Modeling and Abating the Impacts of Sea Level Rise on Five Significant Estuarine Systems in the Gulf of Mexico

October 2013 final report

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Cover Photo

This photo shows how coastal forest (aka swamp, a coastal wetland type) is turning into marsh along Florida's Big Bend coastline. The area was once all coastal forest but as sea level has risen, coastal forest trees have died off creating a mosaic of tree islands in a sea of marsh. This photo was taken at the Withlacoochee Gulf Preserve, an entrance way to Waccasassa Bay in Levy County, Florida.

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Table of Contents

Appendices (separate document)

Figures

Tables

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Our workshops would not have been successful had it not been for the workshop participants. We very much appreciate the time they took out of their busy schedules to attend and participate. Workshop participants are listed in Appendix 9.

Executive Summary

Coastal wetland systems and human communities will be substantially affected whether sea level rises 18-59 cm by 2100, as estimated by the Intergovernmental Panel on Climate Change (IPCC 2007), or at the higher rates predicted by models that include the melting of polar ice caps and other factors (e.g., CCSP 2008; Mitrovica et al. 2009; Overpeck et al. 2006; Rahmstorf et al. 2007; Rahmstorf et al. 2012). While responding to the gradual inundation brought about by sea level rise (SLR) will be challenging, of greater concern is the increased vulnerability of human and natural communities to likely increases in storm surge impacts. Shepard et al. (2011) found that even modest and probable SLR (0.5 m by 2080) vastly increases the numbers of people (+47%) and property losses (+73%) caused by storm surge on the south shore of Long Island, New York. Intact coastal wetlands can help to buffer adjacent human communities from the impacts of storm surge (Arkema et al. 2013) and in a more cost effective manner than engineered solutions (McIvor et al. 2012; UNU-EHS and The Nature Conservancy 2012).

Human communities and coastal wetlands systems at several estuaries along the U.S. Gulf of Mexico coast are especially vulnerable to SLR impacts due to their low-lying nature and extensive development that blocks coastal wetlands from migrating to higher elevations. Improving our understanding of the vulnerability of natural and human communities to SLR provides communities and natural resource managers with the information needed to take appropriate action and minimize the consequences. Taking action now rather than waiting for impacts to accumulate can minimize hazards to human communities and disruptions to natural systems, and can be more cost-effective in the long-term (Titus and Neumann, 2009)

Sea Level Affecting Marshes Model

Among the tools developed to enhance our understanding of the effects of SLR on coastal wetland systems is the Sea Level Affecting Marshes Model (SLAMM). SLAMM was developed in the mid-1980s (Park et al. 1986), with SLAMM 6.2 beta released in December 2012 (http://warrenpinnacle.com/prof/SLAMM/index.html). The model simulates the dominant processes involved in changes to wetland systems and shoreline modifications during SLR. We applied SLAMM to simulate SLR impacts on coastal wetland systems at five estuaries across the U.S. Gulf of Mexico: Corpus Christi Bay in Texas; Mobile Bay in Alabama; and Pensacola Bay, Southern Big Bend and Tampa Bay in Florida. In each estuary, we modeled three SLR scenarios through the year 2100: 0.7 m, 1.0 m and 2.0 m and reported out results in 25 year increments, 2025, 2050, 2075 and 2100. Uncertainty analyses were conducted on selected input parameters to better understand their influence on modeling results. In addition to the SLR modeling, impacts of SLR on the most vulnerable species were assessed and vulnerable infrastructure, historic and cultural resources were identified for use in the workshops described below.

The results of the above described analyses were presented to stakeholders at workshops held in each study area. The purpose of the workshops was to familiarize local stakeholders with predicted effects of SLR and to facilitate the development of locally relevant adaptation strategies to help reduce the impacts of SLR. A summary of the vulnerable species analyzes and other workshop results are provided below. Maps of vulnerable infrastructure, historic and cultural resources are provided in Appendix 5.

