Chapter 13
A Climate Adaptation Monitoring Tool for Sustainable Marine Planning

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Abstract This chapter explores an approach to address the challenge of adaptation planning in the management of marine resources under a changing climate. The authors address this challenge by developing an analytical approach to manage both uncertainties associated with the changing climate and anthropogenic changes and providing marine and coastal resource managers with a prospective assessment of the potential impacts associated with climate change on coastal and marine resources. The study presents the case of southern and central west coast of Florida in the United States, a low-lying landscape highly susceptible to various climate change impacts including sea level rise, changes in temperature and other where the authors worked with numerous scientists, managers, and a broad base of stakeholders to create a participatory process for adaptation planning. It has shown that adaptation planning must be approached in a holistic manner which considers resource vulnerabilities, identifies activities that mitigate those vulnerabilities, and includes components that identify when to implement the activities. Taken together, the approach that was outlined presents a comprehensive treatment of climate adaptation planning which addresses both the interests of species conservation and societal values, both of which must be accounted for if effective species conservation is to be achieved.

Keywords Climate adaptation · Monitoring tool · Sustainable marine planning · Florida

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1 Introduction

In the last 20 years, biodiversity conservation of marine ecosystems is becoming a global priority as fish stocks continue to decline, eutrophication of coastal areas is ongoing, and extinctions of marine species continue.

This article explores an approach to address the challenge of adaptation planning in the management of marine resources under a changing climate. The authors address this challenge by developing an analytical approach to manage both uncertainties associated with the changing climate and anthropogenic changes and providing marine and coastal resource managers with a prospective assessment of the potential impacts associated with climate change on coastal and marine resources. The study presents the case of southern and central west coast of Florida in the United States, a low-lying landscape highly susceptible to various climate change impacts including sea level rise, changes in temperature, and others where the authors worked with numerous scientists, managers, and a broad base of stakeholders to create a participatory process for adaptation planning.

Specifically, the study represents a prototype effort of a scenario-based approach, which will help managers and scientists identify, map, and evaluate marine species' vulnerabilities to climate change. The scenarios integrate terrestrial sources of impacts together with marine resources with the goal of identifying changes in the future coastal environment of Florida under a variety of stressors and changing conditions and to assess potential impacts to "species of greatest conservation need" (SCGN). Florida defines SGCN as "species that are imperiled or are at risk of becoming imperiled in the future" (Florida Fish and Wildlife Conservation Commission, 2012).

The study was designed to build on the previous studies that piloted the process of marine spatial scenario planning, specifically the "Implementation of a Scenario-based Model of Adaptation Planning for the South Florida Marine Environment" (KeysMAP SWG# 1253; Vargas-Moreno et al., 2013). The previous work approach was based on spatial-resilience adaptation planning – the idea that in a changing world, regional biological management activities are best targeted not at fighting change but at improving the ability of habitats and species to adjust to it. This requires both the ability to characterize the challenges and to assemble appropriate stakeholders to work together to address them.

Based on a broad consultation with experts from the Florida Fish and Wildlife Conservation Commission (FWC), the US National Oceanic and Atmospheric Administration (NOAA), and local stakeholders, the study focused on the fundamental interactions between marine resources, climate change, and management actions – a complex system characterized by dynamic and multidimensional cause-and-effect conditions taking place when natural and management changes occur simultaneously.

The work was centered on the climate change exposure to a suite of estuarine-associated fish species that share similar vulnerabilities to climate change and/or other stressors. Using this "common vulnerabilities" approach, our work went beyond vulnerability assessments to develop potential management response scenarios.

Many previous studies, including previous scenario efforts conducted in the region by the authors,[1] have focused at the scale of individual species. However, the "common vulnerabilities" approach operates at a habitat and management area scale and considers management actions that impact multiple species. While many management organizations continue to assess species-level outcomes, the first part of our process uses species' vulnerability and climate scenario analyses to systematically select species as representatives of an entire suite of species sharing common vulnerabilities. This approach aligns closely with FWC's Integrated Conservation Strategy (Florida Fish and Wildlife Conservation Commission, 2016) in which actions can be tied to several SGCN to maximize the benefits and efficiencies of interventions, rather than have a single set of strategies focused on an individual species or habitat. The concept of marine scenarios was retained from our KeysMAP study, but it is enhanced to consider potential management actions both spatially and temporally.

Marine spatial-planning scenarios are a valuable means to engage visualize with stakeholders the consequences of potential management actions interacting with environmental change. In this context, a scenario-based futures approach is different from conventional marine management. Most fundamentally, it requires not only observational data and statistical or mechanistic models based on them but also simulations that play out against future conditions beyond the range of most historical observations. Such long-term work is subject to compounding uncertainties and is generally not possible to do without making important assumptions. The major contribution of scenario planning is not that it makes uncertainty go away but rather that it manages it by making assumptions clear and providing interim guidance.

The concept of "triggers" is an important addition to traditional scenario planning, which has often been undertaken as a relatively isolated, long-term strategic process. Triggers make explicit the links between scenario projections and contingency planning and add emphasis to the importance of monitoring. Monitoring is indicated where and when projections identify potentially troublesome impacts. Meanwhile, contingency planning is needed for two reasons. First, it allows time for scientific research to be done in advance of management need. Second, it allows managers time to develop and implement policies, particularly those which are slow and complex. Policies involving major federal actions with full public review might take a longer timeframe. By estimating triggers in advance of need, this form of adaptive scenario planning can provide managers, scientists, and stakeholders critical advance notice.

In previous work by the authors, climate exposure was found to be an integrating concept well supported by newly available downscaled climate data, including the identification of potential management actions and a proposed a management strategy for considering them. In this study, the prior approach was extended in terms of

[1] See https://public.myfwc.com/crossdoi/fundedprojects/GrantDetails.aspx?ID=218

species, geographic coverage, and the development of triggers and adaptive management choices and monitoring indicators.

Ultimately, the aim of the study is to provide a systemic risk analysis framework and tool to assist authorities in the process of prioritizing from groups of species at highest risk an identification of adaptation approaches that can be monitored and adjusted in space and time. Perhaps most useful about the process was that it supported systematic thinking, across scales and management jurisdictions. In this sense, the ability to spatially simulate a subset of these scenarios as a tool to integrate both management and environmental changes allowed to capture and reduce numerous uncertainties that otherwise escape the decision process in adaptation planning. The use of scenarios provided a crucial contribution, allowing the research team to assess the likely consequences of the simulated futures on habitats and species equipping the consulted stakeholder to derive an appropriate set of adaptation measures.

The application of the approach presented in this article was limited mainly by a short project development time. This impacted the ability to develop a more systemic and exhausting process to identify stakeholders. As such there are potential knowledge gaps in the participatory process. This limitation is relevant to highlight since stakeholder process required participants to both characterize the challenges and to define monitoring indicators for the adaptation process designed.

Another potential limitation is the potential issues rising from the use of species that share similar vulnerabilities to climate change and/or other stressors. The use of the "common vulnerabilities" approach simplifies the process to design, prioritize, and monitor adaptation measures but limits the applicability of the framework and tool to the multiple specific species programs that populate today many environmental management organizations.

2 Organization of the Study

2.1 Area of Context

The study area was focused on the estuaries of Tampa Bay and Charlotte Harbor which are located on the central west coast of Florida, USA (Fig. 13.1). The Tampa Bay harbor and estuary are a heavily utilized recreation and commercial waterway bordered by the greater Tampa – St. Petersburg – Clearwater, area, one of the largest metropolitan areas in the United States with a population of 4.3 million in 2012 and an average annual growth of 2.5% based on US Census Data (https://www.census.gov/).

The area surrounding Charlotte Harbor estuary does not contain the same levels of urbanization as the Tampa Bay area. It is the second largest estuary in the state and is considered one of the most productive wetland complexes in Florida but faces threats from increasing urbanization and natural resource overuse.

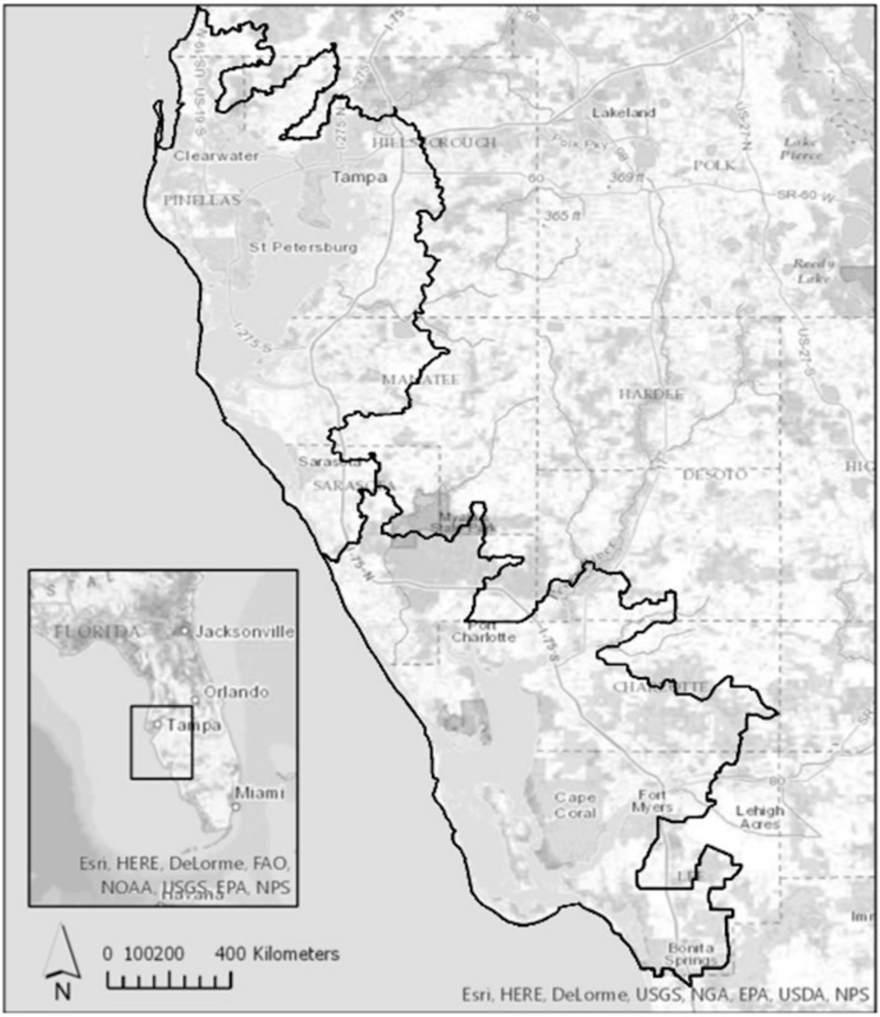

Fig. 13.1 Location of study area and extent of analysis

2.2 Future Land-Use Scenarios

The modeling process that represents potential futures for the state of Florida was produced from spatial representations of climate and land-use changes over time based on a series of drivers that were modified, depending on projections, to generate scenario outputs.

