Final Report to The Kresge Foundation

Grant Request Number 244146:

Adaptation to Sea-level rise in Florida:

Biological Conservation Priorities

August 27, 2014

Reed F. Noss, Ph.D., Principal Investigator
Department of Biology
University of Central Florida
Orlando, FL 32816-2368

Joshua S. Reece, Ph.D, Co-Principal Investigator
Department of Biology
Valdosta State University
Valdosta, Georgia 31698

Thomas Hoctor, Ph.D., Co-Principal Investigator
Michael Volk, M.L.A., Research Associate
Center for Landscape Conservation Planning
University of Florida
Gainesville, FL 32611

Jon Oetting, M.S.P., Co-Principal Investigator
Florida Natural Areas Inventory
1018 Thomasville Road, Suite 200-C
Tallahassee, FL 32303

EXECUTIVE SUMMARY

Florida is extremely susceptible to the effects of sea-level rise caused by climate change due to a combination of low land elevations, a high water table, peninsular geography, vulnerability to tropical storms, and a large and growing human population that is largely concentrated near the coasts. Climate change and specifically sea-level rise are primary threats to many of the endemic and most imperiled species and natural communities in Florida. Coupled with interacting impacts from human population growth, increasing urbanization, and projected changes in temperature and precipitation (including more extreme weather and increasingly intense storms), this may constitute the most important challenge facing biodiversity conservation in Florida. Moreover, Florida serves as an instructive case study for low-elevation coastal regions globally that are facing the threats that sea-level rise poses to human and natural communities, threats that are already quite evident but will become increasingly severe in coming decades.

This report reviews the research funded by the Kresge Foundation and the Florida Fish and Wildlife Conservation Commission (FWC); both grants were for essentially the same project, with the FWC-funded research beginning and ending sooner. The Kresge Foundation provided the largest share of the funding, which permitted us to conduct new and complex analyses beyond the scope of the FWC grant. The goal of this project was to create a detailed assessment of the combined impacts of sea-level rise, land-use changes (especially increasing urbanization and changed patterns of development), and to a lesser extent climate (temperature and precipitation) change, on imperiled species and natural communities throughout the state of Florida. Specifically, as articulated in our contract with The Kresge Foundation, our objectives were to:

1) Assess the vulnerability of [species and] natural communities in Florida to projected sea-level rise combined with land-use change;

2) Conduct a critical evaluation of adaptation options for reducing the combined impacts of sea-level rise and urban development, as well as options for reducing conflicts between adaptation for humans and adaptation for nature;

3) Develop the foundation for a statewide adaptation strategy that will aim to minimize losses of biodiversity and mitigate ecosystem impacts from sea-level rise and concurrent changes in land use;

4) Initiate a statewide public education campaign and outreach to decision makers to help them make better-informed decisions in preparation for sea-level rise.

In keeping with these objectives, we analyzed the vulnerability of 300 species of conservation concern in Florida to sea-level rise, land-use change, and (in less detail) climate change, species by species, as well as the vulnerability of 30 natural communities, as classified by the Florida Natural Areas Inventory. We then assessed the appropriateness, feasibility, and probability of success of six conservation or adaptation options for each species and identified groups of species with similar conservation/adaptation needs based on geography or ecosystem type.

We used this detailed assessment to develop spatially explicit, science-based adaptive strategy recommendations to assist policy decisions and to form a basis for continuing public outreach and education. For example, we identified stretches of coastline at greatest risk of biotic impoverishment from sea-level rise, stretches where species and communities have a good chance of moving landward without human assistance (which were areas with minimal conflict between adaptation for humans and adaptation for nature), and stretches where human assistance (i.e., assisted colonization) will likely be needed to move species out of harm's way (and where conflicts between adaptation for humans and adaptation for nature are likely to be more intense). We identified a surprisingly large number of species for which confinement in captivity is the only reasonable alternative to extinction; most of these species are island endemics. The majority (65%) of the 236 species for which we evaluated adaptation options were restricted to South Florida and/or the Florida Keys. Of these, 22% were endemic to South Florida and/or the Florida Keys. Most of these species, which are extremely vulnerable to inundation from sea-level rise, are unable to relocate further inland. This problem is much less severe in the Panhandle/Big Bend region of Florida. When viewed by ecosystem type, the best conservation/adaptation option for most natural communities is to protect their current distribution, although the potential success of this option diminishes for all ecosystems by the year 2100. For many natural communities, especially those restricted to the Florida Keys and extreme South Florida, maintaining captive populations of their characteristic species is the only adaptation option likely to prevent extinctions.

The only viable in situ adaptation strategy for coastal natural communities and the species associated with them is one based on the protection and restoration of these communities. This strategy will at least “buy time” and allow natural and human communities to adjust to sea-level rise and, where possible, migrate or relocate to higher elevations. The protection, creation, and restoration of coastal ecosystems is a form of “ecological engineering,” which reduces impacts of sea-level rise and storm surge without the destructive impacts of traditional engineering approaches such as sea walls, dikes, revetments, and bulkheads. Sea walls and other coastal armoring may be needed to protect the built environment in some local areas where urban development directly abuts the coast. However, such structures are well documented to increase erosion of neighboring coastal areas and have many deleterious impacts on natural communities. Because intertidal wetlands and other natural communities are situated between these structures and the sea, coastal armoring results in “shoreline squeeze,” where wetlands are eroded at the seaward margin and prevented by the structures from migrating landward. This erosion has direct negative consequences for human communities because mangroves and other coastal natural communities provide abundant ecosystem services to humans, including protection from the destructive wave energy associated with storms. Hence, the preferred approach from an ecological standpoint is avoid coastal armoring and, instead, work with natural communities to derive the optimal benefits of harmonizing adaptation for humans with adaptation for nature.

Despite uncertainty due to limited information, conservation and adaptation measures for high-priority species at risk of extinction should be implemented as quickly as possible, certainly within the next few years. Delays in implementation will preclude some options (for example, as potential recipient habitat is converted to urban area or as stretches of coastline are altered by dikes, seawalls, or new development) and increase the risk of extinction for these species. Meanwhile, continued research to learn more about the geographic distribution, life histories, and other aspects of autecology of these species must be funded and pursued vigorously so that detailed and robust adaptation strategies can be developed and implemented. This project is a starting point for future assessments of the impacts of sea-level rise and adaptation options, and will form an essential foundation for future research and outreach efforts that build on the results and methodology of this project.

Coastal Grassland and Beach Dune communities, Topsail Hill State Park, Walton Co., Florida

ACKNOWLEDGMENTS

We gratefully acknowledge the essential contributions of several groups and organizations to this project. These include members of our Technical Advisory Group including: Kim Gulledge (FNAI), Richard Flamm (FWC), Ryan Butryn (FWC), Joseph Donogue (FSU), Gary Mitchum (USF), Keqi Zhang (FIU), Tim Chapin (FSU), Stefan Rayer (BEBR), Peggy Carr (UF), Mike Ross (FIU), Chris Bergh (TNC), Greg Kiker (UF), and Doria Gordon (TNC). They reviewed data and reports, attended meetings, and offered comments and suggestions that were vital to the completion of this project. In addition we thank the FWC staff, including Beth Stys and Bob Kawula, who provided valuable assistance, data, and input towards the project, as well as members of the UF Geoplan Center, who provided the same. We extend appreciation to all other collaborators at UF, FSU, and UCF who provided input and assistance on the project.

This project was funded by a State Wildlife Grant (grant number 10289) through the Florida Fish and Wildlife Conservation Commission's Florida's Wildlife Legacy Initiative and the U.S. Fish and Wildlife Service, and by the Kresge Foundation (Grant Request Number 244146).

TABLE OF CONTENTS

EXECUTIVE SUMMARY i

ACKNOWLEDGMENTS v

TABLE OF CONTENTS vi

INTRODUCTION 1

METHODS 6

Summary 6

Technical Advisory Group 9

Data Collection and Development 11

Literature Review 11

Sea-level rise Projections 12

Sea-level rise Affecting Marshes Model (SLAMM) Projections 14

Future Land-use change Projections 14

Natural Community Model Updates 17

Species Habitat Model Updates 17

Florida Ecological Greenways Network Updates 18

Impact Assessments: Natural Communities 18

Natural Community Model Overlay Analysis 18

SIVVA-NatCom 19

Impact Assessments: Focal Species 20

Summary 20

SGCN Initial Information and Risk Assessment 21

Species Occurrence Overlay Analysis 21

Standardized Index of Vulnerability and Value Assessments (SIVVA) 21

Habitat Model Overlay Analysis 22

Predictive Distribution Modeling 23

Spatially Explicit Population Viability Analysis 24

Adaptation Option Analyses 24

Impact Assessments: Ecological Connectivity 28

Education and Outreach 30

RESULTS 32

Impact Assessment Results: Natural Communities 32

Impact Assessment Results: Focal Species 39

Impact Assessment Results: Ecological Connectivity 46

Impact Assessment Results: Land Use and Sea-level rise Impact Hotspots 57

Education and Outreach 67

RECOMMENDATIONS AND ADAPTATION STRATEGIES 71

Recommendations for Future Urban Land Use and Development 71

Potential Adaptation Options for Species Vulnerable to Sea-level Rise in

Combination with Threats from Changes in Land Use and Climate 74

Recommendations for Conservation of Coastal Natural Communities to Minimize Impacts to Vulnerable Species and Natural and Human Communities 75

Recommendations for Maintaining Landscape Connectivity in the Face of Sea-level Rise and Land-use Change 80

DISCUSSION 88

CONCLUSIONS 89

LITERATURE CITED 90

APPENDIX 1A: PRELIMINARY LITERATURE REVIEW

APPENDIX 1B: LITERATURE REVIEW UPDATE

APPENDIX 1C: PRIORITIZING SPECIES BY CONSERVATION VALUE AND VULNERABILITY

APPENDIX 1D: A VULNERABILITY ASSESSMENT OF 300 SPECIES

APPENDIX 2: FINAL SEA-LEVEL RISE SCENARIOS

APPENDIX 3: SUMMARY OF SLAMM MODEL

APPENDIX 4: 2060 LAND-USE CHANGE SCENARIOS AND POWERPOINT

APPENDIX 5: NATURAL COMMUNITY MAPPING REVISIONS

APPENDIX 6: FNAIHAB SPECIES MODEL UPDATE LIST

APPENDIX 7: FEGN UPDATE CORRIDOR PRIORITIZATION OPTIONS

APPENDIX 8A: ISMP SPECIES LIST COMPARISON

APPENDIX 8B: SGCN SPECIES ASSESSMENTS

APPENDIX 8C: SPECIES OCCURRENCE OVERLAY ANALYSIS

APPENDIX 8D: HABITAT AND NATURAL COMMUNITY MODEL OVERLAY ANALYSIS

APPENDIX 9A: SIVVA FOR NATURAL COMMUNITIES

APPENDIX9B: FLORIDA FOREVER PRIORITY IMPACTS FROM 1M SEA-LEVEL RISE

APPENDIX 9C: IMPACTS TO FLORIDA MANAGED AREAS FROM 1M SEA-LEVEL RISE

APPENDIX 10: SURVEY OF FLORIDA COUNTIES

(Note: appendices have been provided as separate documents with this report)

INTRODUCTION

The level of the sea has been rising and falling for millions of years in response to plate tectonics and global climate change. Glacial periods of the Pleistocene led to much of the oceans being locked in ice, lowering sea levels 120-130 m below today's (Lambeck and Chappell 2001) and more than doubling Florida's land area. In contrast, much of Florida and the Southeastern Coastal Plain was inundated during the last Pleistocene interglacial 125,000 years ago, when sea level was 6.6-8.3 m higher than today (Muhs et al. 2011). A major consequence of modern climate change induced by greenhouse gases from the burning of fossil fuels and other sources is a rapid rise in sea level. The level of the sea rises due to thermal expansion of water, melting of mountain glaciers, and melting and collapse of polar ice sheets. Tide gauge data show that global sea level has risen by about 20.3 cm (8 inches) since reliable record keeping began in 1880 (National Climate Assessment 2014). Experts differ in their projections of sea-level rise in the future, but virtually all recognize that the rate of sea-level rise has been increasing and will continue to increase over the next century and longer. Some data suggest a slowdown of the rate of sea-level rise over the past decade, corresponding to a pause in global warming associated with cooler Pacific Ocean surface waters (from upwelling) producing a heat sink (Kosaka and Xie 2013). However, correcting for interannual climate variability related to the El Niño-Southern Oscillation causes the apparent slowdown in sea-level rise to disappear (Cazenave et al. 2014).

The recent National Climate Assessment (2014) projected an increase in sea level of 1 to 4 feet by 2100, which is similar to but probably more realistic than the projections made by the Intergovernmental Panel on Climate Change (IPCC 2014), which predicts sea-level rise by 2100 of 0.43 m or 1.4 feet (0.28 to 0.60 m, or 0.9 to 2 feet) under a low CO_2 and temperature scenario to 0.73 m or 2.4 feet (0.53 to 0.97 m, or 1.7 to 3.2 feet) under the highest CO_2 and temperature scenario. These projected rates are considered overly conservative by many climate scientists. "Semi-empirical" models of sea-level rise based on the statistical relationship between past rates of globally averaged temperature change and sea level prooject rates of sea-level rise from about 0.8 m to 1.8 m by 2100, depending on the emissions scenario (e.g., Vermeer and Rahmstorf 2009, Rahmstorf et al. 2012). The National Climate Assessment (2014) suggested that "In the context of risk-based analysis, some decision makers may wish to use a wider range of scenarios, from 8 inches to 6.6 feet by 2100…the high end of these scenarios may be useful for decision makers with a low tolerance for risk."

Florida is extremely vulnerable to the effects of sea-level rise due to a combination of low land elevations, a high water table, peninsular geography, susceptibility to tropical storms, and a large and growing human population that is largely concentrated along the coasts. Pilkey and Young (2009) concluded that Florida has more to lose from sea-level rise than any other U.S. state, yet has done less than any state to prepare for it. The vast majority of Floridians (80%) live or work in one of the state's 35 coastal counties—most of them within ten miles of the coast. With so much low-lying area near the coasts, even a modest increase in sea level will lead to large areas of land being inundated. The National Climate Assessment (2014) concluded that Florida cities such as Miami, Tampa, and Fort Lauderdale are particularly vulnerable to sea level rise and its economic impacts. An insurance analyst with Swiss Re, the world's second largest reinsurer, testified at a Senate hearing that portions of Florida could become uninsurable due to sea level rise by 2100 (Miami Herald 2014). This would have a cascading effect on Florida's economy, beginning with a rapidly dropping value of coastal real estate. In Miami-Dade County, sea-level rise has already resulted in extreme high tides and flooding in Miami Beach and other coastal communities and likely contributed to beach erosion and extensive damage to highway A1A in Ft. Lauderdale during Hurricane Sandy. These flooding events will become more frequent with higher sea levels. Damages from recent storms in Florida have run into the hundreds of millions and even billions of dollars (Harrington and Walton 2008). Sea-level rise and increased intensity of storm surges in Florida are leading to erosion of beaches and barrier islands, greater property damages, salt-water intrusion into drinking water supplies, and adverse impacts on coastal ecosystems and species (Noss 2011).

Climate change and specifically sea-level rise are primary threats to virtually all of the Species of Greatest Conservation Need (SGCN) and priority natural communities identified in the Florida Comprehensive Wildlife Conservation Strategy (FCWCS). Many of these species are endemic or near-endemic to Florida, which means that if they are going to avoid extinction, conservation and adaptation measures must be implemented here. Coupled with interacting impacts from human population growth, urbanization, and other land-use changes – which will be exacerbated by sea-level rise – this may constitute the most important challenge facing biodiversity conservation in Florida. Moreover, Florida serves as instructive case study for low-elevation coastal regions globally that are facing the threats that sea-level rise poses to human and natural communities, threats that are already evident but will become increasingly severe in coming decades.

Fortunately, there are ways to reduce the impacts of sea level rise and storm surge on Florida's coasts. Options for responding to sea-level rise and increased storminess fall into three basic and non-mutually exclusive categories: (1) coastal hardening ("stand your ground"); (2) managed retreat or withdrawal (relocation landward); and (3) ecological engineering. Coastal hardening, such as by use of dikes, sea walls, revetments, bulkheads, and other structures is at best a short-term option to protect valuable human infrastructure until a more effective long-term solution can be implemented. In the long run it is ecologically and economically unsustainable, as is the related practice of beach nourishment. Sea walls and other hard structures also typically increase erosion of neighboring coastal areas, both developed and undeveloped (Pilkey and Wright 1988, Hall and Pilkey 1991). Because intertidal wetlands are situated between these structures and the sea, coastal armoring results in "shoreline squeeze," where wetlands are eroded at the seaward margin and prevented by the structures from migrating landward (Kirwan and Megonigal 2013).

The second option, managed retreat and relocation of human communities, buildings, and infrastructure landward of low-lying coastal areas, is also expensive, as well as socially disruptive, but may be the only feasible long-term solution if the high-end scenarios of sea level rise play out. A related, interim option of vertical re-development (i.e., raising buildings and infrastructure above anticipated future sea level) may be appropriate and feasible in some areas, but would be dangerous in the face of extreme hurricanes or if the sea rises faster and higher than expected.

The goal of this project was to create a detailed assessment of the combined impacts of sea-level rise, land-use changes (especially increasing urbanization and changed patterns of development), and to a lesser extent climate (temperature and precipitation) change, on imperiled species and natural communities throughout the state of Florida. From this information, we then develop, evaluate, and recommend actions for adaptation and conservation of species and natural communities. Specifically, as articulated in our contract with The Kresge Foundation, our objectives were to:

1) Assess the vulnerability of [species and] natural communities in Florida to projected sea-level rise combined with land-use change.

2) Conduct a critical evaluation of adaptation options for reducing the combined impacts of sea-level rise and urban development, as well as options for reducing conflicts between adaptation for humans and adaptation for nature.

3) Develop the foundation for a statewide adaptation strategy that will aim to minimize losses of biodiversity and mitigate ecosystem impacts from sea-level rise and concurrent changes in land use.

4) Initiate a statewide public education campaign and reach out to decision makers to help them make better-informed decisions in preparation for sea-level rise. (This last objective was downgraded in priority because, as a result of our funding being $100K less than requested, we made the decision to concentrate on Objectives 1-3 and to seek supplementary funding for #4, which was unsuccessful.)

A sea-level rise vulnerability assessment is necessary for developing conservation strategies, including identification and protection of functional landscape connectivity, that will avoid, minimize, and mitigate anticipated impacts of sea-level rise and interacting threats. This work will form a foundation for revising conservation land acquisition priorities, land-use planning and management strategies, and adaptation measures for at-risk species and natural communities to promote resistance and resilience to climate change. Funding for this project was provided from two sources: the Florida Fish and Wildlife Conservation Commission State Wildlife Grants program, and the Kresge Foundation, which provided the bulk of the funding; as a result the project results are more robust thanks to their combined support. In addition, we were able to capitalize on the involvement of our team members in several other projects related to this one, for example the Conservation Lands and Waters Identification Project (CLIP), the Florida Ecological Greenways Network project (FEGN), the North American Coastal Plain Biodiversity Hotspot project, a book project on Forgotten Grasslands of the South (i.e., many of these “grasslands” are coastal and in Florida, e.g., coastal grassland, pine rockland, and Keys cactus barren), and an adaptation project on the Matanzas Inlet near Jacksonville. The added value from those projects to this one allowed us to increase the scope and depth of this project without added expense.

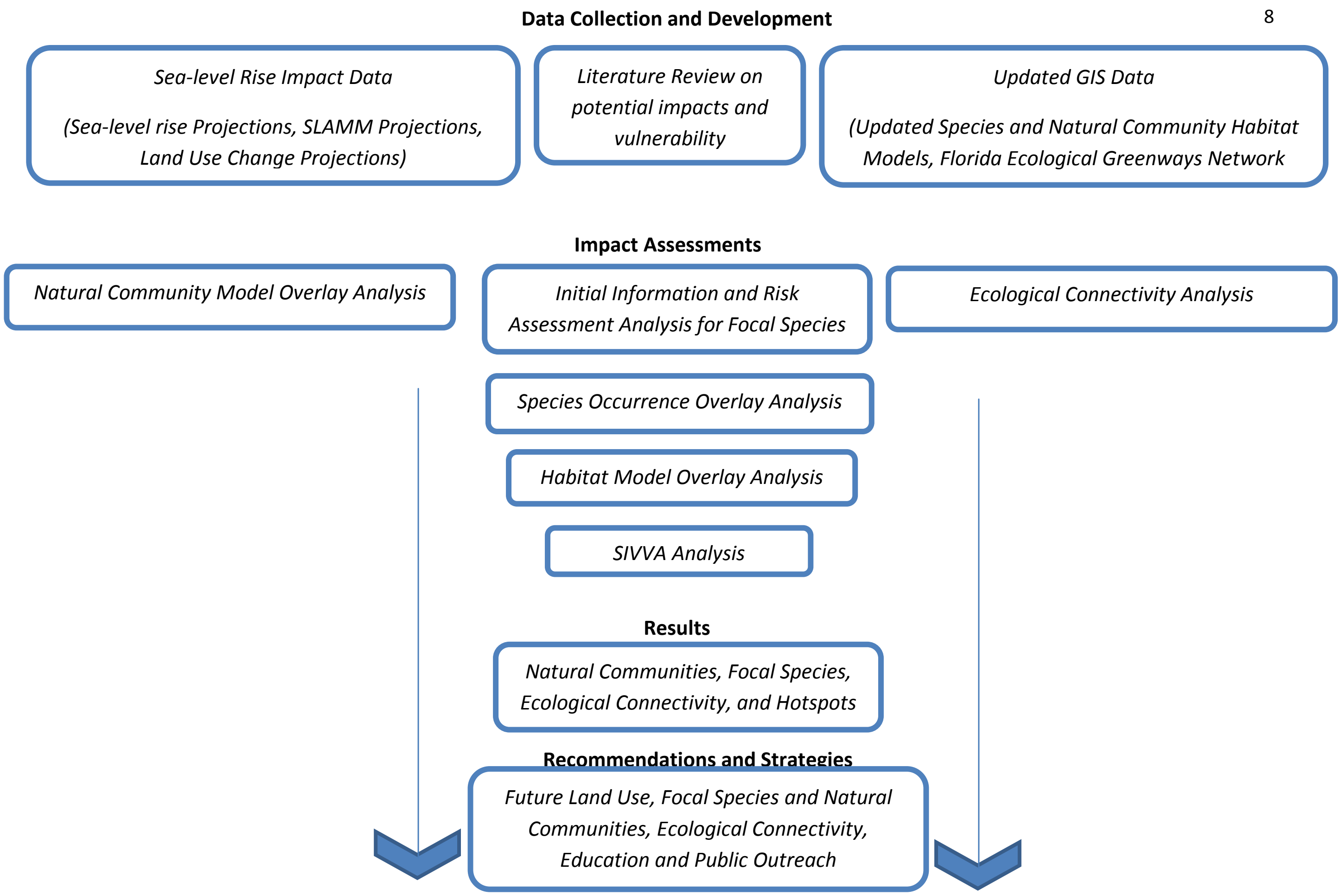
METHODS

Summary

The methodology for this project was organized into two primary phases: 1) Data Collection and Development, and 2) Impacts Assessment, which formed the basis for the Recommendations and Strategies provided at the end of this report. Data collection and development consisted of an expert and literature based review of species and natural community vulnerability and adaptive capacity as part of the SIVVA analysis (see description below), and critical foundational data obtained and created to assess the combined impacts of sea-level rise and land-use changes on imperiled species and communities in coastal areas. Information developed for use in impact assessment work included a range of sea-level rise projections based on the best available digital elevation data, SLAMM (Sea Level Affecting Marshes Model) data, and future population and land-use projections for Florida. In addition, updated natural community and habitat models were developed as needed for imperiled species and natural communities to ensure that impact assessments were as accurate as possible. Finally, an update to the Florida Ecological Greenways Network (FEGN) occurred concurrently with the first part of this project and also provided base data.

Based on the data we collected and developed, we assessed the potential impacts of sea-level rise and future land use on imperiled focal species, natural communities, and habitat corridors as a basis for developing specific conservation and adaptation strategies. This included both quantitative GIS overlay assessments, as well as qualitative and quantitative assessments using a tool developed specifically for this project, the Standardized Index of Vulnerability and Value Assessments (SIVVA). Two versions of SIVVA were developed and are described here: one tailored to natural communities and a separate one intended for focal species assessments. The SIVVA tool is comparable to tools such as the IUCN Red List criteria, the US Endangered Species Act (ESA) listing criteria, and the NatureServe’s Conservation Status Assessments and Climate Change Vulnerability Index (CCVI), using expert reviewers and primary literature, as well as other sources such as herbaria and the grey literature, to assess the vulnerabilities of species and natural communities. Despite the utility of these previously developed tools for a variety of purposes, we found it necessary to create a customized novel vulnerability assessment tool that would be used specifically for this project but could also be applied in future work worldwide. We demonstrated that SIVVA is more flexible, transparent, and better equipped to address combined impacts of sea-level rise and other stressors than any previously developed tool. The rationale behind SIVVA, including comparisons and improvements to existing tools, is described in *Appendix 1b- Literature Review Update.*

The flow diagram on the following page illustrates the basic process of data collection, impact assessment, and identification of adaptive strategies that we followed in this project. Using the best available data (collected and created), we conducted a variety of quantitative analyses, some of which were then fed into the qualitative/quantitative SIVVA tool, providing a comprehensive picture of vulnerability and adaptive capacity for the species assessed. Other analyses such as ecological connectivity did not directly feed into SIVVA, but were cross-referenced. The results from these impact assessments are summarized in the impact assessment and results section of this report, and synthesized in our recommendations.