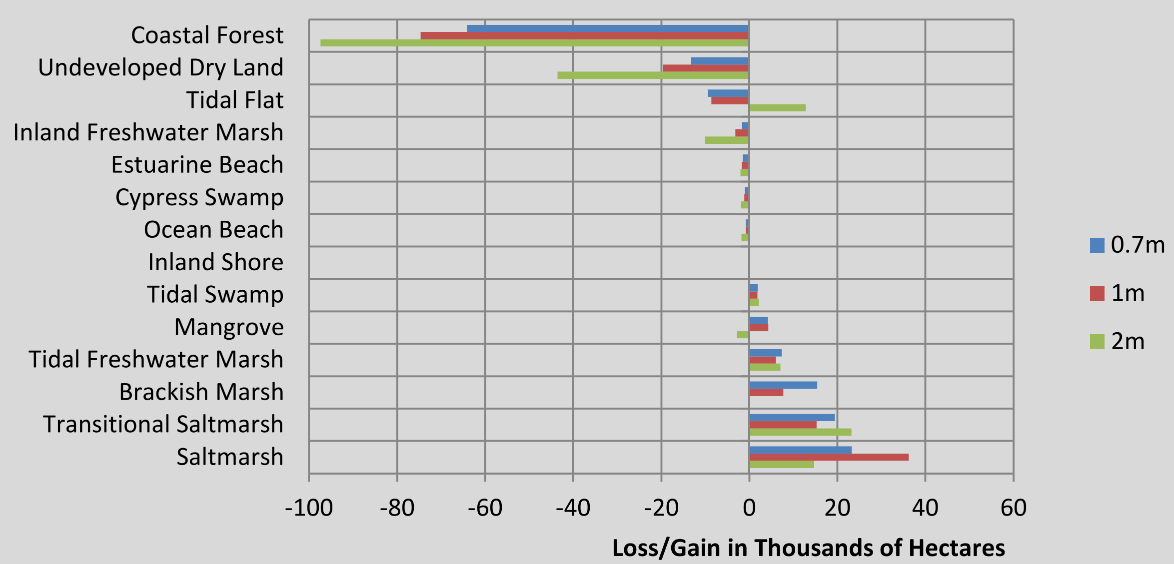
Results

SLR Modeling Results

While the five study areas represent only a subset of Gulf of Mexico estuaries, the results provide an indication of which coastal wetland systems are likely to experience the greatest change and the direction of change (gain or loss) in this region by the year 2100. Predicted impacts of SLR for the five study areas indicate that coastal forest (-74,670 ha; -288 square miles) and undeveloped dry land (-19,570 ha; -76 square miles) will face the greatest loss in cover by the year 2100 (Figure ES1). The largest gains in cover are predicted for saltmarsh (+36,157 ha; +140 square miles), transitional saltmarsh (+15,301 ha; +59 square miles), brackish marsh (+7,727 ha; +30 square miles) and tidal freshwater marsh (+6,039 ha; +23 square miles).

Figure ES1. Predicted Change in Wetland System and Adjacent Dry Land Cover at the Five Estuary Sites under 3 SLR Scenarios through the year 2100

Developed Dry Land Protected from Change



Predicted impacts of SLR on coastal wetlands and adjacent human communities at the five study areas varied considerably due to different amounts and types of coastal wetlands, elevation of the area and the amount of developed area (Table ES1). Of the five study areas, Tampa Bay and Corpus Christi Bay were predicted to experience the greatest net loss in coastal wetland systems. The Southern Big Bend Study Area was the only estuary with a predicted net gain in coastal wetlands due to the transition of undeveloped dry land into coastal wetlands. Below we provide a few insights into what the predicted changes might mean at each study area.

Table ES1. Change in coastal wetland systems and undeveloped dry land by year 2100 under 1 m SLR scenario (developed dry land protected from changing) Units are in Hectares						
Coastal System	Corpus Christi Bay	Mobile Bay	Pensacola Bay	Southern Big Bend	Tampa Bay	TOTAL
Coastal Forest	-6	-41,187	-6,408	-24,655	-2,413	-74,670
Undeveloped Dry Land	-2,907	-2,658	-1,071	-9,066	-3,868	-19,570
Tidal Flat	-1,874	4,780	1,770	1,333	-14,628	-8,619
Inland Freshwater Marsh	-987	-141	-1,048	-758	-276	-3,210
Estuarine Beach	-1,144	-654	17	57	-24	-1,748
Cypress Swamp	0	-621	-370	-140	-36	-1,166
Ocean Beach	-169	-136	-386	40	-130	-782
Inland Shore	-126	-9	-1	0	-3	-139
Tidal Swamp	-1	3,130	-983	-353	0	1,793
Mangrove	0	0	0	-121	4,453	4,331
Tidal Freshwater Marsh	-2	4,562	1,532	-12	-41	6,039
Brackish Marsh	-935	8,353	381	107	-180	7,727
Transitional Saltmarsh	1,436	1,078	1,208	11,592	-14	15,301
Saltmarsh	-1,611	19,905	3,617	15,736	-1,491	36,157
Net Change in Coastal Wetlands	-5,418	-940	-671	2,826	-14,783	-18,985