A historical baseline and several marine future scenarios were generated from expert workshops, available spatial data, and simulation modeling. Conceptually, the scenarios track IPCC Representative Concentration Pathway (RCP) Scenarios

4.5 and 8.5 (Pachauri, Rajendra et al., 2014), for climate, and previously define "business-as-usual" statewide scenarios for conservation and development) (see http://peninsularfloridalcc.org/page/climate-change-scenarios). The scenarios also leverage an extension set of data from field observations collected by FWC over the last 30 years in a program known as "Fisheries-Independent Monitoring¨ (FIM). The combination of these data sources and simulation model outputs represents a relative comprehensive and deep look at estuarine and nearshore environments as they have been measured over recent decades and are expected to respond to both climate change and continued coastal development.

The scenario set recognizes three drivers of change in the marine and estuarine environment. These include seawater temperature, salinity, and sea level rise. In the littoral environment, the drivers are salinity, vegetation change, conservation, and urbanization.

Based on these factors, three different scenarios representing two major future land-use directions were developed for the project. Scenario 1: Plan/Trend 2060 RCP 8.5 forecasts the continuation of growth rates and conservation priorities currently occurring in Florida, under a high sea level rise (1.0 m) assumption by year 2060. Scenario 2, Proactive, and Scenario 3, Proactive Plus, are similar in nature to each other but different from Scenario 1. Scenarios 2 and 3 include the assumptions that additional funds and policies would support increased conservation measures across the state and follow University of Florida's Geoplan's Critical Lands and Waters Identification Project (CLIP) conservation prioritizations.[2]

The difference between these two scenarios is the method of conservation acquisition. For all scenarios, climate change forecasts remain the same as Scenario 1 and incorporate sea surface temperature, salinity, and sea level rise as environmental drivers. Because Scenarios 2 and 3 were so similar, for this project, Scenarios 1 and 3 were assessed for the adaptation strategy processes.

Two of the three scenarios, which were developed for use in the species exposure analyses, were chosen for further integration into the adaptation strategy assessment portion of the project. Considering the importance of the different drivers that are altered depending on the scenario chosen, the variables were integrated for Scenario 1 Plan/Trend and Scenario 3 Proactive Plus into the STAPLEE (Social, Technical, Administrative, Political, Legal, Economic, and Environmental) methodology (see Adaptation Prioritization section). These two scenarios recognize six drivers of change: SST (sea surface temperatures), salinity, SLR (sea level rise), changes in salt tolerant coastal vegetative species, conservation areas, and urbanization areas. The scenarios forecast different configurations of potential outcomes by varying the intensity or development of the drivers. The scenarios' potential effect on the prioritization and selection of relevant adaptation strategies was examined by creating a separate STAPLEE chart for each scenario. Ranking of the criteria was performed

[2] CLIP stands for Critical Lands and Waters Identification Project (CLIP) a geospatial identification of critical lands for Conservation in Florida, developed by researchers at the University of Florida, USA. See Version 4.0. Technical Report – September 2016. Jon Oetting, Tom Hoctor, and Michael Volk

for each scenario, considering its assumptions, drivers, and potential outcomes on the environment and species in question.

2.3 Participatory Workshops

Two participatory workshops were held to gain information, direct project efforts, collect opinions from biological and ecological experts in the region, and formulate baseline data. The first workshop, held in April 2015, involved estuarine and coastal marine species and habitat experts to develop suites of species, which both represented the range of habitats in the bays and were sensitive to climate change stressors. The description of species suites indicates both the pros and cons of using species representatives; however, in this case a "common vulnerabilities" approach allows for groups of similar species to be considered in subsequent analyses through the representation of each ecosystem by a single species:

> These suites are designed to represent a "coarse filter" from a conservation planning point of view. They are purposefully chosen to be representative of the common vulnerabilities faced by a much larger set of species using Southwest Florida's coastal waters. While there is always some potential for bias in selecting any form of indicator or umbrella species, in this case the risk was mitigated using an electronically-enhanced Delphi process and an abbreviated form of a well-tested Climate Vulnerability Process previously developed by NOAA.[3]

The results of the first workshop determined a species representative for each of the 12 estuarine and coastal habitat types in question, as well as a representative species for all estuarine and coastal habitat types.

3 Methodology Overview

The identification and stressor-specific prioritization of potential adaptation strategies represents the core of the study and the first phase of work. Strategies were assembled from the result of a participatory workshop with biological and ecological experts and integrated with additional strategies gathered from literature review and case studies from similar geographical areas. The resulting 27 potential adaptation strategies were divided in 3 groups: nonstructural, structural, and combined strategies.

[3] The key previous work developed by the National Oceanic and Atmospheric Administration (NOAA) include the 2010. Adapting to Climate Change: A Planning Guide for State Coastal Managers. NOAA Office of Ocean and Coastal Resource Management. http://coastalmanagement.noaa.gov/climate/adaptation.html

The STAPLEE methodology[4] used by the Federal Emergency Management Agency (FEMA, 2003) was adapted for this project to prioritize the adaptation strategies. This methodology was implemented using specific indicators tailored to the geographic area. The STAPLEE method was completed twice for two different alternative future scenario models to illustrate the differentiation of each scenario's effects on strategy prioritization. The team considered the different impacts on each of the STAPLEE method's criteria according to the description of each scenario (Scenario 1, Plan/Trend, or Scenario 3, Proactive Plus; see Sect. 2.3 for complete descriptions of scenarios).

The results coming from the modified STAPLEE methodology were integrated with a subjective assessment of each strategy's potential to reduce climate vulnerability for the project's focal species. The method uses seven criteria for evaluating a mitigation action (social, technical, administrative, political, legal, economic, and environmental), and each criterion is divided into sub-indicators that are evaluated individually using a scoring procedure. At the end of the process, final rankings of each adaptation strategy for the two different scenarios and for each focal species are presented.

The second phase of the project identified and determined climate change exposure triggers (=trigger points) which initiate adaptation strategies to increase resilience of the species to the identified climate stressors. Specific triggers were identified for three indicators of climate change that affect estuarine species and their habitats: sea surface temperature, salinity, and shoreline change. The shoreline change indicator was divided into three sub-indicators: (1) erosion rate, (2) persistence of saline wetlands, and (3) persistence of mangroves. The trigger values for these three indicators were defined based on literature review, expert opinion, and collected biological information, such as focal species' thermal and saline thresholds. These specific factors will be described in the results section of this study.

The final phase of the project developed two important programs: a suite of monitoring programs that help inform when the triggers are reached and a monitoring tool associated with each indicator and trigger to inform managers which adaptation strategies to initiate upon being triggered. Tracking the tool phase by phase, it is possible to follow the entire process of the project through to the determination of the most appropriate adaptation strategies to be implemented, dependent on the scenario chosen.

The participatory and consultative workshops represented a structural component of the study. As such the authors began its analysis by first hosting a series of workshop discussions on the scenario exposure and adaptation strategies in January 2016. In this workshop, the participants were presented with the results of the exposure assessments developed and were asked to evaluate and rank the degree of

[4] STAPLEE allows emergency managers to apply a consistent analysis to the range of mitigation options they are considering. The term STAPLEE is an acronym that stands for the following evaluation criteria: social technical, administrative, political, legal, economic, and environmental. Each of these terms represents an opportunity or constraint to implement s particular mitigation option.

significance of the potential stressors (sea surface temperature, salinity, and coastal change) on the representative species for each ecosystem. The participants felt that for most of the species, exposure significance was predicted to be minimal to moderate. Only a handful of species, mostly estuarine representatives, received votes for potentially high exposure impacts. The final tally indicated that experts felt three species (two estuarine, one coastal) would be negatively impacted by rising sea surface temperatures; three species (two estuarine, one coastal) would be negatively impacted by rising salinities; and that six species (three estuarine, three coastal) would be negatively impacted by coastal changes.

The second part of the workshop entailed a brainstorming session, asking participants to suggest a comprehensive list of potential adaptation strategies applicable to each stressor for the impacted species and management areas in question. The brainstorming session originally focused on areas of each estuary subdivided by location, but it soon became apparent that the participants felt the suggested strategies should be applicable to all locations throughout the estuaries in either location. It was decided to divide the suggested list of strategies into three categories based on the method of implementation: policy, management-based, or nonstructural strategies (10), physical implementation-based or structural strategies (9), and a third category, which includes strategies that combine both structural and nonstructural elements (6).

Salinity modeling – Environmental data for Charlotte Harbor, Tampa Bay, and Florida Bay including the nearby coastal zones were obtained from the Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute's Fisheries-Independent Monitoring Program. The data were separated into two classes representing the summer (i.e., rainy season: May 15th to October 14th) and the winter season (October 15th to May 14th). Using ArcGIS Pro, the data were further subdivided into two geographic regions representing Tampa Bay and Charlotte Harbor. Kernel Interpolation with barriers (i.e., excluding land) was used to create three classes of salinity: (1) fresh/brackish water: 0 ppt–17 ppt, 2) saline:17–35 ppt, and 3) > 35 ppt. Interpolated salinity values outside a realistic range (i.e., <0 ppt) were removed.

To develop future scenarios representing current (i.e., "normal") conditions, RCP 4.5 and RCP 8.5, rasters were created which were based on the historical salinity data. To accomplish this, a polygon was created using the area where salinity was estimated to have values of 0–17 ppt because it was concluded that this class will see the greatest change under future climate change scenarios. These data points were imported into SPSS (Statistical Package for Social Science) and, based on results from an ANOVA (analysis of variance), split into five bins based on years according to average salinities. The first bin included the 2 most saline years in the dataset, the second bin was comprised of the next 4 high-salinity years, the third bin was made up of 15 years with salinities in the middle range of the distribution, and the last two bins were made up of the 6 years with the lowest salinities, and these were not used in constructing the rasters.

Scenarios were developed from maps created from the bins. The first bin was used to represent RCP 8.5, and the second highest salinity bin was used in making a raster that represents RCP 4.5. The remaining 15 years represented the "normal" state of the estuaries. The 6 years with the lowest salinities were left out of the raster creation.

4 Results

4.1 Adaptation Strategies Identification

4.1.1 Description of the Strategies

Based on relevant literature and team experience, the research team organized the adaptation strategies into three different groups: nonstructural, structural, and combined strategies.

Nonstructural strategies are those that reduce the effects of a hazard using nonphysical solutions such as land-use planning, zoning, early warning systems, simulations, policies, laws, etc. (UNISDR, 2009; FIFMTF, 1992). The nonstructural measures may be proposed by public or private initiatives. There are many stakeholders who can implement such measures including government authorities, NGOs, international organizations, and private sector companies. NOAA's habitat restoration program calls these types of projects "passive restoration, which involves changes to management practices and use of landscapes."

Structural measures for mitigation are those that reduce the effects of a hazard involving a physical intervention such as dams, dykes, levees, elevated buildings, retaining walls, seawalls, etc. (UNISDR, 2009; FIFMTF, 1992). NOAA's habitat restoration program calls these types of projects "active restoration, which involves 'on-the-ground' or 'dirt-moving' activities." Usually, these are traditional engineering strategies that require a significant financial investment but are only designed to address a specific type and intensity of hazard. These types of strategies are typically at odds with conservation and natural systems and can reduce local species' resilience to extreme events, as well as affect overall ecosystem function.

An initial list of adaptation strategies was derived using brainstorming in a workshop within which participants proposed a comprehensive list of potential adaptation strategies applicable to each stressor for the impacted species and management areas in question. A literature review was also conducted with the goal of identifying case studies that addressed similar approaches and provided the case studies provided additional adaptation approaches.

