Predicting and Mitigating the Effects of Sea Level Rise and Land Use Changes on Imperiled Species and Natural Communities in Florida

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ABSTRACT

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 virtually all of the Species of Greatest Conservation Need (SGCN) and priority natural communities identified in the Florida Comprehensive Wildlife Conservation Strategy (FCWCS). Coupled with interacting impacts from human population shifts and land-use changes – which will be exacerbated by sea level rise – this may constitute the most fundamental and important challenge facing biodiversity conservation in Florida.

The goal of this project was to create a detailed assessment of the combined impacts of sea level rise and land-use changes on imperiled species and habitat throughout the state, which have been used to develop spatially explicit, science-based adaptive strategy recommendations to assist policy decisions. 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 that builds on the results and methodology of this project.
ACKNOWLEDGEMENTS

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 (FFWCC), Ryan Butryn (FFWCC), 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. Finally, we thank the FWC State Wildlife Grant management staff and our reviewers at FWC for their able assistance managing the grant and providing useful suggestions for improving the reporting of this work.

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INTRODUCTION

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 virtually all of the Species of Greatest Conservation Need (SGCN) and priority natural communities identified in the Florida Comprehensive Wildlife Conservation Strategy (FCWCS). Coupled with interacting impacts from human population shifts and land-use changes – which will be exacerbated by sea level rise – this may constitute the most fundamental and important challenge facing biodiversity conservation in Florida.

The goal of this project was to conduct an assessment of the potential impacts of sea level rise and land-use change in Florida on high priority natural communities and species identified in Florida’s Comprehensive Wildlife Conservation Strategy. Such an assessment is necessary for developing conservation strategies, including identification and protection of functional connectivity, that will avoid, minimize, and mitigate anticipated impacts. 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; as a result the project results are more robust thanks to their combined support.
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 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 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) data, and future 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 that 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 defining specific adaptive strategies. This included both quantitative GIS overlay assessments, as well as qualitative and quantitative assessments using a tool developed specifically for this project called 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 natural communities SIVVA results will be provided at completion of the Kresge funding. The SIVVA tool is comparable to tools such as the IUCN Red List criteria, the US Endangered Species Act (ESA) listing criteria, and NatureServe’s Conservation Status Assessments or Climate Change Vulnerability Index (CCVI), using expert reviewers and primary literature to assess the vulnerabilities of species and natural communities. However, for a variety of reasons, we felt it was necessary to create a customized vulnerability assessment tool that would be used specifically for this project but could also be applied in future work. The rationale behind this tool, 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 Update)

Impact Assessments

- Natural Community Model Overlay Analysis
- SGCN Initial Information and Risk Assessment Analysis for Focal Species
- Ecological Connectivity Analysis

- Species Occurrence Overlay Analysis
- Habitat Model Overlay Analysis
- SIVVA Analysis
- Additional Analyses

Results

- Natural Communities, Focal Species, Ecological Connectivity, and Hotspots

Recommendations and Strategies

- Future Land Use, Focal Species and Natural Communities, Ecological Connectivity
Technical Advisory Group

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 this report, a summary of the meeting, and our topics of discussion to the entire TAG, including those who weren't present after the meeting. There were no consensus recommendations that came out of the TAG, but 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; however, comments from the TAG may be incorporated into future land use change
scenario modeling. In addition there were several technical questions about the SLAMM models and their incorporation into SIVVA and other impact analyses, which didn’t 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, which will be devoted to this project and contain relevant project data and information. Currently the website contains a project synopsis and links to relevant publications. The final project report will be uploaded to the site upon final approval by FFWCC, with direct links to any specific information/appendices from the project that are important to highlight. The current link for this website is:

http://conservation.dcp.ufl.edu/Projects.html. Additionally, we have developed a listserv of TAG members, individual partners, agencies, and institutional contacts. Upon final approval of our report by FFWCC, we will send a link to our website, along with information about the project, resources available, final report, and continuing work on the project. We will continue to update the website with new information as it is developed for the Kresge portion of this project, and will periodically notify this network of partners as new resources are available.

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 (described elsewhere) 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 (in press, 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. *(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 FFWCC (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. 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 3 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 been run for the Florida Keys, but this data was 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 worked with 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.

**Updated 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. A full description of the FEGN update and data are provided in the final report for State Wildlife Grant project number 10066.