Data Collection and Development
Sea-level Rise Impact Data
(Sea-level rise Projections, SLAMM Projections, Land Use Change Projections)
Literature Review on potential impacts and vulnerability
Updated GIS Data
(Updated Species and Natural Community Habitat Models, Florida Ecological Greenways Network
Impact Assessments
Natural Community Model Overlay Analysis
Initial Information and Risk Assessment Analysis for Focal Species
Ecological Connectivity Analysis
Species Occurrence Overlay Analysis
Habitat Model Overlay Analysis
SIVVA Analysis
Results
Natural Communities, Focal Species, Ecological Connectivity, and Hotspots
Recommendations and Strategies
Future Land Use, Focal Species and Natural Communities, Ecological Connectivity, Education and Public Outreach

Technical Advisory Group

We recruited a number of leading experts on Florida's biodiversity, sea-level rise, climate change, and land-use change in Florida to join a Technical Advisory Group (TAG) for this project. The TAG was an essential part of this project, providing review of our various data and impact assessment products as they were produced, and opportunities to develop expert consensus on how these should best be integrated into the project as a whole. TAG members had relevant scientific or technical expertise in habitat and species science, climate change and sea-level rise science, land use and population modeling, and adaptive strategies and design. The TAG members for this project were as follows, categorized roughly by expertise:

Habitat and species science and modeling

1. Kim Gulledge (Florida Natural Areas Inventory)
2. Richard Flamm (Florida Fish and Wildlife Conservation Commission)
3. Ryan Butryn (Florida Fish and Wildlife Conservation Commission)

Climate change and sea-level rise science and modeling

4. Joseph F. Donoghue (Florida State University)
5. Gary Mitchum (University of South Florida)
6. Keqi Zhang (Florida International University)

Land use and population modeling

7. Tim Chapin (Florida State University)
8. Stefan Rayer (Bureau of Economic and Business Research)
9. Peggy Carr (University of Florida)

Adaptation strategies and design

10. Mike Ross (Florida International University)

11. Chris Bergh (The Nature Conservancy)

12. Greg Kiker (University of Florida)

13. Doria Gordon (The Nature Conservancy)

Additional collaborators and advisors

Beth Stys and Bob Kawula (FWC collaborators on habitat and species modeling)

Amy Knight and Kim Gulledge (Florida Natural Areas Inventory)

FWC Climate Workgroups

Paul Zwick (University of Florida)

We held our first TAG meeting in June 2011. Discussions included identifying the best available DEM and sea-level rise projection data and range of sea-level rise projections worthy of analysis. Suggested alterations to our approach and work at that time were minimal; however we did receive input regarding potential sources of SLAMM data, DEM, and sea-level rise projections that were incorporated into our subsequent work. We provided a second digital update to the TAG in August 2012 with little significant feedback received. In December 2012 we organized a follow-up TAG meeting to discuss the work completed in 2012. This included a brief review of the overall goals of the project, funding, and timeline; a discussion of our updated sea-level rise scenarios and data; the natural community and species impact assessments, SIVVA, and the land-use change scenarios. This meeting was held on January 7, 2013 via conference call and desktop sharing, with 12 people either calling in or attending in person. We emailed a version of our most recent report, a summary of the meeting, and our topics of discussion to the entire TAG, including those who were not present, after the meeting. There were several questions and discussion points regarding the Natural Communities SIVVA, SLAMM, and the draft land-use change scenarios that we responded to. There were no critical changes to our methods that were suggested from the meeting. Finally, we held a TAG meeting on November 20, 2013 to present our final impact analyses and land-use change scenarios, and receive TAG input into our adaptation strategy recommendations. Primary input from this meeting included several questions about the assumptions and parameters for the land-use change scenarios. At the time of the TAG meeting there were no further revisions that we could make to the scenarios. In addition there were several technical questions about the SLAMM models and their incorporation into SIVVA and other impact analyses, which did not have a major effect on our work going forward.

An additional goal for this project was to ensure that final project results are disseminated upon project completion to relevant agencies, organizations, and individuals to maximize their impact and use. To this end we have developed a portion of the website for the UF Center for Landscape Conservation Planning and the Florida Climate Institute at UCF, which will be devoted to this project and contain relevant project data and information. Currently the websites contain a project synopsis and links to relevant publications. The current link for the UF website is: http://conservation.dcp.ufl.edu/Projects.html and relevant links to the UCF website can be found at http://ucf.floridaclimateinstitute.org/outreach-education/.

Data Collection and Development

Literature Review.— Our scope of work for the FWC portion of this project included a literature and expert based review of autecology and risk factors for specific species. In 2011 we completed a *preliminary* literature review that described 1) a potential methodology for assessing species and natural community impacts, 2) methods for prioritizing species and natural communities for assessment and adaptation planning, and 3) a review of criteria for assessing vulnerability to sea-level rise and the feasibility of modeling habitat spatial patterns and population processes under a range of sea-level rise scenarios. This is included in *Appendix 1a- Preliminary Literature Review.*

In 2012, in the process of developing the SIVVA tool for species and natural communities we conducted an extensive review of other conservation assessment tools (such as the NatureServe Conservation Assessments). A synopsis of this work as of July 2012, and how it would likely be used in our upcoming analysis was provided in *Appendix 1b- Literature Review Update.* *(Note that Appendices 1a and 1b describe potential methodology for this work on this project that has since been completed).*

In 2013, we completed work on the SIVVA tool for focal species assessments, and completed all species assessments. To do this, we reviewed the available literature on species prioritization protocols and vulnerability assessments. Summaries of this work can be found in the introduction and in Table 1 of Reece and Noss (2014, *Natural Areas Journal* and included as *Appendix 1c- Prioritizing Species by Conservation Value and Vulnerability*), as well as in the introduction and discussion of Reece et al. (2013, *PLoS ONE* and included as *Appendix 1d-A Vulnerability Assessment of 300 Species in Florida*).

Over 300 species were assessed using the SIVVA tool. These species were selected from the Florida Natural Areas Inventory tracking list based on their exposure to sea-level rise, although additional species were selected at the request of FWC (see *Appendix 1d*). The protocols for expert assessments of species are detailed in *Appendices 1c and 1d*, but basically involved expert opinion, peer-reviewed literature specific to the species and compiled by FNAI and our team, and projections of future climate, land-use patterns, and sea-level rise. Experts consulted the literature to make judgments on the reproductive rates, dispersal capabilities, and sensitivity of species to specific stressors, among other factors. In addition, for each species, experts used the available literature to assess the amount of information available with respect to life history, demography, or environmental niche requirements, genetic diversity, and current or historical responses to sea-level rise and climate change (Table 3, Figures 1 and 2 of *Appendix 1d*).

Sea-level rise Projections.—Our goal for this project was to develop at least three sea-level rise scenarios using the best available digital elevation model (DEM) data and with TAG input. Our final scenarios include projections for approximately 0.5m, 1m, 1.5m, and 2m by 2100 (note that actual numbers used vary slightly due to the 2060 values needed for our land-use change models, interpolated based on the IPCC A1B curve. See further description in *Appendix 2- Final Sea-level rise Scenarios)*. The final scenarios are tidally adjusted for mean high higher water (MHHW) and are based on the best available inland DEM and coastal LiDAR data collected by the UF GeoPlan Center. A full description of these scenarios is included in *Appendix 2*, and shown in **Figure 1**.

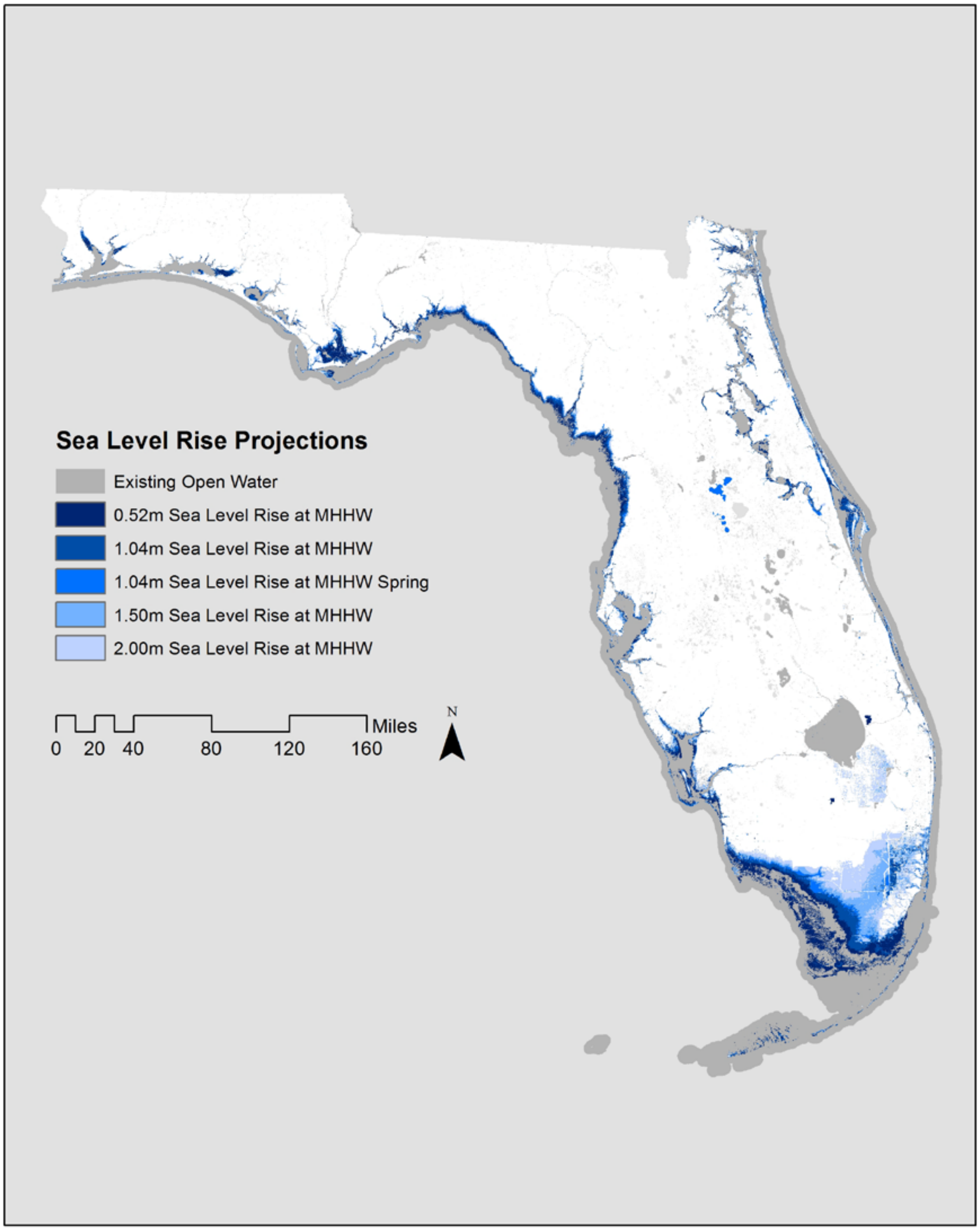


Figure 1. Tidally Adjusted Sea-level rise "Bathtub" Projections based on mean higher high water (MHHW) elevations and the best available LiDAR based DEM.

Sea Level Affecting Marshes Model (SLAMM) Projections.—As part of our effort to collect data related to potential sea-level rise impacts, we also collected SLAMM data for most of the state. The rationale was that this data could be compared with our coarse bathtub projections to provide a different picture of potential impact that incorporated land cover change. To this end, we coordinated with several researchers to obtain SLAMM models for Florida coastal areas, including The Nature Conservancy (TNC), FWC (Bob Glazer and Beth Stys), and UF.

The final SLAMM models that we used were created by Greg Kiker at the University of Florida. They are based on a preliminary version of the DEM data that was used for our sea-level rise projections, as well as a version of the Cooperative Land Cover (CLC) dataset crosswalked to SLAMM categories. A description of the final SLAMM data is included in *Appendix 3- Summary of SLAMM Model*. Importantly, note that SLAMM was not produced for the Everglades and Florida Keys. This point is referenced in later sections where we compare and discuss SLAMM and DEM bathtub model impacts from sea-level rise to species and natural communities. Reasons for the omission include limited availability of information for the parameters required by the SLAMM model in the Everglades, and technical hurdles posed by the unique geography of the Everglades which were beyond the scope of our project to address. To our knowledge SLAMM has not been successfully run in the Everglades. SLAMM has now been run for the Florida Keys, but these data were not ready in time for our analyses.

Future Land-use change Projections.— Our goal for the land-use scenario portion of this project was to create or collect the best available land-use change scenarios, which in combination with our sea-level rise scenarios would be used to assess impacts to species and natural communities.

To help us plan and execute this work, we contracted Dr. Paul Zwick and Peggy Carr from the University of Florida. Dr. Zwick and Professor Carr produced the 2006 *Florida 2060* report for 1000 Friends of Florida that outlines population distribution scenarios for Florida, and both have extensive experience in land-use change modeling including the development of the Land Use Conflict Identification Strategy (Carr and Zwick 2007). We also had several discussions with staff from GeoAdaptive, who recently completed land-use scenario work in South Florida, and others to review and where possible coordinate our land-use modeling efforts with other work that is existing or currently underway.

For this project Dr. Zwick and Professor Carr created three updated statewide land-use change scenarios. Based on their recommendation we chose one of these for our impact assessments. The basic parameters, including maps illustrating each scenario, are described in *Appendix 4-2060 Land-use change Scenarios.* However, in short the three scenarios include the following:

1) A "trend" scenario was created that includes projected population growth by 2060 based on projections by the Bureau of Business and Economic Research (BEBR) but no sea-level rise. Future development is allocated based on suitability and current development trends and densities.
2) A sea-level rise scenario (named SLR1) was created that includes projected population growth and 1 meter of sea-level rise. In this scenario, no new population was allocated in coastal areas with an elevation lower than 1.5 meters. All projected population, plus population displaced by sea-level rise was reallocated statewide based on suitability and current development trends.
3) A second sea-level rise scenario (named SLR2) was created that includes the same population growth and 1 meter sea-level rise projection as the first sea-level rise scenario. However, unlike the first sea-level rise scenario, this one began with the trend scenario. Then only new and existing development inundated by sea-level rise was reallocated statewide based on suitability and current development trends. Like the first scenario, no new population was allocated in coastal areas with an elevation lower than 1.5 meters.

Modeling Modifications.—As an outcome from this work, we also identified potential modifications to the modeling techniques that may be made in future models. The research team has been careful to clearly articulate the assumptions on which the three alternative scenarios were based, but there are many variations that if applied would yield differing results. Following is a priority list of alternatives that we recommend for future modeling, based on the current modeling assumptions listed in *Appendix 4-2060 Land-use change Scenarios*. It is helpful to review the initial assumptions in tandem with these potential modifications.

Assumptions: Population.—

- A straight-line population projection beyond BEBR's 2040 middle projection was used for all three scenarios in this study. Alternatively a flattening curve could be used beyond 2040 with the result that the new 2060 population to be accommodated would be less than that used in this study. This consideration is based on input from Stefan Rayer, a TAG member on this project with the Bureau of Economic and Business Research (BEBR), which provided the population projections used for our modeling.
- This study assumed all population to be relocated due to inundation will remain in the State. A range of alternatives could be developed, each with its own rate of emigration from 0 to 100%.

Assumptions: Redevelopment Rates.—

- Redevelopment Rates were established and applied for the 2060 time frame for all three scenarios. Alternatively if multiple time interval results were prepared for each scenario, redevelopment rates could be graduated over time, e.g., a Trend model with a snapshot at 2020, 2040 and 2060, each with an increasing redevelopment rate for every county.

Assumptions: Greenfield Development Mask.—

- No alternatives would have priority status for these assumptions. For example, in our modeling the greenfield mask used for the Trend scenario formed the foundation for the SLR 1 and 2 masks. The SLR 1 and 2 scenarios could have an entirely unique greenfield development mask, and/or the 1.5m development buffer used in scenarios SLR 1 and SLR 2 could be eliminated.

Assumptions: Urban Suitability Surface.—

- It is highly recommended that the urban suitability surface used for sea-level rise scenarios be differentiated from the surface used for a trend scenario(s). In other words, uplands that might be highly or moderately suitable for development under a trend scenario may not be equally suitable after sea-level rise.

Assumptions: Allocation Process.—

- The county by county population distribution approach used for the Trend and SLR 2 Scenarios is considered more realistic than the statewide distribution used in the SLR 1

Scenario. The displaced population could also be redistributed on a county by county basis to produce a different result, whereas even in our current SLR 2 scenario displaced population was redistributed statewide.

Assumptions: Gross Urban Density.—

- Just as the redevelopment rates could be graduated over time, so too could be the gross urban densities.
- Gross urban densities were applied consistently within each county, but more nuanced alternatives could be developed if densities within each county varied by sector/neighborhood/municipality, etc.

Natural Community Model Updates.— Our goal for this objective was to compile and update existing natural community models and develop new models as needed for priority terrestrial habitats identified in the Florida State Wildlife Action Plan (FSWAP). To this end we created a list of natural communities which we considered priority communities for this project due to their potential impacts from sea-level rise. We then assessed the status of existing land cover models and data in the Cooperative Land Cover (CLC) dataset and prioritized community updates based on this information. Priority updates were completed by Florida Natural Areas Inventory staff. A description of the updates completed is included in *Appendix 5- Natural Community Mapping Revisions*.

Species Habitat Model Updates.— The goal of the species habitat and corridor modeling objective for this project was to compile and develop updated habitat models for selected priority species identified in the FSWAP. Updates to species habitat models were completed by Florida Natural Areas Inventory staff and are listed in *Appendix 6- FNAIHAB Species Update List*. This appendix lists updates to all FNAI species habitat models used in the Rare Species Habitat Conservation Priorities (also known as the FNAIHAB) model, including plants. The previous version of the FNAIHAB model (version 2.2) included 248 species. The new update includes 287 species. Of these, 77 are new species not included in version 2.2, 183 are species formerly included but with updated habitat models, and 27 are species still using the version 2.2 model. These updates have been completed with funding from multiple sources.

Florida Ecological Greenways Network (FEGN) Updates.— Concurrent with this project, State Wildlife Grant funding was provided for an update of the Florida Ecological Greenways Network (FEGN). The FEGN identifies the opportunities to protect large, intact landscapes important for conserving Florida's biodiversity and ecosystem services, and serves as a backbone for biodiversity and ecosystem protection efforts in Florida. Since the original FEGN boundary delineation, many new GIS data layers identifying areas of conservation significance have been developed. A comprehensive update of the FEGN was needed to ensure that Florida's biodiversity conservation priorities are effectively addressed when identifying the large, intact landscapes across Florida.

Relevant elements of the FEGN Update included the identification of areas of ecological connectivity from current coastal natural communities to areas inland up to 5 km beyond a 3m sea-level rise, with the goal of maintaining potential opportunities for coastal species to functionally retreat as sea-level rise progresses. In addition, the FEGN priorities were examined to determine whether any high priority corridors might be impacted by sea-level rise and whether there were options for mitigating these projected impacts by adding additional areas or by shifting priorities. This work was completed in July 2013, and updates to the base boundary and prioritization scheme resulting from the broader update of the FEGN were used to inform the corridor assessments and priorities for this project. *Appendix 7- FEGN Update Corridor Prioritization Options* contains a powerpoint presentation summarizing these results.

Impact Assessments: Natural Communities

Natural Community Model Overlay Analysis.—Based on the updated natural community models described above, SLAMM, DEM based bathtub models, and land-use change projections were used to quantitatively assess natural community impacts via GIS overlay analyses. Natural community models were overlaid on all SLAMM, DEM, and land-use change scenarios, and areas of overlap were calculated. Percent "loss" was calculated as areas of each community that overlapped with either rising sea levels, incompatible land cover types (SLAMM scenarios), or development (land-use scenarios). A summary of the results is included in *Appendix 8d-Habitat and Natural Community Model Overlay Analysis*.

Standardized Index for Vulnerability and Value of Natural Communities (SIVVA-NatCom).— Whereas the model overlay analysis calculated the threats to natural communities from sea-level rise, climate change, and land-use patterns, such an approach does not provide information on the current status/health of each natural community, or their ecological, evolutionary, and economic value. Following the success of our SIVVA for species model (Reece et al. 2013, Reece and Noss 2014), we developed SIVVA for Natural Communities (SIVVA-NatCom). This model is based on existing ecosystem assessments such as the IUCN (Rodriguez et al. 2011) and NatureServe (Faber-Langendoen et al. 2009), and several published studies (Holdaway et al. 2012, Benson 2006, Nicholson 2009, Paal 1998), but includes more quantitative information on threats and separate modules on the value of natural communities. The SIVVA-NatCom tool includes three modules: 1) Ecosystem Status, 2) Vulnerability, and 3) Conservation Value. An example Excel Sheet of the tool is provided in *Appendix 9a- SIVVA NatCom*. Ecosystem Status assesses the historical decline in extent and ecosystem function. The Vulnerability module assess the model-based quantitative estimates of area lost directly to sea-level rise, land-use change, fragmentation from the same, vulnerability to altered disturbance regimes, hydrology, invasive species, constraints on the ability of the system to shift in response to threats, and other factors that degrade abiotic or biotic components of the ecosystem. Lastly, the Conservation Value module assess the endemism of the natural community, its complement of endemic, disjunct, or evolutionarily distinct species, and the value of ecosystem services provided by that community. Natural community assessments were evaluated by an expert at the Florida Natural Areas Inventory, in consultation with the authors of SIVVA. Each assessment was re-evaluated by a second expert at FNAI, and a third check for consistency and justification was completed by the tool authors (Noss and Reece). Results are discussed under a value scheme that places equal emphasis on each of the three modules, but alternative approaches have been made available to agencies who might wish, for example, to value Ecosystem Status over Vulnerability and Conservation Value.

Impact Assessments: Focal Species

Summary.— Focal species impacts from sea-level rise and land-use change were assessed using SLAMM, DEM based bathtub projections, and the future land-use scenarios. Using the updated species habitat models described earlier, we conducted several types of assessment at progressive levels of detail.

The results of all deliverables completed for the FWC contract have been used to inform the analyses of sea-level rise/development impacts and adaptation strategies included in this report to Kresge. Deliverables 1-3 informed primarily from a non-spatial perspective (for example, prioritizing species' need for adaptation strategies), while Deliverables 4-6 inform primarily from a spatial perspective (for example, prioritizing places in need of conservation priority or where adaptation strategies should be focused). The direct outcome of the species and natural community modeling constitute the results and inform the recommendations provided in this report. To this end the six focal species assessment deliverables that we originally outlined for the Kresge and FWC grants are listed in **Table 1**.

Table 1. List of deliverables for FWC and Kresge grants.

Assessment	FWC Deliverable	Kresge Deliverable
1) SGCN Initial Information and Risk Assessment	Analysis of all 1036 species from the draft revised SGCN	Analysis of 1036 species from the draft revised SGCN
2) Species Occurrence Overlay Analysis	Analysis of approximately 700 animal species	Analysis of approximately 1049 species including plants
3) Standardized Index of Vulnerability and Value Assessments (SIVVA)	Analysis of approximately 216 SGCN species	Analysis of approximately ~325 species including plants
4) Habitat Model Overlay Analysis	Analysis of approximately 150 animal species	Analysis of ~150 species plus additional species as needed
5) Predictive Distribution Modeling	--	Analysis of ~50 focal species
6) Spatially Explicit Population Viability Analysis	--	Analysis of ~10-15 focal species

1) SGCN Initial Information and Sea-Level Rise (SLR) Risk Assessment (Deliverable 1).—This deliverable constitutes the first step in selecting species from the Species of Greatest Conservation Need (SDCN) identified by FWC for further analysis and is included in *Appendix 8b- SGCN Species Assessments*. The deliverable includes a list of all 1036 SGCN species crosswalked to the FNAI tracked species list, with brief comments on potential vulnerability to sea-level rise and/or suitability for additional analyses. Most importantly it documents which SGCN species were chosen for assessment in each of the six deliverables listed above. Not all species were selected for further review beyond Deliverable 1, and those that were not selected include a brief note describing why they were not selected. Reasons for exclusion were generally limited vulnerability to sea-level rise or lack of available information. Note that we have also compared this list to FWC's Imperiled Species Management Plan (ISMP) list of species. All of the species on the ISMP list were assessed to at least the Deliverable 2 level in this project. The comparison is included in *Appendix 8a-ISMP Species List Comparison.*

2) Species Occurrence Overlay Analysis with Sea-level rise Projections (Deliverable 2).—For this deliverable we conducted an assessment of potential sea-level rise impacts to the SGCN using an overlay analysis of SGCN and other species with sea-level rise scenarios. SGCN and other species in this assessment were those with spatial occurrence data (primarily the approximately 700 animal species tracked by FNAI plus additional plant species for a total of approximately 1049 species). The goal was to determine which species have 50% or more of their element occurrences (polygons of varying size created from geo-referenced known observations of species) inundated by at least 50% of their area under 2 meters of sea-level rise.

Based on the list of 1049 species assessed, we identified 268 species, 50% of whose occurrences were projected to be 50% or more inundated. Approximately 120 of these are plants. A spreadsheet describing this analysis is included as *Appendix 8c- Species Occurrence Overlay Analysis.*

3) Standardized Index of Vulnerability and Value Assessments (SIVVA) (Deliverable 3).— Deliverable 3 identifies which species from Deliverable 2 (overlay analysis) are most imperiled and in need of conservation action. Other species in addition to those from Deliverable 2 were also assessed. A total of 325 plant and animal species were assessed in this deliverable.