The case studies were also used to provide information to evaluate the strategies including (1) the potential impacts on species and ecosystems, (2) the cost of implementation, (3) popular or political support, and (4) degrees of success. The strategies derived within the workshop were supplemented by the additional strategies from the case study review, and a final list of 27 potential adaptation strategies was created. The list consisted of 12 nonstructural strategies, 9 structural strategies, and 6 combination strategies (Table 13.1). Of the nine structural strategies, four were related to the temperature stressor, further four were related to the salinity stressor, and one was related to the shoreline change stressor. Of the nonstructural adaptation strategies, two addressed temperature, two addressed salinity, and eight addressed the shoreline change. For the mixed structural/nonstructural category, two addressed temperature, one addressed salinity, and three addressed shoreline changes (Table 13.1). Subsequently, the adaptation strategies were subdivided according to the three different triggers. These are addressed in the subsequent section.

4.1.2 Adaptation Strategies Prioritization

Standard advice from business and economics is to invest in activities where the rates of return on investment (ROI) are the highest (Wilson et al., 2007). For this approach to be most effective, an explicit statement of overall objectives is required (Klein et al., 2010). ROI has been applied to the conservation of terrestrial biodiversity (Murdoch et al., 2007), but it has yet to be applied to marine conservation.

A literature review was performed to identify the best methodology for prioritizing adaptation strategies based on ROI. The STAPLEE methodology developed by FEMA (FEMA, 2003) was selected as a prioritization criteria tool because of its holistic approach that addresses many issues of societal importance. This method uses seven criteria for evaluating an adaptation action: social, technical, administrative, political, legal, economic, and environmental. Each criterion is divided into sub-indicators that are scored individually. This methodology is used to examine opportunities (benefits) and constraints (costs) of implementing each action from the perspective of all seven of the STAPLEE criteria. The goal of prioritizing the list of potential strategies is to assist managers in directing the flow of funds and effort to effectively address the stressors identified in the analysis.

The evaluation of each adaptation strategy was informed by the criteria of each STAPLEE category (Table 13.2) and was adapted specifically for this project by including elements from KeysMAP. Questions used to assess each category were also developed to better guide the evaluation. The associated scores were weighted in three different levels: three for easy/yes/low, two for moderate/maybe/medium, and one for unfeasible/no/high (Table 13.3).

4.1.3 Species as a Strategy Prioritization Tool

Ultimately, the objective for prioritizing adaptation strategies for this study was to determine which strategy(ies) have the greatest effectiveness in reducing vulnerability of specific species to climate change stressors. One species was selected by experts as representative from each of six (estuarine) or seven (coastal) habitats representing the full range of environments in the study area (Table 13.4). The selections were based on information available on its life history and habitat associations. The species were selected based on consideration if the species was SGCN, the importance of the species as an FWC managed species, and/or if the species is

Table 13.1 Adaptation strategies identified by category. Stressors addressed by each category are temperature (T), salinity (S), and shoreline change (Sc)

Adaptation strategy	Stressor addressed
Nonstructural strategies	
1. Reduce groundwater withdrawal in the watershed, better groundwater management	S Sc
2. Conservation and land-use policies that limit sprawl development	T
3. Design water discharge to focus on historically important areas of the critical life history stages of these fish	T Sc
4. Manage for high temperature-sensitive fish	Sc
5. Tax breaks for reducing shoreline hardening; incentivize natural shorelines	Sc
6. Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures	Sc Sc
7. Establish slow speed/no wake zones to reduce shoreline erosion	Sc
8. Education of homeowner associations and politicians on benefits of soft shoreline engineering alternatives	Sc Sc
9. Prohibit physical coastal structures from being built	
10. Define needed marine migration corridors and integrate those areas into conservation through incentives	
11. Public education and outreach to foster a broad awareness of climate change issues	
12. Minimizing the impacts of any future development on the highest priority areas for biodiversity	
Structural strategies	
1. Increase vegetation cover along shoreline and along tributaries to provide shade and to reduce evapotranspiration	T T
2. More shading along ponds, ditches, and canals to moderate temps of storm water flow within drainage systems into bay	T, Sc T
3. Reduce shoreline hardening; increase living shorelines	T, Sc
4. Divert cooler deep water to coastal areas	S
5. Hybrid shorelines where natural shorelines are put ocean-side of the hardened shorelines	S S
6. Cloud seeding	
7. Private sector storage such as water farming or dispersed water storage, followed by better water operations/releases to address salinity increases	
8. Engineer pipelines for water discharge into areas of high salinity	
Structural and nonstructural strategies	
1. Reclaim, reuse, and discharge treated stormwater used in urban activities to increase freshwater flows to estuary	S S
2. Creation of a system dynamics model and increased governance capacity, to balance freshwater flows to estuaries during periods of water stress (high salinities)	T Sc Sc
3. Eliminate unnatural features that minimize water circulation	Sc
4. Beneficial reuse of clean dredge materials (creation of wetlands, islands, shoreline stabilization)	
5. Removal of barriers (political, regulatory, urban) to inland migration of habitats	
6. Restore purchased properties to reduce flooding hazards rather than just removing the structure(s) and maintaining parkland	

Table 13.2 Adaptation of the STAPLEE methodology to the prioritization of climate adaption strategies for Florida

STAPLEE category	Criteria and questions associated with each category
Social	The public must support the overall implementation strategy and specific mitigation actions
Community acceptance	*Is the proposed action socially acceptable to the community?*
Equal impacts on population	*Are there equity issues involved that would mean that one segment of a community is treated unfairly?*
Technical	
Technically feasible	*Is the technology developed enough to implement successfully?*
Secondary impacts	*Will it create more problems than it solves?*
Habitat restoration	*Is it the most useful action with respect to other community(s) goals?*
Administrative	Is there staffing, funding, and maintenance capacity to implement the action?
Staff competency	*Can the community(s) implement the action?*
Maintenance/ operations needs	*Is there sufficient capacity (*i.e.*, funding, staff, and technical support) available?* (criteria from KeysMAP project)
Political	
Political support	*Is the action politically acceptable?*
Public support	*Is there public support both to implement and to maintain the project?*
Legal	Without the appropriate legal authority, the action cannot be implemented
State and federal authority	*Is there a clear legal basis or precedent for this activity?*
Existing local authority	*Will the community(s) be liable for action or lack of action?*
Land-use policy	*Is the proposed action allowed by a comprehensive land policy?*
Economic	States and local communities with tight budgets may be more willing to undertake a mitigation initiative if it can be funded, at least in part, by outside sources. "Big ticket" adaptation actions, such as large-scale acquisition and relocation, are often considered for implementation in a post-disaster scenario when additional federal and state funding for mitigation is available
Benefit of action	*What are the costs and benefits of this action? Do the benefits exceed the costs?*
Cost of action (criteria from KeysMAP project)	*Are initial, maintenance, and administrative costs taken into account? Has funding been secured for the proposed action?*
Contributed to the economic goals	*How will this action affect the fiscal capability of the community(s)?*
Financial sustainability	*Does the action contribute to other community goals?*
Environmental	Impact on the environment is an important consideration because of public desire for sustainable and environmentally healthy communities
Effect on land/ water	*How will the action affect the environment?*

(continued)

Table 13.2 (continued)

STAPLEE category	Criteria and questions associated with each category
Consistent with community environmental goals	*Will the action need environmental regulatory approvals?*

imperiled. Vulnerability to future climate conditions was assessed for the selected species by the experts using the NOAA climate change vulnerability calculator within the MeetingSphere Group Decision Support Systems online application (www.meetingsphere.com).

Each adaptation strategy was evaluated for each indicator species to determine its effectiveness at mitigating the effects of climate change by scoring the strategy in a manner similar to the STAPLEE methodology criteria. For each species, a criteria ranking coefficient was used (1 yes, 2 maybe, 3 no) to score the potential effectiveness of the strategy at reducing vulnerability to climate change stressors. Total scores for each species were multiplied by a factor of ten and added to the STAPLEE output scores to create a spread in the resulting scores. The adaptation strategies receiving higher overall scores imply that they will be more effective at addressing the species' vulnerability(ies). In that respect, the final ranks are obtained by: STAPLEE methodology rank + (species coefficient × 10).

The final ranks were scored with a total value greater than 60 as positive (triangles), neutral with a total value less than 60 but greater than 50 (question marks), and not significant when the total value was less than 50 (circles) (Table 13.5).

To evaluate the efficacy of each adaptation strategy, an average value was calculated for each strategy and applied the same final ranking classification.

4.2 Identification of Triggers

Triggers, or "trigger points," are critical for identifying thresholds beyond which adverse outcomes occur. These are also the points at which adaptation options should have been implemented to mitigate the impacts of the stressor.

The experts identified triggers for species associated with tolerance levels for the temperature (Table 13.6) and salinity (Table 13.7). A third stressor, physical changes to the coast was based on a combination of sea level rise impacts, conversion of upland habitat types to wetland, and the shifting of mangrove habitats within the estuaries. The thresholds were identified from the scientific literature and input from species' experts.

The triggers were used to determine the risks of exposure to adverse future conditions. Using the predicted future conditions from the spatially explicit modeling outputs, the experts evaluated the degree of exposure of each indicator species to three climate stressors and ranked the significance of this forecasted exposure from "no significant exposure" to "high significance." The species chosen for further

Table 13.3 Ranking adaptation strategies related to the shoreline change stressor for Scenario 1: Plan/Trend

		Geographic area		STAPLEE methodology																	
				Social		Technical			Administrative		Political		Legal			Economic				Environment		
Strategy	Structural (S), non-structural (NS)	Tampa Bay	Charlotte Harbor	Community acceptance	Equal impacts on population	Technically Feasible[a]	Secondary impacts	Habitat Restoration	Staff competency	Maintenance/operations needs[a]	Political support	Public support	State and federal authority	Existing local authority	Land use policy S1	Benefit of action	Cost of action ($)[a]	Contributes to economic goals	Financial sustainability	Effect on land/ water	Consistent with community environmental goals	Total Score S1 (Plan/Trend)
Shoreline changes stressor																						
Erosion rate																						
Reduce shoreline hardening; increase living shorelines	S, NS	x	x	2	2	3	2	2	3	3	2	2	2	2	1	3	2	1	2	3	2	**39**
Tax breaks for reducing shoreline hardening; incentivize natural shorelines	NS	x	x	3	3	3	1	2	3	2	2	3	2	2	1	3	1	3	2	2	2	**40**
Beneficial reuse of clean dredge spoil	S, NS	x	x	1	2	2	2	2	2	2	2	2	3	1	1	2	1	3	2	2	2	**34**
Establish slow speed/ no wake zones to reduce shoreline erosion	NS	x	x	1	1	2	1	1	2	2	2	2	3	3	1	2	1	2	1	1	2	**30**

(continued)

Table 13.3 (continued)

Strategy	Structural (S), non-structural (NS)	Geographic area		STAPLEE methodology																		Total Score S1 (Plan/Trend)
				Social		Technical			Administrative		Political		Legal			Economic				Environment		
		Tampa Bay	Charlotte Harbor	Community acceptance	Equal impacts on population	Technically Feasible[a]	Secondary impacts	Habitat Restoration	Staff competency	Maintenance/operations needs[a]	Political support	Public support	State and federal authority	Existing local authority	Land use policy S1	Benefit of action	Cost of action ($)[a]	Contributes to economic goals	Financial sustainability	Effect on land/ water	Consistent with community environmental goals	
Education of homeowner associations and politicians on benefits of soft shoreline	NS	x	x	3	3	3	2	2	3	3	3	2	3	3	2	3	3	3	2	1	1	**45**
Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines	S	x	x	2	1	2	2	2	2	2	2	2	2	3	1	2	2	3	2	3	2	**37**
Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools	NS	x	x	3	1	3	2	1	2	3	3	3	3	3	2	3	3	2	3	2	2	**44**