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.*

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. Each level of assessment will constitute a deliverable for either FWC and/or the Kresge Foundation. The focal species assessments that are FWC deliverables have been completed. However once our grant with the Kresge Foundation is complete in mid-2014, results from the remaining assessments will be provided as well.

The results of ALL deliverables completed for FWC have been used to inform the analyses of sea level rise/development impacts and adaptation strategies included in this report. 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 that we have completed to date are the results and 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 below.

<table>
<thead>
<tr>
<th>Assessment</th>
<th>FWC Deliverable</th>
<th>Kresge Deliverable</th>
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<tbody>
<tr>
<td>1) SGCN Initial Information and Risk Assessment</td>
<td>Analysis of all 1036 species from the draft revised SGCN</td>
<td>Analysis of 1036 species from the draft revised SGCN</td>
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<tr>
<td>2) Species Occurrence Overlay Analysis</td>
<td>Analysis of approximately 700 animal species</td>
<td>Analysis of approximately 1049 species including plants</td>
</tr>
<tr>
<td>3) Standardized Index of Vulnerability and Value Assessments (SIVVA)</td>
<td>Analysis of approximately 216 SGCN species</td>
<td>Analysis of approximately ~325 species including plants</td>
</tr>
<tr>
<td>4) Habitat Model Overlay Analysis</td>
<td>Analysis of approximately 150 animal species</td>
<td>Analysis of ~150 species plus additional species as needed</td>
</tr>
<tr>
<td>5) Predictive Distribution Modeling</td>
<td>--</td>
<td>Analysis of ~50 focal species</td>
</tr>
<tr>
<td>6) Spatially Explicit Population Viability Analysis</td>
<td>--</td>
<td>Analysis of ~10-15 focal species</td>
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</table>
1) SGCN Initial Information and SLR Risk Assessment (Deliverable 1).—This deliverable constitutes the first step in selecting species from the SGCN 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. Species to be assessed for the Kresge Foundation in Deliverables 5-6 are still being finalized.

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 whose occurrence data was 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 were 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 Hagan, 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 now 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, and are in the process of analyzing results. 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.

Additional Analyses.—These additional analyses are deliverables for our Kresge Foundation grant so will not be complete by the end of our contract with FWC. However results will be provided to FWC upon completion of the Kresge project.

5) Predictive Distribution Modeling (Deliverable 5).—For approximately 50 plant and animal species (chosen based on data availability and vulnerability to sea level rise), we will
conduct predictive distribution modeling (Maxent, hierarchical Bayesian, etc.) based on a range of possible climate, geophysical, and other environmental variables to further assess potential impacts of climate change and sea level rise (as indicated by sea level rise projections, SLAMM model results, and other natural community modeling). We are collaborating 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, and niche modeling analyses are ongoing.

6) Spatially Explicit Population Viability Analysis (Deliverable 6).—For up to 10-15 SGCN species for which extensive demographic and life history data are available and which are most representative of conservation challenges related to sea level rise, we are planning to conduct spatially explicit population viability analysis (e.g. Ramas or Hexsim) to further assess sea level rise impacts (as indicated by sea level rise scenarios, SLAMM, and other natural community modeling). Primary work on this deliverable has yet to begin, and it’s possible that this work will not be completed as part of the Kresge Foundation project due to unanticipated large amount of time required for the species distribution (niche) modeling, the natural communities vulnerability assessment, and the species-specific evaluation of adaptation options.

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 retreat inland based on current available habitat and intact landscapes leading inland; and 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. One additional analysis was also conducted, which is also relevant to ecological connectivity. This 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 to future coastal habitat inland. 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 a 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 CLIP Landuse Intensity (Landuse Intensity is one of the two landscape indices used to create the CLIP Landscape Integrity dataset) values of 5 or higher, 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 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; 2) we developed a GIS layer that identifies the maximum elevation that each opportunity area patch reaches (up to 3 meters); 3) 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) Coastal species heavily inland retreat opportunity examples.—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 lands 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.
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

**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. 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 left out 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 actual sea level, the changes to sea level will cause other communities (likely salt marsh and mangrove in most cases) to shift into areas of 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-meter sea level rise scenarios. For communities mapped comprehensively across the state, five show a loss of at least 50% of 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. Additional communities mapped in limited sites show significant impacts, including coastal rockland lake, keys cactus barren, and coastal hydric hammock.

