt Marsh Snake and Key Deer.

In these cases, the nature of the surrounding barriers becomes critical, as does species population and habitat size. There are two common barriers: open water, and urbanization. In their extreme forms and in wide spatial configurations, these represent absolute constraints. For example, Key Deer cannot swim across open ocean, and Salt Marsh Snakes do not cross high density urban areas. However, Key Deer are known to swim short distances between Keys, and Salt Marsh Snakes might travel short distances through low density areas with suitable cover characteristics.

The interesting and previously-unexpected characteristic of this particular climate change management context is that existing habitat models appear to be of significantly higher quality than those for wide-ranging species. This is presumably a consequence of narrow geographic range: it is relatively easier to obtain more complete ecological understanding of such species, and existing modeling techniques are relatively well-tuned to such circumstances. The two species considered for this prototype were the only ones of our set in which species experts proposed no major changes to underlying habitat or impact models. It is also true that management of such species is more geographically compact, allowing more efficient use of limited resources. So while in some ways the conservation of such species poses the hardest social challenge, there are some compensating factors.

Adaptation Strategies Identified

Strategy 1: Metapopulation Research

Almost by definition, such species and management contexts involve limited or geographically-fragmented ranges. Therefore, the most appropriate general form of consideration of such species habitat configurations is spatial, using interpatch dispersal and species metapopulation studies to derive relatively detailed understandings of the influence of barriers and subpopulation distributions on survival. Once such coefficients are known, several GIS and related

metapopulation modeling tools are available to predict effects of particular land use configurations (Scheumaker 2008).

The other aspect of such research is detailed study of the effect of habitat quality and area on species fecundity and survival characteristics. In birds, for example, this can involve detailed nesting studies correlating various habitat and landscape ecology characteristics with fledgling success rates. The advantage of such work is that it is made significantly more tractable by the narrow ranges under consideration.

Strategy 2: Habitat Quality Improvement Concentrated in ‘Uplands’

The species in this management context tend to be habitat and sub-population-limited. Since by definition, the total amount of habitat is unlikely to be increased, habitat quality improvement is one of the few remaining viable options short of translocation. Given geographic constraints, the most important areas are generally uplands (or at least upland of existing habitat areas). It is noteworthy that the same strategy was independently identified in two very different example contexts (for the Salt Marsh Snake in the NE, and for the Key Deer in the South), even though the specific management actions would vary between cases.

For the Key Deer, experts recommended a series of specific management actions, including prescribed fire, disease management, mosquito ditch removal, and freshwater source protection. They recommended concentrating these efforts in the specific areas likely to remain as habitat even after SLR. For the Salt Marsh Snake, upper marshes are the relative “high ground” and experts recommended activities be concentrated in those locations.

Strategy 3: Climate Corridor Identification and Public/Private Conservation

This strategy is only available for species confronting ongoing urbanization in the path of potential habitat changes. This was not the case for the Key Deer, since it was mostly threatened by SLR. It was only a partial solution for the Atlantic Salt Marsh snake, only because this species’ habitat is almost entirely surrounded already by development. Experts recommended measures such as “rolling conservation easements” and public/private partnerships in these areas, depending on existing uses.

The major challenge here is that almost all historical conservation has focused on specific habitat types, assuming that they would remain relatively constant in geographic space. However, under climate change this is clearly no longer true. Moreover, the direction – if not the magnitude – of SLR gradients can already be determined.

Ideally, the first step in “climate corridor” identification identified by our experts would be to run dynamic models predicting future habitats under SLR. An example of such a model, which specifically treats salt water marsh habitats, is the “SLAMM” model. Our experts unanimously agreed that it would be a high priority to run such models in these circumstances.

However, short of such formal modeling, geodesign exercises such as the ones shown here can already begin to identify likely areas. Since the management actions in these areas largely involve private stakeholders, the value of such early identification should not be ignored. In general, actions in such management contexts require community support and public education. It is not too early to commence such activities within the identified areas, especially because “citizen science” may prove to be important in improving the information base necessary for next steps. Because many of these coastal habitats