Corpus Christi Bay, Texas

Loss of tidal flat, salt and brackish marsh and estuarine beach will have implications for dependent species like shorebirds, wading birds and fish, especially those that use marshes as nursery areas. In addition, beach, tide flat, marsh and undeveloped dry land areas act to slow and reduce coastal storm wind and surge energy, and in the case of marsh can dampen the effects of flooding (Arkema et al. 2013). Loss of these habitats will increase the vulnerability of adjacent developed areas. Newly submerged lands may eventually become seagrass or other valuable subtidal habitat.

Mobile Bay, Alabama

Loss of such a large area of coastal forest to marsh and tidal flat (41,187 ha) could have huge implications for species dependent on this habitat like the white ibis and the Alabama redbelly turtle. In addition, coastal forest can act to slow and dampen coastal storm wind and surge energy; mitigating effects that will be diminished with the loss this habitat. The loss of undeveloped dry lands will increase the vulnerability of adjacent upland areas to coastal storm effects. Newly submerged lands may eventually become seagrass or other valuable subtidal habitat.

Pensacola Bay, Florida

Transition of a large area of coastal forest to marsh could have substantial implications for species dependent on this habitat like the white-top pitcher plant. In addition, coastal forest can act to slow and dampen coastal storm wind and surge energy. These capabilities will be diminished with the loss of coastal forest trees. Areas transitioning to marsh could eventually benefit species dependent on this habitat such as wading birds and fish, especially those that use marsh as nursery habitat.

Southern Big Bend, Florida

Loss of such a large area of coastal forest (including tidal swamp; nearly 25,000 ha) could have substantial implications for species dependent on this habitat. In addition, the reduction of costal storm wind and surge energy provided by these forests would be lost. Newly created saltmarsh could be beneficial to dependent species such as wading birds and fish, especially those that use marsh as nursery habitat. The loss of undeveloped dry lands will increase the vulnerability of adjacent upland areas to coastal storm and flooding effects.

Tampa Bay, Florida

The substantial loss of tidal flat, coastal forest and saltmarsh (18,532 ha total) will likely have substantial impacts on dependent species. Mangroves are likely to increase substantially favoring species dependent on this system. Upland areas adjacent to the newly forming mangrove areas will likely benefit from increased protection from coastal storm wind energy and surge as the mangrove forests mature. Newly submerged lands may eventually become seagrass or other valuable subtidal habitat.

Effects of Sea Level Rise on Vulnerable Species at the Five Study Estuaries

Using the SLAMM results at each study estuary, loss of habitat was predicted for a selection of species thought to be vulnerable to SLR impacts. Although, in some cases SLAMM predicted that individual species would gain habitat, we did not include this gain in the estimates of change because it is unknown whether the species could successfully become established in the newly created habitat. However, the potential for new habitat indicates that some species may be less threatened by SLR than others. Results of the vulnerable species analysis are summarized in Table ES2.