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.
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 approximately a 3m sea level rise projection (Figure 3). From a statewide perspective based on largest swaths of included land, examples of the best opportunities include the Everglades, Big Bend, Cape Canaveral National Seashore and Merritt Island National Wildlife Refuge, and northeast Florida. However, we would also like to make clear that this analysis result is just as important for what is not included as what is. Coastal natural communities and especially estuarine wetlands are common across Florida even in developed areas. However, 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 is would seem unlikely to occur at a scale relevant for significant shifts inland to address potential sea level rise ranging from 1-3m). 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.
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 4). Second, we developed a GIS layer that identifies the maximum elevation that each
opportunity area patch reaches up to 3m (Figure 5). 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 6).

Figure 4. This map shows the areas of coastal to inland connectivity areas 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 3m) are considered to provide the best opportunities.
Figure 5. This map shows 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 6. This map shows the 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) 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 above 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. 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 7-8 and Tables 1-2).

Figure 7. This map shows inland retreat opportunity for salt marsh vole habitat where habitat in green is considered to have higher potential for inland retreat whereas the habitat in red is considered to low to no potential.
Figure 8. This map shows inland retreat opportunity for Atlantic saltmarsh snake habitat where habitat in green is considered to have higher potential for inland retreat whereas the habitat in red is considered to low to no potential.

Table 1. Acres of salt marsh vole habitat in elevation average classes.

<table>
<thead>
<tr>
<th>Average Elevation (meters)</th>
<th>Acres</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>187.4</td>
<td>4.0%</td>
</tr>
<tr>
<td>1.2</td>
<td>20.2</td>
<td>0.4%</td>
</tr>
<tr>
<td>1.5</td>
<td>4,701.5</td>
<td>99.6%</td>
</tr>
</tbody>
</table>

Table 2. Acres of Atlantic saltmarsh snake habitat in elevation average classes.

<table>
<thead>
<tr>
<th>Average Elevation (meters)</th>
<th>Acres</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>6,630.7</td>
<td>86.23%</td>
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<tr>
<td>1.1</td>
<td>676.2</td>
<td>8.79%</td>
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<td>1.2</td>
<td>154.7</td>
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</tr>
<tr>
<td>1.3</td>
<td>3.3</td>
<td>0.04%</td>
</tr>
<tr>
<td>1.5</td>
<td>222.4</td>
<td>2.89%</td>
</tr>
<tr>
<td>2.0</td>
<td>0.4</td>
<td>0.01%</td>
</tr>
<tr>
<td>2.1</td>
<td>2.0</td>
<td>0.03%</td>
</tr>
</tbody>
</table>
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, and 1) the most recent Florida Forever Board of Trustees Project database, obtained from FNAI, and 2) the most recent dataset of Florida Managed Areas, also obtained from FNAI (Figures 9-10). 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. 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. 200 properties are projected to lose 90% or more. Appendices 9a and 9b contain detailed projected inundation calculations for both existing conservation lands and Florida Forever priorities.

A couple basic conclusions can be drawn from this analysis. For example, 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 hopefully an additional goal may be to continue to expand existing
conservation areas beyond existing acreages to further assist in species adaptation to sea level rise and to mitigate potential impacts of land use change. 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 9. Impacts to Florida Forever Acquisition Projects from 1m Sea Level Rise
Figure 10. Impacts to Existing Managed Areas and Conservation Lands from 1m Sea Level Rise
Impact Assessment Results: Land Use and Sea Level Rise Impact Hotspots

One way to summarize species and natural community impacts is to overlay existing models of conservation priorities for species and communities onto sea level rise and development projections. For clarity, only the DEM 1-meter projections were used for the SLR overlays, while the development projections are limited to Scenario “SLR 2”.

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 heritage global and state rarity 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 (Figure 11). About 20 percent of the highest priorities are impacted at 1-meter of sea level rise, and 11% of all priorities (Table 3). Projected impacts from development in 2060 are more dispersed, but notable in both southwest and northeast Florida (Figure 12). About five percent of high priorities are impacted by development, and 11 percent overall (Table 4). Combined impacts from SLR and development amount to about a quarter of high priorities, and 21 percent overall (table xxx).