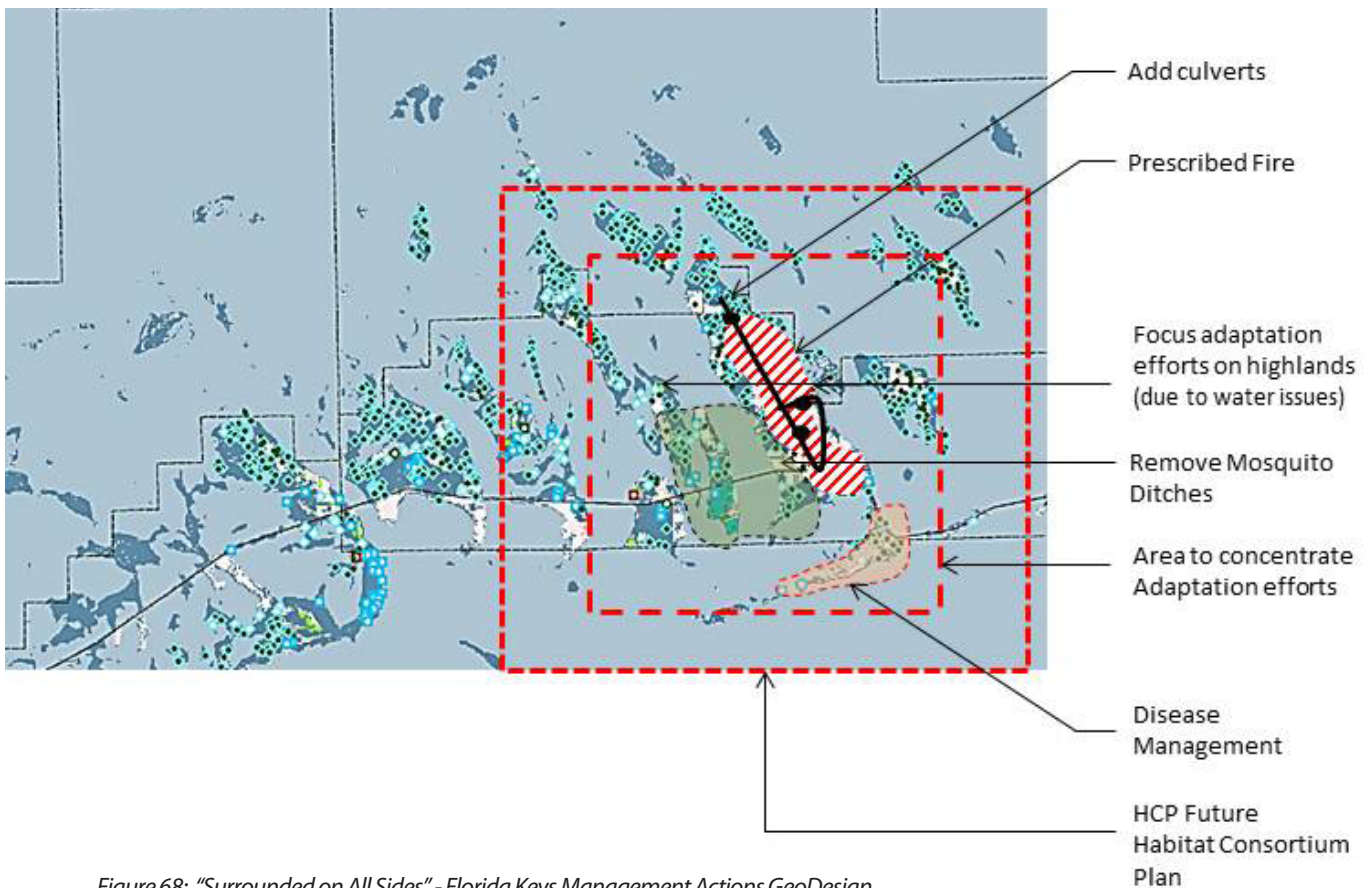


Figure 68: “Surrounded on All Sides” - Florida Keys Management Actions GeoDesign

are already highly contested and highly developed, it is likely that a variety of approaches will be necessary, as dictated by resources, rates of change, and specific local conditions.

An early policy action by FWC would be to officially recognize the importance of such areas, and to support a pilot project for their identification and for targeted community outreach in such zones. The areas identified here for the Key Deer and Atlantic Salt Marsh Snake may provide good initial cases. However, this mechanism appears to be general throughout this management context.

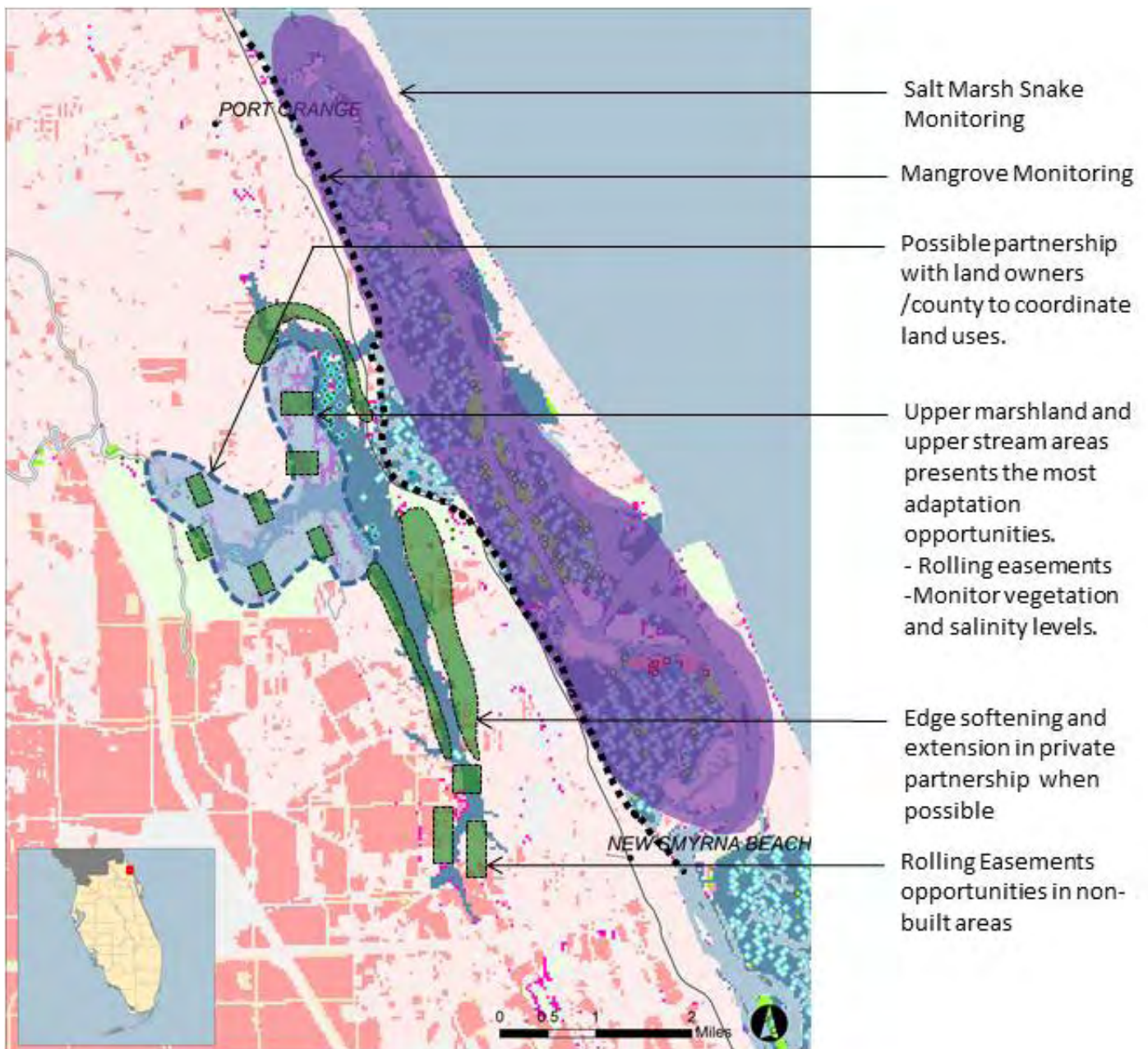


Figure 69: "Surrounded on All Sides" Geodesign Context Area 2

Adaptation Strategies and GeoDesigns

5.2.3 “Dealing with the Neighbors”

This management context is significantly more challenging for conservation because of its mixed ownership. That important species habitat remains in these areas is due to three factors which vary by geography and by species. First, many of these areas are unsuitable for intensive cultivation or urban development. They function as “de facto” conservation. Some maintain natural cover and disturbance regimes, and others are heavily modified, containing significant numbers of invasive species. Second are areas which might otherwise be developed or farmed, but where prior land use planning has effectively excluded incompatible uses. These are effectively conservation areas, but may or may not be actively managed as such, and in most cases are embedded in a matrix of other land uses. Finally, there are lands which are privately owned and managed for a variety of uses, but which thanks to good land use stewardship maintain significant valuable habitat. These include many large ranches, forested lands, and some low density residential areas.