To do this we used the previously described vulnerability assessment tool (SIVVA). A total of 216 SGCN species were assessed using the SIVVA for the FWC portion of this deliverable, along with an additional 109 species assessed under the Kresge portion. Of the 325 total species assessed, 268 species was identified from Deliverable 2, plus species that were being studied by colleagues at MIT (Juan Carlos Vargas and Michael Flaxman), UCF (John Weishampel, Betsy Von Holle, Chris Parkinson, Eric Hoffman, Scott Hagen, and Linda Walters) and UF (James Watling), and several species specifically suggested by our previous FWC reviewer, Anna Farmer. Additional species were added to the list being assessed via the SIVVA based on our review of the SGCN list. Per FWC request, we completed assessments of 25 additional shorebird species that are included in the totals listed above. All of the focal species assessments are complete and a full description of the assessments and results can be found in *Appendices 1c and 1d.* The most up-to-date version of the species assessment version of SIVVA, including the instructions and maps provided to expert reviewers using the tool can be found at the following link- http://noss.cos.ucf.edu/publications/sivva. The list of species that were assessed can be seen in *Appendix 8b-SGCN Species Assessments*.

4) Habitat Model Overlay Analysis (Deliverable 4).—The goal of Deliverable 4 was to conduct GIS overlays of updated potential habitat models on sea-level rise scenarios, SLAMM, and future land-use scenarios to assess potential impacts. As previously described FNAI completed habitat model revisions for an updated version of the FNAIHAB model. The previous version (version 2.2) included 248 species. The new update includes 287 species. Of these, 77 are new species not included in version 2.2, 183 are species formerly included but with updated habitat models, and 27 are species still using the version 2.2 model. *Appendix 6-FNAIHAB Species Update List* is a complete list of those species, which were used to conduct habitat model overlays.

Using the updated habitat models, we conducted GIS overlays of all FNAI habitat models and FWC potential habitat models on SLAMM, DEM, and future land use projection scenarios. As with natural community models, species models were overlaid on all SLAMM, DEM, and land-use change scenarios, and areas of overlap were calculated. Percent “loss” was calculated as areas of each species’ habitat that overlapped with either rising sea levels, incompatible land cover types (SLAMM scenarios), or development (land-use scenarios). Results are compiled in *Appendix 8d- Habitat and Natural Community Model Overlay Analysis*.

5) Predictive Distribution Modeling (Deliverable 5).— To assess vulnerability to climate change for threatened species occurring in the state of Florida, we developed climate envelope models for a group of 50 threatened species or subspecies (*Appendix 8b- SGCN Species Assessments*). Climate envelope models relate species occurrences to mapped climate variables using mathematical algorithms, in order to determine the set of climatic conditions in which the species occurs (the “climate envelope”). Using this information, the algorithm can highlight geographic areas where similar climatic conditions exist (we use the term “suitable climate area”; SCA) in contemporary or future time periods, using climate projections from regional or global climate models. In this project, we related species occurrences to nine bioclimatic variables (which are summaries of average monthly temperature and precipitation) under contemporary climate conditions (called the “2000” time period), and projected the models to future climate conditions (2041-2060, called the “2050” time period), which were estimated by a regional climate model (https://floridaclimateinstitute.org/resources/data-sets/regional-downscaling).

In our modeling process, we used three different algorithms (random forests, Maxent, and GBM) in an ensemble method to determine SCA for the 50 species in this study, for both the 2000 and 2050 time periods. For each species, we combined individual-algorithm prediction maps, and marked areas where 2/3 algorithms agreed as SCA for the species. The same process was used for the 2050 time period, but replicated for three different GCMs under the A2 emissions scenario. An additional 2/3 ensemble (across GCMs) was then used to produce the species 2050 SCA prediction.

We collaborated with James Watling from the University of Florida and his colleagues to complete this work. Species that are being assessed from the SGCN have been added to *Appendix 8b- SGCN Species Assessments*.

6) Spatially Explicit Population Viability Analysis (Deliverable 6).— After consulting with our partners in management agencies, we decided that rather than focus on developing spatially explicit population viability analysis for 10-15 species, conservation efforts would be better served by a more empirical and extensive review of species-specific adaptation options. Given limited time and budgets, we opted to expand our analysis of adaptation options for individual species at the cost of developing spatially explicit population viability models. Thus, instead of developing models that may or may not factor into conservation efforts for up to 15 species, we evaluated adaptation options for all 300 species in our analyses.

7) Adaptation Option Analyses.— As shown by the abundant empirical support for Henry Gleason's (1926) "individualistic concept of the plant association" (Whittaker 1962), we assume that each species responds individualistically and somewhat independently to environmental change in space and time. Hence, especially for species at high risk of extinction, each must be evaluated independently in terms of the appropriateness of various conservation, management, restoration, or adaptation options. In evaluating adaptation options for the highest priority species, in terms of conservation value, vulnerability to sea-level rise (SLR) and other threats, information availability, and other factors (based on SIVVA; Reece et al. 2013, Reece and Noss 2014), we restricted our attention to species that are being or likely will be directly impacted by SLR by the year 2100. Out of the 300 species evaluated in our study, we eliminated 46 that are unlikely to be strongly affected by SLR, but are more vulnerable to other threats. An additional 18 species were not analyzed because we lacked sufficient information to evaluate them (e.g., unknown life history, geographic range, or habitat associations), which resulted in 236 evaluations.

For these 236 species we scored each species for six adaptation options that were developed through an examination of the relevant literature and discussion with the TAG. These adaptation options were evaluated in terms of the suitability (appropriateness), feasibility, and estimated probability of success of that option for the species in question. Each species was scored both for short term (≤ year 2050) and long term (≥2100) time scales. The categorical scores we assigned to species were: (1) Not Applicable or Not Likely to Succeed (N), (2) Low Suitability/Feasibility/Probability of Success (L), (3) Moderate

Suitability/Feasibility/Probability of Success (M), or (4) High Suitability/Feasibility/Probability of Success (H), based on information obtained from the literature during or subsequent to SIVVA analysis for each species. Such information included specific geographic range, proportion of known or modeled habitat likely to be inundated by 1 m of SLR, life history characteristics, habitat affiliation, existing captive propagation or translocation programs for the species, and other species-specific information relevant to scoring each adaptation option by species. Although scores were assigned species by species, groups of species (which might be called management or adaptation guilds) emerged that could be addressed by the same adaptation strategy (i.e., combination of options). We also identified species for which knowledge of their distribution and biology are so limited that scores could not be assigned with confidence.

Reed Noss and Josh Reece jointly scored all 236 species based on a review of the available literature and other data and discussion of the appropriateness of different adaptation options for each species. The six adaptation options we considered are reviewed below. These options are usually not mutually exclusive, with some combination of options being appropriate for enhancing persistence of most species in the face of SLR and interacting threats.

Option 1: Protect and manage existing habitat for as long as possible, including natural vegetation buffers to SLR and storm surge (coral reefs, oyster reefs, salt marshes, mangroves).— We assessed this option both over the short term ($\leq$ year 2050) and the long-term ($\geq$ year 2100). For many species, protection and management (e.g., prescribed fire, control of invasives) of the current habitat is an appropriate and favorable option, at least in the short term. Because most of the species in our priority list have low-lying, near-coastal distributions, the suitability of this option diminishes rapidly over time, with few species showing higher than a low suitability/feasibility/probability of success past the year 2100, given a 1 m projection of SLR. Nevertheless, habitat protection and management is a “no regrets” action that will benefit numerous species and provide ecosystem services to humans in the interim. The additional action of protecting, creating, and restoring coastal ecosystems that provide natural buffers against SLR and storm surge is an “ecological engineering” approach that is usually far preferable to traditional engineering approaches (e.g., sea walls and dikes), especially for stretches of coastline where urban development is not already directly on the coast (Cheong et al. 2013, Duarte et al. 2013, Temmerman et al. 2013).

Option 2: Protect and manage projected future (recipient) habitat.—This option is appropriate for those species for which inland "migration" of their habitat is possible as the sea rises, or where potentially suitable habitat exists at inland locations on the other side of an anthropogenic barrier. This potential recipient habitat must be identified, protected, and managed appropriately to allow potential natural dispersal or managed relocation of populations to this new habitat.

Option 3: Protect and manage existing corridors to projected future (recipient) habitat.—This option can be pursued jointly with Option 2 in cases where a natural corridor links current habitat with projected future habitat. Its suitability would be limited to cases where the species possesses an inherent dispersal capacity that would allow it to reach the recipient habitat without human assistance.

Option 4: Restore/create corridors to recipient habitat (including wildlife crossings/ecopassages).—This option can be pursued jointly with Option 2 in cases where natural corridors between existing and projected future habitat never existed or have been destroyed. Like Option 3, the suitability of this option would be limited to cases where the species possesses an inherent dispersal capacity that would allow it to reach the recipient habitat, but in this case human assistance is required in the form of habitat restoration within the corridor or construction of wildlife crossings under or over roads or other linear anthropogenic barriers. Corridor habitat may have to be managed (e.g., with prescribed fire) in perpetuity.

Option 5: Provide assisted colonization (managed relocation) to recipient habitat.—Option 5 differs from the previous two options in that, although recipient habitat exists or could be created or restored through management, barriers to dispersal between current and potential recipient habitat are deemed insurmountable or, alternately, the species in question has a very limited dispersal capacity and would not be able to travel to recipient habitat on its own. Although assisted colonization is controversial and vigorously debated among conservation biologists (e.g., Hoegh-Guldberg et al. 2008, Ricciardi and Simberloff 2009), the debate has centered on translocation scenarios of considerable geographic distances in response to projected (and relatively uncertain) changes in temperature, and to regions where the species in question usually has not been documented to occur in the past and where it might behave as an invasive exotic.

In the case of SLR, the probability of inundation within the relatively near future is quite high for many of the species we considered. Additionally, the distances required for translocation are generally short (a few miles to a few dozen miles), the species in many cases have probably existed in these areas during past high sea-level stands, and the probability that the species will behave as an invasive exotic or will create undesirable genetic changes through hybridization with close relatives is low. This said, we do not recommend assisted colonization of island endemics to mainland Florida, where they probably never existed in the past, where they have low probability of survival, or where hybridization/introgression with close relatives is likely.

Option 6: Provide ex situ conservation in zoos, aquaria, botanical gardens, seed and gene banks.—

When none of the Options 1 through 5 are appropriate or likely to succeed, or as an insurance action even if some other options may succeed, then ex situ conservation is called for. For most island endemics in low-lying habitats, long-term captivity or preservation of seeds or tissues in seed or gene banks is the only potential alternative to extinction. Whenever it is feasible, we suggest that ex situ conservation is a superior option to extinction, for evolutionary (i.e., preservation of genetic material and adaptations), educational, and ethical reasons, even in cases where reintroduction into the wild is unlikely to succeed within the foreseeable future.

Finally, we conducted summary analyses by natural community and geographic region of Florida for the ability/inability of species to migrate inland or poleward in response to rising sea-levels, or feasibility of managed relocation for species that might not be able to move but could potentially be moved to suitable habitat further inland. Species were considered able to migrate when the following conditions were met: 1) defending current habitat was untenable by 2100, 2) potential habitat outside of its current distribution either existed or has a high probability of being created (e.g., as predicted by SLAMM model results), and 3) assisted colonization was tenable given the organism's life history. Species were considered unable to migrate inland when 1) current habitat was not likely to persist into 2100 (due to sea-level rise, climate change, or land-use change), and either 2) future habitat was not likely to be created or 3) assisted colonization was untenable. Lastly, species were considered candidates for managed relocation when they were deemed unable to migrate inland, but suitable habitat existed or was likely to exist outside of their current range and the species was amenable to managed relocation (i.e., previous attempts at translocations have been successful).

Impact Assessments: Ecological Connectivity

There are three elements of ecological connectivity analysis in this report: 1) Identification of opportunity areas for facilitating inland retreat from current coastal natural communities to areas up to 3m above sea level through intact or relatively intact landscapes throughout the state; 2) Examples of current coastal species heavily threatened by sea-level rise that have either apparently good or poor opportunities to migrate inland based on current available habitat and intact landscapes leading inland; 3) Identification of major south to north corridors impacted by either sea-level rise or projected new human development, and options for modifying the Florida Ecological Greenways Network to address these threats where relevant; and 4) An additional analysis relevant to ecological connectivity was also conducted, which was an overlay assessment of potential impacts from a 1m sea-level rise to Florida Forever Board of Trustees projects and existing Florida Managed Lands.

1) Identification of Coastal to Inland Retreat Opportunities.—This analysis identifies the areas of intact or relatively intact landscape across the state that could potentially facilitate retreat of coastal species from current coastal habitat landward to future coastal habitat. This analysis is necessarily broad and landscape based; it combines both estuarine natural communities and specific coastal upland types (such as maritime hammocks) and then uses an ESRI ArcGIS cost distance based approach to identify potentially functional swaths of intact landscape from coastal natural communities to areas up to 5km beyond a 3m sea-level rise project. The steps in the process included:

- Identified all areas in Florida within 5 kilometers upland of a 3 meter sea-level rise projection based on our hybrid DEM data.
- Identified estuarine wetlands and coastal natural communities using CLC v2.3 landcover/land use data.
- Used the CLC v2.3 data from FNAI to identify all natural and semi-natural land use including all natural communities, forest plantations, unimproved pastures/rangelands, and improved pastures.
- Identified all areas of well connected natural and semi-natural land (including improved pasture) that also had Critical Lands and Water Identification Project (CLIP) Land-use Intensity (Land-use Intensity is one of the two indices used to create the CLIP Landscape Integrity dataset) values of 5 or higher (i.e., more intact landscapes with less influence from intensive human activities and fragmentation), which were also connected to the identified coastal natural communities and up to five kilometers beyond the 3 meter sea-level rise projection.

After identifying these landscape areas potentially capable of facilitating inland retreat, we further characterized them in several ways to facilitate their use in assessing potential inland retreat opportunities. These steps included: 1) we identified areas of coastal to inland connectivity that were or were not connected to the Florida Ecological Greenways Network; 2) we developed a GIS layer that separates these coastal to inland connectivity areas into projected sea-level rise increments of 0.5m up to 3m to assist identification of opportunity areas that allow for a wider range of elevational adaptation; 3) we developed a GIS layer that identifies the maximum elevation that each opportunity area patch reaches (up to 3 meters); 4) we developed a GIS layer that identifies the average elevation of each opportunity area patch, based on the assumption that patches with higher average elevations generally provide better inland retreat options than those with lower averages.

2) Examples of coastal species with inland retreat opportunity.— We selected two species significantly threatened by sea-level rise to serve as examples of species with both potentially good and poor opportunities for coastal to inland retreat from sea-level rise. The two species selected were Florida salt marsh vole (*Microtus pennsylvanicus dukecampbelli*) and Atlantic saltmarsh snake (*Nerodia clarkii taeniata*). We adapted the average elevation of coastal to inland retreat opportunity areas data layer described above in the previous section to create maps depicting potential inland retreat opportunity for each species.

3) Identification of threats to statewide wildlife corridor priorities from sea-level rise and projected future urban development.—We assessed the potential threat of both sea-level rise and potential future urban development on the new version of the Florida Ecological Greenways Network (FEGN) completed in July 2013 in coordination with this project (a full description of the FEGN update and data are provided in the final report for State Wildlife Grant project number 10066). This assessment included both comparison of the new FEGN base boundary and the higher FEGN priorities (Priorities 1-3) to sea-level rise projections and the "SLR 2" 1 meter sea-level rise development scenario created by Paul Zwick and Peggy Carr for this project. The methods and results for this assessment are included in *Appendix 7-FEGN Update Corridor Prioritization Options*.

4) Impact assessment of threats to Florida Forever Board of Trustees Projects and Florida Managed Areas.—We assessed the potential threat from a 1m sea-level rise to both Florida Forever Board of Trustees projects and existing Florida Managed Areas (FLMA). To do this, we clipped the existing FLMA and Florida Forever datasets so that only terrestrial areas were included (since some of these properties also included areas that are currently submerged). We then calculated the area of overlap between our tidally adjusted 1m sea-level rise scenario, and FLMA and Florida Forever properties, both in terms of acreage and percent inundated.

Education and Outreach

We have three education and outreach initiatives. First, our talks to the public and to our scientific peers and collaborators in land management represent one avenue of outreach. Second, Dr. Pamela Pannozzo, who recently obtained her PhD under the advisement of Reed Noss, worked with Dr. Noss to develop a Florida Counties Conservation Planning Survey, in which county planners were asked questions related to planning within their counties that is related to biodiversity conservation. The survey was specifically designed to inform statewide conservation planning and adaptation to land-use change, climate change, and sea-level rise.

Dr. Pannozzo was ideally suited to carry out this work, as her previous education includes a law degree and a master's degree in wildlife ecology and conservation. The survey methodology, results, and discussion are included in the report in *Appendix 10- Survey of Florida Counties*.

Third, we developed a set of high school-level labs with multimedia content that are freely available to teachers and that are coordinated with the next generation standards on which teachers must base their lesson plans. Education materials were developed in collaboration with local high school biology teachers, were field tested in local classrooms, and reviewed by the Florida Sea Grant sea-level rise coordinator. A deliverable from this project was a video on the topic of sea-level rise in Florida: https://www.youtube.com/watch?v=xGP8JbvWUWw.

RESULTS

Impact Assessment Results: Natural Communities

Summary.— Results of Natural Community overlays with SLAMM, DEM, and land-use change projections are detailed in *Appendix 8d- Habitat and Natural Community Model Overlay Analysis,* and are also summarized below.

SLAMM Results.— SLAMM modeling provides projections not only of habitat loss to inundation, but shifts from one natural community type to another due to changes in salinity, hydrology, etc. resulting from sea-level rise. Table 8d-1 in *Appendix 8d- Habitat and Natural Community Model Overlay Analysis* shows changes in area for SLAMM land cover types from Initial Condition (present sea level) through 2 meters of sea-level rise. Those changes are summarized in **Figure 2** below. SLAMM modeling projects a significant influx of estuarine open water, along with increases of tidal flat and salt marsh. Losses are seen in developed and undeveloped uplands, swamp, and possibly mangrove (much of the mangrove extent in Florida is outside the SLAMM study area).

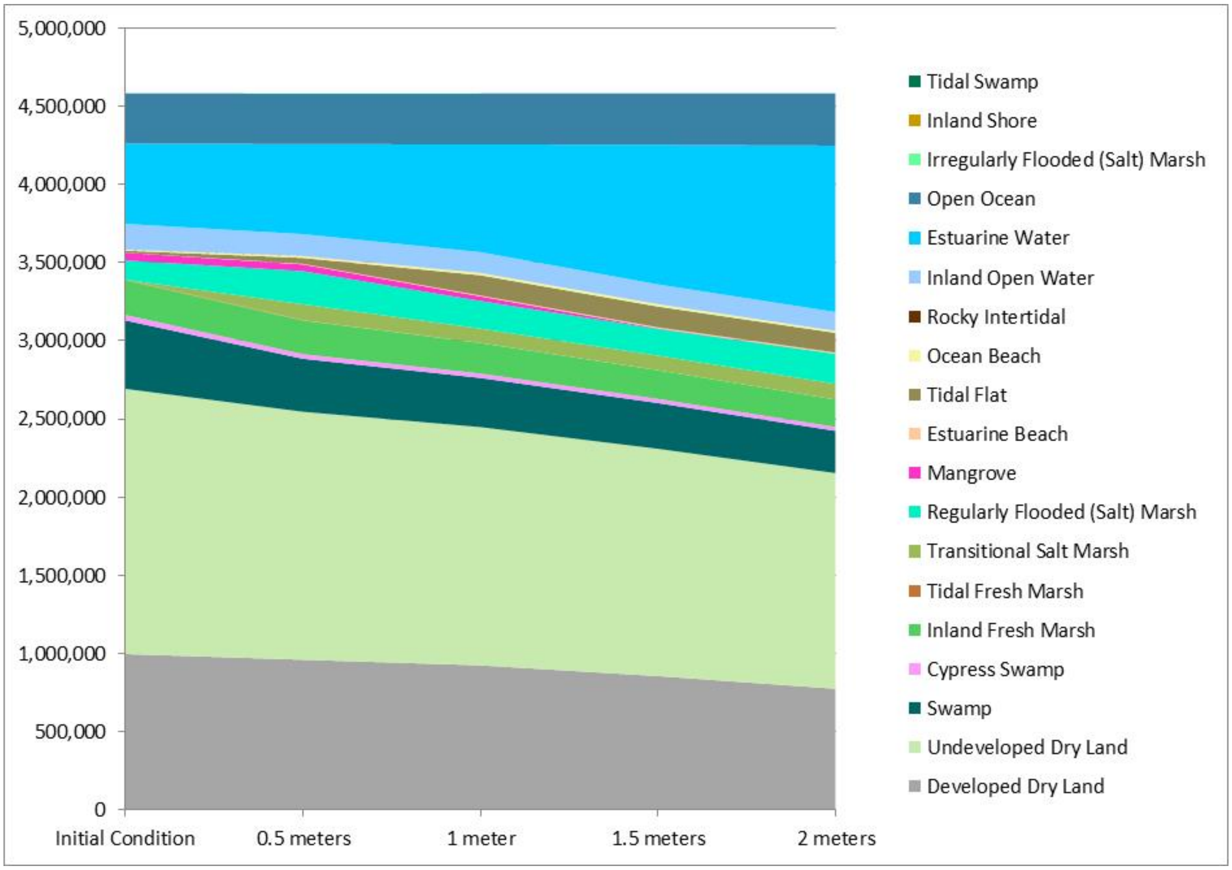


Figure 2. SLAMM-Projected Land Cover Changes with Increasing Sea Level. The Y-axis is hectares of geographic extent.

SLAMM vs. DEM Comparison.— This study offers the ability to compare differences between a "bathtub"-style sea-level rise projection and the SLAMM approach of modeling changes to coastal communities. Table 8d-2 in *Appendix 8d- Habitat and Natural Community Model Overlay Analysis* summarizes impacts to natural communities for each sea-level rise scenario, and lists the difference in percent-impact between SLAMM and DEM projections for each natural community. Blue shading indicates at least 10% difference in favor of DEM models, while orange indicates at least 10% difference in favor of SLAMM models. In general, the DEM bathtub models tend to show slightly higher impacts than SLAMM projections. This may be due in part to the fact that the LiDAR-based DEM data indicates substantial areas of coastal wetlands as at or below sea level, while they are still classed as terrestrial communities by SLAMM (depending on definitions, they are functionally both). DEM models also tend to show greater area inundated than SLAMM at a given level of sea-level rise, which may be due to factors such as differences in spatial resolution (120 meters for SLAMM vs. 15 meters for DEM), or SLAMM input parameters (including possible differences in tidal corrections).

For the most part, however, SLAMM and DEM projected impacts to natural communities are within 10 percentage points of each other. Nearly all of the differences greater than 10% can be explained by communities that are not fully covered by the SLAMM study area (pink shading in Table 8d-2; SLAMM was not available for the Florida Keys and most of the Everglades). The following communities illustrate meaningful differences between SLAMM and DEM:

Maritime hammock. – In this case, SLAMM modeling shows greater loss than DEM projections. SLAMM indicates that, while maritime hammock may not be inundated by ocean, the changes to sea level will cause other communities (likely salt marsh and mangrove in most cases) to shift into areas currently occupied by maritime hammock.

Coastal interdunal swale. – This appears to be an example where the DEM is indicating areas inundated that could be still functioning as wetlands, or simply following the pattern that the DEM is identifying more area as inundated overall.

Coastal dune lake.– SLAMM is showing greater impact, particularly at 1.5 meters of sea-level rise. SLAMM indicates these primarily-freshwater lakes are being connected with the sea sooner than DEM models do, which could be a factor of the differences in spatial resolution.

Coastal hydric hammock. – DEM is showing greater inundation in these areas, which is most likely attributable to the overall higher levels of inundation in DEM projections.

Natural Community Impacts.— Table 8d-3 in *Appendix 8d- Habitat and Natural Community Model Overlay Analysis* summarizes impacts to focal natural communities in the 1-m sea-level rise scenarios. For communities mapped comprehensively across the state, five show a loss of at least 50% of their current extent based on either SLAMM or DEM projections: coastal interdunal swale, mangrove swamp, coastal berm, saltwater marsh, keys tidal rock barren, and maritime hammock. Of those, salt marsh may be misleading, as SLAMM projects an inland shift and moderate expansion of salt marsh (as noted above). The percentage loss of mangrove may be even higher if the extensive mangroves along Florida Bay were included in the SLAMM analysis (they were not, for reasons explained earlier). Additional communities mapped in limited sites show significant impacts, including coastal rockland lake, keys cactus barren, and coastal hydric hammock. However, we noted a significant reduction in the ability of SLAMM to accurately model the impacts of SLR in South Florida. In the cases where a natural community was restricted to South Florida and/or a significant portion of the extent of that natural community was restricted to South Florida, tidally-adjusted DEM models of SLR inundation were used for both the direct estimates of SLR and for the joint sea-level rise and land-use change analyses.

The results of our SIVVA-NatCom analyses will be used by land managers at the FWC to guide conservation efforts. We evaluated all natural communities tracked by FNAI (and cross-walked with FWC and legacy natural community names) that had some exposure to SLR, although in some cases natural communities of limited extent were grouped with similar communities and assessed jointly. **Figure 3** lists the 30 natural communities with exposure to SLR inundation. Of these 30, we focused our analyses on the twelve natural communities for which upwards of 10% of their geographic extent was modelled to be lost under the joint impacts of sea-level rise and land-use change **(Figure 3)**. It is important to note that some coastal communities, notably mangrove swamp, did not make this cutoff. While counter-intuitive due to the proximity of this natural community to rising sea-levels, the low loss of its projected extent can be explained by the evidence that mangrove swamps appear able to migrate inland with SLR of 1 m by 2100, even when coupled with modeled land-use change.