The Florida Fish and Wildlife Conservation Commission’s Strategic Habitat Conservation Areas (SHCA) focus on habitat conservation needs for vertebrates, and include all of the FWC habitat models included in this study. SHCA impacts are focused in similar areas as FNAIHAB, with additional higher priority impacts seen in the Charlotte Harbor region and Merritt Island (Figure 13). About 15% of the highest priorities are impacted at 1-meter of sea level rise, and
13% of all priorities (Table 3). As with FNAIHAV, projected impacts from development are more dispersed but are notable in northeast and north central Florida (Figure 14). About five percent of highest priorities and eight percent overall would be impacted. Combined impacts from SLR and development amount to about 20 percent of high priorities and overall (Table 4).

Under-represented natural communities are a subset of Florida natural communities that have been identified as priorities for the Florida Forever program (and CLIP). These communities are considered under-represented on conservation lands in proportion to their historic extent in the state. While not all of the focal communities of this study are included, they represent consensus priorities for conservation. Impact areas are similar to those for species habitat, but are particularly concentrated on barrier island coastal uplands, salt marsh and mangrove wetlands, and the Florida Keys (Figure 15). High G1 community impacts (34%) are entirely pine rocklands, while very high impacts for G5 communities (70%) are expected due to coastal wetlands (primarily salt marsh and mangrove) (Table 3). Projected impacts from development are notable in north central Florida (Figure 16). Impacts from development are slight among the priority G1 communities (upland glade and pine rockland) and eight percent overall (Table 4).

These overlays address impacts to current conservation priority areas. In future analyses we will explore re-weighting species and community models based on sea level rise and climate change and projected development impacts, using SIVVA and GIS overlay results, to assess how and where conservation priorities may change in response to projected impacts.
Figure 11. FNAI Rare Species Habitat Conservation Priority Impacts from 1m Sea Level Rise
Figure 12. FNAI Rare Species Habitat Conservation Priority Impacts from 2060 Development
Figure 13. Florida Forever Priority Natural Community Impacts from 1m Sea Level Rise
Figure 14. Florida Forever Priority Natural Community Impacts from 2060 Development
Figure 15. FWC Strategic Habitat Conservation Priority Impacts from 1m Sea Level Rise
Figure 16. FWC Strategic Habitat Conservation Priority Impacts from 2060 Development
### Table 3. Impacts of Sea Level Rise on Species and Natural Community Conservation Priorities

#### FNAI Rare Species Habitat Conservation Priorities

<table>
<thead>
<tr>
<th>Priority</th>
<th>Total Hectares</th>
<th>Hectares Impacted at 1-meter SLR</th>
<th>Percent Impacted</th>
</tr>
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<tbody>
<tr>
<td>Priority 1</td>
<td>329,831</td>
<td>63,185</td>
<td>19%</td>
</tr>
<tr>
<td>Priority 2</td>
<td>1,068,504</td>
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<tr>
<td>Total</td>
<td>8,175,224</td>
<td>878,695</td>
<td>11%</td>
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Data version: FNAIHAB-CLIP version 3.0, Nov 2013

#### FWC Strategic Habitat Conservation Areas

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<tr>
<th>Priority</th>
<th>Total Hectares</th>
<th>Hectares Impacted at 1-meter SLR</th>
<th>Percent Impacted</th>
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<tbody>
<tr>
<td>Priority 1</td>
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<td>77,116</td>
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<td>Priority 2</td>
<td>4,664,288</td>
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<td>Priority 3</td>
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<td>286,798</td>
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<tr>
<td>Priority 5</td>
<td>444,701</td>
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<tr>
<td>Total</td>
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Data version: SHCA 2009 update, as prioritized for CLIP

#### Florida Forever Conservation Needs Assessment: Under-Represented Natural Communities

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<thead>
<tr>
<th>Global Heritage Rank</th>
<th>Total Hectares</th>
<th>Hectares Impacted at 1-meter SLR</th>
<th>Percent Impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>6,790</td>
<td>2,317</td>
<td>34%</td>
</tr>
<tr>
<td>G2</td>
<td>286,918</td>
<td>6,134</td>
<td>2%</td>
</tr>
<tr>
<td>G3</td>
<td>451,045</td>
<td>8,503</td>
<td>2%</td>
</tr>
<tr>
<td>G4</td>
<td>943,466</td>
<td>25,794</td>
<td>3%</td>
</tr>
<tr>
<td>G5</td>
<td>571,537</td>
<td>398,330</td>
<td>70%</td>
</tr>
<tr>
<td>Total</td>
<td>2,259,756</td>
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</table>