The Florida Panther and Short-tailed Hawk were indicator species for this management condition, since they both have extensive ranges across privately held lands.

Adaptation Strategies Identified

Strategy 1: Payment for Ecosystem Service

Our experts felt that payment for ecosystem services (PES) is an appropriate policy response in some of these areas. In particular, while they felt that core habitats and corridors should be established and maintained using fee-simple ownership and dedicated conservation management, PES should be geographically targeted to a “buffer zone” surrounding these areas. In the case of the Short-tailed Hawk, this might take the form of identifying landowners with significant wooded wetland habitat holdings, and compensating them initially for maintaining such habitats and facilitating or conducting monitoring. The advantage in this particular case is that such habitats are both wooded and seasonally inundated, and thus under less conversion pressure than other lands. However such habitats do continue to be lost, and so targeted PES incentives might be highly efficient in those areas of high development pressure.

Strategy 2: Public Education and Signage

This strategy was recommended in particular for the primary habitat of the

Florida Panther, and especially in those areas where road collisions remain a major source of mortality. In this case, the strategy could be geographically targeted. In the case of the Short-tailed Hawk, a broader education campaign would be required, although this might also be targeted to landowners of major parcels containing known or likely habitat. Because this species is secretive by nature, it might well form a good target for a citizen-science based effort in order to update occurrence inventories across private lands.

Strategy 3: Road Effects Research

The major source of incompatible uses with wide-ranging species is not always land cover conversions – in many cases it is more directly related to road-related mortality. Because they have been extensively monitored and tracked at the individual level, this is particularly clear for the Florida Panther. Thousands of miles of roads of various types transect primary Florida Panther habitat, and collisions are known to be a major source of mortality.

The challenge in such cases is that road effects can be highly species-dependent, and indeed with Florida Panther can vary based on sex and life history stage. However across large areas, interventions such as fencing can be very expensive. The other potential management action is even more expensive, and that is to provide wildlife “underpasses” beneath major roads and interstates.

In the case of the Florida Panther, one major barrier has already been identified: Interstate I-75 (Foster and Humphrey 2005). It separates the existing established population with a large area of potential habitat to the North of the Caloosahatchee. Therefore, our experts felt that concentrating research on potential design options in this area was a particularly high priority.

More generally, FWC should consider state DOT and Federal partnerships to study the issue of road effects across a range of species. The spatial analytic techniques currently exist to identify and quantify such corridors, and they are potentially critical to species adaptation under climate change. However, this is an area of a large science gap: species behavioral characteristics relative to roads have been extensively studied elsewhere (Foreman, “Road Ecology”), but are a priority for Florida wildlife research.