Conservation and land use policies that limit sprawl development	NS	x	x	2	2	3	2	2	2	3	1	2	2	3	1	2	1	1	2	3	2	**36**
Prohibit physical coastal structures from being built	NS	x	x	2	3	2	3	2	2	2	2	2	2	3	1	3	3	3	1	2	1	**39**
Saline wetlands extent																						
Restore properties that are purchased to reduce flooding hazards rather than just removing the structure and maintain parkland – Allow it to revert to marsh/mangrove to provide services	S, NS	x	x	2	1	3	2	2	2	2	2	2	3	3	1	2	2	2	2	1	2	**36**
Removal of barriers (political, regulatory, urban) to inland migration of habitats	S, NS	x	x	2	1	2	3	2	1	2	2	2	3	3	1	2	2	3	3	3	2	**39**
Beneficial reuse of clean dredge spoil	S, NS	x	x	1	2	2	2	2	2	2	2	2	3	1	1	2	1	3	2	2	2	**34**
Education of homeowner associations and politicians on benefits of soft shoreline	NS	x	x	3	3	3	2	2	3	3	3	2	3	3	2	3	3	3	2	1	1	**45**

(continued)

Table 13.3 (continued)

Strategy	Structural (S), non-structural (NS)	Geographic area		STAPLEE methodology																		Total Score S1 (Plan/Trend)
				Social		Technical			Administrative		Political		Legal			Economic				Environment		
		Tampa Bay	Charlotte Harbor	Community acceptance	Equal impacts on population	Technically Feasible[a]	Secondary impacts	Habitat Restoration	Staff competency	Maintenance/operations needs[a]	Political support	Public support	State and federal authority	Existing local authority	Land use policy S1	Benefit of action	Cost of action ($)[a]	Contributes to economic goals	Financial sustainability	Effect on land/ water	Consistent with community environmental goals	
Prohibit physical coastal structures from being built	NS	x	x	2	3	2	3	2	2	2	2	2	2	3	1	3	3	3	1	2	1	**39**
Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives	NS	x	x	2	1	2	2	2	2	2	2	2	2	2	1	2	2	3	2	3	2	**36**
Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines	S	x	x	2	1	2	2	2	2	2	2	2	2	3	1	2	2	3	2	3	2	**37**

Minimizing the impacts of any future development on the highest priority areas for biodiversity	NS	x	x	1	1	2	2	2	3	2	2	2	3	3	1	3	3	2	2	2	2	**38**
Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools	NS	x	x	3	1	3	2	1	2	3	3	3	3	3	2	3	3	2	3	2	2	**44**
Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures	NS		x	2	2	2	3	2	3	3	2	2	3	2	2	2	1	2	2	3	2	**40**
Mangrove extent and migration Minimizing the impacts of any future development on the highest priority areas for biodiversity	NS	x	x	1	1	2	2	2	3	2	2	2	3	3	1	3	3	2	2	2	2	**38**

(continued)

Table 13.3 (continued)

Strategy	Structural (S), non-structural (NS)	Geographic area		STAPLEE methodology																		Total Score S1 (Plan/Trend)
				Social		Technical			Administrative		Political		Legal			Economic				Environment		
		Tampa Bay	Charlotte Harbor	Community acceptance	Equal impacts on population	Technically Feasible[a]	Secondary impacts	Habitat Restoration	Staff competency	Maintenance/operations needs[a]	Political support	Public support	State and federal authority	Existing local authority	Land use policy S1	Benefit of action	Cost of action ($)[a]	Contributes to economic goals	Financial sustainability	Effect on land/ water	Consistent with community environmental goals	
Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools	NS	x	x	3	1	3	2	1	2	3	3	3	3	3	2	3	3	2	3	2	2	**44**
Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures	NS		x	2	2	2	3	2	3	3	2	2	3	2	2	2	1	2	2	3	2	**40**
Removal of barriers (political, regulatory, urban) to inland migration of habitats	S, NS	x	x	2	1	2	3	2	1	2	2	2	3	3	1	2	2	3	3	3	2	**39**

Restore properties that are purchased to reduce flooding hazards rather than just removing the structure and maintain parkland – Allow it to revert to marsh/mangrove to provide services	S, NS	x	x	2	1	3	2	2	2	2	2	2	3	3	1	2	2	2	2	1	2	**36**
Prohibit physical coastal structures from being built	NS	x	x	2	3	2	3	2	2	2	2	2	2	3	1	3	3	3	1	2	1	**39**
Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives	NS	x	x	2	1	2	2	2	2	2	2	2	2	2	1	2	2	3	2	3	2	**36**
Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines	S	x	x	2	1	2	2	2	2	2	2	2	2	3	1	2	2	3	2	3	2	**37**

[a]Criteria coming from the first "KeysMAP" project

Easy / yes / Low 3

Medium / maybe / medium 2

Unfeasible / no / high 1

Non-structural strategy: Does not change the natural hazard but involves preventative actions such as policy or management that improve infrastructure to reduce the damages or improve coordination of resources

Structural strategy: Inhibit a natural hazard through construction such as a sea wall or physically improve a condition of the environment

Table 13.4 Habitat and the species selected by experts to represent environments for southwest Florida estuaries and coastal zones. "All systems" represents species found throughout the entire estuarine system. Superscripts indicate species that were identified as vulnerable to temperature (t), salinity (s), or coastal changes (c)

Habitat	Representative species selected
Estuarine	
Mangrove fringe	Gray snapper (*Lutjanus griseus*)^{s}
Upper estuary (freshwater to brackish water)	Red drum (*Sciaenops ocellatus*)
Lower estuary	Spotted sea trout (*Cynoscion nebulosus*)^{t,s,c}
Open water estuary	Tarpon (*Megalops atlanticus*)
Benthic estuary/seagrass	Lined seahorse (*Hippocampus erectus*)^{t,s,c}
All systems	Pink shrimp (*Farfantepenaeus duorarum*)^{c}
Coastal	
Mangrove fringe	Gray snapper (*Lutjanus griseus*)^{s}
Seagrass	White grunt
Tidal flat	Bonefish
Coastal/tidal river	Smalltooth sawfish
Bivalve reef	Red drum (*Sciaenops ocellatus*)^{t,c}
Beach/surf zone	Pompano
All systems	Striped mullet^{c}

analysis are those ranked by experts as most likely to sustain moderate or greater exposure to the stressors.

For both the temperature and salinity stressors, three species for each stressor were ranked by experts as being sensitive to exposure: these species were used as representatives of value ranges with maximum thresholds. The maximum threshold for each range of values becomes the trigger for that range, and each range with its trigger is termed a "bin." Triggers for each tolerance bin were calculated based on the 95% percentile of each tolerance groups' maximum tolerance limit (Tables 13.6 and 13.7). By using these "tolerance thresholds" as triggers for adaptation activities, the adaptation activities are implemented prior to the tolerance limit being reached.

4.2.1 Sea Surface Temperature Indicator and Trigger Development

Measurements of SST have been collected and recorded by FIM trawl-sampling data in and around Tampa Bay and Charlotte Harbor estuaries since the mid-1990s (FWRI, 2016). These data were used to determine the historical and potential future temperature profiles based on the predicted number of days that temperatures and salinities will exceed thresholds in the different estuarine habitats. For each of the representative species, GIS maps were developed to spatially depict predicted exposure of each of the sensitive species to SST under Scenario 1: Plan/Trend RCP8.5 to 2060.

Table 13.5 Ranking adaptation strategies to species prioritization – shoreline change stressor (output for Scenario 1: Plan/Trend)

Strategy	Structural (S), non-structural (NS)	Geographic		TOTAL score S1 (Plan/Trend)	Coastal species						Estuarine species						Average score
		Tampa Bay	Charlotte Harbor		Southern stingray (Dasyatis americana) Unconsolidated Bottom		Red drum (Sciaenops ocellatus) Bivalve Reef		Striped mullet (Mugil cephalus) All Coastal Species		Spotted seatrout (Cynoscion nebulosus) Lower Estuary		Pink Shrimp (Farfantepenaeus duorarum) All Estuarine Systems		Lined Seahorse (Hippocampus erectus) Benthic Estuary/Seagrass		
					Species coefficient	**Final rank S1**	Species coefficient	**Final rank S1**	Species coefficient	**Final rank S1**	Species coefficient	**Final rank S1**	Species coefficient	**Final rank S1**	Species coefficient	**Final rank S1**	
Shoreline changes stressor																	
Erosion rate																	
Reduce shoreline hardening; increase living shorelines	S, NS	x	x	**39**	2	**! 59**	3	**✓ 69**	3	**✓ 69**	2	**! 59**	3	**✓ 69**	3	**✓ 69**	● **66**
Tax breaks for reducing shoreline hardening; incentivize natural shorelines	NS	x	x	**40**	2	**✓ 60**	2	**✓ 60**	2	**✓ 60**	2	**✓ 60**	3	**✓ 70**	3	**✓ 70**	○ **67**
Beneficial reuse of clean dredge spoil	S, NS	x	x	**34**	2	**! 54**	1	**✕ 44**	2	**! 54**	1	**✕ 44**	2	**! 54**	1	**✕ 44**	◆ **47**
Establish slow speed/no wake zones to reduce shoreline erosion	NS	x	x	**30**	3	**✓ 60**	3	**✓ 60**	2	**! 50**	2	**! 50**	2	**! 50**	3	**✓ 60**	Δ **53**
Education of homeowner associations and politicians on benefits of soft shoreline	NS	x	x	**45**	2	**✓ 65**	2	**✓ 65**	3	**✓ 75**	3	**✓ 75**	2	**✓ 65**	2	**✓ 65**	○ **68**
Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines	S	x	x	**37**	2	**! 57**	2	**! 57**	2	**! 57**	3	**✓ 67**	2	**! 57**	2	**! 57**	○ **60**

continued

Table 13.5 (continued)