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 4. Combined Impacts of Sea Level Rise and Development Projections on Species and Natural Community Conservation Priorities

<table>
<thead>
<tr>
<th>FNAI Rare Species Habitat Conservation Priorities</th>
<th>Hectares Impacted by 1-meter SLR OR 2060</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Hectares</td>
<td>Development</td>
</tr>
<tr>
<td>Priority 1</td>
<td>329,831</td>
</tr>
<tr>
<td>Priority 2</td>
<td>1,068,504</td>
</tr>
<tr>
<td>Priority 3</td>
<td>1,110,649</td>
</tr>
<tr>
<td>Priority 4</td>
<td>2,017,245</td>
</tr>
<tr>
<td>Priority 5</td>
<td>2,160,989</td>
</tr>
<tr>
<td>Priority 6</td>
<td>1,488,007</td>
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<tr>
<td>Total</td>
<td>8,175,224</td>
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</tbody>
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Data version: FNAIHAB-CLIP version 3.0, Nov 2013

<table>
<thead>
<tr>
<th>FWC Strategic Habitat Conservation Areas</th>
<th>Hectares Impacted by 1-meter SLR OR 2060</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Hectares</td>
<td>Development</td>
</tr>
<tr>
<td>Priority 1</td>
<td>583,818</td>
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<tr>
<td>Priority 2</td>
<td>4,664,288</td>
</tr>
<tr>
<td>Priority 3</td>
<td>1,668,971</td>
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<tr>
<td>Priority 4</td>
<td>32,679</td>
</tr>
<tr>
<td>Priority 5</td>
<td>444,701</td>
</tr>
<tr>
<td>Total</td>
<td>7,394,456</td>
</tr>
</tbody>
</table>

Data version: SHCA 2009 update, as prioritized for CLIP

<table>
<thead>
<tr>
<th>Florida Forever Conservation Needs Assessment: Under-Represented Natural Communities</th>
<th>Hectares Impacted by 1-meter SLR OR 2060</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Hectares</td>
<td>Development</td>
</tr>
<tr>
<td>G1</td>
<td>6,790</td>
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<tr>
<td>G2</td>
<td>286,918</td>
</tr>
<tr>
<td>G3</td>
<td>451,045</td>
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<tr>
<td>G4</td>
<td>943,466</td>
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<tr>
<td>G5</td>
<td>571,537</td>
</tr>
<tr>
<td>Total</td>
<td>2,259,756</td>
</tr>
</tbody>
</table>

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
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 identified a series of recommendations and adaptation strategies for species and 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 Patterns

Changes in Urban Density.— This study and the pattern of urban development that results from population growth and static gross urban densities reinforces previous results to clearly demonstrate that continued suburban greenfield development, particularly at low densities, will result in the loss of productive agricultural lands and natural areas so important to maintaining Florida’s quality of life. The 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 and the potential for habitat migration that may become essential to species survival with the advent of climate change.

Recommendations.— To prevent or minimize these losses we recommend that the density of new development and areas being redeveloped be increased, and that protections be established for high priority natural and agricultural lands. 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 were 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.

**Increased Urban Density.**— Increased urban densities 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 just that with even minor increases in density, the land needed to support population growth can be reduced and the quality of life can be enhanced. It is also noted that 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. However 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 deserve, natural areas and agricultural lands are needed if for no other reason than to protect the ecosystem services on which we depend. 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 Response to Sea Level Rise.**—The advent of sea level rise for our peninsular State, requires additional changes to the allocation of land regardless of urban densities. The recommendations are very obvious, but certainly worth underscoring.

**Recommendations.**—Cease construction and redevelopment in areas projected to be inundated in the next fifty years including:

1) Coastal areas, and
2) Low-lying inland areas, especially those adjacent to our rivers.
Potential Adaptation Options for Species Vulnerable to Sea Level Rise in Combination with Threats from Changes in Land Use and Climate (Temperature and Precipitation)

As shown by the abundant empirical support for Henry Gleason’s (1926) “individualistic concept of the plant association” (Whittaker 1962), 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 40 highest priority species, we eliminated six that are unlikely to be strongly affected by SLR, but are more vulnerable to other threats: Florida grasshopper sparrow, whooping crane, Florida scrub-jay, snail kite, Blue Spring hydrobe snail, and red-cockaded woodpecker.