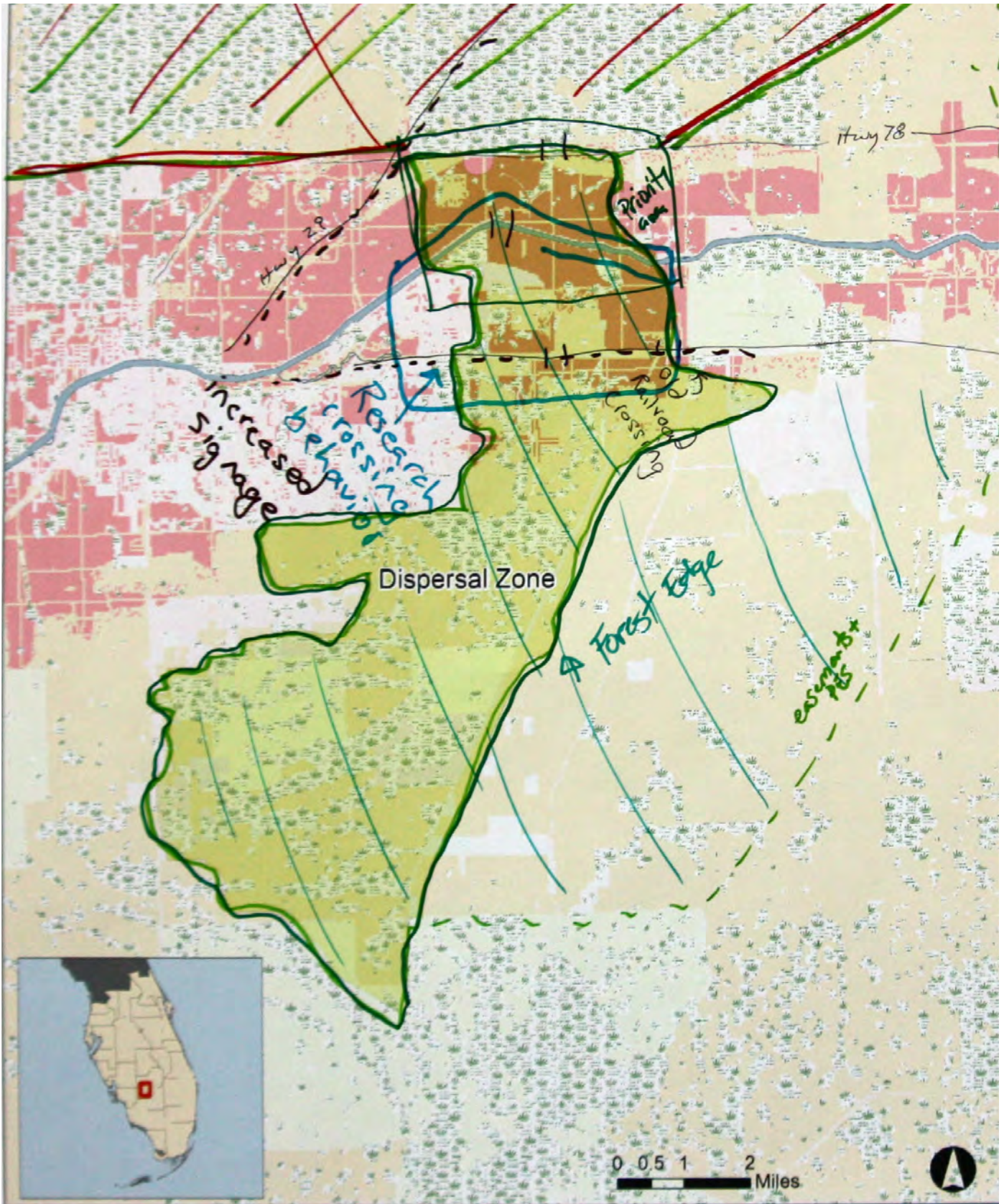


Figure 70: "Dealing with the Neighbors" Geodesign Context Area 1 (Florida Panther Dispersal Region)

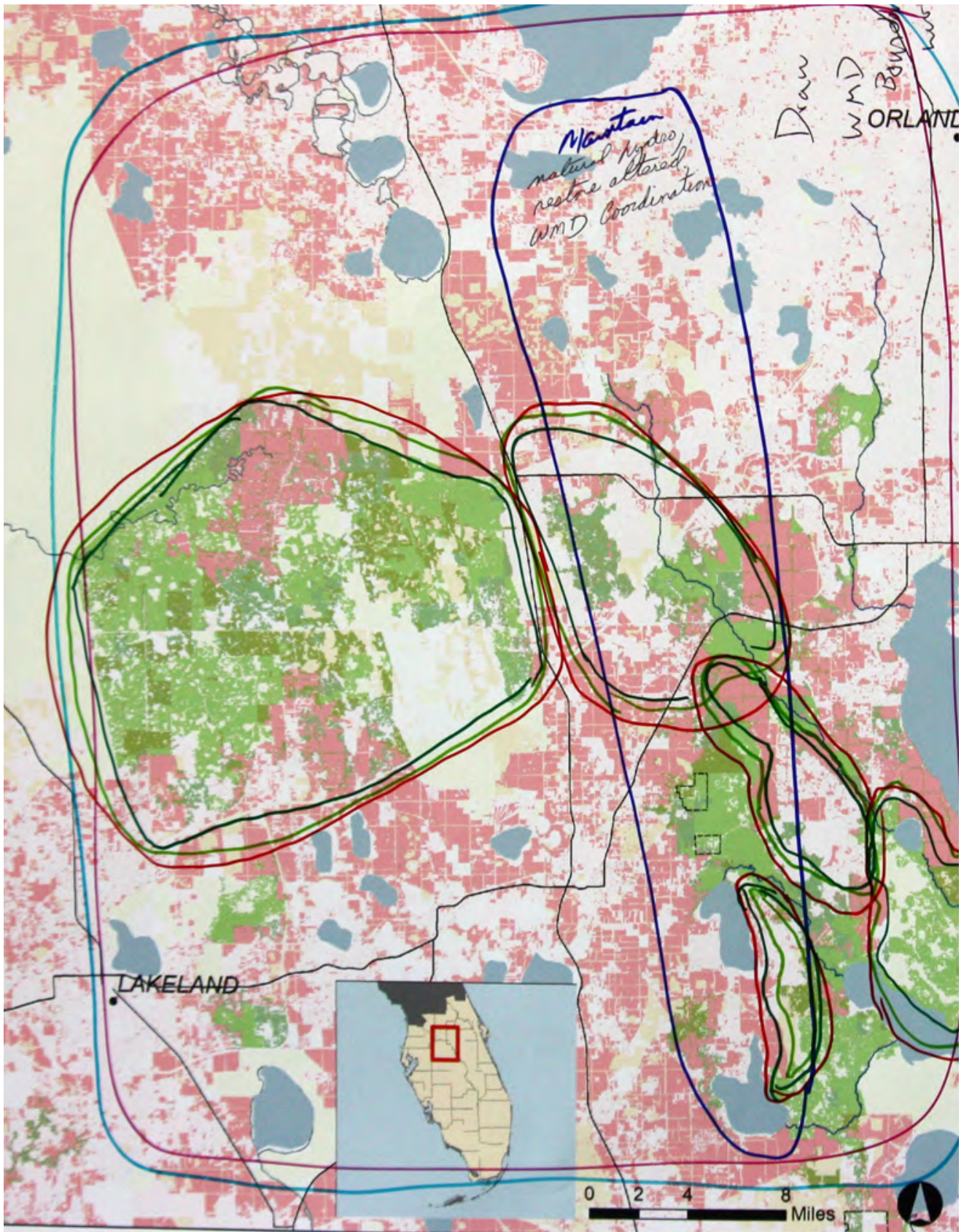


Figure 71: "Dealing with the Neighbors" Geodesign Context Area 2

6.0 General Process Conclusions

6.1 Towards a Hybrid Approach

This pilot represents an early experiment in developing an approach capable of accommodating and productively integrating a variety of wildlife management perspectives at several spatial and temporal scales. The fundamental insight it brings to the topic is the value of landscape-scale spatial scenario assessment and planning techniques. At the origination of this study, we expected that spatial approaches might best be undertaken as a second level of detail after first having conducted species climate vulnerability assessments using approaches such as those of TNC as applied by the Defenders of Wildlife. However, the experience of this project led us to a more nuanced conclusion. In our opinion, the best possible combination is not a simple sequencing of prior approaches, but rather an “interleaving.”

The major advantages of species-level vulnerability assessment methods such as the CCVI is that they can operate with less data than spatial methods, relying more on expertise. From this point of view, they are similar to a variety of rapid assessment protocols. This formulation is also open to a wider variety of information, and can thus accommodate a variety of characteristics of species behavior or life history. This is what led us initially to consideration of this approach as an “initial screening pass” for climate planning, simply to identify those species at highest known vulnerability and prioritize planning or monitoring resources on those species.