Table ES2. Summary of results - vulnerable species assessment all study areas under the 1 meter sea level rise scenario (developed dry land protected from change)

Species predicted to lose more than 75% of their habitat in the study areas	
Corpus Christi Bay Study Area	seaside sparrow (*Ammodramus maritimus*) piping plover (*Charadrius melodus*)
Pensacola Bay Study Area	Florida burrhead (*Echinodorus floridanus*) blackmouth shiner (*Notropis melanostomus*) Florida pondweed (*Potamogeton floridanus*)

Table ES2 continued	
Species predicted to lose 51% to 75% of their habitat in the study areas	
Corpus Christi Bay Study Area	reddish egret*(*Egretta rufescens*), glasswort-saltwort series (*Salicornia virginiana-batis maritime* series) sea turtle group**
Mobile Bay Study Area	snowy plover (*Charadrius alexandrines*) piping plover (*C. melodus*)
Pensacola Bay Study Area	narrowleaf naiad (*Najas filifolia*)
Southern Big Bend Study Area	late flowering beach sunflower (*Helianthus debilis* ssp. *tardiflorus*)
Species predicted to lose 26% to 50% of their habitat in the study areas	
Corpus Christi Bay Study Area	Gulf saltmarsh snake (*Nerodia clarkia)*
Mobile Bay Study Area	hairy-peduncled beakrush (*Rhynchospora crinipes*)
Pensacola Bay Study Area	bog spicebush (*Lindera subcoriacea*) Escambia map turtle (*Graptemys ernsti*)
Southern Big Bend Study Area	Cedar Key mole skink (*Plestiodon egregious insularis* Crystal siltsnail (*Floridobia helicogyra* pinkroot* (*Spigelia loganioides*)
Tampa Bay Study Area	Loggerhead sea turtle** (*C. caretta*) wintering shorebirds (piping plover and red knot) nesting shorebirds (black skimmer, least tern, snowy plover, American oystercatcher and Wilson's plover)
Species predicted to lose 10% to 25% of their habitat in the study areas	
Corpus Christi Bay Study Area	Texas diamondback terrapin (*Malaclemys terrapin littoralis*) three flower broomweed (*Thurovia triflora*) sea oats-bitter panicum series (*Uniola paniculata-panicum amarum* series).
Mobile Bay Study Area	Godfrey's golden-aster (*Chrysopsis godfreyi*) reddish egret (*E. rufescens*) speckled burrowing crayfish (*Fallicambarus danielae*) white-top pitcherplant (*Sarracenia leucophylla*) Alabama redbelly turtle (*Pseudemys alabamensis*).
Pensacola Bay Study Area	Santa Rosa beach mouse (*Peromyscus polionotus leucocephalus*) Perdido Key beach mouse (*P. polionotus trissyllepsis*) saltmarsh topminnow (*Fundulus jenkinsi*)
Southern Big Bend Study Area	Scott's seaside sparrow (Ammodramus maritimus peninsulae) pinewood dainties (*Phyllanthus leibmannianus* ssp. *platylepis*)
Tampa Bay Study Area	statira (*Aphrissa statira*) Nuttall's rayless goldenrod (*Bigelowia nuttallii*) Tampa vervain* (*Glandularia tampensis*) hairy beach sunflower (*Helianthus debilis* ssp. *vestitus*)
Species predicted to lose less than 10% of their habitat in the study areas	
Corpus Christi Bay Study Area	South Texas ambrosia (*Ambrosia cheiranthifolia*) plains gum weed (*Grindelia oolepis*) slender rushpea (*Hoffmannseggia tenella*) brown pelican (*Pelecanus occidentalis*) Tharp's rhododon (*Rhododon angulatus*)

Table ES2 continued	
Mobile Bay Study Area	white ibis (*Eudocimus albus*) diamondback terrapin (*Malaclemys terrapin*) Gulf salt marsh snake (*N. clarkii clarkia*) Alabama beach mouse (*P. polionotus ammobates*) night-flowering wild petunia (*Ruellia noctiflora*)
Pensacola Bay Study Area	Reticulated flatwoods salamander (*Ambystoma bishop*) piping plover (*C. melodus)* white-top pitcherplant (*S. leucophylla*) Kral's yellow-eyed grass (*Xyris stricta var. obscura*) Gulf sturgeon (*Acipenser oxyrinchus desotoi*)
Southern Big Bend Study Area	Florida hasteola (*Hasteola robertiorum*) salt marsh vole (*Microtus pennsylvanicus dukecampbelli*) coastal lowland cave crayfish* (*Procambarus leitheuseri*) Gulf hammock dwarf siren (*Pseudobranchus striatus lustricolus*) North Florida spider cave crayfish (*Troglocambarus maclanei*)
Tampa Bay Study Area	Florida goldenaster (*Chrysopsis floridana*)

*For Florida sites occupied habitat loss was calculated; **Beach habitat only.