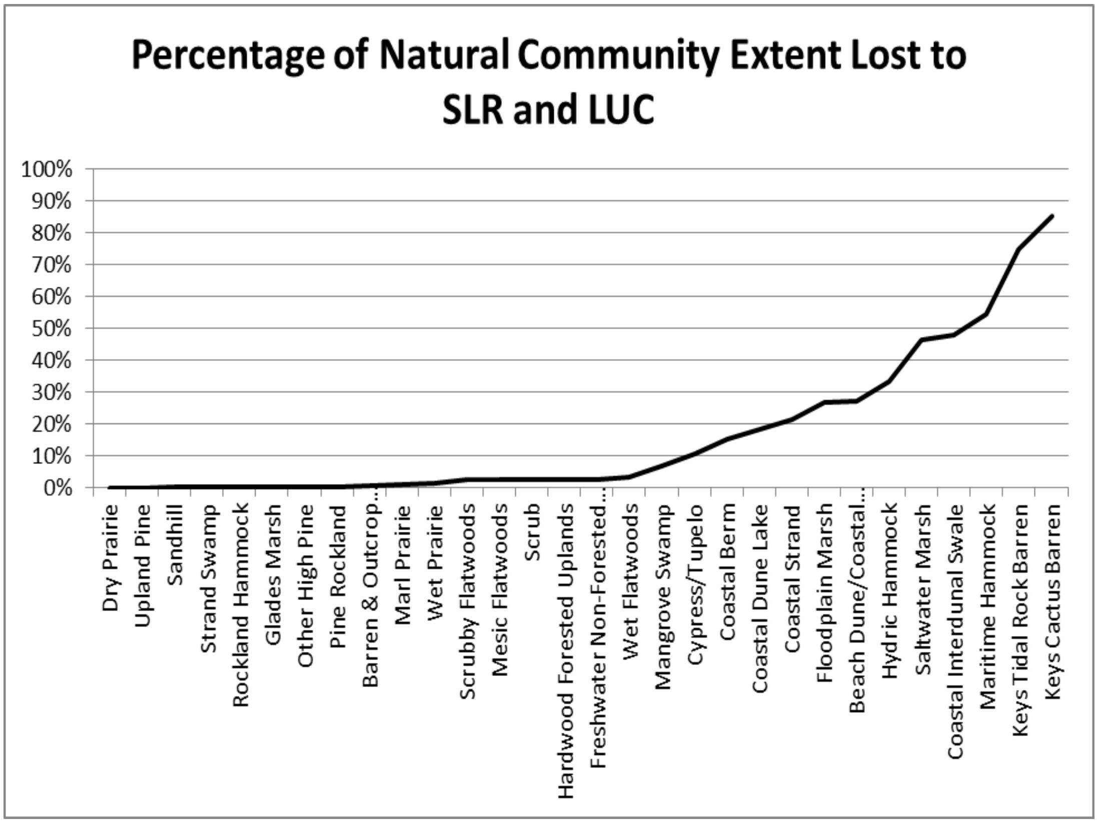


Figure 3. This figure depicts the percentage of natural community extent that is projected to be lost to the combined impacts of sea-level rise (SLR) and land-use change (LUC) for 30 natural communities in Florida.

Prioritizations for all 30 natural communities are given in **Figure 4**, listed from highest to lowest priority with the contribution of each module to the total prioritization score denoted.

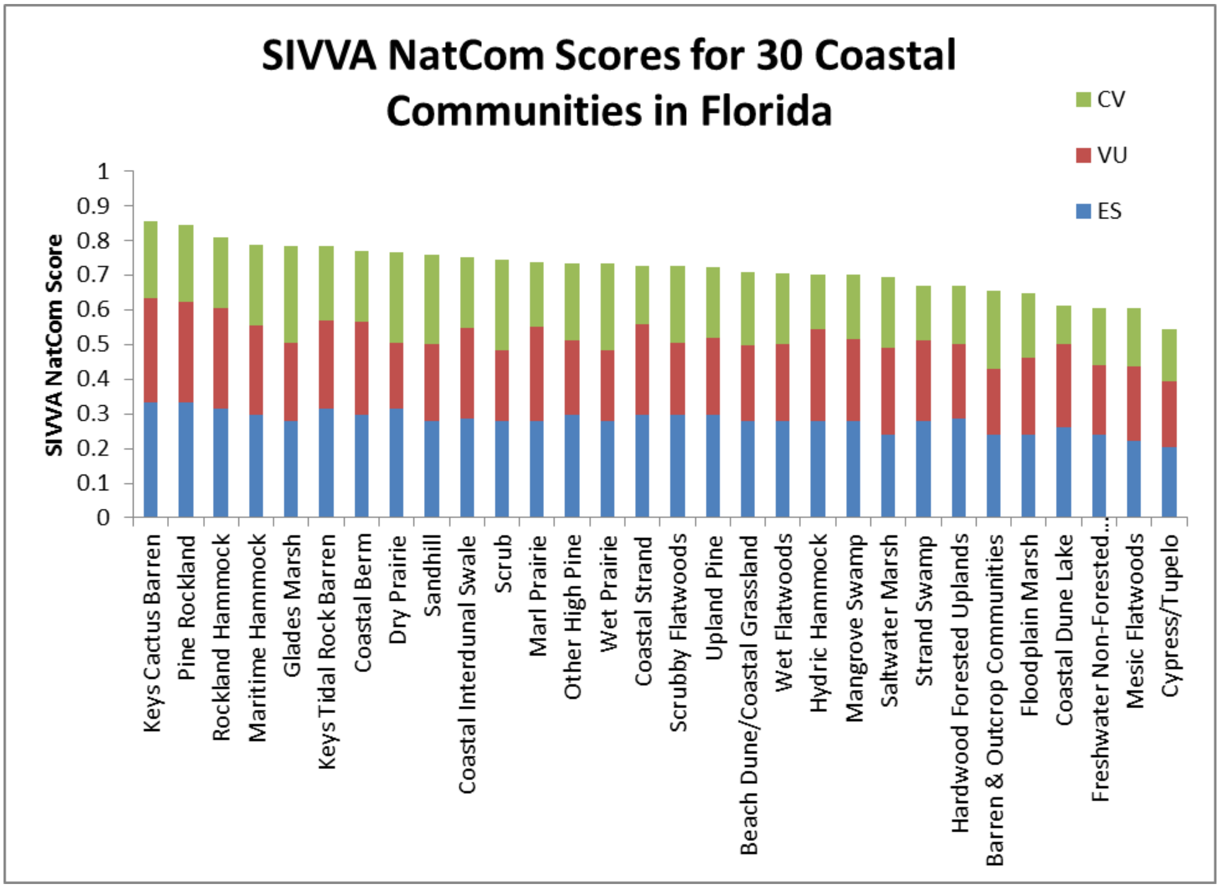


Figure 4. SIVVA for Natural Communities (SIVVA-NatCom) scores (ranging from 0 to 1 as a proportion of maximum risk/value) for 30 coastal natural communities in Florida. Communities are ordered from overall highest scores, but note that species with the highest overall score may not be those with the greatest scores for Vulnerability (blue), Ecosystem Status (red), or Conservation Value (green).

Interestingly, existing prioritizations for natural communities, such as Conservation Status Assessment S-scores (statewide extent) are correlated with SIVVA-NatCom scores for Ecosystem Status (P-value = 0.002, R^2 = 0.34), but are not correlated with Vulnerability Scores (P-value = 0.28, R^2 = 0.05). This suggests that current strategies focus on the rarity (i.e., limited distribution or area) or function of ecosystems as they are now, and not on sea-level rise and other threats facing natural communities today and in the future. SIVVA-NatCom addresses this issue by assessing both current and future threats. However, the overall correlation between CSA S-scores for natural communities and overall SIVVA scores (for all three modules combined), is fairly strong (P-value = 0.02, R^2 = 0.20). As an example of consistency between the overall SIVVA-NatCom score and the CSA S-score, all three of the S1-ranked natural communities we evaluated score high in our system, and two of them are among the most highly ranked overall (Pine Rockland and Keys Cactus Barren) (**Figures 5 and 6**).

Figure 5. Keys Cactus Barren (G1/S1) on Crawl Key (Valhalla). Characteristic plants seen in this photograph are false cissal (*Agave decipiens*) and erect pricklypear (*Opuntia stricta*).

Figure 6. Pine rocklands (G1/S1) on Big Pine Key. Note abundant exposed limestone.

Impact Assessment Results: Focal Species

Results of species habitat model overlays with SLAMM, DEM, and land-use change projections are detailed in *Appendix 8d- Habitat and Natural Community Model Overlay Analysis.* In *Appendix 8d*, Table 8d-4 summarizes impacts to species habitat for the 1-meter sea-level rise scenarios. Thirty-six of the FNAIHAB species models, and 14 FWC models, showed 50% or greater loss in either SLAMM or DEM scenarios. Five FNAIHAB species showed greater than 90% loss. Additional details on the SIVVA analyses of focal species are summarized in *Appendix 1d- A vulnerability Assessment of 300 Species in Florida*.

Predictive distribution modeling.—

The regional climate model projections for 2050 covered a large part of the southeastern United States (though excluded the Florida Keys). We analyzed how suitable climate area for the 50 species changed within this area. For 3/50 species in the present time period, and 10/50 species in the 2050 time period, no suitable climate area (SCA) existed in this region. Twentyone species experienced a reduction in SCA (eight of which were 100% loss), four showed no change, and 25 showed an increase (nine of which at least doubled their SCA). On average, species maintained 50% of their 2000 SCA in the 2050 time period (nine species retained 0%).

We overlaid SCA for all 50 species to identify "hotspots" where many species share suitable climate. For the 2000 period, SCA is concentrated in the Florida peninsula, with peak overlap in southern Florida (27 species). In 2050, SCA for this group of threatened species is concentrated in coastal areas, with hotspots on the Gulf Coast of Florida and the Georgia and South Carolina coasts, with a peak overlap of 24 species (**Figure 7**). Most notably, southern Florida becomes less climatically suitable for a large number of species.

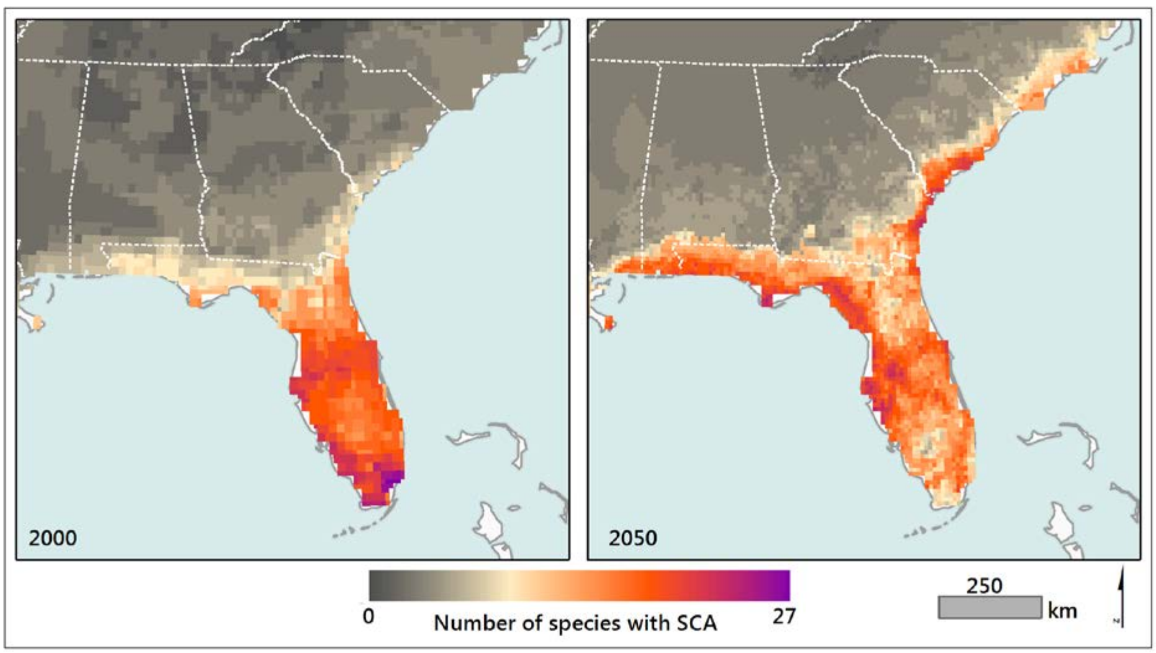


Figure 7. Overlap of suitable climate area (SCA) for all 50 species in the predictive distribution modeling component of this study (Appendix 8b). We also calculated the geographical displacement of the center of each species suitable climate area from 2000 to 2050, as an estimate of how species' ranges might shift in the future. For the 39 species that had SCA in both time periods, we calculated the distance and orientation of the shift. Shifts ranged from zero (no change; three species) to 476 km, with a mean of 113 km. Twenty-five of these shifts were primarily in a northerly direction, three in a southerly direction, and the remaining eight shifted westward (**Figure 8**). Across all species, the linear directional mean shift trended to the northwest, moving from central Polk County, FL to central Citrus County, FL.

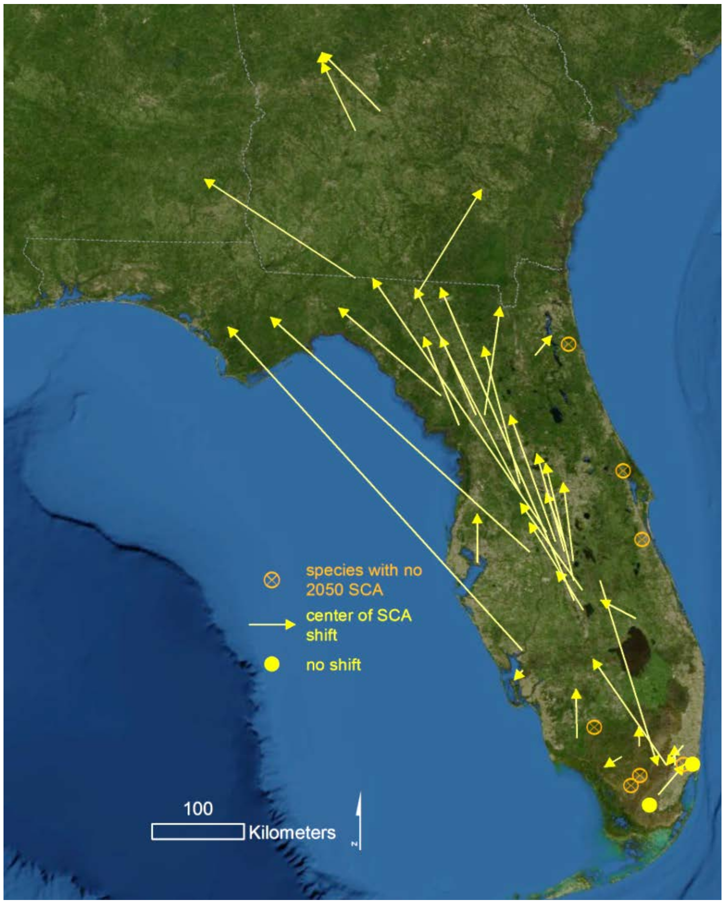


Figure 8. Shifts of species' centers of suitable climate area (SCA), 2000 to 2050.

Adaptation option results.—

The majority of the 236 species for which we evaluated adaptation options were restricted to South Florida and/or the Florida Keys (65%). Of these, 22% were endemic to South Florida and/or the Florida Keys. **Figure 9** shows that most of these species, which are extremely vulnerable to inundation from SLR, are unable to relocate further inland. This problem is much less severe in the Panhandle/Big Bend region of Florida (**Figure 9**). When viewed by ecosystem type (**Figure 10**), the best adaptation option for most natural communities is to protect their current distribution, although the potential success of this option diminishes for all ecosystems surveyed by 2100. For many natural communities, especially those restricted to the Florida Keys and extreme South Florida, maintaining captive populations of their characteristic species is the only adaptation option likely to prevent extinction (**Figure 10**).

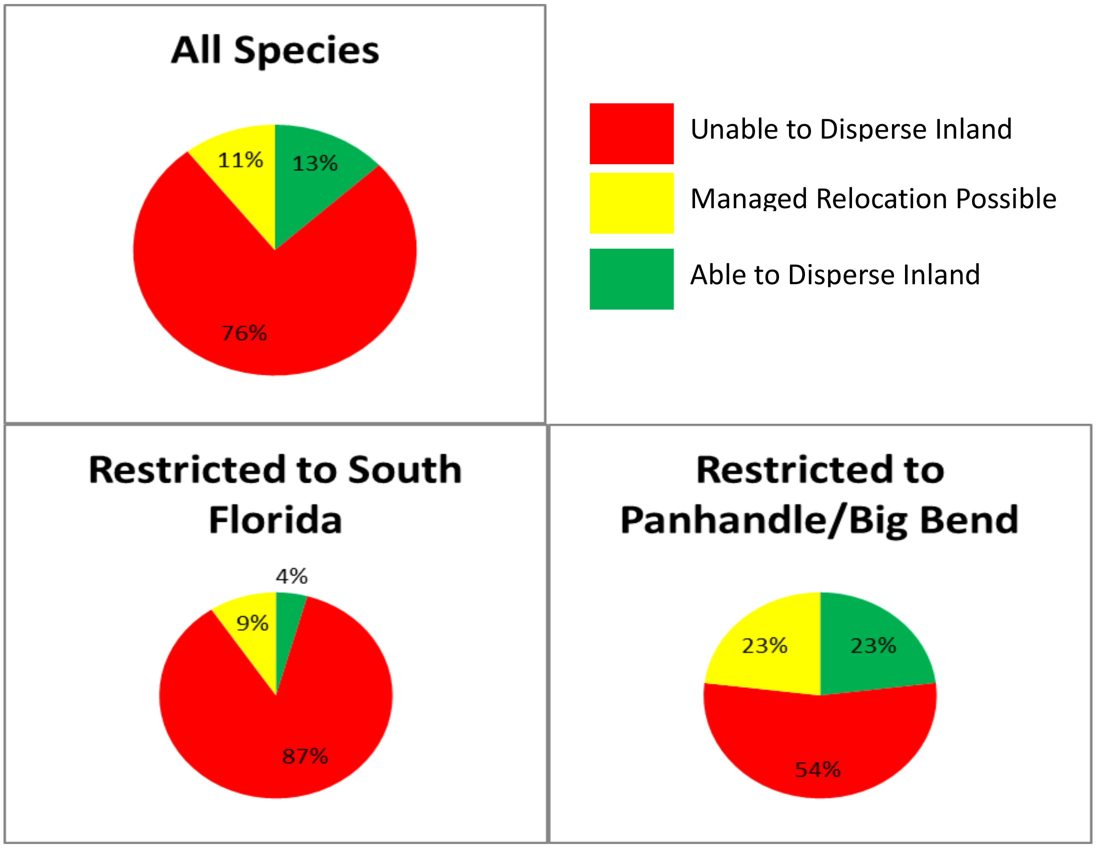


Figure 9. These pie charts depict the ability of species to move or be moved (managed relocation) according to our evaluation of adaptation options (see methods). Note that while overall, most species are unable to disperse inland, this response is much more prevalent in South Florida than it is in the Panhandle/Big Bend region.

Among the six adaptation options examined, option 1: Protect existing habitat for as long as possible, yielded the most consistently high score as being Good or Fair for nearly 50% of all species. Ranked in order of mean score, overall the best adaptation options were to protect existing habitat (for both the 2050 and 2100 timeframe), to protect future habitat, ex situ conservation, managed reloaction, protect existing corridors, and lastly, restore or create corridors. This is somewhat surprising, because it suggests that the best options for preventing the extintion of most species, especially those in South Florida, is to protect their existing habitat for as long as possible and then to bring them into captive populations, both of which are controversial as the former is admittedly short-sighted and the later is expensive and removes the species from the natural environment.

Overall, our evaluation of adaptation options serves two purposes. First, successful adaptation options are presented for 236 species. Second, general trends by ecosystem type, geographic area, and across all taxa, can serve to guide broad-scale conservation efforts.

Adaptation Options	Hardwood forested uplands	High pine scrub	Pine flatwoods and dry prairie	coastal strand	hammock, shell mound	sinkhole, limestone outcrop, keys cactus barren	wetlands	Freshwater forested wetlands	vegetated wetlands part I- salt marsh	vegetated wetlands part II- mangrove swamp	Rockland lakes	Ponds and lakes	Rivers and streams	Shallow intertidal
1 (2050)	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Marginal	Good	Good
1 (2100)	Marginal	Marginal	Poor	Marginal	Marginal	Poor	Marginal	Marginal	Poor	Marginal	Poor	Poor	Marginal	Marginal
2	Poor	Marginal	Poor	Marginal	Poor	Poor	Marginal	Marginal	Marginal	Marginal	Poor	Poor	Good	Good
3	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Marginal	Poor	Poor	Poor	Good	Marginal
4	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
5	Poor	Marginal	Poor	Poor	Marginal	Poor	Poor	Marginal	Poor	Poor	Poor	Poor	Marginal	Marginal
6	Good	Marginal	Good	Marginal	Good	Good	Marginal	Good	Good	Marginal	Good	Marginal	Good	Poor
Number of Species (3 unknown)	77	9	57	51	12	21	24	17	30	28	1	3	4	2

Figure 10. List of mean adaptation option assessment for all six adaptation options (option 1 was evaluated at both the 2050 and 2100 timeline) for 14 groups of natural communities. Groupings of natural communities followed the FNAI Natural Community Guide.

Impact Assessment Results: Ecological Connectivity Assessment

1) Identification of Coastal to Inland Retreat Opportunities.— The coastal to inland connectivity analysis identified large areas in the state still capable of supporting potential functional ecological connectivity between current coastal natural communities and intact to relatively intact land cover and landscapes to up to 5 km beyond an approximately a 3m sea-level rise projection (**Figure 11**). From a statewide perspective based on largest swaths of land, examples of the best opportunities include the Everglades (encompassing the Ten Thousand Islands and parts of Big Cypress Preserve), the Big Bend region (where the Florida peninsula joins the Panhandle), Cape Canaveral National Seashore and Merritt Island National Wildlife Refuge, and portions of northeast Florida. However, we emphasize that this analysis result is just as important for what is not included as for what is. Coastal natural communities and especially estuarine wetlands are common across Florida even in developed areas. Nevertheless, due to the extensive development of adjacent and nearby upland areas, many of these coastal natural communities are cut off from opportunities for inland retreat except for the possibility that some currently developed lands may be abandoned and reclaimed as sea-level rise progresses (though this would seem unlikely to occur at a scale relevant for significant shifts inland to address potential sea-level rise ranging from 1-3 m). Therefore, in general, it can be assumed that areas not included as potential coastal to inland retreat opportunities have been affected by habitat loss and fragmentation to the extent that any non-volant species within coastal natural communities in those areas have very poor to no opportunities for functional inland migration.

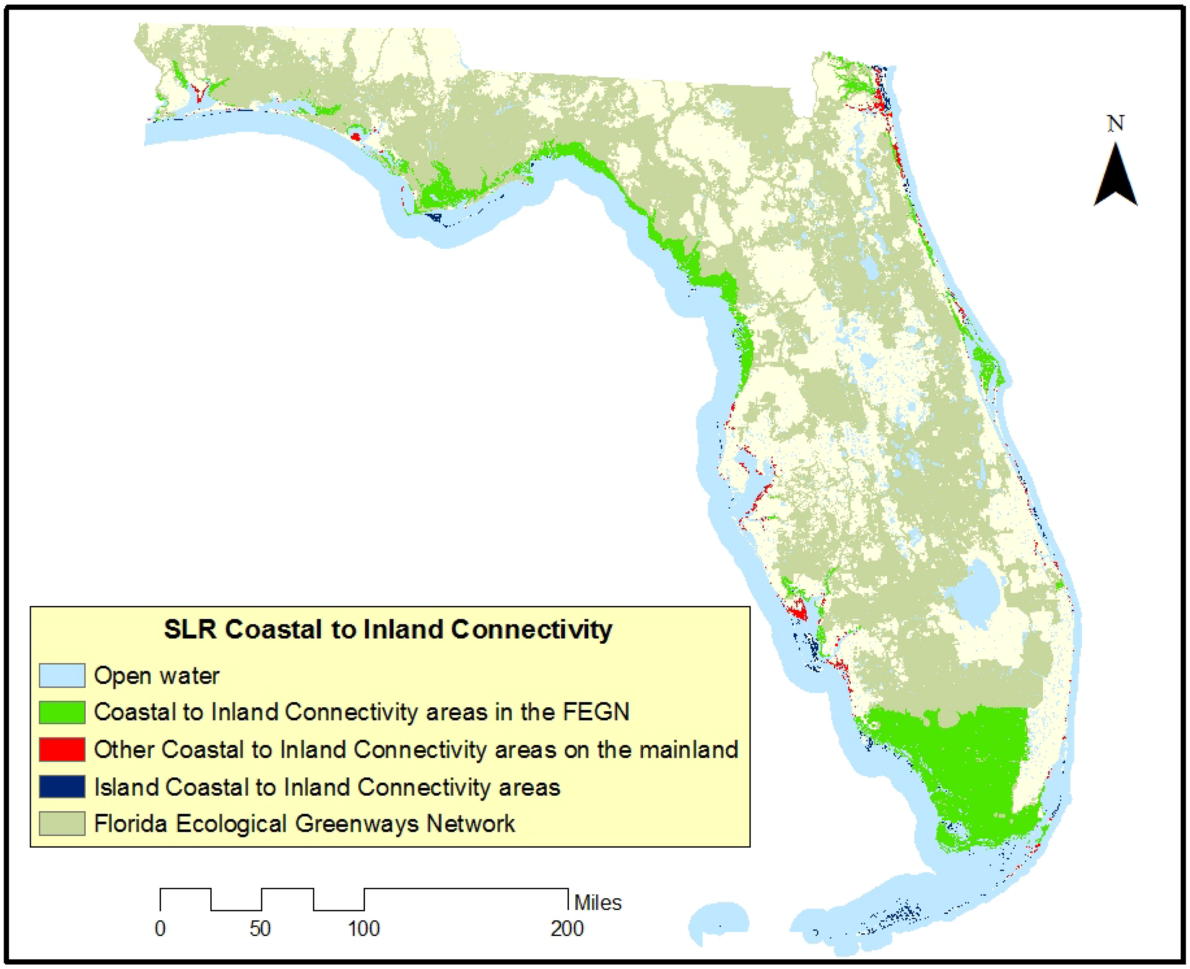


Figure 11. Areas of potential ecological connectivity from current coastal locations to areas inland with higher elevations. Areas in bright green are in mainland portions of the Florida Ecological Greenways Network (FEGN). These areas incorporate larger, intact, functionally connected swaths of land from current coastal natural communities that are likely the most significant opportunity areas for facilitating retreat/migration for a 3 meter sea-level rise projection or beyond. Areas in red are more limited coastal to inland connectivity areas on the mainland but not connected to the FEGN. These areas may be important for providing coastal to inland migration opportunities depending on location, focal species, and elevation gain, but they are also likely in closer proximity or at least partially isolated by intensive land uses. The dark blue areas are water edge to inland gradients on islands (or archipelagos) that likely provide only very limited opportunities for isolated inland migration within these islands only.