Because of time constraints, we were unable to test this particular formulation in this study, as we conducted both types of approaches in parallel. However, it would now be possible to take the results of the Defender’s CCVI vulnerability index work and use it to select a new subset of species to subject to spatial assessments.

Nonetheless, when we consider the issues more carefully, it is apparent that the vulnerability index approach itself uses spatial data, but of a different scale than the landscape assessment approaches. In particular, the exposure

components of the index are based on a single national or continental scale IPCC scenario downscaled to species habitat range-level data. Therefore, the existing vulnerability index approach actually contains simplified versions of both spatial modeling and scenario planning. It picks a single future climate change scenario as a benchmark, and judges exposure relative to that using globally-available data sets.

Therefore, in concept it is perfectly possible to replace the single-scenario macro-scale exposure assessment components of such vulnerability indices with a scenario approach. The existing CCVI method and supporting spreadsheets can support sensitivity testing, so in principal experts could be asked to evaluate how their species of interests would likely respond under different scenarios. However, the harder question there is to what degree high-confidence assessments could be derived without considering interactions with habitat and land cover change. The CCVI approach uses species range-level information and purposefully limits itself to climate change-related vulnerabilities only.

Answering such questions would require further research, since we were not in position to test variations of the CCVI or SRP approaches. We can, however, draw some narrower comparisons based on our observations of the processes and the six species for which both approaches were conducted.

The basic comparison of explicit outcomes is shown in the table below. In general, the results are roughly similar, which is comforting, if not conclusive. The SEVA figures are reported as a range from lowest to highest impact, but because scenario probability distributions are not known, a median cannot reasonably be computed. The high value may best represent “vulnerability” but is inherently noisy in that it is vulnerability given relatively extreme climate change. The most vulnerable species is the American Crocodile, followed by the Key Deer, and both have identical ordinal rank by each method. The least vulnerable are the Florida Panther and the Short-tailed Hawk, and again the methods roughly concur. SEVA disagrees with CCVI in showing

slight declines rather than stability, but these are driven by habitat loss from urbanization, not climate change.

In such a comparison it is important to keep in mind three caveats. First, the CCVI rating purposely include only climate influences, while SEVA ratings also consider land use changes. Second, the pilot SEVA habitat loss figures account only for inundation due to SLR, and do not include impacts of ground water hydrology or vegetation change on habitat. CCVI ratings can reflect a qualitative estimate of such factors. Third and finally, these are not fully independent samples since the very same experts were consulted in the application of both methods.

Comparison of Results (CCVI rating vs. SEVA Habitat Loss Range)

<i>Species</i>	<i>CCVI Rating</i>	<i>SEVA Habitat Loss Range</i>
American Crocodile	Extremely Vulnerable	0-98% (counting shifts)
Short-Tailed Hawk	Moderately Vulnerable	5-18% habitat loss
Florida Panther	Not Vulnerable/Presumed Stable	1-8% (of full range)
Key Deer	Highly Vulnerable	32-75%
Least Tern	Highly to Extremely Vulnerable	4-75% habitat loss (highly scale-dependent)

Beyond the high-level similarities, we can also see some subtle but important differences. For this sample, our conclusion is that spatial modeling varied significantly in its vulnerability conclusions mostly in the case of wide-ranging species, and for species where new habitat creation was a realistic possibility. This included the American Crocodile, the Florida Panther, the Short-tailed Hawk, and the Salt Marsh snake (4 of 6 species). In the case of the Panther and Hawk, the species are omnivorous and relatively tolerant of climatic shifts. Species survival in these cases is influenced by a range of factors within the climatic range of the species, notably human settlement patterns and treatment of wooded wetlands. These species received low to moderate CCVI “climate vulnerability” scores which is appropriate when the narrow focus of that designation is considered. These are Threatened and Endangered species for a set of reasons which predate climate change, and they are wide-ranging enough that climate change is a relatively minor stressor.

The American Crocodile and Salt Marsh Snake are cases in which manage-

ment context combines with sea level rise sensitivity in ways which are not apparent using simple vulnerability assessment methods based on coarse exposure data. Crocodile habitat was predicted by experts to migrate extensively, and this pattern required use of detailed elevation data to track appropriately. The snake's habitat also responded to SLR and elevation in complex ways, but in this case was also heavily constrained by development. Again, these factors would not appear in a national-scale data. These variations are not very apparent in overall habitat summary scores, but are quiet visible in the proxy habitat maps generated by our experts. In the case of the crocodile, for example, habitat-migration is supported by existing management and geography for the mainland populations, but not for the Keys. It is currently unknown if this migration can occur given particular rates of SLR. However it is abundantly clear from our mapping that the survival of the species within Florida depends on the answer.

Finally, in terms of species, the Least Tern provides a distinct example of cases in which SEVA methods encounter serious problems, and for which CCVI was more robust. In this case, there was no prior wildlife habitat suitability modeling work done, so SEVA was left without one of its major required inputs. At the same time, the species life history characteristics themselves presented a worst-case for regional geographic analyses. The species occurs over much of the coastline of Florida, requiring mapping over very broad extents. But it only occurs along a spatially very narrow band and is sensitive to changes at a spatial scale at the limits of delectability with regional land cover and terrain elevation data, requiring fine spatial grain.

As post-workshop sensitivity analyses were able to determine, the choice of datasets and methods had a larger consequence on reported impacts than the variance between extreme scenarios. Also, the dynamic nature of beach erosion with and without shoreline hardening measures is poorly simulated using basic overlay methods. Other authors have used GIS to simulate beach dynamics under SLR, but not at regional scales: they used field survey and GPS (Fish 2008). This method might be feasible using LIDAR data, since it mostly requires dune heights so as to calculate the slope of the shoreface. However, at 50m resolution, our regional data averaged foredunes into shoreline elevations, so this was not feasible to attempt in this pilot.