For the remaining 34 species (See Appendix 10. Note that Appendix 10 should be reviewed in conjunction with Appendix 1d, which provides further description of items included in the table) we scored each species for six adaptation options, in terms of the suitability, feasibility, and estimated probability of success of that option for the species in question. 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 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 34 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 (< year 2050) and the long-term (> 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. Additionally, the distances required for translocation are generally short (a few miles to a few dozen miles), the species in many cases have 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, 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.

**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 vulnerable species
go extinct. Further information obtained through research would improve confidence in our
results (*Appendix 10*) 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 low 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, but the feasibility of
specific adaptation actions for this group is highly uncertain.

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. 120,000 years ago? We lack information to answer this 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 these high-priority species at risk of extinction should be implemented as quickly as possible, certainly within the next decade. 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 and seawalls) 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 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 Mecgonigal 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). This is an adaptive response and 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 through 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. Currently this 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. However, local conservationists have been working to protect this corridor including efforts to get 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.** The last recommendation for modifying priorities or other modifications to the FEGN involve a more general consideration of climate change. The FEGN has been primarily focused on prioritizing and protecting functional ecological connectivity to create a
statewide ecological network from the Everglades to the tip 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 or nearby 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 considering adding specific resource or ecological process priorities as a subset of the FEGN database. For the purposes of this project, 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. However, 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/](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--Based on the results of our coastal to inland ecological connectivity analysis, focal areas for maintaining opportunities of coastal species to potentially retreat inland include:

a. The Everglades ecosystem south of Lake Okeechobee
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 to Alligator Point/Apalachicola National Forest

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 report we identified intact or relatively intact landscapes that provide potential opportunities for facilitating functional retreat from sea level rise. One important objective 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 the Tom Hoctor in previous work to identify potential corridor between habitat diversity hotspots below and above projected sea level rise levels. In this case, we would 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 possibly 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

Though much work remains to be done to address the potential impacts of sea level rise, this study gives natural resource policy and planning professionals, researchers, land managers, and the conservation community in Florida the first opportunity to begin re-considering existing conservation priorities (i.e. the Florida Ecological Greenways Network, Strategic Habitat Conservation Areas, Florida Forever Acquisition list, CLIP, FNIAHAB, and others) and policies in light of sea level rise, climate change, and development projections. This is one of the next large steps in conservation planning in Florida. As can be seen in this study, there are still opportunities 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 impacts resulting from all of these variables. Obvious significant areas of impact are in the Everglades, Florida Keys, Merritt Island area, and Big Bend. Existing natural communities in these areas must be managed for greater resiliency, barriers should be reduced and avoided that inhibit the opportunities for adaptation, and proactive action may be necessary in the case of some focal species to assist in adaptation. Protecting existing coastal to inland ecological connectivity opportunities, and expanding the terrestrial portions of existing managed areas will also be
important. Of course, additional research is needed in various areas to continue to add detail to potential ecological responses, adaptive potential of focal species, potential human responses to sea level rise (e.g., where will people move to 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 or at least focal impact areas). However, this 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 priorities for maintaining and restoring both coastal to inland ecological connectivity and a statewide ecological network essential for facilitating adaptation to both sea level rise and climate change in general.

CONCLUSIONS

The challenges to Florida’s native biodiversity are severe, but we also believe that with careful planning it should be possible to mitigate some of the potential impacts from sea level rise and future land use change. As stated in our original scope, the work completed in this project is a first broad stroke at the research necessary to adequately plan for and assist in adaptation of our natural communities, native species, and landscapes. Additional work that we will conduct for the Kresge Foundation includes continued detailed assessments of selected focal species, completion of the natural communities SIVVA work, expansion of our strategy recommendations to include additional species, additional connectivity analyses, and additional analyses synthesizing the various impact assessments we have completed. We look forward to
the completion of this work, and continuing our work to assist in protection of Florida’s natural resources for future generations.

LITERATURE CITED

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