After identifying those landscape areas potentially capable of facilitating inland retreat, we further characterized them in several ways to facilitate their use in assessing potential inland retreat opportunities. First, we developed a GIS layer that separates these coastal to inland connectivity areas into projected sea-level rise increments of 0.5m up to 3m to assist identification of opportunity areas that allow for a wider range of elevational adaptation (**Figure 12**). Second, we developed a GIS layer that identifies the maximum elevation that each opportunity area patch reaches up to 3m (**Figure 13**). Most patches that can be discerned in a map at the statewide scale contain areas of up to 3m elevation, but there are also a number of smaller coastal areas included in this layer that have elevations of only 1m or slightly higher. Third, we developed a GIS layer that identifies the average elevation of each opportunity area patch, based on the assumption that patches with higher average elevations generally provide better inland retreat options than those with lower averages (**Figure 14**).

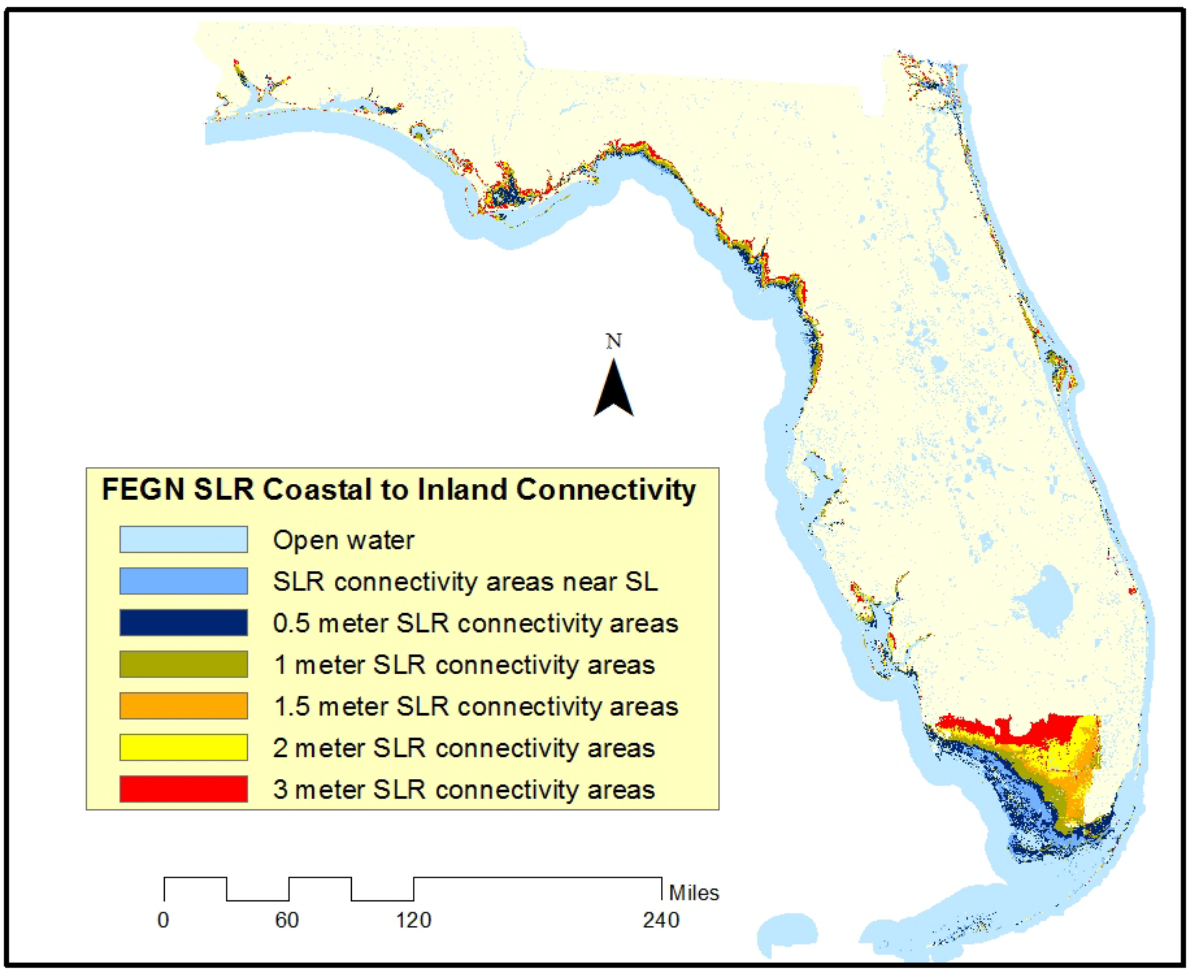


Figure 12. Areas of coastal to inland connectivity in a range of potential sea-level rise (elevations) from 0.5-3m. This layer and map is intended to provide more information on

potential coastal to inland retreat opportunities where in general areas including higher elevations (up to 5 km beyond 3m SLR) are considered to provide the best opportunities.

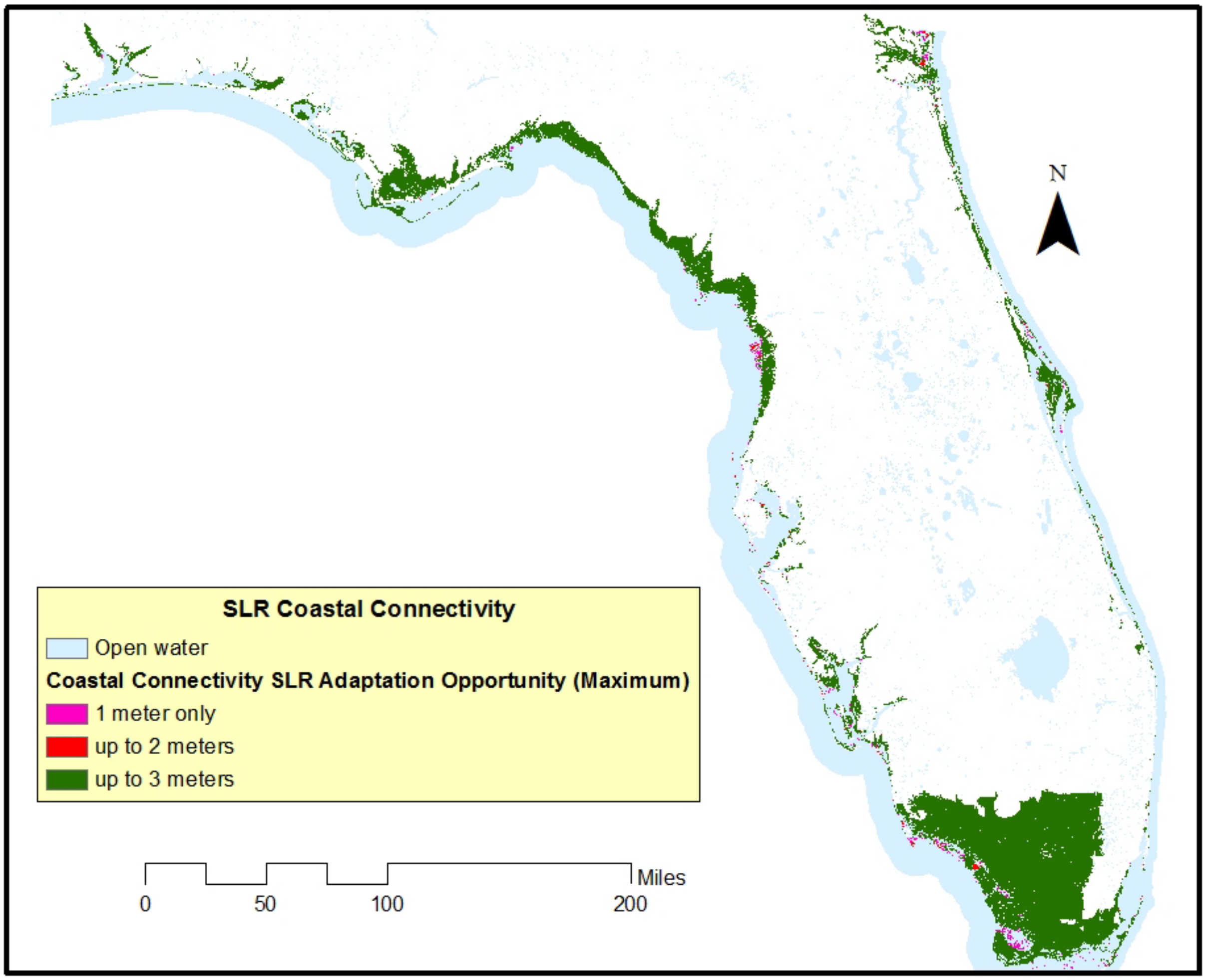


Figure 13. A GIS layer that identifies the maximum elevation that each opportunity area patch reaches up to 3m. Most patches that can be discerned in a statewide scale map contain areas up to 3m but there are a number of smaller coastal areas included in this layer that have elevations of only 1m or slightly higher.

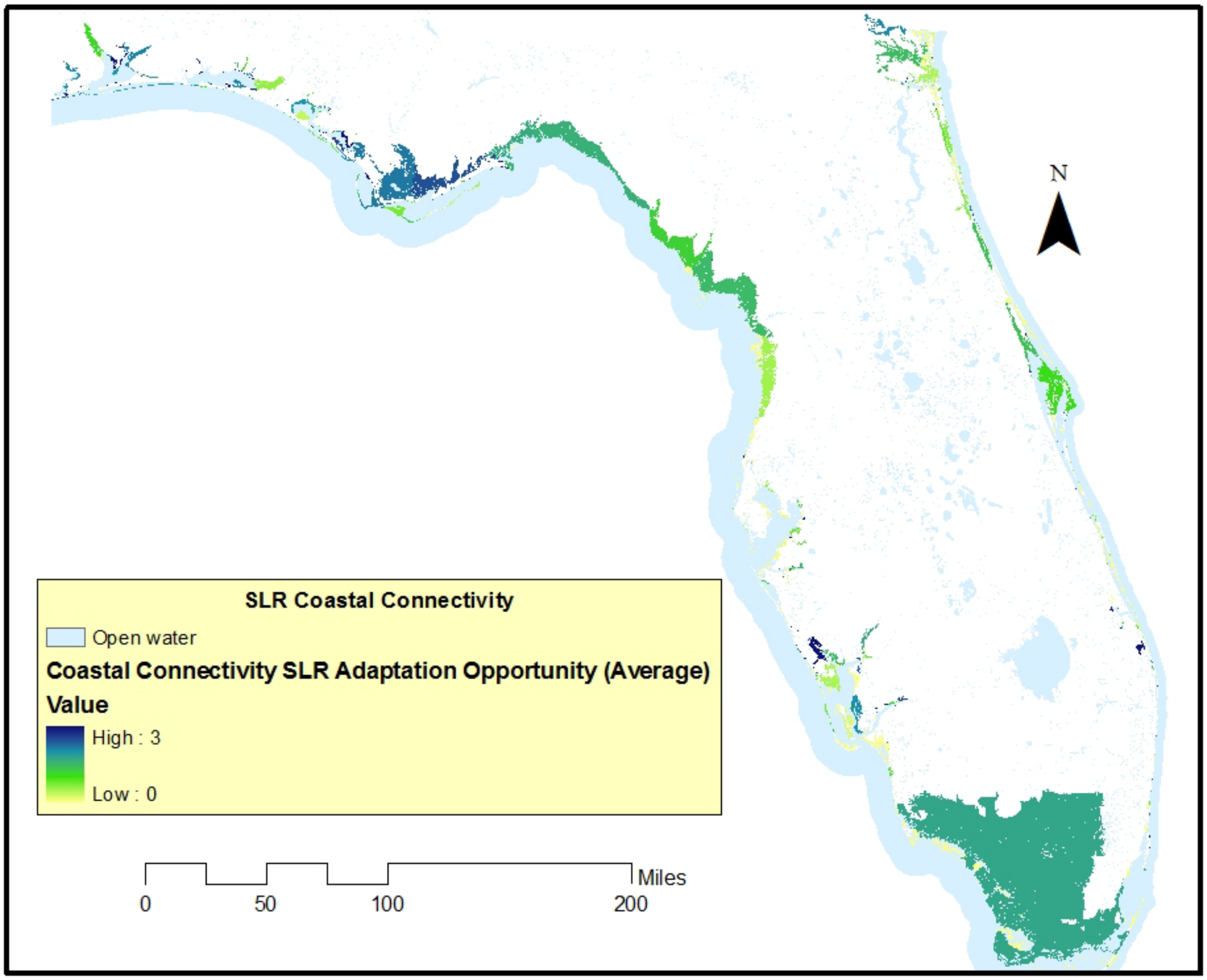


Figure 14. Average elevation of each opportunity area patch, based on the assumption that patches with higher average elevations generally provide better inland retreat options than those with lower averages.

2) Coastal species inland retreat opportunity examples.— We selected the Florida salt marsh vole and Atlantic saltmarsh snake to serve as examples of both potentially good and poor opportunities for coastal to inland retreat of coastal species significantly threatened by sea-level rise. We adapted the average elevation of coastal to inland retreat opportunity areas data layer described in the previous section to create maps depicting potential inland retreat opportunity for each species. To create these analysis layers, we calculated the average elevation of every distinct patch of identified habitat for each species using habitat models created by FNAI. We considered all patches with average elevation values below 1.5m to have little to no inland migration opportunity and patches with average elevations of 1.5m or higher to have good potential for inland migration. Based on these methods and results, it is clear that Florida salt marsh vole appears to have much better opportunities for potential inland retreat than the Atlantic saltmarsh snake (**Figures 15-16** and **Tables 2-3**).

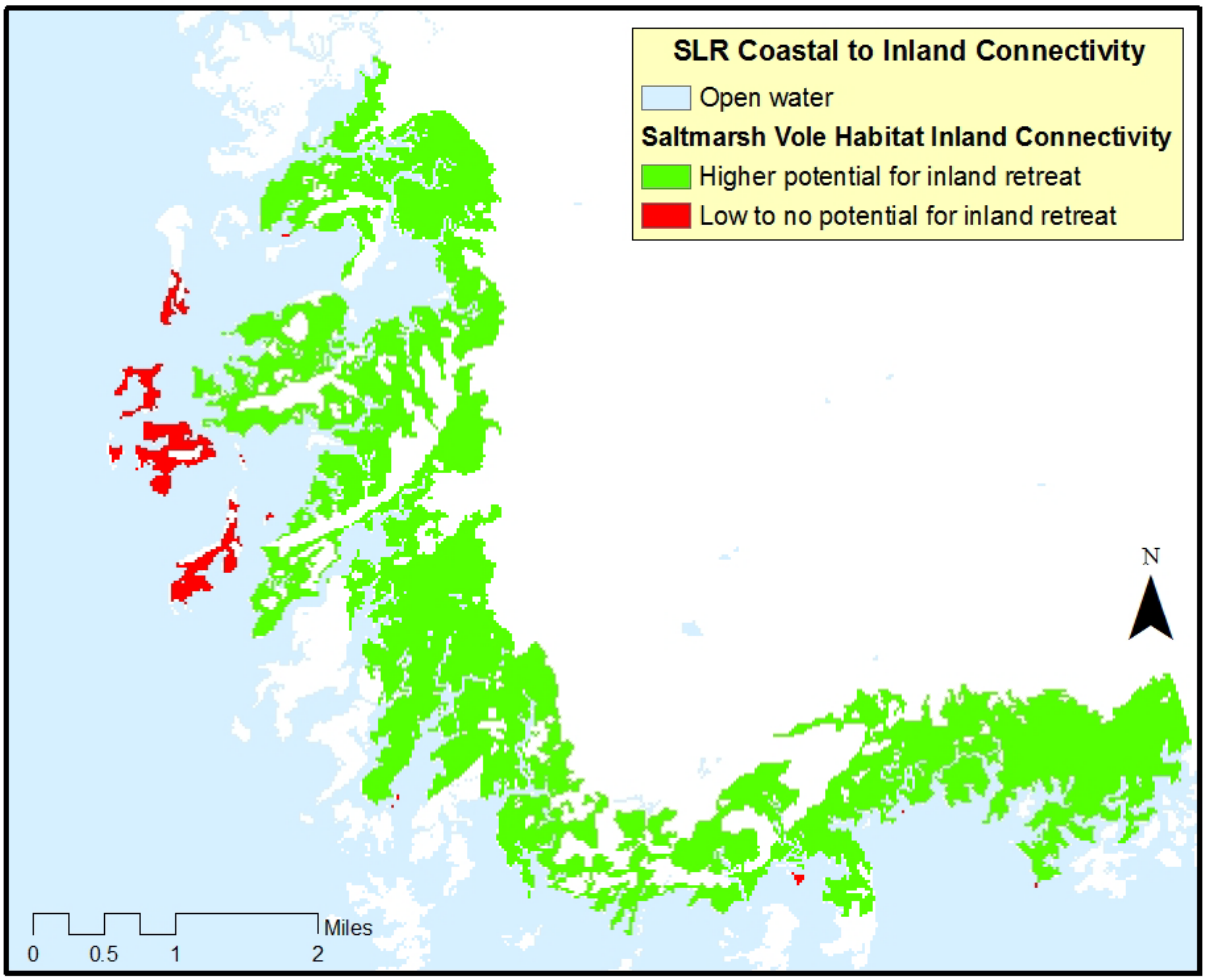


Figure 15. Inland retreat opportunity for salt marsh vole; habitat in green is considered to have higher potential for inland retreat, whereas habitat in red is considered low to no potential.

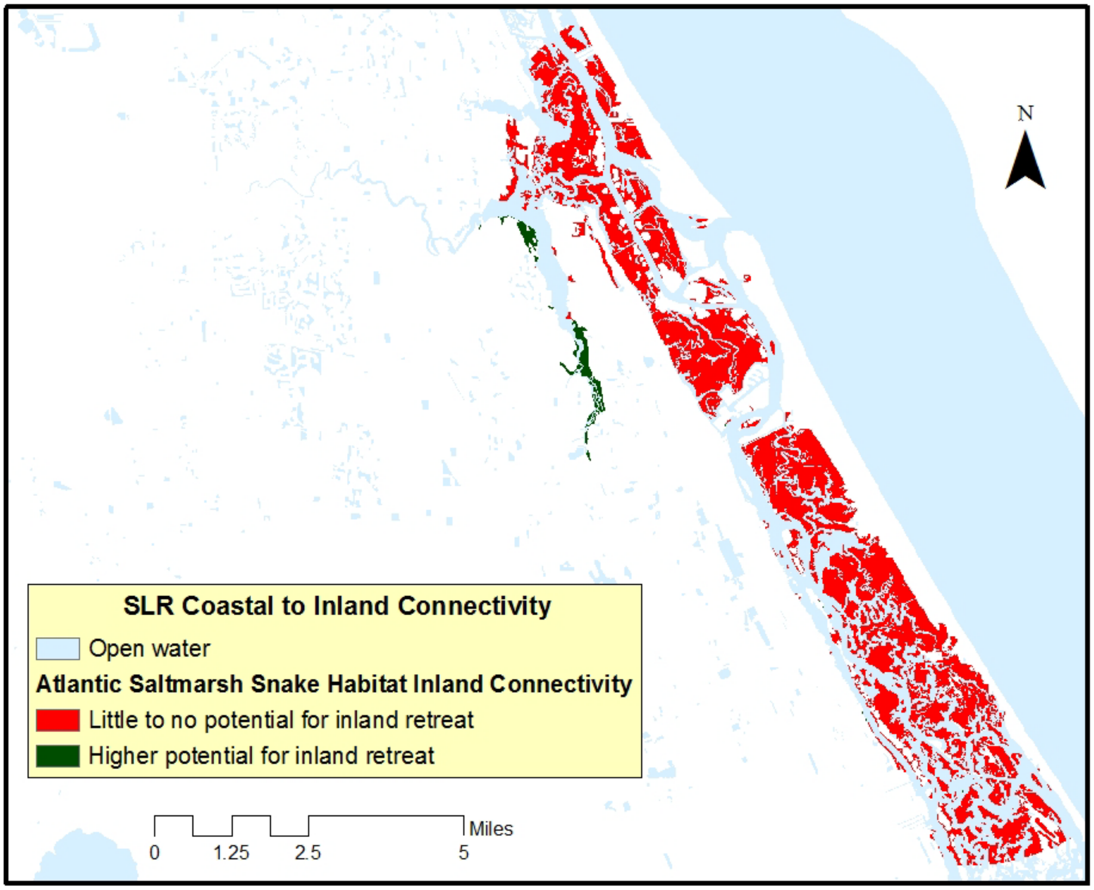


Figure 16. Inland retreat opportunity for Atlantic saltmarsh snake; habitat in green is considered to have higher potential for inland retreat, whereas habitat in red is considered low to no potential.

Table 2. Acres of salt marsh vole habitat in elevation average classes.

Average Elevation (meters)	Acres	Percent
1.0	187.4	4.0%
1.2	20.2	0.4%
1.5	4,701.5	99.6%

Table 3. Acres of Atlantic saltmarsh snake habitat in elevation average classes.

Average Elevation (meters)	Acres	Percent
1.0	6,630.7	86.23%
1.1	676.2	8.79%
1.2	154.7	2.01%
1.3	3.3	0.04%
1.5	222.4	2.89%
2.0	0.4	0.01%
2.1	2.0	0.03%

3) Identification of threats to statewide wildlife corridor priorities from sea-level rise and projected future urban development.— The results for this assessment are included in *Appendix 7-FEGN Update Corridor Prioritization Options*.

4) Impact assessment of threats to Florida Forever Board of Trustees Projects and Florida Managed Areas.—A simple overlay assessment was conducted between our 1m tidally adjusted sea-level rise scenario, the most recent Florida Forever Board of Trustees Project database (obtained from FNAI), and the most recent dataset of Florida Managed Areas, also obtained from FNAI (**Figures 17-18**). Calculations were based on current terrestrial acreage projected to be inundated. As might be predicted, impacts to Florida Forever projects are greatest in Monroe County (much of which encompasses the Florida Keys). In fact, the first 18 projects (in order of greatest impact) are all in Monroe County, including 7 projects projected to lose 100% of their current terrestrial area to sea-level rise. In our analysis of potential impacts to current Florida Managed Areas, 37 current managed properties are projected to lose 100% of their current terrestrial acreage to sea-level rise, and 200 properties are projected to lose

90% or more. *Appendices 9b and 9c* contain detailed projected inundation calculations for both existing conservation lands and Florida Forever priorities.

A couple basic conclusions can be drawn from this analysis. First, a current conservation priority is to maintain and protect lands that are contiguous with existing conservation lands in order to enhance overall landscape connectivity. Expanding the upland portions of existing conservation areas will become even more important as coastal inundation occurs. The minimal goal may be to preserve the existing terrestrial acreage of conservation lands with “no net loss,” but an additional goal should be to expand conservation areas beyond existing acreages to further assist in species adaptation to sea-level rise and to mitigate potential impacts of land-use change. Second, a next step in this process could include a more detailed assessment of existing conservation lands and adjacent unprotected lands (including Florida Forever projects) that span strategic coastal to inland habitat gradients and might provide the best opportunities for adaptation to sea-level rise through inland retreat.