The general lesson to be drawn here is that for species for which poor spatial habitat data exist, high caution is warranted before attempting to deploy SEVA methods. But a second interesting observation, is that experts were able

to make progress, and that despite significant limitations, the results do show a path forward. A very clear recommendation in this regard is that a separate habitat mapping and SEVA process should be undertaken for coastal zones in particular. While methods will have to be adjusted to accommodate the unique nature of these habitats and SLR impacts upon them, appropriate data are available in many areas.

Scalability Issues with Methods Used

If the methods piloted here are to be brought “to scale” for the management of all of Florida’s wildlife, this brings up a complex trade-off. Vulnerability screening methods using habitat ranges and national datasets have already been partially automated and can be applied in “batch” fashion across large number of species. On the other hand, the expert interview processes required proved to be significantly more labor intensive than the technical methods deployed. The results are very difficult to compare fairly with the more detailed landscape approaches taken here, since they do not measure the same thing at the same scale. When habitat quality, ownership patterns, terrain and development are taken into account, vulnerability estimates often go up significantly, and the focus typically tightens to a small portion of overall potential habitat. This is a logical consequence of consideration of a broader range of factors.

The issue which then comes to the foreground is how easy or difficult it might be to scale up a landscape-based approach. Our conclusion here is that the actual technical mechanism of spatial overlay could be easily and widely applied, given the availability of appropriate data. However, the preparation of such data has highly uneven costs depending on both prior work and species characteristics. Where prior habitat modeling efforts met with expert approval, and relevant scenarios were available, the overlay process was almost trivial technically. However, we found great variations in the level of confidence that our experts had in the prior FWC habitat modeling work done. Because that work did not include a systematic error assessment process, we have difficulty drawing a general conclusion from a sample of 6. Currently, FWC has an archive of roughly 60 species modeled in this fashion. If an equal level of effort was expended on average for review and revision of each of these models, total project time commitment on this task alone would be approximately 60 man-months of effort.

The development of efficient internet-based habitat model view tools could significantly improve the efficiency of the expert reviews needed in conducting such assessments. However, such tools have yet to be deployed and tested for this use.

6.2 Procedural Conclusions (Organized by Original Task)

1. Spatial overlay analysis for 6 selected species under 5 MIT scenarios.

We completed two rounds of this analysis. The first round was conducted using the FWC 2009 wildlife habitat model outputs as published. These results were then presented to species experts for review in person, with follow-ups via phone and email as needed. Based on comments received, as well as those additional data made available to us, we revised most of the habitat models. Only two (of six) species habitat models were considered by experts to require no significant revisions: that of the Key Deer, and of the East Coast population of the Salt Marsh Snake. Notably, these were the two narrowest-ranging species considered. Four of six models required significant revisions, and the largest revisions were generally for the widest-ranging species.

In two cases of these cases, experts felt that it was essential to distinguish habitat quality (Florida Panther and American Crocodile). In several other cases, seasonality was felt to be important in assessing climate change exposure, notably for the Short-tailed Hawk. However the original FWC habitat modeling process did not provide this information. Finally, most detected model errors were errors of omission and not commission. This is likely because the original FWC modeling process blended “potential” and “actual” habitat modeling approaches by requiring observational evidence of species occurrence. As survey effort is uneven and FWC species modelers used national-level observation datasets rather than regional ones, this appears to have caused some underestimation of habitat.

No changes to the scenarios were felt to be necessary within the scope of this project. However, two major omissions were noted across multiple species. The first is that the scenarios lack simulations of vegetation change under climate change, with the exception of inundation. This is a rather major problem, but unfortunately is a challenging one to address in the Southern Florida context. There are no appropriate vegetation change models generally available. There are some habitat-specific models, for example for mangrove, and some multi-community models, for example for sea level rise affecting marsh-

es. The Everglades National Park has recently released a modeling framework (Elves) for creating such models, but as currently available this contains estimates only for the freshwater portion of the Everglades. Essentially, this is a major science gap, and until it is filled, major uncertainties will remain in any vulnerability assessment process.

The second general scenario omission widely noted was treatment of disturbance regime. The scenarios as construed represent long-term median conditions. However many scientists felt that disturbance regimes are important enough in this region to require representation in the scenarios. For example, Key Deer habitat under sea level rise is likely to be limited by salt water inundation during season storm surges, thus it is difficult to estimate habitat impacts without having storm surge frequency mapped. In other habitats, fire and water regimes are dominant influences. This represents another difficult request, at the edge of currently available science. For example, storm surge modeling under existing conditions is not widely available, and has not to our knowledge yet been conducted under various climate change scenarios. The most likely next steps here might be to incorporate explicit disturbance regimes as “assumptions” within scenario bundles. These would be consistent with the overall scenario narrative, but not a model output or prediction. An example might be the simulation of restoration of historic flow patterns and rates within scenarios that have full CERP Everglades restoration.

2. Develop charts and tables quantifying potential impacts.

As previously, this task was also done in two rounds with intervening expert review. In the first round, we aggregated possible land cover changes and sea level rise, then tracked the “fate” of species habitat within each scenario. An example from the American Crocodile can be found below. In the case of this species, the table makes rather clear that the primary climate vulnerability is due to habitat inundation. This was a reasonable first approach, especially when combined with maps using identical coloring. We found that we had to develop a special cartographic routine to show these impacts well at regional scales.

However two or three important issues were not well-captured using this approach. The first was the issue of driving forces operating across scenarios. This is relatively easily remediated simply by plotting those variable responsible for the variance. For example, consider the relationship between SLR across scenarios and crocodile habitat.

A second issue found was the potential replacement of inundated habitat with new habitat. This can be tricky, depending on species agility and underlying geomorphology. We took a geodesign approach and had experts draw on our maps where they thought potential future habitat would be located, as well as to try to identify the decision rules they were using in drawing, so that we could replicate or improve the spatial resolution of these drawings using GIS at a later time. For example, the map below represents expert opinion on future habitat suitability under moderate sea level rise.

This issue of potential new habitat proved to be significant for several species and to some degree requires new ways of thinking about and describing such areas. These relationships are not always simple linear ones. Consider the odd case of the East Coast population of the Salt Marsh Snake. This species actually does better under low SLR scenarios than under current conditions, then the same or worse under moderate to high SLR.