To assess potential climate change impacts to species beyond SLR, we applied the Climate Change Vulnerability Index (https://connect.natureserve.org/science/climate-change/ccvi) to three of the vulnerable species analyzed at each site. The results of this analysis are presented in Table ES3 below. Beach dependent species appear to be the most vulnerable to the overall effects of climate change.

Table ES3. Results of Climate Change Vulnerability Index for Species Evaluated in the Study Areas

Study Area	Common Name	Vulnerability Index
Corpus Christi	reddish egret	moderately vulnerable
	Gulf saltmarsh snake	moderately vulnerable
	three flower broomweed	moderately vulnerable
Mobile Bay	piping plover	highly vulnerable
	Alabama beach mouse	highly vulnerable
	hairy-peduncled beakrush	moderately vulnerable
Pensacola Bay	piping plover	highly vulnerable
	Alabama beach mouse	highly vulnerable
	hairy-peduncled beakrush	moderately vulnerable
Southern Big Bend	late flowering beach sunflower	moderately vulnerable
	Pinkroot	moderately vulnerable
	coastal lowland cave crayfish	presumed stable
Tampa Bay	Egmont Key mole skink	moderately vulnerable
	Tampa vervain	presumed stable
	black skimmer	presumed stable

Stakeholder Workshops to Develop Adaptation Strategies

Stakeholders developed a diversity of adaptation strategies during facilitated discussions at each workshop in each study area. In addition, workshop participants were administered brief pre- and post-workshop surveys to determine whether their knowledge of SLR adaptation options improved, the species they were most concerned about changed, and if their top three adaptation strategies shifted as a result of the workshop.

Many promising strategies emerged during the workshops. A total of 420 individual adaptation strategies were developed during the workshop and categorized to facilitate summarization. The types of adaptation strategies mentioned most frequently during the workshops were education, outreach and communication (n=103; Table ES4) and research needs (n=89). Education, outreach and communication strategies were very diverse and focused on educating elected officials, community leaders, agency staff, educators, the general public and students on potential impacts from SLR, what's at stake, what we can do about it and the cost of doing nothing. Research needs were equally broad and included better understanding ecological responses and socio-economic effects, improving forecasting of future conditions and better understanding the role of natural shorelines and coastal areas in slowing and/or buffering SLR impacts. Some recommendations identified actions that could be taken in the study areas such as buffering shorelines through additional land acquisition and/or habitat restoration. Other recommended strategies will require action at state, regional or national levels such as insurance reform to encourage rebuilding outside of flood prone areas (e.g., modifying the National Flood Insurance Program) and expanding the list of properties covered by the Coastal Barriers Resources Act.

Table ES4. Number of Adaptation Strategy Types Identified During Stakeholder Workshops

Adaptation Types	Corpus Christi Bay	Mobile Bay	Pensacola Bay	Southern Big Bend	Tampa Bay	Total
Education, outreach and communication	38	37	7	8	13	103
Research needs	8	20	17	23	21	89
Land use planning and building regulation	9	14	7	11	8	49
Conservation of natural areas	11	5	5	4	6	31
Tax and Market-based approaches	10	5	4	5	5	29
Beaches, beach and shoreline management	9	5	4	0	5	23
Transportation and infrastructure	5	8	2	2	4	21
Emergency response planning	2		8	2	4	16
Water supply and delivery; water resources	1	2	5	8	0	16
Miscellaneous/General Comments	6	2	1	6	1	16
Land protection	4	3	5	1	2	15
Conservation of terrestrial species	3	2	0	2	0	7
Conservation of marine life	0	0	3	2	0	5

Workshop Participant Survey Results

The pre-workshop survey indicated that participants had a good general sense of what would happen to the coastal wetlands in the study area in response to SLR over the next 100 years. However, they were not aware of the types and magnitude of predicted change. Regarding potential species impacts, respondents noted a concern for the following: coastal birds, sea turtles, fish, shrimp, coastal forest species, beach mouse, terrapin, oysters and mole skink. After learning about the specific types of changes predicted to be caused by SLR, respondents adjusted their recommendations for the types of adaptation strategies needed, with education, outreach and communication strategies dominating the list for every study area. Based on the survey results, the workshops appear to have influenced the participants both in what they understand about the consequences of SLR as well as what they believe are the most appropriate actions to take to better adapt to SLR.