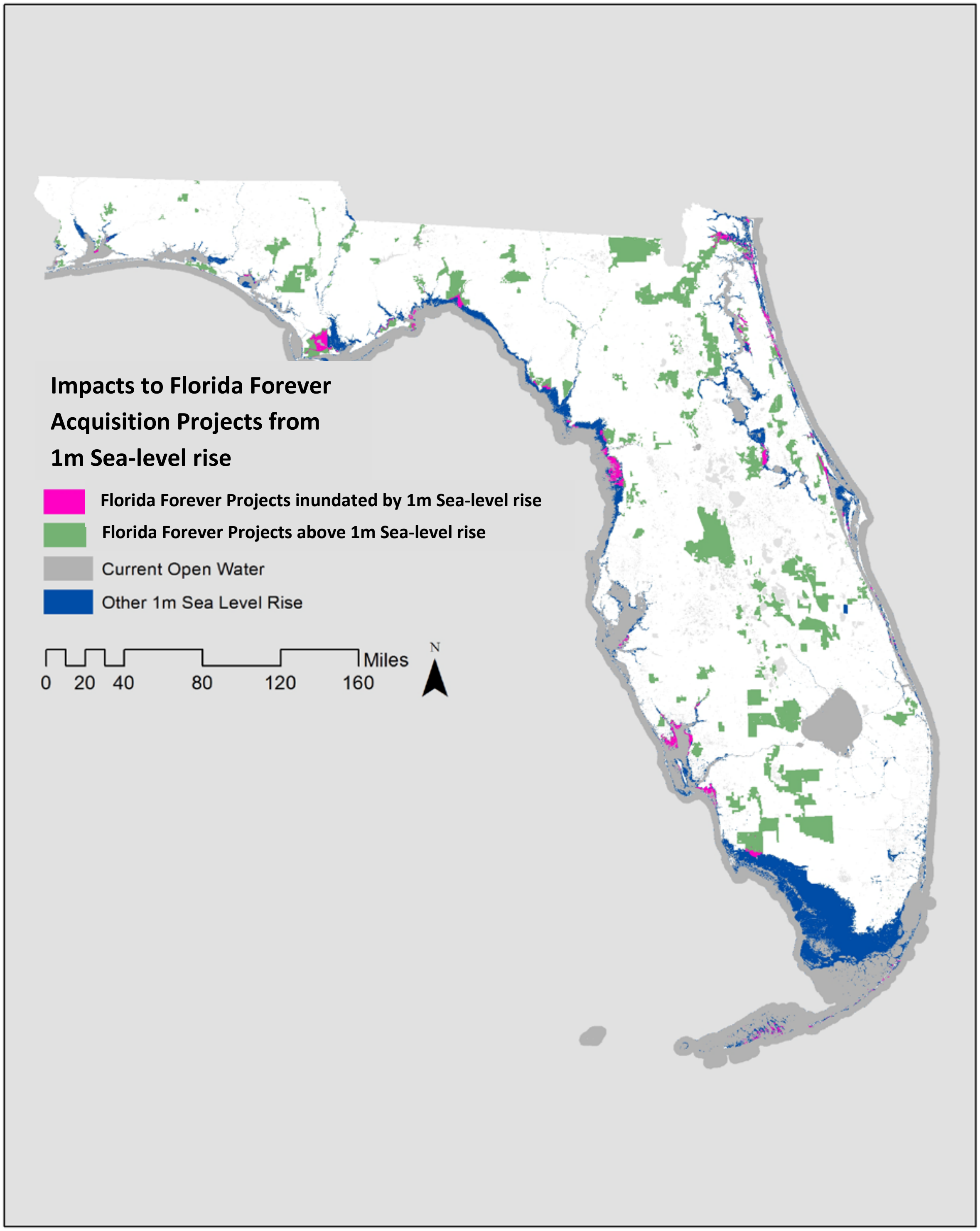


Figure 17. Impacts to Florida Forever acquisition projects from 1m of sea-level rise.

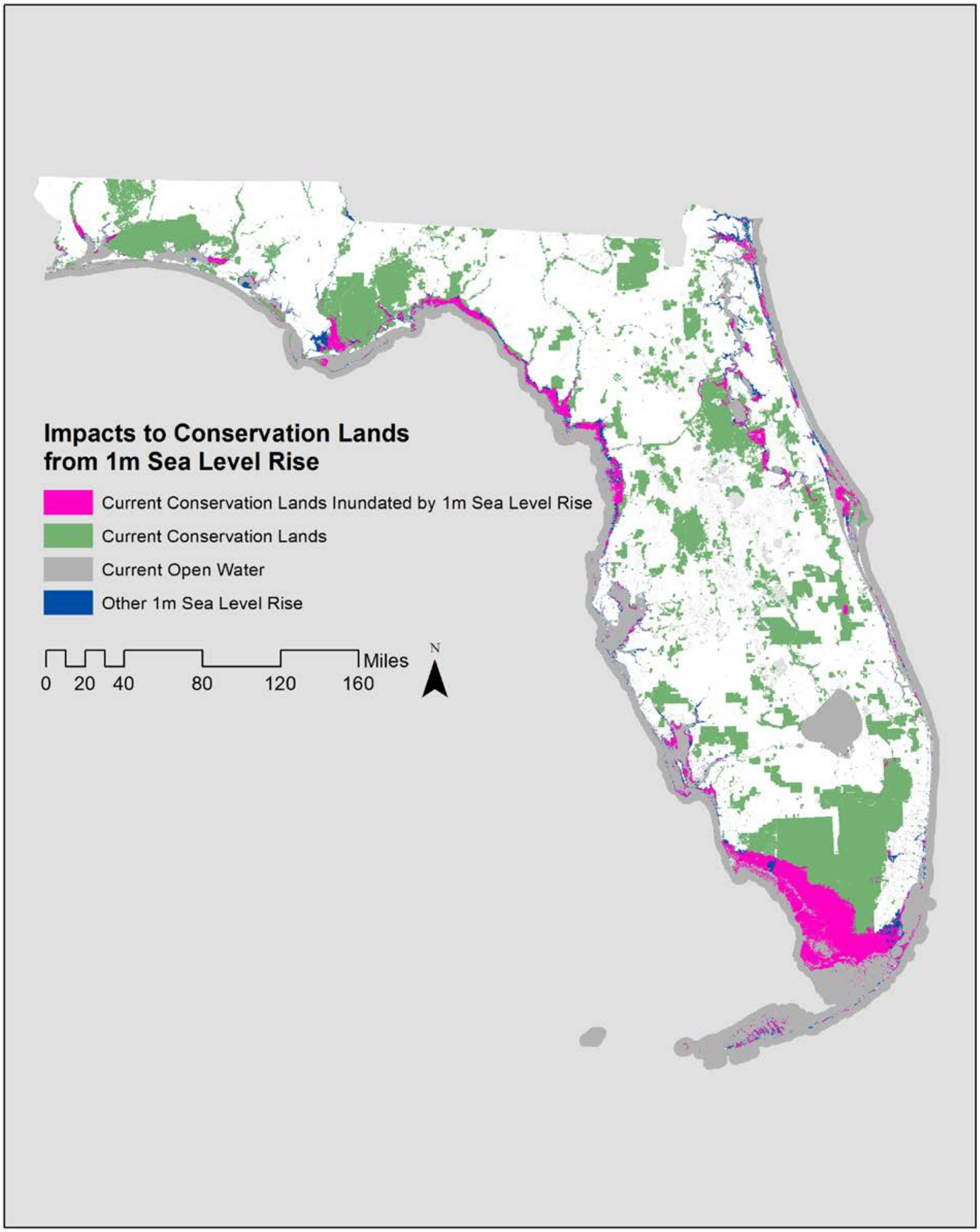


Figure 18. Impacts to existing managed areas and conservation lands from 1m of sea-level rise.

Impact Assessment Results: Land Use and Sea-level rise Impact Hotspots

One way to summarize impacts to species and natural communities is to overlay existing models of conservation priorities for species and communities onto projections of sea-level rise and urban development. The FNAI Rare Species Habitat Conservation Priorities (FNAIHAB) model is a weighted overlay of 281 species habitat models (including all of the FNAI habitat models included in this study) developed originally for the Florida Forever Conservation Needs Assessment and later adapted for the Critical Lands and Waters Identification Project (CLIP). Using the CLIP version, which weights species simply by Conservation Status Assessment global and state (G/S) ranks, we see SLR impacts focused in particular areas, including Panhandle river mouths, Big Bend salt marsh, the Everglades, the Florida Keys, and the St Johns River (**Figures 19**). About 20% of the highest priorities, and 11% of all priorities, are impacted by 1 m of sea-level rise (**Table 4**). Projected impacts from development in 2060 are more dispersed, but notable in both southwest and northeast Florida (**Figure 20**). About 5% of high priorities are impacted by development, and 11% overall (**Table 5**). Combined impacts from SLR and development amount to about a quarter of high priorities, and 21% overall.

We mapped conservation hotspots based on the combined assessment of vulnerability and value in SIVVA in **Figure 21**, which reveals hotspots in extreme South Florida and the Florida Keys, as well as along several barrier islands.

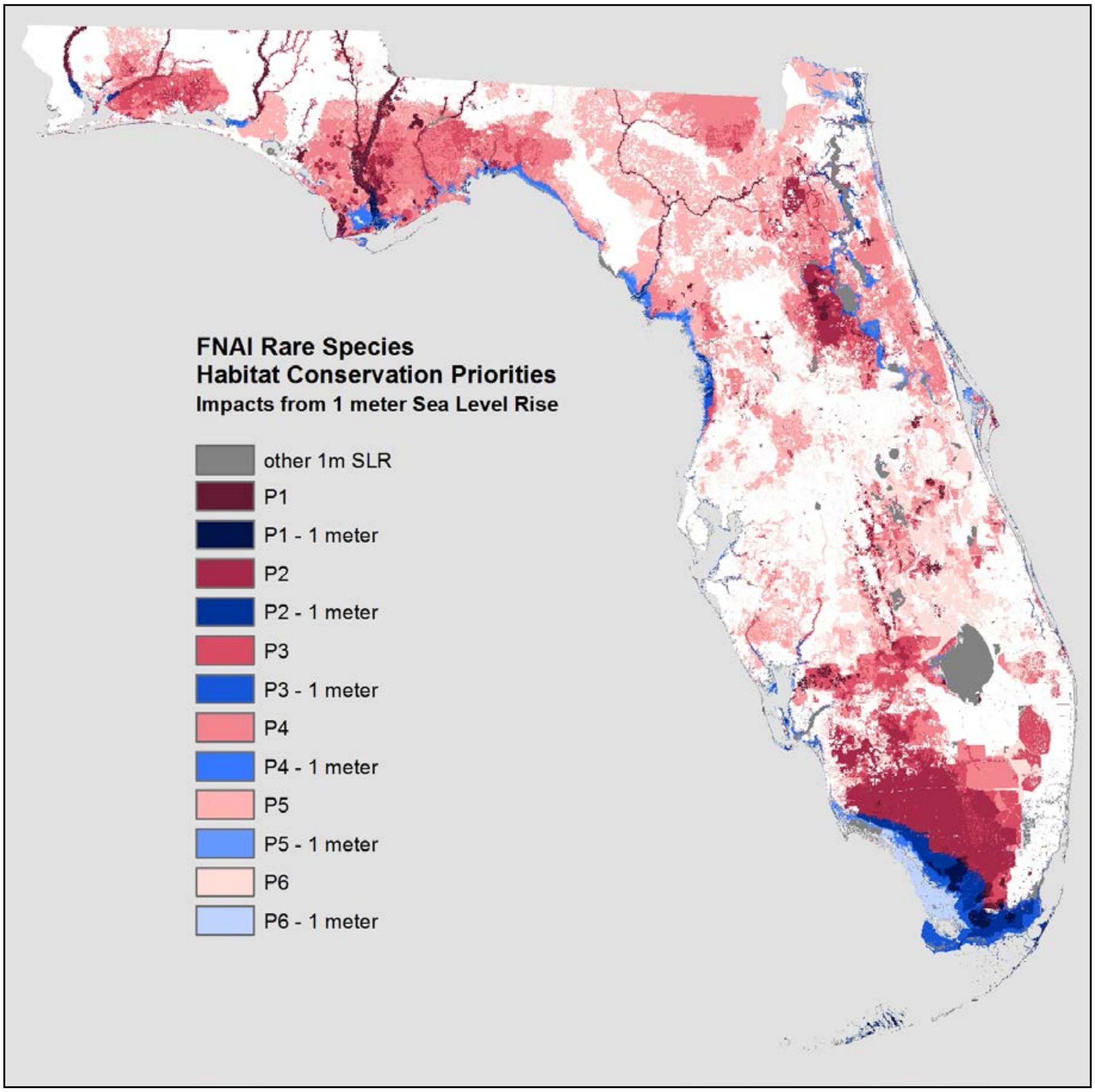


Figure 19. FNAI rare species habitat conservation priority impacts from 1m of sea-level rise.

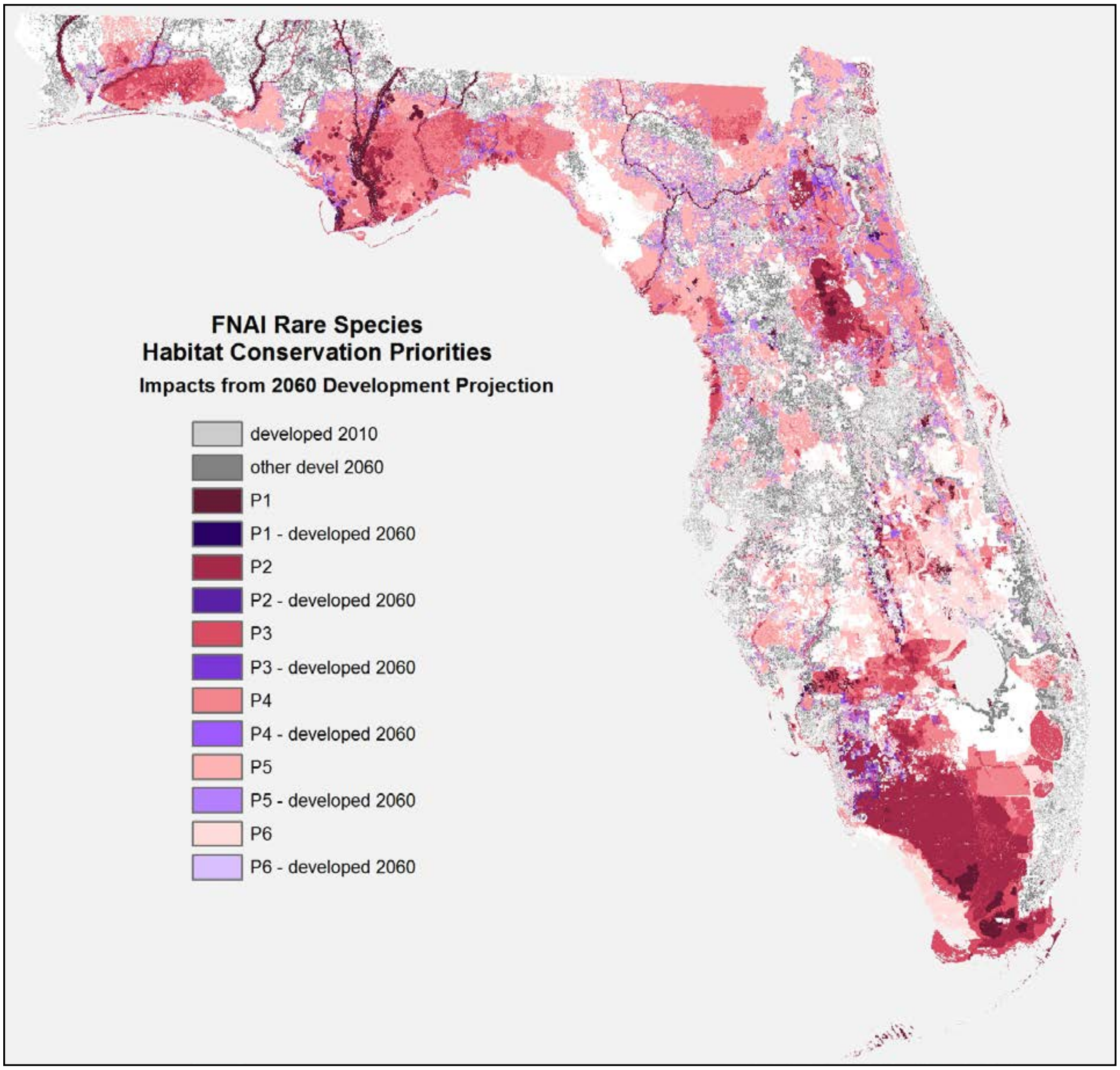


Figure 20. FNAI rare species habitat conservation priority impacts from 2060 development.

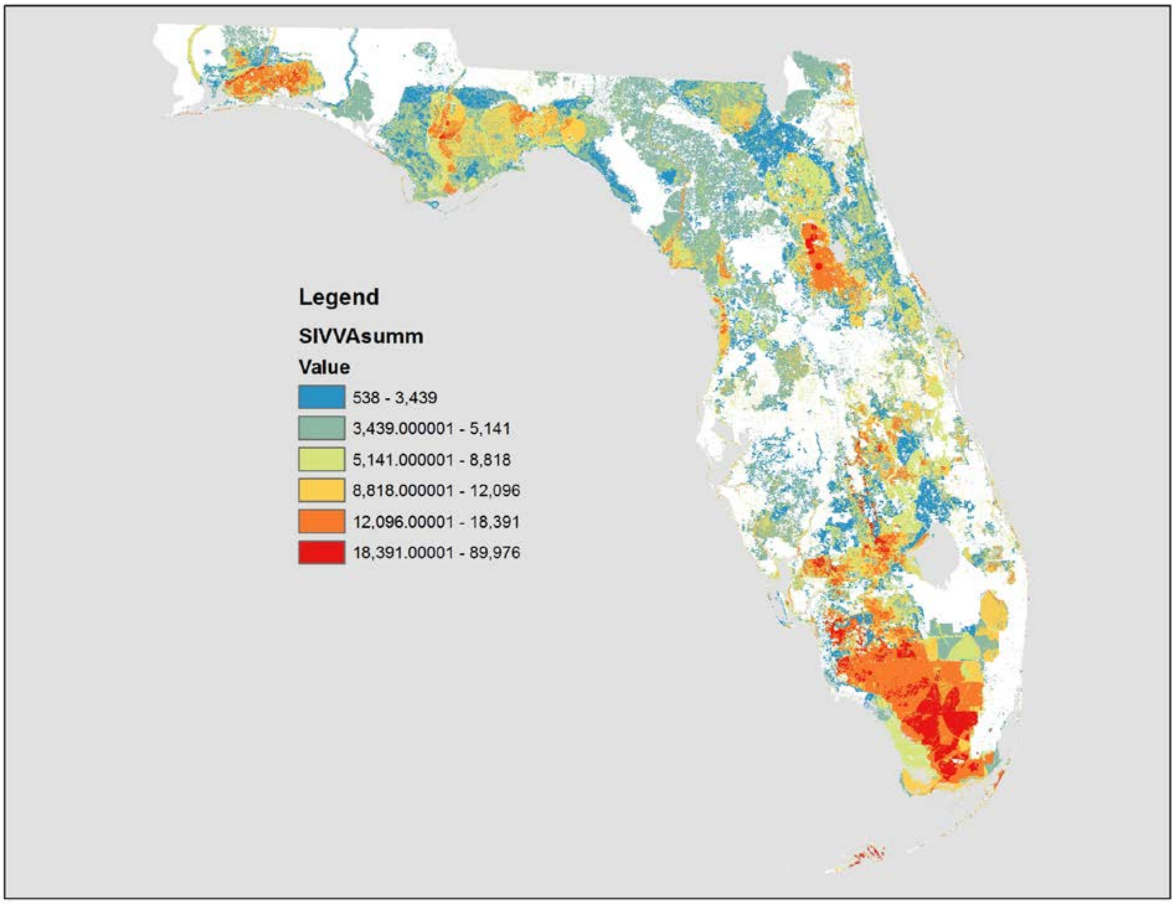


Figure 21. Hotspots of species with high vulnerability and value as calculated by SIVVA (data in Appendix 1d). The legend depicts a quantitative score that is calculated based on the SIVVA score for species in that area, number of species with overlapping distributions in that area, and the suitability of the habitat for those species. Species were grouped into six classes of increasing vulnerability/value, with warm colors being the highest priority and cool colors the lowest.

Table 4. Impacts of Sea-level rise on Species and Natural Community Conservation Priorities

FNAI Rare Species Habitat Conservation Priorities

	Total Hectares	Hectares Impacted at 1-meter SLR	Percent Impacted
Priority 1	329,831	63,185	19%
Priority 2	1,068,504	201,792	19%
Priority 3	1,110,649	216,722	20%
Priority 4	2,017,245	156,715	8%
Priority 5	2,160,989	81,895	4%
Priority 6	1,488,007	158,386	11%
Total	8,175,224	878,695	11%

FWC Strategic Habitat Conservation Areas

	Total Hectares	Hectares Impacted at 1-meter SLR	Percent Impacted
Priority 1	583,818	77,116	13%
Priority 2	4,664,288	585,165	13%
Priority 3	1,668,971	286,798	17%
Priority 4	32,679	4,652	14%

Priority 5	444,701	34,562	8%
Total	7,394,456	988,294	13%

Data version: SHCA 2009 update, as prioritized for CLIP

Florida Forever Conservation Needs Assessment: Under-Represented Natural Communities

Global Heritage Rank	Total Hectares	Hectares Impacted at 1-meter SLR	Percent Impacted
G1	6,790	2,317	34%
G2	286,918	6,134	2%
G3	451,045	8,503	2%
G4	943,466	25,794	3%
G5	571,537	398,330	70%
Total	2,259,756	441,077	20%

Data version: CLIP version 3.0, Nov 2013

Communities included:

G1 - upland glade, pine rockland

G2 – scrub/scrubby flatwoods, rockland hammock, dry prairie, seepage slope, coastal lakes

G3 – coastal uplands, sandhill, sandhill upland lakes, upland pine

G4 - pine flatwoods

G5 - upland hardwood, coastal wetlands

Table 5. Combined Impacts of Sea-level rise and Development Projections on Species and Natural Community Conservation Priorities

FNAI Rare Species Habitat Conservation Priorities

	Total Hectares	Hectares Impacted by 1-meter SLR OR 2060 Development	Percent Impacted
Priority 1	329,831	85,370	26%
Priority 2	1,068,504	237,339	22%
Priority 3	1,110,649	270,905	24%
Priority 4	2,017,245	333,862	17%
Priority 5	2,160,989	437,500	20%
Priority 6	1,488,007	372,493	25%
Total	8,175,224	1,737,470	21%

Data version: FNAIHAB-CLIP version 3.0, Nov 2013

FWC Strategic Habitat Conservation Areas

	Total Hectares	Hectares Impacted by 1-meter SLR OR 2060 Development	Percent Impacted

Priority 1	583,818	111,826	19%
Priority 2	4,664,288	788,799	17%
Priority 3	1,668,971	587,479	35%
Priority 4	32,679	6,512	20%
Priority 5	444,701	96,788	22%
Total	7,394,456	1,591,404	22%

Data version: SHCA 2009 update, as prioritized for CLIP

Florida Forever Conservation Needs Assessment: Under-Represented Natural Communities

Global Heritage Rank	**Total Hectares**	**Hectares Impacted by 1-meter SLR OR 2060 Development**	**Percent Impacted**
G1	6,790	2,403	35%
G2	286,918	35,897	13%
G3	451,045	78,629	17%
G4	943,466	167,080	18%
G5	571,537	450,961	79%
Total	2,259,756	734,969	33%

Data version: CLIP version 3.0, Nov 2013

Communities included:

G1 - upland glade, pine rockland

G2 - scrub/scrubby flatwoods, rockland hammock, dry prairie, seepage slope, coastal lakes

G3 - coastal uplands, sandhill, sandhill upland lakes, upland pine

G4 - pine flatwoods

G5 - upland hardwood, coastal wetlands

Education and Outreach

Presentations to the public, scientific and land management communities:

During the course of this project, our staff made many presentations and attended multiple workshops and other meetings that are directly related to this project. **Table 6** provides a list of these activities in chronological order from May 2012 through July 2014. These presentations, meetings, and other activities collectively provided the bulk of the communication, education, and outreach related to this project over the past 2.5 years. These activities represent a tremendous amount of communication about our project, the underlying science, and the policy implications, to other professionals, students, decision makers, and the public. This communication represents an essential form of interaction with stakeholders, which in turn benefits the ultimate goal of this project – to reduce the threat of sea-level rise, climate change, and land-use change to species and ecosystems in Florida, and to develop adaptation strategies and other policy and management responses that will harmonize the needs of humans and nature.

Table 6. List of outreach activities.