Finally, the relatively complex interaction effects unearthed in initial overlay and expert review lead us to reconsider the relationship between climate-induced habitat change and the management context for an particular geography.

3. Review Potential Impacts with Species Experts

As described above, all work conducted was subject to review by 1-3 species experts. Reviews were conducted largely in workshop format, but also by phone and email follow-up when appropriate. In addition to the substantive findings, which are described in detail elsewhere, we also learned a bit about the procedural issues which must be considered should a larger version of this kind of pilot project be organized.

The first is that logistics is a major part of the time and cost of such endeavors. In this project, we were fortunate to have the assistance of the Florida Wildlife Federation, and both staff and student volunteers. We also leveraged the efforts of the Defenders of Wildlife, so as to get multiple benefits from the participation of each species expert. All of this activity consumed many hours of project and staff time. Our species experts contributed 2-4 full time days of their time, and travelled from various locations around the state.

We found that we generally spent much more time reviewing and revising the habitat modeling efforts than we had originally intended. FWC habitat modeling and mapping efforts were generally well done and well document-

ed. However, they were done by different people at different times, and with different purpose. Each of these habitat maps is typically the result of a relatively simple GIS model. We had the metadata for each model, but we did not have the code for the models or their components available for the experts to review. This made it significantly more difficult to revise the models to use for climate change planning. Unfortunately, we learned much of this during the first workshop, and not before it. This consumed time and made some of the impact overlays less useful than they would otherwise have been.

In retrospect, we feel that we could have made much better use of information technology in conducting initial or follow-up sessions with these experts. While there was very significant value in bringing together folks to discuss these issues jointly, we likely could have made some significant early inroads using a combination of webinar and interactive web mapping technologies. Along similar lines, we would suggest virtually bringing together the original habitat model creators with the users during an initial session focused simply on explaining and potentially revising the habitat models. This is not strictly speaking a climate-change planning activity, but it turns out to be essential for sensible spatial planning to understand this major input in greater depth than our pilot process allowed.

A second scaling strategy might also prove important given the large size and geographic diversity of the state of Florida, and that would be to hold “bio-regional” submeetings focused on geographic subsets of species and their management contexts.

4. Develop Conceptual Models of Stressors and Adaptation Mechanisms

This phase of activity was conducted over several hours by each species expert group. This process generally went well. As expected from prior work, providing starting cards prepopulated with the concepts from the prior wildlife action plan for each species proved to be a useful jump start. Because of this, and since experts were already familiar with that plan, work started right away.

The groups rapidly reviewed and organized current conceptions, and generally spent most of the time weighting and assessing existing components relative to climate change. Since this was a synthetic process, it is hard to tell how much of which changes came simply from conducting the process, and how much was informed by prior recent review of the CCVI and impact maps. In conversational terms, all of these subprocesses were repeatedly referenced, as was external knowledge and experience.

5. Adaptation Actions GeoDesign

This final step in the process was also in practice highly conversational, and varied significantly in focus and level of detail between groups. Organizing this activity using management context areas transcending species groups proved to be an effective strategy in that it allowed participants to bring geographic knowledge as well as species and land management concerns into play.

There were two tradeoffs made which are difficult to second-guess without having the ability to run paired control processes. The first is the relative benefit of organizing geodesign at the area level, rather than at a species level. As mentioned, this allowed for and even required a higher level of synthesis to be performed by the experts. In this regard, there was a triage aspect due to time constraints. Experts had limited time, and were aware of this from the outset. Thus management actions which they placed on the landscape were more indicative of priorities than they were necessarily comprehensive. The process itself favored management actions which would be good for multiple species. This is certainly a reasonable place to start, but at this point it is not clear if another round of species-level clarifications and upgrades wouldn't have been useful.

The second trade-off is more subtle still: we as a research team selected example areas within the full region and pre-plotted maps of those areas. This allowed us to use purposefully low-tech manual methods for map markup. These are generally still faster, more participatory and more fluid than digital ones. However, this choice came at the expense of being able to arbitrarily zoom in and pan, or to bring up supporting map layers and orthophotography.

The results were also much sloppier and sketchier than had a digital geodesign system been used. This made final interpretation post-workshop very slow, in many cases requiring reference to the audio transcripts for clarifications.

This is an area in which we would recommend further practical testing and research. There is actually very little theory or published practical work providing guidance in this regard. Effectively, we are asking scientists and land managers to use a style of work which is common in design and planning schools, but highly unusual in their normal professional practice. There is an inherent awkwardness involved, and a tension between using low-tech methods such as manual markup versus using high-tech alternatives. There are also several levels of technological enhancement possible, many of which

we have brought to bear in other contexts.

The first level of technological enhancement here would be to set up a “palette” of management actions connected to computer drawing tools. This could be done with existing software “out of the box” but would require large pen-sensitive flat panels. These are not trivial in cost, and the logistical requirements of this workshop required at least three parallel sessions, which would have required more hardware than feasible within the project budget.

A second level of enhancement would be to customize existing software so as to automate SEVA assessments and to make these interactively available to evaluate potential mitigation actions. As a simple example, it would have been extremely useful to get a running count of the management actions’ total number of applications, total land area, and estimated cost. Similarly, a dynamic histogram of species habitat area by type or by quality would have been highly informative. This kind of “design-time feedback” is well known within the broader landscape planning field to positively influence design performance across multiple criteria, and to improve both user satisfaction and objective independent reviews of resulting plans.

Because this technology investment wasn’t feasible within a pilot process, we can only speculate as to its potential contributions. Realistically, all advanced technology tends to bring with it initial usability and reliability problems which require multiple rounds of pretesting and interface refinement. Therefore, creating a customized SEVA software assessment tool was clearly beyond the scope of a pilot project.

However, we do know from other landscape planning domains that the process of making indicators dynamic and providing financial as well as ecological feedback is an important step in making plans more realistic and feasible. When an opportunity arises to do so, the work done within this pilot would provide the specification needed to generate appropriate tools.