Strategy	Structural (S), non-structural (NS)	Geographic		TOTAL score S1 (Plan/Trend)	Coastal species						Estuarine species						Average score
					Southern stingray (Dasyatis americana) Unconsolidated Bottom		Red drum (Sciaenops ocellatus) Bivalve Reef		Striped mullet (Mugil cephalus) All Coastal Species		Spotted seatrout (Cynoscion nebulosus) Lower Estuary		Pink Shrimp (Farfantepenaeus duorarum) All Estuarine Systems		Lined Seahorse (Hippocampus erectus) Benthic Estuary/Seagrass		
		Tampa Bay	Charlotte Harbor		Species coefficient	**Final rank S1**	Species coefficient	**Final rank S1**	Species coefficient	**Final rank S1**	Species coefficient	**Final rank S1**	Species coefficient	**Final rank S1**	Species coefficient	**Final rank S1**	
Public education and outreach to foster a broad awareness of climate change issues; increase SLR awarness using photo and other visualization tools	NS	x	x	**44**	2	**✓ 64**	2	**✓ 64**	1	**! 54**	2	**✓ 64**	2	**✓ 64**	2	**✓ 64**	**● 64**
Conservation and land use policies that limit sprawl development	NS	x	x	**36**	2	**! 56**	2	**! 56**	2	**! 56**	2	**! 56**	2	**! 56**	2	**! 56**	**Δ 56**
Prohibit physical coastal structures from being built	NS	x	x	**39**	3	**✓ 69**	3	**✓ 69**	3	**✓ 69**	3	**✓ 69**	2	**! 59**	2	**! 59**	**● 62**
Saline wetlands extent																	
Restore properties that are purchased to reduce flooding hazards rather than just removing the structure and maintain parkland- allow it to revert back to marsh/ mangrove to provide services	S, NS	x	x	**36**	1	**× 46**	2	**! 56**	2	**! 56**	2	**! 56**	2	**! 56**	2	**! 56**	**Δ 56**
Removal of barriers (political, regulatory, urban) to inland migration of habitats	S, NS	x	x	**39**	1	**× 49**	2	**! 59**	2	**! 59**	1	**× 49**	1	**× 49**	1	**× 49**	**◆ 49**
Beneficial reuse of clean dredge spoil	S, NS	x	x	**34**	2	**! 54**	1	**× 44**	2	**! 54**	1	**× 44**	2	**! 54**	1	**× 44**	**◆ 47**
Education of homeowner associations and politicians on benefits of soft shoreline	NS	x	x	**45**	2	**✓ 65**	2	**✓ 65**	3	**✓ 75**	3	**× 75**	2	**✓ 65**	2	**✓ 65**	**● 68**

Prohibit physical coastal structures from being built	NS	x	x	39	3	✓ 69	3	✓ 69	3	✓ 69	3	✓ 69	2	! 59	2	! 59	○ 62
Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives	NS	x	x	36	3	✓ 66	3	✓ 66	2	! 56	3	✓ 66	2	! 56	3	✓ 66	○ 63
Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines	S	x	x	37	2	! 57	2	! 57	2	! 57	3	✕ 67	2	! 57	2	! 57	○ 60
Minimizing the impacts of any future development on the highest priority areas for biodiversity	NS	x	x	38	2	! 58	3	✓ 68	2	! 58	2	! 58	2	! 58	2	! 58	Δ 58
Public education and outreach to foster a broad awareness of climate change issues; increase SLR awarness using photo and other visualization tools	NS	x	x	44	2	✓ 64	2	✓ 64	1	! 54	2	✓ 64	2	✓ 64	2	✓ 64	○ 64
Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures	NS		x	40	2	✓ 60	2	✓ 60	2	✓ 60	1	! 50	2	✓ 60	2	✓ 60	Δ 57
Mangrove extent and migration																	
Minimizing the impacts of any future development on the highest priority areas for biodiversity	NS	x	x	38	2	! 58	3	✓ 68	2	! 58	2	! 58	2	! 58	2	! 58	Δ 58
Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools	NS	x	x	44	2	✓ 64	2	✓ 64	1	! 54	2	✓ 64	2	✓ 64	2	✓ 64	○ 64
Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures	NS		x	40	2	✓ 60	2	✓ 60	2	✓ 60	1	! 50	2	✓ 60	2	✓ 60	Δ 57
Removal of barriers (political, regulatory, urban) to inland migration of habitats	S, NS	x	x	39	1	✕ 49	2	! 59	2	! 59	1	✕ 49	1	✕ 49	1	✕ 49	◆ 49
Restore properties that are purchased to reduce flooding hazards rather than just removing the structure and maintain parkland- allow it to revert back to marsh/ mangrove to provide services	S, NS	x	x	36	1	✕ 46	2	! 56	2	! 56	2	! 56	2	! 56	2	! 56	Δ 56
Prohibit physical coastal structures from being built	NS	x	x	39	3	✓ 69	3	✓ 69	3	✓ 69	3	✓ 69	2	! 59	2	! 59	○ 62
Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives	NS	x	x	36	3	✓ 66	3	✓ 66	2	! 56	3	✓ 66	2	! 56	3	✓ 66	○ 63
Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines	S	x	x	37	2	! 57	2	! 57	2	! 57	3	✓ 67	2	! 57	2	! 57	○ 60

Table 13.6 SST indicator bins and related trigger values. All values are in C[0]

	Low-tolerance species bin	Moderate tolerance species bin	High tolerance species bin
Upper limit (degrees C)	30.0	36.0	50
95% of tolerance	27.6	34.2	47.5
90% of tolerance	26.1	32.4	45.0
Trigger	27.6	34.2	47.5

Table 13.7 Salinity indicator bins and related trigger values. All figures are in ppt

	Low-tolerance species bin	Moderate tolerance species bin	High tolerance species bin
Upper limit (ppt)	38	45	70
95% of tolerance	36.1	42.75	66.5
90% of tolerance	32.3	38.25	59.5
Trigger	36.1	42.75	66.5

Based on the comments collected during the second workshop, the experts identified representative estuarine and coastal system fish species expected to be impacted by temperature under the predicted future conditions (Table 13.8).

The critical thermal maximum of marine organisms varies widely between fish species and is often influenced by acclimation time (Vinagre et al., 2015; Eme & Bennett, 2009; Mora & Maya, 2006; Rajaguru, 2002).

All species were assigned membership to one of the three temperature-tolerance "bins" (i.e., low tolerance, medium tolerance, high tolerance; based on spatially explicit temperature trigger maps for the representative species of that bin (e.g., Fig. 13.2 for lined seahorse).

4.2.2 Salinity Indicator and Trigger Development

The FIM program has also recorded salinity measurements trawl data in and around Tampa Bay and Charlotte Harbor estuaries at multiple sampling points since the 1990s (FWRI, 2016). Due to the plasticity of habitat used by fish species in estuarine environments, the salinity requirements during their life cycle and their saline limits are often difficult to identify for a species outside of a lab environment; however, FIM trawl data provide an important picture as to how fish species are associated with salinity profiles.

Based on the comments of biologists and ecologists attending the second workshop, three representative estuarine and one coastal system fish species are expected to have a moderate or high impact from a salinity stressor (Table 13.9).

The experts also identified a representative coastal system fish species expected to have a moderate or greater impact from a salinity stressor.

Table 13.8 Representative temperature-sensitive estuarine and coastal fish species

Representative fish species	Ecosystem represented	Temperature-tolerance bin
Estuarine		
Spotted sea trout (*Cynoscion nebulosus*)	Lower estuary	Moderate
Lined seahorse (*Hippocampus erectus*)	Benthic estuary/ seagrass	Low
Coastal		
Red drum (*Sciaenops ocellatus*)	Bivalve reef	High

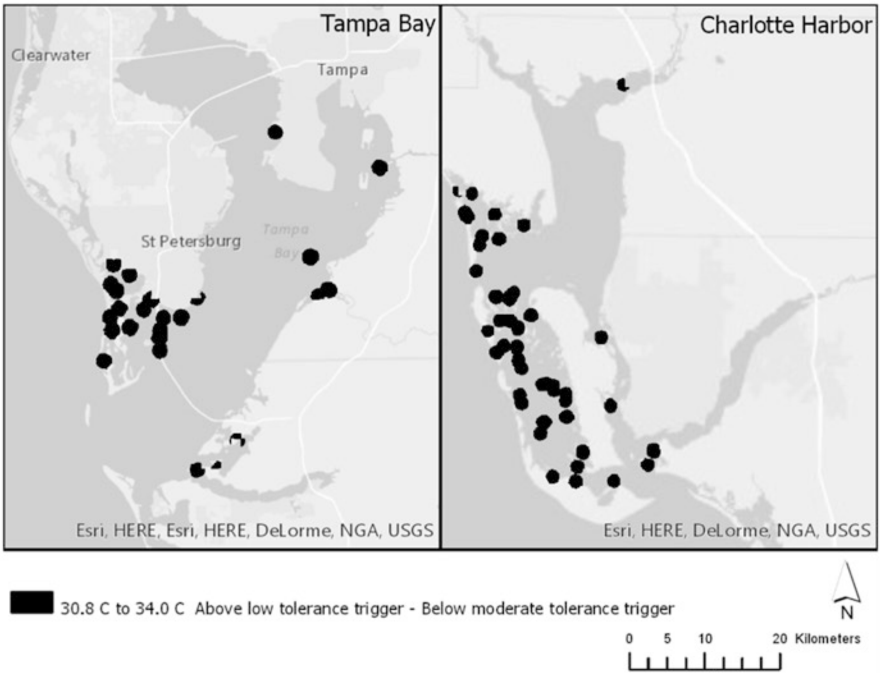

Fig. 13.2 Lined seahorse (low-temperature-tolerance species) sea surface temperature trigger map by 2020 for RCP 8.5. The black circles depict FIM sampling areas that are predicted to exceed the triggers for low-temperature-tolerance species. No locations are identified in either system where temperatures will remain below the trigger for low thermal tolerance species

All species were assigned to salinity-tolerance "bins" using the same method as that employed for the temperature tolerances. The trigger for each tolerance bin was calculated based on the 95% percentile of each tolerance groups' maximum tolerance limit (Table 13.9). Thus, the trigger is actuated before the salinity threshold is reached, allowing the necessary time for adaptation strategies to be developed, approved, and deployed.

Table 13.9 Representative salinity-sensitive estuarine and coastal fish species

Representative fish species	Ecosystem represented	Salinity-tolerance bin
Estuarine		
Gray snapper *(Lutjanus griseus)*	Mangrove fringe	High
Spotted sea trout *(Cynoscion nebulosus)*	Lower estuary	Moderate
Lined seahorse *(Hippocampus erectus)*	Benthic estuary/seagrass	Low
Coastal		
Gray snapper *(Lutjanus griseus)*	Coastal mangrove fringe	High

For each of the representative species, GIS maps were developed to depict predicted exposure of each of the sensitive species to salinity under Scenario 1: Plan/Trend RCP8.5 to 2060 (Fig. 13.3).

4.2.3 Shoreline Change Indicator

For the shoreline change stressor, potential indicators were identified to allow monitoring protocols to evaluate the impact of the shoreline change stressor mechanisms and effects. In particular, the team focused our attention on a class of physical indicators. Unlike the salinity and sea surface temperature indicators, which have one value of measurement, the shoreline change stressor according to the literature review (Berger, 1998; Berger & Iams, 1996) was selected as a combination of sea level rise impacts, conversion of upland habitat types to wetland, and the shifting of mangrove habitats within the estuaries and is based upon erosion rates, saline wetlands extent, and sea level rise.

A number of representative estuarine system fish species were identified which are expected to have a moderate or high impact from a coastal change stressor (Table 13.10).

Additional representative coastal system fish species were expected to have a moderate or high impact from a coastal change stressor.

4.2.3.1 Coastal Change Trigger Development

Erosion Rate

Potential erosion assessments were divided in to three different indicator levels for monitoring and severity assessments:

1. Severe erosion: dunes absent, vegetation absent, man-made shoreline structures, etc. (potential high erosion): 1 m/yr. loss (Manley, 2004).
2. Moderate erosion: dunes scarped or breached, narrow beach or no high-tide beach, ephemeral vegetation, erosion levels necessitating intervention, etc.: 0.6 m/yr. loss (Bush et al., 1999).