Conclusions

The analyses detailed in this report show that coastal wetland systems will likely change substantially as a result of SLR and that these changes will increase in magnitude as SLR progresses. SLAMM is a useful tool for characterizing these changes in a quantitative, spatial and temporal manner. By applying SLAMM, we found that some habitats will steadily gain spatial extent, others will steadily lose spatial extent, and some will gain spatial extent during one time period and lose spatial extent in subsequent time periods. The changes to coastal wetland systems brought about by SLR will affect some species more than others, with some being substantially affected. SLR will also adversely affect the human communities at our study sites in a variety of ways including impacts to infrastructure (e.g., roads, bridges and water treatment facilities), cultural and historical resources, and increased vulnerability to storms and flooding. Improving our understanding of these changes improves our ability to predict how, when and where vulnerable species and human communities will be impacted. These quantitative, spatial and temporal data will help us develop, refine and implement adaptation strategies to minimize the impacts of SLR on these natural systems and human communities. For example, the spatial results can be used to identify promising locations for restoration based on where coastal wetlands are likely to become open water, where coastal forests are likely to become marshes, and where undeveloped dry land is likely to become wetlands. Vulnerable developed areas can be identified in the scenarios allowing developed dry land to transition with SLR.

The workshops surveys identified that informed members of the study area communities were not always familiar with how coastal wetland systems and human communities were likely to be affected by SLR. Specific quantitative, spatial and temporal information about coming changes can be used to educate all sectors of the study area communities and will help planners, natural resource managers, elected officials and other community members develop specific, locally relevant strategies to minimize the impacts to natural systems and the build environment. The quantitative, spatial and temporal information on coastal wetland change produced by this study can also be used to assist in the development of monitoring programs to signal when on-the-ground change is happening and at what rate. The modeling results and uncertainty analyses conducted on a selection of input parameters, can be used to pinpoint the input parameters that are most important for focused data collection (e.g., marsh accretion) and which ecosystem responses are most important to monitor (e.g., transition of coastal forest to marsh).

Improving our understanding of SLR impacts on coastal wetland systems also improves our understanding of impacts to dependent species and adjacent human communities. Although SLR is just one impact of global climate change, examining how coastal wetland systems will change provides insights into how species dependent on these systems might be impacted. This information will be useful in the prioritization of species that should be monitored more closely than others. The change in coastal wetlands adjacent to human communities will also affect their vulnerability to coastal storms and flooding. Knowing what these changes are likely to be, where they will occur and the timing of these changes can inform the development and implementation of adaptation strategies.

The adaptation strategies developed by the stakeholders participating in project workshops point to the actions communities can take now to minimize the long-term impacts of SLR. For example:

- Reducing the rebuilding of vulnerable structures in high risk areas by altering insurance and other compensation (subsidies) that currently incentivize re-building following storm and flooding damage (e.g., using disaster relief dollars to relocate to less vulnerable areas rather than paying people to rebuild in vulnerable sites.)
- Protecting undeveloped upland and wetland buffers now will allow for coastal wetlands migration with SLR rather than expensive efforts to protect structures and infrastructure built on those vulnerable sites.
- Assisting species experiencing temporary habitat bottle necks rather than allowing them to be extirpated from an area.
- Taking into account SLR as vulnerable infrastructure is replaced, repaired or relocated over the next 85 years which will be less expensive and reduces service interruptions than responding to an emergency infrastructure need.
- Educating people of all ages in every sector of society about the issues and predicted consequences so that they can take and urge informed action.
- Improving communication about SLR vulnerability and potential solutions among and between private and government sectors and the community to expedite proactive response to SLR.

This study provides the seeds of many promising ideas for helping human communities and natural systems adapt to SLR. It is up to local stakeholders from each study area community to further refine and implement these strategies. Our hope is that other GOM communities where SLR has been modeled will be inspired to develop and implement adaptation strategies of their own. Implementing adaptation strategies now will be the most cost-effective and safest response to the environmental changes that we know are coming.