6.3 SRP Summary Conclusions

In substantive terms, we find that climate change is likely to have major impacts on a number of already-imperiled Florida species. While only accounting for a few of the many known, our pilot methods registered habitat losses ranging from 8-98%. Even the low end of that range is of concern for species which already face serious challenges to their survival. For species on the higher end of the range, immediate monitoring and species-specific climate change science is clearly indicated. Beyond that, our spatial planning methods have identified a number of “no regrets” conservation areas which should receive more careful investigation. These are areas likely to convert to incompatible uses whose incorporation into conservation networks is important regardless of the level of climate change.

The state wildlife action planning process can and should be modified to recognize the importance of such areas. Our proactive conservation scenarios are simulations of the existing “Florida Forever” priorities as provided to us by the Florida Natural Areas Inventory. These are explicit, quantitative, and continuously monitored and recorded. This means that we can state definitively state that they give a 10% initial weight to habitat connectivity, but in practice end up with less than 10% of acquisitions in the highest priority connectivity areas. Methodologically, the problem is that they use an equally-weighted average of all criteria to establish initial priorities, and this averages away areas of highest connectivity priority. Other areas, including those which are important habitat but sensitive to climate change science uncertainties, should be considered for lower cost and potentially-reversible actions, such as voluntary conservation incentives. This might be appropriate for “climate adaptation corridors” preserving options for long-range species habitat migration.

We found that three basic conservation management contexts exist within the state, and that appropriate adaptation actions may vary between them, even for species with similar biological needs. The highest priority should be those species whose entire range is constrained by water or urbanization “Surrounded on All Sides.” In our pilot, these included the Salt Marsh Snake and the Key Deer. In those cases where potential habitat corridors still exist, these represent a new form of critical habitat. In those cases where no alternative habitat exists, the focus must necessarily be on improving habitat quality. The second highest priority are those species which have the majority of their habitat on private lands under high development pressure. Conservation actions in these cases don’t vary significantly in climate adaptation planning relative to conventional conservation planning. However the location and

urgency of such conservation may well be influenced by climate change pressures. Finally, Florida is fortunate in having some of the largest protected areas on the East coast, and significant local and national support for Everglades restoration. The Everglades National Park and SW Florida more generally are under high risk from SLR. Under high SLR scenarios, up to 40% of ENP could be inundated. The best defense in this case is a good offense: restoration of the Everglades Agricultural Area and of water flows to the historic Everglades can restore soil accretion processes which counter SLR, and improve habitat quality. This would be of benefit to a very large number of Florida's species which depend on this resource.

In methodological terms, we conclude that a spatially-explicit vulnerability assessment (SEVA) approach to climate adaptation planning for Florida's wildlife could represent a significant improvement over prior methods, and can very usefully be interleaved with CCVI-style species vulnerability index development. The methods intersect in terms of exposure calculations, which are currently computed in a similar manner conceptually, but at different spatial resolutions. CCVI complements SEVA by addition ecological depth to the risks and mechanisms considered. It is less data-intensive than the SEVA approach, although more labor-intensive. Meanwhile, SEVA could be used as an input to CCVI, improving the spatial accuracy of vulnerability assessments, as well as making them more robust by incorporating a range of local and IPCC scenarios rather than a single one.

This initial pilot indicates that extension of SEVA to larger numbers of species and habitats would be rather straightforward for the 60-100 terrestrial vertebrates for which spatial habitat models are currently available. Beyond that set of species, the approach would bear the additional cost of wildlife habitat modeling and associated field and GIS work. Even when using such previously-generated models, our experience is that a significant level of effort can sometimes be required to upgrade such models to reflect current scientific expert knowledge and data. This issue is not limited to climate adaptation planning, however: improving such models would be an overall conservation benefit because they are fundamental to wildlife action planning. Our recommendation would be to proceed first by upgrading and extending vegetation succession models for the state, so that wildlife-habitat associations could flow from that base. This should be done systematically over time, and published online in digital formats which facilitate the sharing of models, and not only model outputs. In that way, a "digital library" of climate-sensitive species habitat models could be created and shared for multiple conservation

and management purposes. Other states have begun such efforts, notably California, where future vegetation habitat under various IPCC scenarios are already available online.

Beyond extending the number and climate-sophistication of supporting wildlife habitat models, the next major recommendation would be to regenerate state-wide scenarios incorporating this information. Ideally these would be set up to be regularly updated, for example every 5 years. They would be multipurpose, and the development costs could be shared across agencies. The state of California has recently implemented such a system, and this has the benefit of providing consistency across agencies, spawning extensive academic work at no direct cost to government, and of reducing costs for each participating agency.

As described above, the lesson from this pilot is that such scenarios should include explicit depictions of vegetation and disturbance regimes, even if these must currently reflect stated assumptions rather than scientific model output. Given the current early state of climate adaptation science, the reality is that all such projects will need to make a series of assumptions. The availability of explicit documented scenarios reduces the use of “ad hoc” assumptions outside of an individual or institutions main area of expertise, and allows for useful management comparisons across agencies and scientific disciplines.

Finally, this pilot indicated that future progress in this area would be substantially increased by the use of most-efficient tools for web and cell-phone based sharing of spatial information. Spatial impact assessment of scenarios is a fundamental activity for the data and model review activities which underpin climate change adaptation planning and should be considered part of the core IT infrastructure which the state develops to conduct efficient wildlife action planning. Similarly, explicit infrastructure-level support for customized geodesign tools would hugely benefit the state by allowing the distribution of adaptation planning tasks to dozens of simultaneous ongoing planning efforts. The provision of a “climate adaptation toolkit” to all local FWC offices should be strongly considered. This could have a training component, an end-user software component, and a centralized FWC geospatial server.

Because Florida is a large state, conducting all such activities using in-person expert meetings rapidly becomes the most expensive and time-consuming part of such studies. FWC should plan and create a spatial data infrastructure supporting its major management needs, including climate change adapta-

tion planning. Since this is a long-term problem and science is rapidly evolving, change is indeed the only constant here. FWC should assume that better downscaled climate projections will continue to become available, as well as better species-climate science. In preparing for this inevitability, an effort is required to go from “snapshot” assessments such as this pilot, to ongoing programs with management analyses and visualizations available on-demand. This can be done step-by-step, but should be done systematically so that scenarios, climate-sensitive wildlife habitat models, and analyses remain compatible and comparable.

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