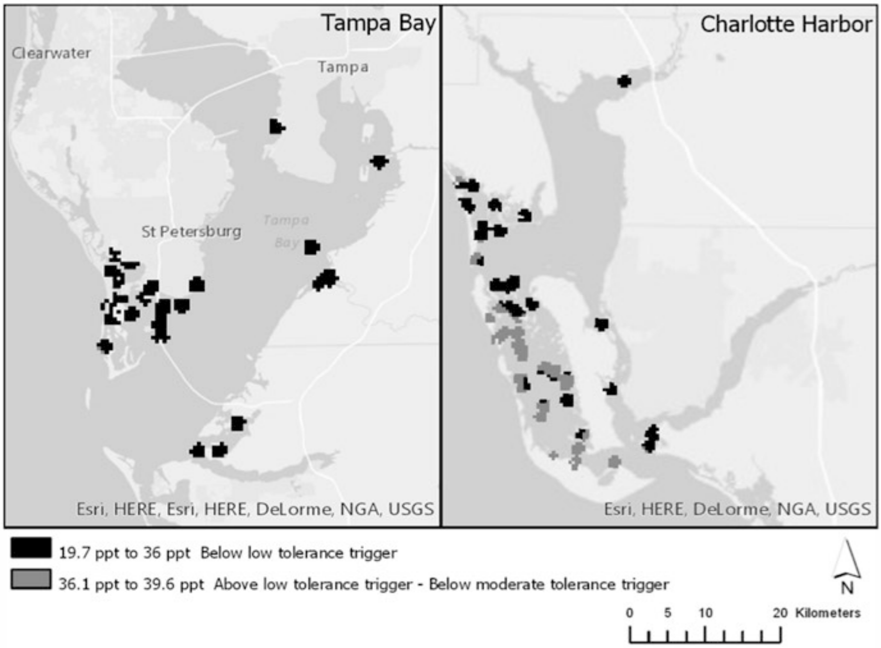

Fig. 13.3 Lined seahorse salinity low-tolerance bin trigger map by 2020 for RCP 8.5 The black circles represent FIM sampling locations where salinities are expected to remain below the low-tolerance trigger. Grey circles represent FIM sampling locations where predicted salinities will exceed the trigger for low-tolerance species

Table 13.10 Critical exposure assessment for the estuarine and coastal species representatives

Representative/ecosystem	Exposure assessment
Estuarine	
Spotted sea trout: Lower estuary	Minimal to moderate exposure
Lined seahorse: Benthic estuary/seagrass	Moderate to high exposure
Pink shrimp: All estuarine ecosystems	Moderate exposure
Coastal	
Southern stingray: Unconsolidated bottom	Minimal to moderate exposure
Red drum: Bivalve reef	Moderate exposure
Striped mullet: All coastal ecosystems	Moderate exposure

3. No erosion: accretion or long-term stability of the coastal area, dunes and beach ridges robust, un-breached wide beaches, well-developed vegetation, etc. (potential none or minimal erosion). No erosion <0.2 m/yr.; low erosion is considered to be >0.2 m/yr. (Hapke et al., 2006).

For this project, the recommended erosion trigger for the shoreline change stressor is moderate erosion, 0.6 m/yr. or greater loss of substrate.

Saline Wetland Extent

When considering the variables involved in wetland creation, permanence, and damage, it is important to monitor geological and biological parameters to assess the health and extent of wetlands as a coastal change indicator. The following variables were used to assess saline wetland extent:

1. Areal extent and distribution of vegetation, including changes in wetland boundaries (erosion, marine transgression).
2. Vegetation diversity/community structure: changes in the occurrence of particular (indicator) species or in the distribution of various plant communities within a wetland.
3. Surface morphology: (e.g., development of hummocks and hollows in a smooth Sphagnum lawn may reflect disturbance of the wetland system).

For this project, the recommended saline wetland extent trigger is a total rate of loss greater than, or equal to, a half percent annually, based on comparison to the total acreage of saline wetlands for the previous year.

Mangrove Extent, Migration, and Vertical Growth

An accurate indicator of the potential for mangrove persistence is the amount of accretion of sediment deposits within mangrove forests that create enough soil surface elevation gain to allow mangroves to keep pace with sea level rise (Krauss et al., 2013; McIvor et al., 2013). Recent calculations indicate that the global mean sea level rise, as of 2013, was 3.2 + 0.4 mm/yr., with variations in this average based on location; rates now appear to be accelerating (Krauss et al., 2013). However, when only the Florida locations were separated out of the group, and local SLR values were used, the surface elevation change ranged from 0.61 to 3.85 mm/yr. with a SLR rate of 2.1 mm/yr., indicating a higher likelihood of Florida mangroves keeping pace with local SLR impacts.

For this project, the mangrove extent indicator for the coastal change trigger is an annual increased value of vertical accretion that is equal to or less than current annual SLR measurements.

The coastal change stressor has a number of trigger subcategories, but the list of sensitive species remains the same: spotted sea trout, lined seahorse, red drum, southern stingray, and pink shrimp. The trigger maps produced for the coastal change stressor (Fig. 13.4) depict the areas of potential future saline wetlands and mangroves at 1.0 m of sea level rise (RCP 8.5 at 2060), as well as the potential distribution of sensitive species relative to wetland expansion.

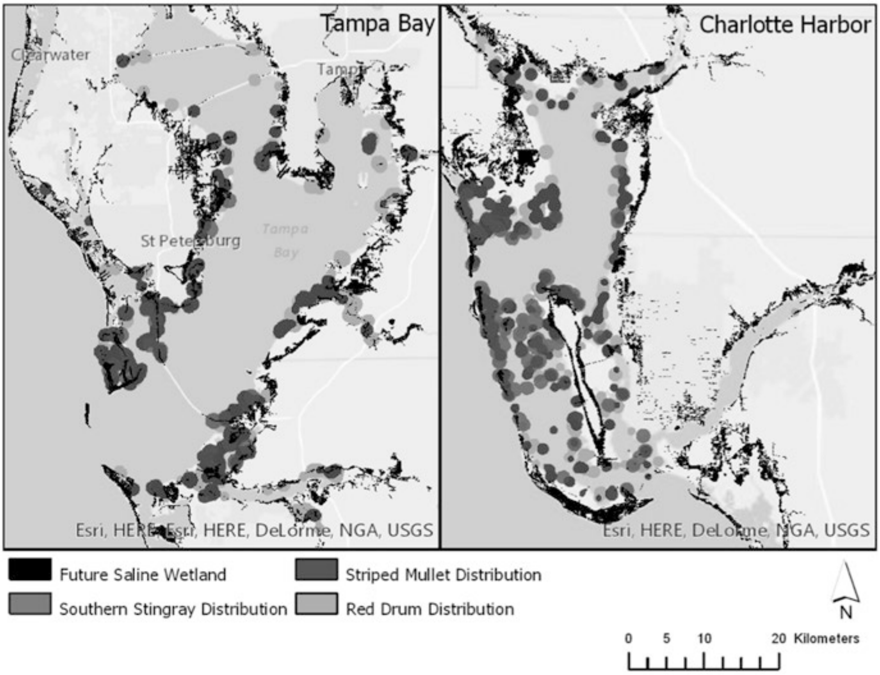

Fig. 13.4 Distribution of species sensitive to coastal change (i.e., southern stingray, striped mullet, and red drum) relative to predicted expansion of future saline wetlands and mangroves under Scenario 1: Plan/Trend by 2020 for RCP 8.5

4.3 Monitoring Tool

4.3.1 Building a Monitoring Tool to Support Adaptation Planning

The objective of the monitoring tool developed for this project was to provide decision makers with a logical and stepwise approach to identify when a trigger has been reached and then activating an appropriate adaptation strategy(ies). The trigger activation step in the monitoring tool specifically directs users to select adaptation strategies which could be successfully implemented within the framework of specific future scenarios, initializing different pathways with sensitivity to the current state of the political and environmental climate. Five key characteristics were derived to identify potential trigger activation: (1) temperature maximums, (2) salinity maximums, (3) erosion, (4) loss of wetland area, and (5) mangrove soil accretion. All of these require a monitoring program to support the collection of data and examine the timing of trigger activation.

The development of the tool identifies the entry point using existing monitoring programs as a protocol for the indicators and ongoing assessments of the information gained for each indicator. Proposed indicators for the temperature stressor are the 15-day average SST readings for the three temperature-tolerance bins; for the

Table 13.11 Monitoring tool for Scenario "Plan Trend" for shoreline change stressor (indicator: erosion rate and saline wetlands extent)

Scenario	Stressor	Indicator	Monitoring frequency	Trigger	Ecosystem	Species affected			Adaptation strategies		
Plan trend	Shoreline changes	Erosion rate	1 year	0.6 m/yr	Lower estuary ecosystem	Spotted seatrout, *Cynoscion nebulosus*	**TRIGGER MAPPING**	**STAPLEE**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 75]**	*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines* **[FINAL RANK: 67]**
					Benthic estuary/ seagrass ecosystem	Lined seahorse, *Hippocampus erectus*			*Tax breaks for reducing shoreline hardening; incentivize natural shorelines* **[FINAL RANK: 70]**	*Reduce shoreline hardening; increase living shorelines* **[FINAL RANK: 69]**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 65]**
					All estuarine ecosystem	Pink shrimp, Farfantepenaeus duorarum			*Tax breaks for reducing shoreline hardening; incentivize natural shorelines* **[FINAL RANK: 70]**	*Reduce shoreline hardening; increase living shorelines* **[FINAL RANK: 69]**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 65]**
					Bivalve reef ecosystem	Red drum, *Sciaenops ocellatus*			*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Reduce shoreline hardening; increase living shorelines* **[FINAL RANK: 69]**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 65]**
					Unconsolidated bottom	Southern stingray, Dasyatis americana			*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 65]**	*Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools* **[FINAL RANK: 64]**
					All coastal ecosystems	Striped mullet, Mugil cephalus			*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 75]**	*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Reduce shoreline hardening; increase living shorelines* **[FINAL RANK: 69]**

Scenario	Stressor	Indicator	Monitoring frequency	Trigger	Ecosystem	Species affected			Adaptation strategies		
		Saline wetlands extent	1 year	≥ 0.25% loss of previous year's wetlands total acreage	Lower estuary ecosystem	Spotted seatrout, *Cynoscion nebulosus*	**TRIGGER MAPPING**	**STAPLEE**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 75]**	*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines* **[FINAL RANK: 67]**
					Benthic estuary/ seagrass ecosystem	Lined seahorse, *Hippocampus erectus*			*Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives* **[FINAL RANK: 66]**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 65]**	*Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools* **[FINAL RANK: 64]**
					All estuarine ecosystems	Pink shrimp, *Farfantepenaeus duorarum*			*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 65]**	*Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools* **[FINAL RANK: 64]**	*Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures* **[FINAL RANK: 60]**
					Bivalve reef ecosystem	Red drum, *Sciaenops ocellatus*			*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Minimizing the impacts of any future development on the highest priority areas for biodiversity* **[FINAL RANK: 68]**	*Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives* **[FINAL RANK: 66]**
					Unconsolidated bottom	Southern stingray, *Dasyatis americana*			*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives* **[FINAL RANK: 66]**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 65]**
					All coastal ecosystem	Striped mullet, *Mugil cephalus*			*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 75]**	*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures* **[FINAL RANK: 60]**

(continued)