Event	Goal/Participants	Dates	Location
Assembling the Tree of Life Workshop	Work with experts to understand phylogenetic distribution of sea-level rise vulnerability	5/18-20/2012	DC
Meeting with UF, USGS scientists	Met with collaborators from agencies to discuss joint sea-level rise research opportunities	6/6/2012	Orlando
Peninsular Florida LCC meeting	USFWS, LCC, FWCC, other agencies- share results of sea-level rise research	6/13-14/2012	St. Petersburg
FAU SLR Summit	Present educational materials on sea-level rise research (included undergraduate poster presentation)	6/20-22/2012	Boca Raton
Conference call with Orange County School District	Consult with biology teachers about design of educational materials on climate change and sea-level rise	6/25/2012	-
World Affairs Council of Central Florida	Met with representatives from Belize, Liberia, Panama, Saudi Arabia, and Tanzania to discuss climate change and sea-level rise environmental policy	7/3/2012	UCF
Conference call Defenders of Wildlife	Discuss collaborative projects on prioritizing conservation efforts in Florida with respect to climate, sea-level rise, and other criteria	7/20/2012	-
Ecological Society of America Meeting	Oral presentation on species prioritization research and new tool (SIVVA) for evaluating species vulnerability to sea-level rise and associated threats	7/5-10/2012	Portland, OR

Gopher Tortoise Council Meeting	Oral presentation on vulnerability of reptiles and amphibians in Florida to climate change and sea-level rise	9/4-6/2012	Bainbridge, GA
Meet with coastal engineer Randall Parkinson	Discuss coastal sea-level rise vulnerabilities with respect to coastal engineering	10/1/2012	UCF
Florida Ornithological Meeting	Assess vulnerabilities of birds to climate, sea-level rise and land-use change	10/12-14/2012	Archbold Biological Station
Departmental seminar	Presented results of our research on sea-level rise vulnerabilities in Florida	10/15/2012	UCF
Meet with Thomas Ruppert	Met with Florida Sea Grant environmental law specialist to consult on zoning and liability issues for coastal communities	10/26/2012	UCF
George B. Harzog Award Presentation	Presentation on considering conservation strategy within a broader spatial temporal context, including climate change	10/29-30/2012	Clemson
The Florida Panther Festival	Discussed panther habitat conservation and connectivity needs including potential impacts of SLR on habitat in south Florida.	11/12/2012	Naples, FL
Santa Fe Chapter of the Audubon Society	Discussed important of statewide wildlife corridor planning including in regards to facilitating adaptation to climate change.	11/14/2012	Melrose, FL
Conference call Center for Biological Diversity	Consulted on vulnerability of Florida Bonneted Bat	11/28/2012	-
Florida Climate Institute Meeting	Form UCF chapter of Florida Climate Institute	12/11/2012	UCF
Conservation Trust for Florida Annual Meeting	Discussed important of statewide wildlife corridor planning including in regards to facilitating adaptation to climate change.	1/19/2103	Micanopy, FL
International Sea turtle Symposium	Graduate student presented oral presentation on impacts of climate change, land use and sea-level rise to sea turtles	2/2-8/2013	Baltimore, MD
Predicting Ecological Changes in the Florida Everglades	Participated in FAU-CES, USGS, Florida Sea Grant Sponsored Technical Meeting	2/14-15/2013	Boca Raton
Florida Department of Environmental Protection Acquisition and Restoration Council Meeting	Discussed important of statewide wildlife corridor planning including in regards to facilitating adaptation to climate change	2/15/2013	Tallahassee, FL
UF Environmental Law PIEC Conference	Oral presentation on endangered species in Florida and threats from climate change and sea-level rise	2/21-23/2013	UF
Southeastern Ecology and Evolution Conference	Graduate student presented oral presentation on impacts of climate change, land use and sea-level rise to sea turtles	3/1-3/2013	UCF
Collaborative meeting on niche modeling	Colleagues from UF and USGS; purpose was to discuss niche models to predict responses of species to climate change and sea-level rise	3/14-15/2013	Ft. Lauderdale
Climate change and sea-level rise workshop	USGS, USFWS, FFWCC, university researchers met to share results of research	3/20-21/2013	St. Petersburg College

UCF Undergraduate Research Symposium	Student poster on impacts of sea-level rise on marine turtles	4/4/2013	UCF
NatureServe 2014 Biodiversity Without Boundaries Conference	Oral presentation on rethinking species conservation priorities in the face of sea-leavel rise	4/6-10/2014	New Orleans, LA
Conference call Defenders of Wildlife	Discuss collaborative projects on prioritizing conservation efforts in Florida	4/11/2013	-
Florida Sea Grant Sea-level rise Workshop	Share results of sea-level rise modeling and species prioritization research with Florida Sea Grant	4/15-16/2013	Marineland, FL
North Carolina State University	Presented seminar on assessing vulnerability and adaptation options for species and natural communities threatened by sea-level rise in Florida	4/18/2013	Raleigh, NC
Florida Native Plant Society Annual Conference	Discussed Florida ecological connectivity planning including climate change and sea level rise considerations in a keynote presentation.	5/25/2013	Jacksonville, FL
Congressional Hearing on ESA	Testified to House Committee on Natural Resources on continuing threats to endangered species, including climate change and sea-level rise	6/4/2013	Washington DC
Botany 2013 Conference	Gave two presentations on the biodiversity, biogeographic history, and threats to the North American Coastal Plain, including fluctuations in sea level	7/30/13	New Orleans, LA
Ecological Society of America annual meeting	Gave presentation on the biodiversity, biogeographic history, and threats to the North American Coastal Plain, including fluctuations in sea level	8/7/13	Minneapolis, MN
Sea-level rise Summit, Florida Atlantic University	Gave presentation on considering the natural environment in sea-level rise adaptation planning	10/17/13	Fort Lauderdale, FL
Florida Gulf Coast University Science Seminar Series	Discussed Florida ecological connectivity planning including climate change and sea level rise considerations in a seminar presentation.	11/12/2013	Fort Myers, FL
National Association of Biology Teachers	Creating high-school teaching materials that interweave sea-level rise research with Florida's Next Generation Sunshine State	11/20-23/2013	Atlanta, GA
Steering committee meeting for Planning for Sea Level Rise in the Matanzas Basin Project	Presenting work to steering committee members representing private, public, local and regional interests within northeast Florida	12/2013	Marineland, FL
South Anastasia Communities Association	Discussed ecological planning efforts in Florida and northeast Florida including climate change and sea level rise in a presentation.	2/4/2014	Marineland, FL
Biodiversity Responses to Climate Change: Perspectives from the Southeastern US Symposium. East Carolina University	Gave presentation on climate change, sea-level rise, and biodiversity in Florida	3/14-15/14	Greenville, NC
Center for Biological Diversity Panther Symposium	Discussed panther habitat conservation and connectivity needs including potential impacts of SLR on habitat in south Florida.	3/21/2014	Gainesville, FL

37th Annual Herpetology Conference, Florida Museum of Natural History	Gave presentation on effects of sea-level rise, land use, and climate change on the distribution of loggerhead turtle nests, Melbourne Beach, FL*Best Presentation Award	4/4-5/14	Gainesville, FL
Steering committee meeting for Planning for Sea Level Rise in the Matanzas Basin Project	Presenting work to steering committee members representing private, public, local and regional interests within northeast Florida	7/2014	Marineland, FL
North American Congress of Conservation Biology meeting (Society for Conservation Biology)	Gave presentation on multi-track conservation planning in the face of climate change and sea-level rise, with Florida as a case study	7/16/14	Missoula, MT

Survey of Florida County Planners –

Survey questionnaires were mailed to the planning directors of each of the 67 counties in Florida in October 2012. Of the 67 questionnaires sent, 61 responses were received, a response rate of 91%. Survey responses indicated that conservation of nature is of moderate importance in county-level land-use planning and is "frequently" considered in planning.

We found significant differences between Inland and Coastal counties in their consideration of climate change and sea-level rise, and in their conservation planning decision-making and implementation of conservation plans. Not surprisingly, Coastal counties place more importance on climate change and sea-level rise than Inland counties. Coastal counties also engage in significantly more routine and proactive conservation planning than Inland counties, and more frequently implement plans for the conservation of nature than Inland counties.

Unfortunately, few counties (even Coastal) appear to fully appreciate the threats posed by sea-level rise. Sea-level rise was held to be "of little importance" in land use planning to conserve nature for 34% of counties, and "unimportant" for 31% of counties. Coastal counties are more concerned with this issue, as 38% of Coastal counties held this issue to be "moderately important" while for Inland counties the issue was "of little importance" (41%) or "unimportant" (56%). Clearly, more education on these issues is needed for county planners and decision makers.

High school education materials –

University of Central Florida undergraduate Leah Reidenbach (who specializes in developing educational materials that integrate with Florida Next Generation Benchmark guidelines) worked with the Noss Lab to develop educational materials on sea-level rise. The educational materials that we developed are available at http://noss.cos.ucf.edu/outreach. These modules are geared towards high school biology students and integrate sea-level rise and global change science with basic biological principles. These materials have already been requested by dozens of high school teachers and a Florida Sea Grant outreach coordinator. In addition to the lab manuals, a series of companion videos are available on youtube at https://www.youtube.com/watch?v=xGP8JbvWUWw.

RECOMMENDATIONS AND ADAPTATION STRATEGIES

Based on our assessment of land-use and sea-level rise impacts to focal species and natural communities, as well as ecological connectivity, we have developed a series of recommendations and recommended conservation and adaptation strategies for species and natural communities. These are organized into the following categories: 1) recommendations for urban land-use development patterns to minimize impacts on natural communities and focal species, 2) specific strategies for adaptation of the species we have identified as most critically in danger of impacts from sea-level rise, 3) recommendations for conservation of coastal natural communities, and 4) landscape level recommendations to reduce impacts to ecological connectivity from sea-level rise and land-use change.

Recommendations for Future Urban Land Use and Development

Changes in Urban Density.— This study and other projections of urban development that results from population growth clearly demonstrate that continued suburban greenfield development will result in the loss of productive agricultural lands and natural areas so important to maintaining Florida's quality of life. Natural areas not only provide habitat for plant and animal species, some endemic only to Florida, but also provide land for aquifer recharge, natural floodwater management, storm protection, and the potential for landward migration that will become essential to species survival in the very near future.

Recommendations.—To prevent or minimize these losses we recommend that the density of new development and areas being redeveloped be increased within existing urban boundaries, and that protections be established for high priority natural and agricultural lands across the state. Current "urban" development in Florida totals approximately 3,643,786 acres. Under our base Trend scenario without sea-level rise, an additional 3,801,645 acres of new greenfields were developed. However, under the SLR 2 scenario, which was used for our impact assessments in this project, approximately 5,258,228 acres of new land will be developed. These numbers illustrate the sizeable acreage of current greenfields that may be developed under either the Trend or SLR 2 scenarios if development continues at current densities, and underscore the importance of increasing urban densities in appropriate areas rather than dispersing population across larger semi-natural and natural landscapes.

Increased Urban Density.— Increased urban densities will have many benefits beyond the advantage of less land consumption, including:

1) Shorter commute times
2) Greater opportunity for alternative forms of mass transit
3) Increased opportunity for social interaction
4) Improved human health (as exemplified by studies of urban dwellers vs suburban dwellers), and
5) Lower costs for the delivery of urban services (e.g., utilities, police, fire, etc.)

This is not to say that all housing choice be eliminated for the consumer, but rather that with even minor increases in urban density, the land needed to support population growth (which, of course, also must be reduced in order to ensure ecological sustainability) can be reduced and the quality of life can be enhanced. In addition, higher density development patterns require greater up-front investment in public open space and other amenities to support the increased densities. Large and livable cities worldwide have proven this to be true. In spite of the investment necessary, increased availability of well planned urban amenities has been shown to have social, health, and economic benefits that outweigh the costs.

Both incentive and regulatory policies that encourage increased densities are needed to move us toward that goal.

Protections for Natural and Agricultural Lands.— To achieve the quality of life Floridians desire, natural areas and agricultural lands are needed if for no other reason than to protect the ecosystem services on which we depend – although we suggest that the intrinsic value of species and natural communities must receive at least equal consideration. Fee simple acquisition of a network of protected land must provide the skeletal framework, but beyond that more creative approaches must be employed. Among these are:

1) Conservation easements, either purchased or donated
2) Payment for ecosystem services including water storage, and
3) Transfer of development rights

The latter has proven a very unwieldy approach, but studies suggest a redoubled and focused effort in this regard has the potential to be highly cost effective.

Changes in Land Allocation in Response to Sea-level rise.—The increasing rise of the sea in our low-lying peninsular state requires additional changes to the allocation of land regardless of urban densities. The recommendations are obvious, but worth underscoring.

Recommendations.—Cease construction and redevelopment (except vertical redevelopment in special cases) in areas projected to be inundated in the next 50-100 years including:

1) Coastal areas, and
2) Low-lying inland areas, especially those adjacent to rivers.

Potential Adaptation Options for Species Vulnerable to Sea-level rise in Combination with Threats from Changes in Land Use and Climate

***Discussion.*—**Our evaluation of species by potential adaptation options and strategies is a relatively "quick and dirty" attempt to identify appropriate conservation and adaptation measures immediately so that they can be implemented before these highly vulnerably species go extinct. Further information obtained through research would improve confidence in our results and recommendations. Our confidence in our identification of appropriate options and groups of options (adaptation strategies) is relatively high for those species that have been well studied, but lower for those with limited information availability. Protecting existing habitat, searching for new populations (occurrences), and testing the feasibility of captive propagation for low-information species is essential to reduce the uncertainty regarding the feasibility of specific adaptation actions for these low-information species.

Although we considered the total geographic ranges of species during this assessment (for example, some species occur in portions of the West Indies in addition to Florida), we restricted our ranking of options for each species primarily in terms of what might be accomplished within Florida. We did this because detailed knowledge of the distribution of these species outside of Florida is limited, and because conservation agencies and organizations in Florida have little ability to influence conservation practices outside of the state or the United States. Hence, potential adaptation options such as introducing or reintroducing the species (assisted colonization or managed relocation) to islands in the West Indies with greater topographic relief than Florida and presumably higher adaptation potential were not considered (cf. Maschinski et al. 2011).

Moreover, we did not attempt to distinguish the option of "introduce within historic range" from "introduce outside of range" (Maschinski et al. 2011) because knowledge of historic distributions is limited over the temporal scale of major fluctuations in sea level during glacial-interglacial cycles. What, for example, was the distribution of the mangrove terrapin (*Malaclemys terrapin rhizophorarum*) or Miami blue (*Cyclargus thomasi bethunebakeri*) in Florida during the last period of very high sea level ca. 125,000 years ago? We lack information to answer this kind of question for the vast majority of species. Furthermore, it is likely that many taxa (e.g., the variety- or subspecies-level endemics of the Florida Keys) only diverged allopatrically from their close relatives over the past ca. 6,000 years, as the Keys became isolated from the mainland and from each other due to rising post-glacial sea levels (Noss 2013).

We suggest that, despite uncertainty due to limited information, conservation and adaptation measures for high-priority species at risk of extinction should be implemented as quickly as possible, definitely within the next few years. Delays in implementation will preclude some options (for example, as potential recipient habitat is converted to urban area or as stretches of coastline are altered by dikes, seawalls, or new development) and increase the risk of extinction for these species. Meanwhile, continued research to learn more about the geographic distribution, life histories, and other aspects of autecology of these species must be funded and pursued vigorously so that detailed and robust adaptation strategies can be developed and implemented.

Recommendations for Conservation of Coastal Natural Communities to Minimize Impacts to Vulnerable Species and Natural and Human Communities

The only viable *in situ* adaptation strategy for coastal natural communities and the species associated with them is one based on the protection and restoration of these communities. This strategy will at least "buy time" and allow natural and human communities to adjust to SLR and, where possible, migrate or relocate to higher elevations. As noted earlier, the protection, creation, and restoration of coastal ecosystems is a form of "ecological engineering," which reduces impacts of SLR and storm surge without the destructive impacts of traditional engineering approaches such as sea walls, dikes, revetments, and bulkheads (Cheong et al. 2013, Duarte et al. 2013, Temmerman et al. 2013). Sea walls and other coastal armoring may be needed to protect the built environment in some local areas (e.g., the City of Miami) where urban development directly abuts the coast. However, such structures are well documented to increase erosion of neighboring coastal areas and have many deleterious impacts on natural communities (Pilkey and Wright 1988, Hall and Pilkey 1991, Cheong et al. 2013). Because intertidal wetlands and other natural communities are situated between these structures and the sea, coastal armoring results in "shoreline squeeze," where wetlands are eroded at the seaward margin and prevented by the structures from migrating landward (Kirwan and Megonigal 2013). Hence, the preferred approach from an ecological standpoint is avoid coastal armoring and, instead, work with natural communities to derive the optimal benefits of harmonizing adaptation for humans with adaptation for nature.

Up to some threshold rate of SLR, coastal wetlands actively resist erosion by increasing vertical accretion of sediments as the sea rises. The relationship is a positive feedback, with mineral sediments filtering out of the water column during periods of tidal or storm-induced flooding, and plant biomass increasing with enhanced above-ground growth in response to SLR (Kirwan and Megonigal 2013). This response is well documented for salt marshes and mangrove swamps (McKee et al. 2007). Mangroves are able to trap around 80% of suspended sediment (Furukawa et al. 1997). Historical evidence shows that mangrove surface elevations have kept pace with SLR over thousands of years in some areas, with the key factors being external sediment inputs (i.e., dams on rivers reduce sediment input to estuaries) and the growth of subsurface roots (McIvor et al. 2013). Over recent decades the sedimentation rate in mangrove swamps has still kept pace with SLR (Alongi 2008), although the current rate of SLR – and projected rates over coming decades – is expected to exceed this adaptive capacity. As the sea rises, if there are no insurmountable barriers to movement, the mangrove zone shifts landward. For example, mangroves in the Lower Keys have shifted inland by 1.5 km since the mid-1940s with SLR of 2.3-2.7 mm per year (Ross et al. 2000). Oyster reefs may show the most promise to keep pace with sea-level rise through vertical growth. Measurements of intertidal oyster-reef growth were used by Rodriguez et al. (2014) to develop an empirical model of intertidal oyster-reef accretion. Their results suggest that previous estimates of vertical reef growth may be more than an order of magnitude too slow, and that the oyster reefs they studied should be able to keep up with future accelerated rates of sea-level rise. Vertical growth and landward movement of natural communities in response to sea-level rise are adaptive responses, which should be encouraged and facilitated wherever possible.

By trapping sediments and/or growing vertically, coastal wetlands and nearshore marine communities reduce water velocities from tides, storms, and tsunamis and reduce erosion and flooding of adjacent uplands. Mangroves, salt marshes, seagrass beds, coral reefs, and oyster reefs all serve this function (Arkema et al. 2013, Cheong et al. 2013, Temmerman et al. 2013), as do dunes and other coastal uplands. Maintaining and restoring these ecosystems between human communities and the sea will therefore reduce threats to human communities until the rate and depth of SLR exceeds their capacity to trap sediments and migrate landward. When this threshold of adaptive potential will be reached is uncertain, but it probably will not occur for several decades, which gives human communities time to build vertically or (preferably) relocate to higher elevations inland and away from the rising sea.

There are additional critical reasons for maintaining and restoring marine, estuarine, and coastal upland natural communities. One of these is ecosystem services. Coastal wetlands can be marketed for their tremendous capacity to store and retain carbon. For instance, salt marsh, seagrass, and mangrove ecosystems account for nearly half of the total carbon burial in ocean sediments (Duarte et al. 2013). These “blue carbon” ecosystems have area-based carbon pools and fluxes far exceeding any other ecosystems on earth (Kirwan and Megonigal 2013). Therefore, they play a substantial role in mitigating global warming. Additional direct economic benefits of these ecosystems for humans include improvements in water quality, fisheries production, storm protection, and recreation and tourism. Because tourism is Florida’s leading economic sector, maintaining healthy coastal ecosystems is a high priority for maintaining economic vitality.

Furthermore, maps of imperiled taxa in Florida show that many are concentrated in coastal areas, for example the Florida Keys, Miami Rock Ridge, Atlantic Coastal Ridge, Apalachicola Lowlands, and West Florida Panhandle (Knight 2011). A surprising number of these taxa are endemic or near-endemic to Florida; if they go extinct here, they are lost from the earth. The mangrove bird assemblage in Florida is unique in the United States. It includes the Black-whiskered Vireo, Florida Prairie warbler, Cuban Yellow Warbler, Mangrove Cuckoo, White-crowned Pigeon, Mangrove Clapper Rail, Great White Heron, plus more widespread species such as the Black-crowned and Yellow-crowned High-Heron, Roseate Spoonbill, and many other wading birds. Besides the intrinsic and scientific value of this avian assemblage, it contributes to Florida's economy through ecotourism (birding).

Unfortunately, in addition to the rising sea, coastal ecosystems face other threats. A primary threat is coastal development, which inexplicably proceeds in Florida despite clear evidence of SLR and increasing intensity of storm surge (Noss 2011). Political leaders and planners appear to be in denial about this reality. Pilkey and Young (2009) warned that Florida has more to lose – economically as well as ecologically – than any other state in the U.S. from SLR, yet has done less than any other coastal state to prepare for it. An obvious first step in protecting both human and natural communities in coastal areas from SLR and storm surge is to discourage any new urban development or redevelopment, or other human infrastructure such as roads, in low-lying coastal areas (i.e., anything lower than ca. 3 m above mean sea level, assuming a probable worst-case scenario of ca. 2 m SLR by the year 2100; Vermeer and Rahmstorf 2009).

Keeping coastal natural communities in healthy condition by reducing other stressors is another key recommendation. For example, the turfgrass and fertilizer industries in Florida are leading contributors to nitrogen (N) pollution in streams and lakes (Souto 2012). This N, when it reaches estuaries and coastal waters, contributes to eutrophication of coastal wetlands. Deegan et al. (2012) showed through a remarkable whole-ecosystem experiment that N nutrient levels commonly associated with coastal eutrophication increased above-ground leaf biomass in saltmarsh cordgrass (*Spartina alterniflora*) and smooth cordgrass (*S. patens*), both foundation salt marsh species in Florida, as might be expected with fertilization. However, this N fertilization decreased below-ground growth of bank-stabilizing roots and increased microbial decomposition of organic matter. Loss of below-ground biomass in turn led to reduced geomorphic stability and increased erosion, resulting in creek-bank collapse with large areas of marsh converted to unvegetated mud. Deegan et al. (2012) suggest that:

> "current nutrient loading rates to many coastal ecosystems have overwhelmed the capacity of marshes to remove nitrogen without deleterious effects. Projected increases in nitrogen flux to the coast, related to increased fertilizer use required to feed an expanding human population, may rapidly result in a coastal landscape with less marsh,

> which would reduce the capacity of coastal regions to provide important ecological and economic services."

The study by Deegan et al. (2012) was conducted in Massachusetts, but there is no reason not to expect similar responses of salt marsh to eutrophication in Florida. Protection and restoration of coastal ecosystems to increase their resistance and resilience to SLR and storm surge therefore requires that upland landscapes be managed better. In the case of salt marshes, better management would include increased restrictions on use of N fertilizers, better stormwater management, and reduction of the area of turfgrass (lawns and golf courses) on the landscape.

Recommendations for Maintaining Landscape Connectivity in the Face of Sea-level rise and Land-use change

1) Future modifications (and protection) of the Florida Ecological Greenways Network (FEGN).—The FEGN identifies areas of opportunity for protecting a statewide network of ecological hubs and linkages designed to maintain large landscape-scale ecological functions including focal species habitat and ecosystem services throughout the state and is conceptually based on the Florida ecological network and wildlife corridor proposals by Larry Harris and Reed Noss (Harris 1985; Noss and Harris 1986; Noss 1987; Harris and Gallagher 1989; Harris and Scheck 1991; Harris and Atkins 1991; Harris and Cropper 1992; Noss and Cooperrider 1994). The FEGN aggregates various data identifying areas of ecological significance from the Florida Natural Areas Inventory, Florida Fish and Wildlife Conservation Commission, existing and proposed conservation lands, and other relevant data to identify large, landscape-scale areas of ecological significance (ecological hubs), and a network of landscape linkages and corridors connecting the hubs into a statewide ecological network.

The FEGN is part of the legislatively adopted Florida Greenways Plan administered by the Office of Greenways and Trails (OGT) in the Florida Department of Environmental Protection (Florida Statutes, Chapter 260). The FEGN was delineated as the ecological component of a Statewide Greenways System plan developed by the DEP Office of Greenways and Trails (OGT) and University of Florida, under guidance from the Florida Greenways Coordinating Council and the Florida Greenways and Trails Council. The FEGN guides OGT ecological greenway conservation efforts, and promotes public awareness of the need for and benefits of a statewide ecological greenways network. It is also used as the primary data layer to inform the Florida Forever and other state and regional land acquisition programs regarding the location of the most important conservation corridors and large, intact landscapes in the state. Therefore, updating and maintaining the FEGN data layer over time to reflect all updates in potential landscape ecological conservation priorities including facilitation adaptation to climate change and sea-level rise is a foundation for any efforts to maintaining (or restoring) functional ecological connectivity in the state.