Table 13.12 Monitoring tool for Scenario "Plan/Trend" for shoreline change stressor (indicator: mangrove extent, migration, and vertical growth)

Scenario	Stressor	Indicator	Monitoring frequency	Trigger	Ecosystem	Species affected			Adaptation strategies		
Plan trend	Shoreline changes	Mangrove extent, migration, and vertical growth	1 year	Annual increase in vertical accretion that is ≤ than current annual mean SLR	Lower estuary ecosystem	Spotted seatrout, *Cynoscion nebulosus*	**TRIGGER MAPPING**	**STAPLEE**	*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines* **[FINAL RANK: 67]**	*Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives* **[FINAL RANK: 66]**
					Benthic estuary/ seagrass ecosystem	Lined seahorse, *Hippocampus erectus*			*Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives* **[FINAL RANK: 66]**	*Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools* **[FINAL RANK: 64]**	*Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures* **[FINAL RANK: 60]**
					All estuarine ecosystems	Pink shrimp, Farfantepenaeus duorarum			*Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools* **[FINAL RANK: 64]**	*Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures* **[FINAL RANK: 60]**	*Prohibit physical coastal structures from being built* **[FINAL RANK: 59]**
					Bivalve reef ecosystem	Red drum, *Sciaenops ocellatus*			*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Minimizing the impacts of any future development on the highest priority areas for biodiversity* **[FINAL RANK: 68]**	*Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives* **[FINAL RANK: 66]**
					Unconsolidated bottom	Southern stingray, *Dasyatis americana*			*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives* **[FINAL RANK: 66]**	*Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools* **[FINAL RANK: 64]**
					All coastal ecosystems	Striped mullet, *Mugil cephalus*			*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures* **[FINAL RANK: 60]**	*Removal of barriers (political, regulatory, urban) to inland migration of habitats* **[FINAL RANK: 59]**

salinity stressor, the 30-day averaged water column salinity values for the three salinity-tolerance bins; and for the shoreline change stressor, yearly erosion rates, saline wetlands extent measurements, and mangrove vertical accretion measurements within the estuaries. When the monitoring program(s) demonstrate that the value for a specific indicator exceeds its trigger value (based on the definition of the indicator), the trigger is activated. The scenario state is the second point of entry to the tool and determines the path to move forward on. The current state of coastal development, conservation approach, and policy when triggers are reached will determine which adaptation strategies from the monitoring tool are suitable and feasible to implement to address the stressor in question.

4.3.2 Resulting Evaluation

By evaluating the information presented in the monitoring tool tables (Tables 13.11 and 13.12), it is possible to highlight which adaptation strategies are predicted to have the greatest positive effect. The tool shows the different adaptation strategies to be implemented for each trigger, and the strategies are cumulative as triggers are reached in succession. In the tables, the strategies are presented according to the final ranks resulting from the STAPLEE evaluation.

Starting with the first stressor in the table, shoreline hardening, and progressing across the table, the ranked adaptation strategies are implemented based on which triggers are turned "on." The adaptation strategies listed in the table have STAPLEE ranking values associated with them that indicate the relative importance of the strategy. For example, for the shoreline change stressor, for the "mangrove extent, migration, and vertical growth" indicator (Table 13.12), the prohibition of physical coastal structures has a higher STAPLEE score for both the scenarios. For the other two indicators ("erosion rate" and "saline wetlands extent") different strategies have the highest STAPLEE score: the improving of education and tax breaks for reducing shoreline hardening. Although it may be more complicated to monitor three indicators for one stressor, having a diverse suite of indicators better represents the variations of how shoreline change functions as a stressor to related fish species.

5 Discussion

Climate change forces a more holistic approach in all areas of management, planning, and science. Especially marine adaptation planning must be approached in a holistic manner given the need to consider the constantly changing relationship between species, their environment, and the complex environmental management and institutional decision process. As such, it becomes necessary to depart from the recognition that triggers more than slow onset constant transformational changes in the climate can be indicative to key moments to implement groups of adaptation strategies and actions. This process requires unpacking and sorting uncertainties and identifying and simulating the derailing force of key triggers that can reshape both the natural and decision context. In this study scenario-driven planning has proven to be useful in this process, but it demands substantial political will, flexibility, and investment, as complex institutions and natural forces require to rethink current norms, management strategies, and legal references. Approaches that reduce uncertainty and established systemic monitoring can guide the process of marine adaptation planning in a context where both natural and anthropogenic futures unfold in unforeseen ways. The paring marine spatial-planning scenarios and triggers with key monitoring indicators have represented in this study a valuable contribution from the environmental management perspective, as it provides a means to visualize with stakeholders the consequences of potential actions interacting with the changing environmental. In this sense, scenarios more than conventional marine management should be based not only on observational data and statistical models but also simulations that integrate experts' opinions regarding the prioritization of future adaptation strategies, beyond those based on the range of most historical observations.

5.1 Implications for Public Policy, Management, and Climate Change Adaptation

5.1.1 Policy and Management

Natural resource agencies are charged with managing their trust resources for the benefits of the stakeholders they serve. Whether it's for hunting, commercial, or recreational fishing or other recreational opportunities, stakeholders expect healthy wildlife populations that are sustainably managed (Sensu Stöhr et al., 2014). However, environmental conditions are changing in large part due to impacts to the climate system resulting in challenges to managing natural resources in a business-as-usual environment.

The effects of climate change are already being felt in the South Florida marine environment. Corals are bleaching from increased water temperatures (Wagner et al., 2010), sea levels are accelerating rapidly (Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group, 2015), and fish and plant species' distributions are shirting northward (Perry et al., 2005). Modeling now suggests that rainfall can be expected to decrease in the southern part of the peninsula (Sinha et al., 2018) which will have significant impacts on estuarine systems (Copeland, 1966).

However, climate is not the only variable that must be accommodated when developing effective long-term management strategies to achieve coastal natural resource conservation: urban development is leading to fragmentation of habitats and impacts to nearshore waters (e.g., Airoldi et al., 2008), pollution is reducing marine biodiversity (e.g., Smith et al., 1999), coastal erosion is reducing healthy shorelines (Raabe & Stumpf, 2015) and species' suitable habitats (Fujisaki et al., 2017), invasive species are impacting native populations (Gallardo et al., 2015), and coral diseases are becoming more common and consequential (Peters, 2015). All of these impacts are influencing coastal ecosystems resulting in the inability of those ecosystems to support the biodiversity that they once did. Ultimately, the reduction in coastal biodiversity impacts the services these ecosystems provide society (Worm et al., 2006).

Of these, perhaps the most pernicious impact is the accelerating rate of sea level rise. Models are predicting that sea levels will increase in southeast Florida by 6–10 inches by 2030, 14–26 inches by 2060, and 31–61 inches by 2100 (Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group, 2015). The impacts to both the natural resources and the coastal communities which depend upon them may be devastating without the development of robust adaptation plans (Lorenzen et al., 2017). Clearly managers must be prepared if they are to ensure that the biological, social, and economic resources are to persist and thrive.

For natural resources agencies, the changes are unsettling due to the uncertainties associated with how resources will respond under these pressures. The outcomes from long-term planning become less certain with the result that priorities inevitably shift to the short-term thus becoming less strategic and more ad hoc. Ultimately, how agencies adapt to these changes will depend on how they balance short-term priorities and long-term changes (Paukert et al., 2016).

This study was designed to develop adaptation options under these uncertainties and to provide context for managers from which they can make robust decisions. Given the uncertainties, managers must use tools that anticipate possible futures under a variety of stressors.

Because of the vicissitudes associated with climate change and the inability to control the outcomes, scenario planning has been proposed as one of the more powerful approaches to provide context to managers (Peterson et al., 2002). In this study, both biological and anthropogenic variables were examined in the context of alternative future scenarios and examined the science and consequent adaption solutions that may result from these possible outcomes. In this way, managers may identify possible planning outcomes by examining alternative scenarios thereby providing a framework from which they can develop solutions.

One of the values of using scenarios is that they allow for identifying best possible adaptation strategies based on how each scenario was parameterized and what scenario materializes. For example, when planning for high salinities, the highest STAPLEE score under the Plan/Trend scenario was to increase legislative and governance capacity because this scenario recognized deficiencies in those categories. Because this scenario is essentially business-as-usual, this response argues for developing and implementing approaches that provide greater flexibility in regulatory authority (e.g., adaptive water governance: Hurlbert & Diaz, 2013). However, in the Proactive Plus scenario, the scenario already accounts for enhanced governance therefore planting shoreline cover was identified as the adaptation strategy of choice. In these examples, the most effectual adaptation option was based on the trajectory of political and planning priorities defined within each scenario.

The previous example highlights the importance of identifying the most applicable scenario. If the most reasonable scenario is not selected, or if scenarios are not employed to address uncertainty, then resources could be allocated inefficiently or ineffectively. The identification of the most reasonable scenario, however, is just one of the reasons that an effective monitoring program must be incorporated into a thorough adaptation planning program.

The southwest Florida coastal and estuarine systems, as well as the built environment, are particularly vulnerable to a changing climate given their low-lying elevation, association with tropical systems, and reliance on freshwater. Small changes can have very consequential impacts.

Because of this system-wide vulnerability, agencies must have sufficiently adaptable structures in place to address changing conditions. Policies must respond to the needs of both ecological and social systems (Paukert et al., 2016) to ensure that both are resilient in the face of emerging threats.

Unfortunately, business-as-usual management may be inevitable given its political palatability. In many cases, laissez-faire management will continue until conditions become so untenable that adaptation implementation becomes critical, a point-in-time Werners et al. (2015) term an “adaptation turning point.” The challenge is to ensure adaptation strategies are in place and ready for implementation when this trigger is reached whether the trigger is an “adaptation turning point” or another one associated with a specific strategy or vulnerability.

For the sake of efficiency, the FWC has been identifying suites of species that share common vulnerabilities and, therefore, developing adaptation strategies that may apply to many of them. However, inevitably, individual species will either slip through this coarse filter and will need to be addressed individually.

To accommodate both single and multiples species, this project purposefully focused on single species as representatives of suites of species that share similar vulnerabilities under changing climate conditions. The adaptation options that were developed undoubtedly will provide benefits to other species with similar life histories sharing similar habitats and with common vulnerabilities. For example, planting riparian vegetation will benefit both marine and terrestrial species including reptiles and birds that were beyond the scope of this project.

Developing solutions is relatively straightforward; however, implementing the solutions is compounded by social barriers addressed within the framework of the STAPLEE approach (i.e., categories related to social, technical, administrative, political, legal, economic, and environmental criteria). Yet, the challenges for effective management solutions under a changing climate must address implementation within a social context. This process must recognize that the solutions are not only technical in nature (O’Brien & Selboe, 2015) but also represent adaptive challenges (Sensu Heifetz et al., 2009).

Ensuring that robust adaptation strategies are implemented in policy is an enormous challenge. One approach is to ensure that adaptation strategies are integrated into existing instruments. For example, imperiled species management plans and species recovery plans by definition must recognize and address emerging threats (e.g., climate change), and these should reduce species’ vulnerabilities. To effectively accomplish this, a change in perception by land-use managers may be required since, in many cases, traditional training does not prepare them for changing environments and targeted efforts must be made to ensure they are prepared to make decisions under uncertainty (Doonan et al., 2017).

Because management and policy focus on social systems, approaches must be developed that ensure that both natural resources' and stakeholders' interests are met. Furthermore, because governance is concerned with rule-making systems within the context of sustainable development (Biermann et al., 2009 quoted in Plummer, 2013), their structures must be robust so that solutions can be accepted by diverse suite of stakeholders. The legal authority within statutory structures must be sufficiently flexible to adjust to changing conditions (Camacho & Glicksoman, 2016), especially within a social context (Biermann et al., 2009).

In the end, implementing adaptation strategies and ensuring that they are integrated into policy remain one of the biggest challenges to effective management. This project did not specifically address implementation; nevertheless, identifying and overcoming barriers to implementation remain one of FWC's highest priorities. In a recent FWC workshop (Benedict et al., 2018), the STAPLEE method was used to identify barriers to implementation. The inability for flexibility in governance systems under changing conditions along with governance uncertainty (Camacho, 2009) were identified as two of the largest obstacles to implementing climate adaptation strategies.

There are, however, approaches that can encourage implementation. The relatively recent popularity of adaptive management with respect to climate adaptation (Tompkins & Adger, 2004) is one solution. Unfortunately, this approach has been difficult to implement due to technical, social, and economic barriers.

Fortunately, it has not yet seen the worst of the projected changes to nearshore habitats. It is incumbent upon natural resources agencies to plan for the future as difficult as this may be. The approach outlined provides a framework for identifying adaptation strategies under considerable uncertainty and provides a way forward to conserve the many of the natural resources.

5.1.2 Adaptation Planning

Climate-smart adaptation has become a standard for climate adaptation planning for natural resources (see Stein et al., 2014). This approach integrates science and management into a cycle that includes defining the problem, examining the science, developing and prioritizing adaptation options, and examining effectiveness. For this project, the team employed that climate-smart approach but adapted it to FWC priorities. For example, it was added the concepts of dealing with uncertainty by using scenario planning to frame the future, identifying triggers that indicated when to implement the given adaptation option, and further added monitoring to identify when triggers have been reached. The triggers and monitoring additions to the cycle were included for purely practical reasons: there must be a methodology that identifies when an adaptation option should be implemented. Without this guidance, there is no way to know when to begin implementing adaptation strategies.

Clearly monitoring is a critical component of adaptation planning and implementation. In identifying which scenario emerges, there are three other reasons to monitor, and, given their distinct objectives, each may require different monitoring programs.

First, monitoring can be used to evaluate the impacts to species, habitats, and ecosystems. Generally, this is how most managers view monitoring: what is happening to a resource over time? Entire programs have been built based on this priority such as understanding the effects of climate change on species (e.g., Lepetz et al., 2009), abundance determinations for fisheries management (e.g., Schemmel et al., 2016), identifying long-term ecological changes (e.g., Kennish, 2019), and ecosystem restoration evaluation (e.g., Louhi et al., 2016). In this project, a 24-year dataset was used to understand the long-term changes to both the focal fish species in the study areas as well as the environment that supports them. This in turn helped us to build the model that from which the adaptation options were derived.

Second, monitoring programs can help inform when to implement the given adaption options (i.e., when a trigger has been reached). A well-focused adaptation program must include monitoring for triggers otherwise timing adaptation strategy implementation will be problematic.

Finally, monitoring can help evaluate the efficacy of an implemented adaptation strategy and can inform as to its continued use, modification, or abandonment. Additionally, monitoring for effectiveness helps to determine if maladaptation issues are occurring. For these reasons, monitoring is a critical component of any adaptation plan.

This study highlighted the importance of close interactions between management and science with respect to adaptation planning. Since the focus of the study was understanding what a changing climate and differing policy directives meant for suites of estuarine and coastal species and how to create approaches that address their consequent vulnerabilities, the roles of managers and scientists were inextricably linked. To illustrate this point, in this study, managers defined the goals and objectives of the project, scientists identified the species that were best suited to address the scope, and scientists provided projection on the impacts from a changing climate and policy priorities. After this part of the process, managers and scientists worked closely together to identify possible adaptation options, select the most efficacious adaptation strategies (based on STAPLEE), pinpoint triggers, and develop monitoring plans. In this process, science clearly serves the goals of management.

In addition to input from managers and scientists, it was demonstrated that science alone will not provide the guidance necessary to address the uncertainties and thus develop effective and holistic approaches to adaptation in a changing climate. Emphasis must also be placed on incorporating expert knowledge. Inevitably there will be instances where knowledge is incomplete yet crucial to inform a process and expert input can provide context for important planning decisions (Rinaudoa & Garin, 2005). In this study, a number of variables that are used to classify vulnerability in the fish species (Morrison et al., 2015) in this study were not available in the literature. However, experts provided their knowledge to help categorize the species' vulnerabilities.

Identifying possible adaptation options is a difficult task that often requires creative and, sometimes uncomfortable, idea development. All options should be considered, no matter how unconventional (Stein et al., 2014). For example, when considering adaptation options for the temperature stressor under the Plan/Trend scenario, one of the less conventional options included diverting cooler, deep water to coastal areas. Obviously, this approach requires extensive investments in engineering, the science of localized ocean circulation, and money; the feasibility of implementing this option is certainly questionable. Thus, selecting the best option(s) becomes a very important part of the process.

A high priority for this study was recognizing the importance of selecting adaptation options that were appropriate and had the highest probability of success. As described previously, the STAPLEE approach was applied to prioritize adaption options. This method accounted for technical, financial, social, and political variables as well as others. Thus, a wide diversity of societal values were incorporated into the strategy selection process. In many cases, multiple adaptation strategies will be relevant for multiple stressors; and these are accounted for in the monitoring tool.

However, the team recognize that STAPLEE scores that identify the most efficacious adaptation strategy may be overly simplistic and therefore not be realistic. In certain cases, some strategies may score highly, but one or more components may ultimately override all others. Costs may be prohibitive, "political will" may overwhelm all other considerations, and/or technical obstacles may be too considerable to effectively implement certain high-scoring strategies. Thus, results from STAPLEE need to be carefully evaluated to ensure that they are feasible.

On the other hand, some high-scoring adaptation strategies may be easy to implement. In this study, outreach and education scored very high as an approach to address erosion rate under the shoreline stressor. This is likely a very easy-to-implement strategy that will both incur little expense and likely encounter few governance/political obstacles. A post hoc analysis of the scores from STAPLEE should elucidate strategies that both are easy to implement and provide little downside (i.e., no-regrets strategies).

This project has shown that adaptation planning must be approached in a holistic manner which considers resource vulnerabilities, identifies activities that mitigate those vulnerabilities, and includes components that identify when to implement the activities. Taken together, the approach that was outlined presents a comprehensive treatment of climate adaptation planning which addresses both the interests of species conservation and societal values, both of which must be accounted for if effective species conservation is to be achieved.

Glossary

Abandonment: The decision to permanently leave or to remove existing uses from a site.

Adaptation: The process of adjusting to change, including direct activities, but also supporting legal or cultural practices.

Adaptive infrastructure: Infrastructure intended to alleviate or avoid expected changes. In terms of climate change and development, common adaptive infrastructure includes various forms of shoreline hardening/ armoring, elevating existing or new activities (e.g., houses, boat ramps). In terms of fixed public infrastructure, this can include utility changes (e.g., water desalination plants), diversification, and elevation of transportation (e.g., adding ferry routes or elevating bridges and roads). In both public and private sectors, adaptive measures can also include portable or semiportable infrastructure (e.g., movable terraces or small buildings).

Beneficial impact: Significantly increasing habitat quality or the ability of species to persist over time.

Business as usual (BAU): A common planning phrase indicating policies, practices, or rules which represent a continuation of current practices into the future. **Compatible Impact:** proposed activity has no significant impact on habitat quality or species persistence.

Comprehensive planning: Deals more with interactions between potential uses and the implications of spatial patterns.

Emission scenario: "describe future releases into the atmosphere of greenhouse gases, aerosols, and other pollutants and, along with information on land use and land cover, provide inputs to climate models" (World Meteorological Organization).

Habitat quality scale: A standard qualitative scale used within this study to normalize habitat descriptions across species and within factors used in evaluating habitat characteristics.

Impact assessment scale: A standard qualitative scale used to measure species and population impacts within this study. Assignment to individual categories can be on the basis of best professional judgment, empirical analyses, quantitative modeling, or a combination of the three.

Longer term: For purposes of this study, management activities requiring significant changes to existing institutional arrangements or large amounts of funding were categorized as longer term.

Managed relocation: A broad set of measures, which promote or require movement of fixed infrastructure. In public sector applications, these frequently include development exclusion zones and setbacks, which restrict current and future development, such as Florida's Coastal Construction Control lines. They can also include mandatory mitigation measures, such as enhanced building codes. Managed relocation can also include the nonrenewal of required permits, such as certificates of occupancy. Insurance has an important role in managed relocation. On the public sector side, rule changes to publicly subsidized insurance programs can be significant (e.g., FEMA's repeat loss policies). On the private sector side, insurance companies can adjust rates or refuse coverage in particular circumstances. Many of these measures have cumulative and indirect effects on the likelihood and affordability of siting structures in particular locations.

Management triggers: Conceptual or practice thresholds or observations which indicate that new or different courses of action are indicated. For example, the ratio of sea level rise to mangrove terrain accretion is a likely management trigger within South Florida. If sea level rise stays below the local accretion rate, one set of management responses is indicated. However, if this threshold is exceeded, a completely different set of activities might be undertaken.

Medium-term actions: For the purposes of this study, management activities which are likely feasible within 5 years given current institutional arrangements were considered as medium term.

Moderate impact: Some degradation of habitat or species populations is expected but at a level which could be mitigated on site with normal techniques.

New Representative Concentration (RCP) Pathways: "based on scenarios from four modeling teams/models working on integrated assessment modeling, climate modeling, and modeling and analysis of impacts" (World Meteorological Organization).

No-regrets actions (NR): Management activities, which are invariant relative to the range of variation expressed in scenarios. For example, critical habitat acquisition might be considered "no regrets" if and only if it is expected to continue to meet management goals under climate change.

Primary habitat: Factors/features or conditions which represent or are indicative of the best-known habitat and support its long-term persistence.

RCP 4.5 Stabilization without overshoot pathway to 4.5 W/m^2 at stabilization after 2100.

RCP 8.5: Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100.

Recruitment: "the addition of new individuals to populations or to successive life history stages within populations".

Scenario: Bundles of consistent assumptions, facts, projections, and possible policies.

Sea Level Affecting Marshes Model (SLAMM): "simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea level rise. Map distributions of wetlands are predicted under conditions of accelerated sea level rise, and results are summarized in tabular and graphical form".

Secondary habitat: Factors/features or conditions which represent or are indicative of known habitat but in which some essential elements are either missing or degraded. This category can include habitat, which are only used for a single part of a species life cycle.

Sectoral planning: Seeks to engage particular issues and can do so in great detail, including consideration of individual policies or rules.

Severe impact: Degradation of habitat or species population is expected beyond the ability of normal mitigation practices to remedy on site.

Stressor: A factor that cause stress to a species.

Sublegal: Unfished.

Tertiary habitat: Factors/features or conditions which represent or contain aspects of viable habitat but also have known limitations. For example, habitats which provide cover but not nesting or forage might be placed in this category.

Threshold: Proposed activity is likely to cause permanent extirpation of local habitat or species populations.

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