2) Specific recommendations for FEGN modifications to address SLR/development impacts (to see the maps representing these recommendations see Appendix 7-FEGN Update Corridor Prioritization Options)

a. Consider Critical Linkage or at least P3 status for corridor that circles Tallahassee to the north (to serve as an alternate for St. Marks Critical Linkage). This revision of the FEGN may be necessary to address potentially significant impacts of sea-level rise and possibly projected development south of Tallahassee. The current FEGN Critical Linkage connecting large conservation lands in the Florida peninsula to the Florida Panhandle traverses the very low-lying St. Marks National Wildlife Refuge. In July 2013, the updated FEGN was revised to include the Wakulla River corridor as part of this Critical Linkage. However, both higher sea-level rise from the coast and future urban and suburban development spreading south from Tallahassee could significantly impact the Wakulla River corridor as well. Therefore, another option is to incorporate south to north corridors east of Tallahassee following either or both the Aucilla and St. Marks River and then west and southwest in the Red Hills region north of Tallahassee to connect to the Apalachicola National Forest.

b. Expand Coastal Big Bend Critical Linkage and consider elevating priority of inland Big Bend corridor to address SLR. Like the Critical Linkage through the St. Marks National Wildlife Refuge, the FEGN also identifies a Critical Linkage traversing on or very near the coast of almost the entire Big Bend which is also an extremely low-lying coast with extensive wetlands. Options for addressing this potential sea-level rise impact includes expanding the Critical Linkage and possibly the FEGN base boundary further inland from the coastline and elevating the priority of a more inland route that traverses Mallory Swamp and San Pedro Bay just west of the Suwannee River.

c. Consider expanding Critical Linkage around strategic areas of the St. Johns River to address potential sea-level rise impacts. Bathtub-based sea-level rise projections suggest that portions of the lower and middle St. Johns River will also experience significant inundation from sea-level rise, which in the middle portion south of Lake Harney could turn reaches of a now relatively narrow river (at normal water levels) and wide floodplain into larger, more permanent water bodies that would likely be much less suitable for functional ecological connectivity. It is highly likely that within a century or two, the St. John River will become an estuary again, as it was during past high sea level stands and similar to what the Indian River Lagoon is today. Currently the area around Lake Harney and south of it in Brevard, Seminole, Orange, and Osceola counties support probably the most important wildlife corridor and Critical Linkage in all of Florida. It is by far the best option for connecting large conservation lands south of I-4 to those found in the rest of the state, it is serving to allow subadult male panthers to explore areas of north Florida (and even further north), and it is the best option for restoring genetic connectivity between all Florida black bear populations south of I-4 to those further north. We recommend that portions of the FEGN and surrounding compatible lands not currently part of this Critical Linkage be added to provide at least a wider buffered corridor around the areas of the St. Johns River that could be significantly affected by sea-level rise. However, another important issue is to more firmly establish the effects of sea-level rise to areas along the St. Johns River further from its mouth. One option would be to develop a higher resolution SLAMM model assessment for the St. Johns River that might vary significantly from the potential impacts implied by our bathtub-based inundation projections. Such an analysis would be important both for future conservation efforts for one of Florida's most important riverine ecosystems while also better determining needs for potential modifications of the FEGN.

d. Peace River from P3 to Critical Linkage to provide an additional option to connect south and north Florida. The Peace River corridor is a potential alternative to the Critical Linkage along the St. Johns River connecting the southern half of the Florida peninsula to the rest of the state. Given the potential impact of sea-level rise on the St. Johns River corridor, it is worthwhile to consider elevating the priority and potentially expanding (if feasible) alternative corridors. The Peace River corridor has issues regarding width and potential function for primary focal species including the Florida panther and Florida black bear. However, south of Lake Hancock these width issues could be addressed by protecting and in some cases restoring current agricultural lands around the river that are frequently in lower intensity pasture uses. In addition, working with current phosphate mining reclamation plans and engaging mine landowners in a discussion of other voluntary conservation measures could result in a significantly wider protected Peace River corridor in the future, and local conservation groups are already engaged with mining landowners to discuss additional conservation options that could be relevant to expanding and protecting the Peace River corridor. North of Lake Hancock the corridor is also narrow and is confronted with various bottlenecks in the landscape just east of Lakeland. Local conservationists have been working to protect this corridor, including efforts to get the Florida Department of Transportation (FDOT) to place a water and wildlife crossing under I-4 to connect the corridor to conservation lands in the Green Swamp.

e. Kissimmee to Green Swamp (Four Corners) corridor from P1 to Critical Linkage to provide an additional option to connect south and north Florida. The “Four Corners” corridor in the FEGN traversing the landscape primarily through southwestern Orange County (but also relevant parts of Osceola, Polk, and Lake counties) is another alternative to St. Johns River Critical Linkage to connect large conservation lands south of I-4 to the rest of the state. However, this corridor has feasibility issues based primarily on approved future development or future land use plans. Working with the East Central Florida Regional Planning Council to review existing development plans and potentially help with future plans to ensure that at least a minimally functional corridor can be protected is one option for both further assessment and potential protection of this alternative corridor option.

f. Consider assigning higher priority to south to north corridors within north Florida that connect to areas of conservation significance in Georgia and Alabama. Our final recommendation for modifying priorities or other modifications to the FEGN is to give much more consideration to climate change and sea-level rise. The FEGN has been primarily focused on prioritizing and protecting functional ecological connectivity to create a statewide ecological network from the Everglades to North Florida and westward to the end of the Florida panhandle. However, consideration of climate change adaptation should also call attention to protecting or restoring functional ecological connectivity from Florida to bordering states and specific conservation lands outside of Florida. We recommend a more detailed assessment of conservation priorities in landscapes adjacent to or near the Florida border to determine whether specific south to north corridors leading out of Florida, including various potentially relevant riverine corridors, should be added as high priorities to facilitate adaptation to climate change. Such an assessment would include working with relevant conservation partners in Georgia and Alabama as well as the relevant USFWS Landscape Conservation Cooperatives to obtain relevant data and discuss options and priorities.

3) Recommendation to consider specific resource priorities in future iterations of the Florida Ecological Greenways Network.—The FEGN priorities are intended to identify both state and regional priorities for protecting a functional statewide ecological network. However, these priorities coalesce many different ecological considerations and priorities into a general set of route priorities (with some specifics including priority river corridors), when there can be other types of ecological connectivity priorities for specific resources or ecological processes that may or may not be addressed in the current FEGN priorities. Therefore, we recommend adding specific resource or ecological process priorities as a subset of the FEGN database. This could include identification of the specific portions of the FEGN that are most important for maintaining opportunities for coastal to inland retreat.

4) Recommendations regarding opportunities to protect the FEGN.—It is beyond the scope of this report to go into details about various conservation options for protecting the FEGN to facilitate adaptation to climate change. Nevertheless, it should be clear that protection the FEGN is directly relevant to providing opportunities for species to functionally adapt to climate change, and there are various programs and initiatives relevant to FEGN protection. These include, but are not necessarily limited to Florida Forever, the Rural and Family Lands Protection Act, NRCS Wetland Reserve Program (WRP), the USFWS Everglades Headwaters and other refuge proposal in south-central and southwest Florida), the Florida Fish and Wildlife Conservation Commission's Cooperative Conservation Blueprint, the USFWS Landscape Conservation Cooperatives, the Florida Panther recovery and conservation planning process, the Florida Black Bear State Management Plan, the Florida Black Bear Habitat Management Plan (Maehr et al. 2001), the South Florida Water Management District dispersed water storage program, etc. In particular, the Cooperative Conservation Blueprint regional pilot project provides an important reference for considering collaborative conservation opportunities that could result in regional landscape scale protection of functional ecological connectivity including recommendations for making the most of existing programs and developing new incentives to facilitate conservation (http://www.myfwc.com/conservation/special-initiatives/blueprint/). In addition, revitalizing funding for state land conservation programs including Florida Forever and the Rural and Family Lands Protection Act and ensuring funding for federal conservation programs including WRP and funding for the Everglades Headwaters National Wildlife Refuge is essential for protection for the climate change adaptation opportunities in the FEGN. Another important consideration is the concept that good rural planning is good urban planning and vice versa: protection of the FEGN is also dependent on developing future growth and transportation policies that result in minimization of sprawl and other related impacts on rural landscapes while providing livable communities for people. The work by Paul Zwick and Peggy Carr in this report makes very clear that without intelligent, well designed future growth and transportation plans, it will be extremely difficult to protect statewide functional ecological connectivity directly relevant to sea-level rise and climate change adaptation. Finally, we should also further assess the overlap between Florida panther and Florida black bear habitat and corridor conservation priorities and sea-level rise/climate change adaptation opportunities to foster potential synergies in planning for both, since both will require regional landscape-scale solutions.

5) Coastal to Inland Ecological Connectivity Recommendations— Viewed broadly, only two long stretches of coastline in Florida have good potential for unassisted coast-inland movement of species populations: the southern and western portion of the Everglades ecosystem, including Big Cypress Swamp and the Ten Thousand Islands, and the Big Bend Coast, where the Florida peninsula joins the Panhandle (**Figure 22**).

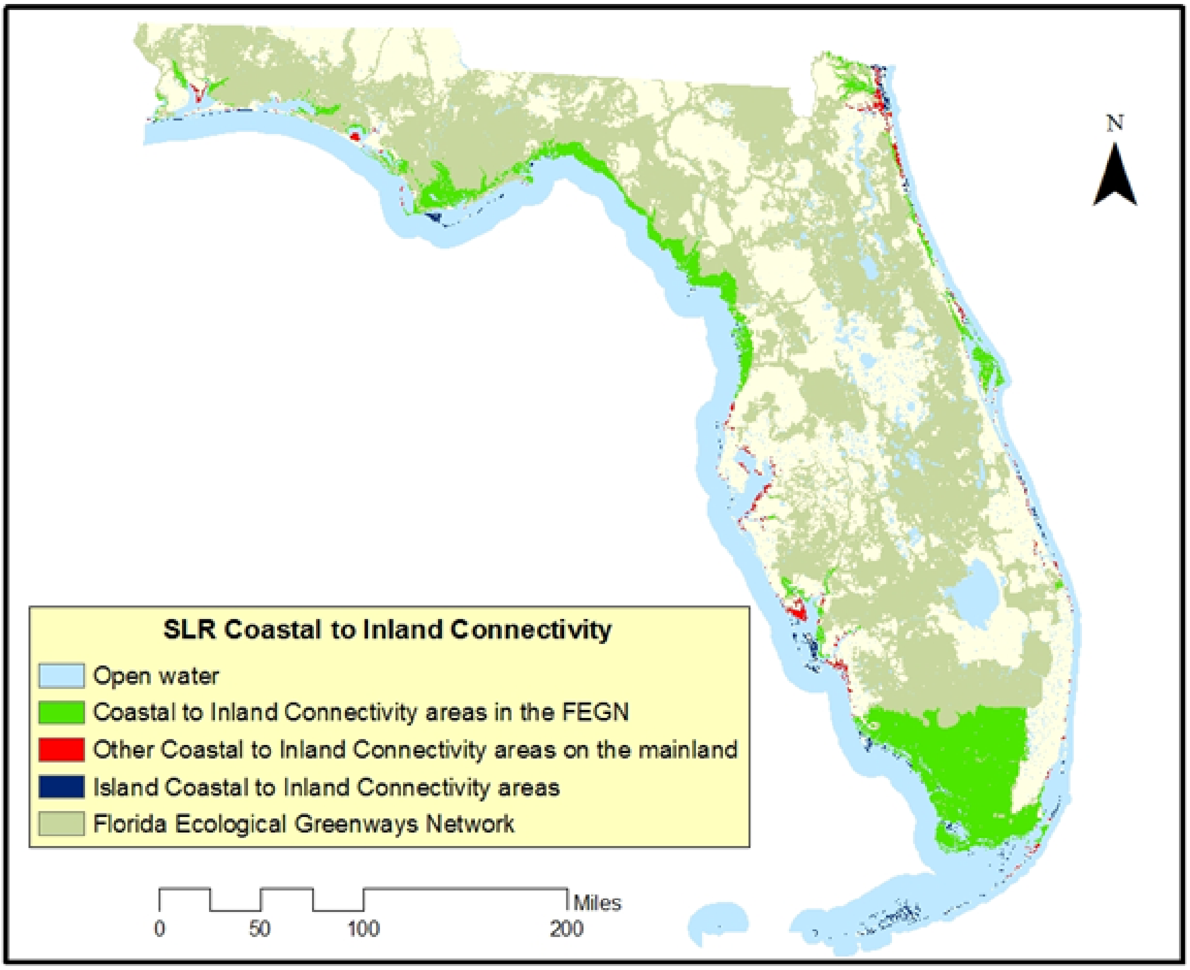


Figure 22 (repeated from Fig. 11). Areas of potential ecological connectivity from current coastal locations to areas inland with higher elevations. Areas in bright green are in mainland portions of the Florida Ecological Greenways Network (FEGN). These areas incorporate larger, intact, functionally connected swaths of land from current coastal natural communities that are likely the most significant opportunity areas for facilitating retreat/migration for a 3 meter sea-level rise projection or beyond. Areas in red are more limited coastal to inland connectivity areas on the mainland but not connected to the FEGN. These areas may be important for providing coastal to inland migration opportunities depending on location, focal species, and elevation gain, but they are also likely in closer proximity or at least partially isolated by intensive land uses. The dark blue areas are water edge to inland gradients on islands (or archipelagos) that likely provide only very limited opportunities for isolated inland migration within these islands only.

A higher-resolution analysis, based on the results of our coastal to inland ecological connectivity analysis, reveals the key focal areas for maintaining opportunities for coastal species to potentially retreat inland (see also the previous section and accompanying maps: Impact Assessment Results: Ecological Connectivity Assessment):

a. The Everglades ecosystem south of Lake Okeechobee, especially its southern and western portions (as opposed to eastern and southeastern portions, which abut much developed land)
b. Various landscapes around the eastern and northern shore of Charlotte Harbor in southwest Florida
c. Smaller habitat gradients around the Loxahatchee River and St. Lucie River in southeast Florida
d. Canaveral National Seashore and Merritt Island National Wildlife Refuge in east-central Florida
e. Guana Tolomato Matanzas National Estuarine Research Reserve in northeast Florida
f. Nassau River and St. Marys River in northeast Florida
g. Smaller habitat gradients around and near Tampa Bay in west-central Florida
h. The entire Big Bend coast from Chassahowitzka in the peninsula to Alligator Point/Apalachicola National Forest in the panhandle
i. Apalachicola Bay and River
j. Portions of intact shorelines along East Bay, West Bay, Choctawhatchee Bay, Pensacola Bay, and the Perdido River in the Florida panhandle.

Next steps for all of these opportunity areas include identifying protected versus unprotected opportunity areas and additional assessment of potential overlap with specific focal species habitat.

6) Recommendations for Next Steps for the Coastal to Inland Connectivity Analysis – For this project we identified intact or relatively intact landscapes that provide potential opportunities for facilitating functional retreat from sea-level rise. One important next step is to build on this analysis to identify additional relevant details and priorities. Proposed next steps include:

a. Conduct cost distance analysis to identify best potential corridors between current coastal natural communities to existing conservation lands beyond at least a 1m SLR.--This analysis would be an adaptation of methods used by FNAI and Tom Hoctor in previous work to identify potential corridors between habitat diversity hotspots below and above projected sea-level rise levels. We should consider using all current coastal natural communities to determine the best corridors from these coastal natural communities to or through (when available) existing conservation lands and Florida Forever projects.

b. Analysis of Additional Specific Species Regarding their Coastal to Inland Retreat Opportunities.--We have provided examples for two species, Florida salt marsh vole and Atlantic saltmarsh snake, regarding evaluation of potential coastal to inland retreat options for coastal species significantly threatened by sea-level rise. We will likely select additional species for similar analyses in the near future.

DISCUSSION

Although much work remains to be done to address the potential impacts of sea-level rise on species and natural communities in Florida, and how adaptation for nature can be best reconciled with adaptation for humans, this study gives natural resource policy and planning professionals, researchers, land managers, and the conservation community in Florida an opportunity to begin re-considering existing conservation priorities (i.e., the Florida Ecological Greenways Network, Strategic Habitat Conservation Areas, Florida Forever Acquisition list, CLIP, FNAIHAB, and others) and policies in light of sea-level rise, climate change, and development projections. This is a critical next step in conservation planning, and land-use planning in general, in Florida. As can be seen from this study, substantial opportunities remain to facilitate adaptation of imperiled species and natural communities, but there are also many potential hurdles and great risks from existing and future development, sea-level rise, climate change, and the unanticipated or unknown feedbacks and synergistic impacts resulting from combinations of these threats. Significant natural areas at risk include the Everglades, Florida

Keys, Merritt Island area, and the Big Bend coast, although all of these areas except the Keys are also significant areas for potential adaptation (e.g., with favorable coast-inland connectivity). Existing natural communities in these areas must be managed for greater resiliency, barriers should be reduced and avoided that inhibit the opportunities for dispersal, and actions taken in the case of some focal species to assist in adaptation, for example through managed relocation. Protecting existing coastal to inland ecological connectivity opportunities, and expanding the terrestrial portions of existing managed areas will also be necessary.

Additional research is needed in various areas to add detail to our knowledge of potential ecological responses, adaptive potential of focal species, potential human responses to sea-level rise (e.g., where will people move when current coastal development has to be abandoned?), and further assessment with existing or future tools for predicting changes in natural communities and species habitat based on sea-level rise projections (such as more detailed SLAMM models or similar assessments) for the entire Florida coastline and St. Johns River. Nevertheless, our assessment provides a strong foundation for selecting focal species and impact areas for more detailed assessments, assessing the potential negative synergies between sea-level rise and future projected development, and determining priorities for maintaining and restoring both coastal to inland ecological connectivity and a statewide ecological network essential for facilitating adaptation to sea-level rise, climate change, and an expanding human population.

CONCLUSIONS

The challenges to Florida's native biodiversity are daunting, but we believe that with careful science-based planning it should be possible to mitigate many of the potential impacts from sea-level rise and future land-use change. The work completed in this project is a first broad stroke at identifying the steps necessary to adequately plan for and assist in adaptation of our natural communities, native species, and landscapes to an uncertain but definitely dynamic future.

Literature Cited

(Note that literature cited is also included separately for each appendix where necessary)

Alongi, D.M. 2008. Mangrove forests: resilience, protection from tsunamis, and responses to global climate change. Estuarine Coastal Shelf Science 76:1-13

Arkema, K.K., G. Guannel, G. Verutes, S.A. Wood, A. Guerry, M. Ruckelshaus, P. Kareiva, M. Lacayo, and J.M. Silver. 2013. Coastal habitats shield people and property from sea-level rise and storms. Nature Climate Change 3:913-918.

Benson, J.S. 2006. New South Wales vegetation classification and assessment: Introduction – the classification, database, assessment of protected areas and threat status of plant communities. Cunninghamia 9: 331-382.

Carr, M. H. and P. D. Zwick. 2007. Smart land-use analysis: the LUCIS model land use identification strategy. ESRI Press, Redlands, California.

Cazenave, A., H.-B. Dieng, B. Meyssignac, K. von Schuckmann, B. Decharme, and E. Berthier. 2014. The rate of sea-level rise. Nature Climate Change 4:358-361.

Cheong, S.-M., B. Silliman, P.P. Wong, B. van Wesenbeeck, C.-K. Kim, and G. Guannel. 2013. Coastal adaptation with ecological engineering. Nature Climate Change 3:787-791.

Deegan, L.A., D.S. Johnson, R.S. Warren, B.J. Peterson, J.W. Fleeger, S. Fagherazzi, and W.M. Wollheim. 2012. Coastal eutrophication as a driver of salt marsh loss. Nature 490:388-392.

Duarte, C.M., I.J. Losada, I.E. Hendriks, I. Mazarrasa, and N. Marbà. 2013. The role of coastal plant communities for climate change mitigation and adaptation. Nature Climate Change 3:961–968.

Faber-Langendoen, D., L. Master, A. Tomaino, K. Snow, R. Bittman, G. Hammerson, B. Heidel, J. Nichols, L. Ramsay, and B. Young. 2009. NatureServe Conservation Status Ranking System: Methodology for Rank Assignment. NatureServe, Arlington, VA.

Furukawa, K., E. Wolanski, and H. Mueller. 1997. Currents and sediment transport in mangrove forests. Estuarine Coastal Shelf Science 44:301-310.

Gleason, H. A. 1926. The individualistic concept of the plant association. Bulletin of the Torrey Botanical Club 53:7–26.

Hall, , M.J., and O.H. Pilkey. 1991. Effects of hard stabilization on dry beach width for New Jersey. Journal of Coastal Research 7:771-785.

Harrington, J., and T. Walton. 2008. Climate Change in Coastal Areas in Florida: Sea Level Rise Estimation and Economic Analysis to Year 2080. Florida State University report funded by a grant from the National Commission on Energy Policy. http://www.cefa.fsu.edu/content/download/47234/327898/file/FSU%208%2014%202008%20final.pdf.

Harris, L. D. 1985. Conservation corridors: a highway system for wildlife. ENFO Report 85-5, Florida Conservation Foundation, Winter Park, Florida.

Harris, L. D., and P. B. Gallagher. 1989. New initiatives for wildlife conservation: the need for movement corridors. Pages 12-34 in G. Macintosh, editor. In defense of wildlife: preserving communities and corridors. Defenders of Wildlife, Washington D.C.

Harris, L. D., and K. Atkins. 1991. Faunal movement corridors in Florida. Pages 117-134 in W.E. Hudson, editor. Landscape linkages and biodiversity. Island Press. Defenders of Wildlife, Washington, D.C.

Harris, L. D., and W. P. Cropper, Jr. 1992. Between the devil and the deep blue sea: implications of climate change for Florida's fauna. Pages 309-324 in R. L. Peters and T. E. Lovejoy, editors. Global warming and biological diversity. Yale University Press, New Haven, Connecticut.

Harris, L. D., and J. Scheck. 1991. From implications to applications: the dispersal corridor approach to the conservation of biological diversity. Pages 189-220 in D.A. Saunders and R. J. Hobbs, editors. Nature conservation 2: the role of corridors. Surrey Beatty and Sons, Chipping Norton, New South Wales, Australia.

Hoegh-Guldberg, O., L. Hughes, S. McIntyre, D.B. Lindenmayer, C. Parmesan, H.P. Possingham, and C.D. Thomas. Assisted colonization and rapid climate change. Science 321:345-346.

Holdaway, R. J., Wiser, S. K. And Williams, P. A. 2012. Status Assessment of New Zealand's Naturally Uncommon Ecosystems. Conservation Biology, 26: 619–629.

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability, http://www.ipcc.ch/report/ar5/wg2/.

Kirwan, M.L., and P. Megonigal. 2013. Tidal wetland stability in the face of human impacts and sea-level rise. Nature 504:53-60.

Knight, G.R., editor. 2011. Atlas of Florida's Natural Heritage: Biodiversity, Landscapes, Stewardship, and Opportunities. Florida State University, Tallahassee.

Kosaka, Y., and S.-P. Xie. 2013. Recent global-warming hiatus tied to equatorial Pacific surface cooling.

Lambeck, K., and J. Chappell. 2001. Sea level change through the last glacial cycle. Science 292:679-686.

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

Maschinski, J., M. Ross, H. Liu, J. O'Brien, E. von Wettberg, and K. Haskins. 2011. Sinking ships: conservation options for endemic taxa threatened by sea-level rise. Climatic Change 107:147-167.

McKee, K.L., D.R. Cahoon, and I.C. Feller. Caribbean mangroves adjust to rising sea level through biotic controls on change in soil elevation. Global Ecology and Biogeography 16:545-556

McIvor, A.L., T. Spencer, I. Möller, and M. Spalding. 2013 The response of mangrove soil surface elevation to sea-level rise. Natural Coastal Protection Series: Report 3. Cambridge Coastal Research Unit Working Paper 42. Published by The Nature Conservancy and Wetlands International. 59 pages. ISSN 2050-7941. URL: http://coastalresilience.org/science/mangroves/surface-elevation-and-sea-level-rise

Miami Herald, April 28, 2014. Task force on rising seas says Miami-Dade County needs step-by-step plan. http://www.miamiherald.com/2014/04/28/4085935/task-force-on-rising-seas-says.html#storylink=cpy

Muhs, D.R., K.R. Simmons, R.R. Schumann, and R.B. Halley. 2011. Sea-level history of the past two interglacial periods: new evidence from U-series dating of reef corals from south Florida. Quaternary Science Reviews 30:570-590.

National Climate Assessment (NCA). 2014. Climate Change Impacts in the United States, http://nca2014.globalchange.gov

Nicholson, E., D.A. Keith, and D.S. Wilcove. 2009. Assessing the threat status of ecological communities. Conservation Biology 23:259-274.

Noss, R. F. 1987. Protecting natural areas in fragmented landscapes. Natural Areas Journal 7:2-13.

Noss, R.F. 2011. Between the devil and the deep blue sea: Florida's unenviable position with respect to sea-level rise. Climatic Change 107:1-16.

Noss, R.F. 2013. Forgotten Grasslands of the South: Natural History and Conservation. Island Press, Washington, D.C.

Noss, R. F., and L. D. Harris. 1986. Nodes, networks, and MUMs: preserving diversity at all scales. Environmental Management 10:299-309.

Noss, R. F., and C. A. Cooperrider. 1994. Saving nature's legacy: protecting and restoring biodiversity. Defenders of Wildlife and Island Press, Washington, D.C.

Paal, J. 1998. Rare and threatened plant communities of Estonia. Biodiversity and Conservation 7:1027-1049.

Pilkey, O.H., and H.L. Wright. 1988. Seawalls versus beaches. Journal of Coastal Research 4:41-64.

Pilkey, O.H., and R. Young. 2009. The Rising Sea. Island Press, Washington, D.C.

Rahmstorf, S., M. Perrette, and M. Vermeer. 2012. Testing the robustness of semi-empirical sea level projections. Climate Dynamics 39:861-875, doi:10.1007/s00382-011-1226-7.

Reece, J.S., and R.F. Noss. 2014. Prioritizing species by conservation value and vulnerability: a new index applied to species threatened by sea-level rise and other risks in Florida. Natural Areas Journal 34:31-45.

Reece, J.S., R.F. Noss, J. Oetting, T. Hoctor, and M. Volk. 2013. A vulnerability assessment of 300 species in Florida: threats from sea-level rise, land use, and climate change. PLOS One 8(11): e80658. doi:10.1371/journal.pone.0080658.

Ricciardi, A., and D. Simberloff. 2009. Assisted colonization is not a viable conservation strategy. Trends in Ecology and Evolution 24:248-253.

Rodriguez, A.B., F.J. Fodrie, J.T. Ridge, N.L. Lindquist, E.J. Theuerkauf, S.E. Coleman, J.H. Grabowski, M.C. Brodeur, R.K. Gittman, D.A. Keller, and M.D. Kenworthy. 2014. Oyster reefs can outpace sea-level rise. Nature Climate Change 4:493-497, doi:10.1038/nclimate2216.

Rodríguez, J. P., Rodríguez-Clark, K. M., Baillie, J. E. M., Ash, N., Benson, J., Boucher, T., Brown, C., Burgess, N. D., Collen, B., Jennings, M., Keith, D. A., Nicholson, E., Revenga, C., Reyers, B., Rouget, M., Smith, T., Spalding, M., Taber, A., Walpole, M., Zager, I. And

Zamin, T. 2011. Establishing IUCN Red List Criteria for Threatened Ecosystems. Conservation Biology, 25: 21–29.

Ross, M.S., Meeder, J.F., Sah, J.P., Ruiz, P.I., Telesnicki, G.J., 2000. The Southwest Saline Everglades revisited: 50 years of coastal vegetation change. Journal of Vegetation Science 11, 101e112.

Souto, L. 2012. Landscaping perceptions and behaviors : socio-ecological drivers of nitrogen in the residential landscape. Dissertation. University of Central Florida, Orlando, FL.

Temmerman, S., P. Meire, T.J. Bouma, P.M.J. Herman, T. Ysebaert, and H.J. De Vriend. 2013. Ecosystem-based coastal defence in the face of global change. Nature 504:79-83.

Vermeer, M., and S. Rahmstorf. 2009. Global sea level linked to global temperature. Proceedings of the National Academy of Science 106:21527-21532.

Whittaker, R. H. 1962. Classification of natural communities. Botanical Review 28:1–239.