Electronic results including geospatial files are available upon request to the project PI, Laura Geselbracht (lgeselbracht@tnc.org). For those unfamiliar with the use of geospatial files, or the sake of convenience, spatial results can be viewed on The Nature Conservancy's Coastal Resilience 2.0 website available at www.coastalresilience.org. The SLR modeling results can be found under the Future Habitats app.

Acronyms

CLC – Cooperative Land Cover (Florida)
CSC - Coastal Services Center (part of NOAA, see below)
CSSP - Climate Change Science Program
DEM – Digital Elevation Model
DTM – Digital Terrain Model
DSAS – Digital Shoreline Analysis System
EPA – Environmental Protection Agency
FDEM – Florida Department of Emergency Management
FGDL – Florida Geographic Data Library
FNAI – Florida Natural Areas Inventory
GIS – Geographic Information System
GOM – Gulf of Mexico
GOMA – Gulf of Mexico Alliance
GSA - Geological Society of Alabama
GT – Great Diurnal Tide
ifSAR – Interferometric Synthetic Aperture Radar
IPCC – Intergovernmental Panel on Climate Change
LiDAR – Light Detection and Ranging
MHHW – Mean Higher High Water
MLLW – Mean Lower Low Water
MOB – Mobile Bay
MRLC - Multi-Resolution Land Characteristics Consortium
MTL – Mean Tide Level
NAVD88 – North American Vertical Datum of 1988
NED – National Elevation Dataset
NLCD – National Land Cover Dataset
NOAA – National Oceanic and Atmospheric Administration
NTAD - National Transportation Atlas Databases
NWFWMD – Northwest Florida Water Management District
NWI – National Wetlands Inventory
NWLON – National Water Level Observation Network
NOAA – National Oceanic and Atmospheric Administration
PADUS – Protected Areas Database of the United States
SLAMM – Sea Level Affecting Marshes Model
SLR – Sea Level Rise
SRWMD – Suwannee River Water Management District
SWFWMD – Southwest Florida Water Management District
TBEP – Tampa Bay Estuary Program
TCOONS – Texas Coastal and Ocean Observatory Network Stations
TPWD – Texas Parks and Wildlife Department
TNC - The Nature Conservancy
USEPA –United States Environmental Protection Agency
USGS – United States Geological Society

Introduction

Coastal wetland systems and human communities will be substantially affected whether sea level rises 18-59 cm by 2100, as predicted by the IPCC (2007), or at the higher rates predicted by models that include the melting of polar ice caps and other factors (e.g., CCSP 2008; Mitrovica et al. 2009; Overpeck et al. 2006; Rahmstorf et al. 2007; Rahmstorf et al. 2012). While responding to the gradual inundation that will be brought about by sea level rise (SLR) will be challenging, of greater concern is the increased vulnerability of human and natural communities to storm surge effects in the face of SLR. Shepard et al. (2011) found that even modest and probable SLR (0.5 m by 2080) vastly increases the numbers of people (+47%) and property losses (+73%) from storm surge. Intact coastal wetlands can help to buffer adjacent human communities from the impacts of storm surge and in a more cost effective manner than engineered solutions (McIvor et al. 2012; UNU-EHS and The Nature Conservancy 2012).

Human communities and coastal wetlands systems at several estuaries along the U.S. Gulf of Mexico coast are especially vulnerable to SLR impacts due to their low-lying nature and extensive development that blocks coastal wetlands from migrating to higher elevations. Improving our understanding of the vulnerability of natural and human communities to SLR provides communities and natural resource managers with the information needed to take appropriate action and minimize the consequences. Taking action now rather than waiting for impacts to accumulate can minimize hazards to human communities, disruptions to natural systems, and be more cost-effective in the long-term (Titus and Neumann, 2009)

Among the tools developed to enhance our understanding of the effects of SLR on coastal wetland systems is the Sea Level Affecting Marshes Model (SLAMM). SLAMM was developed in the mid-1980s (Park et al. 1986), with SLAMM 6.2 beta released in December 2012 (http://warrenpinnacle.com/prof/SLAMM/index.html). SLAMM employs a decision tree that incorporates geometric and qualitative relationships to simulate the dominant processes involved in changes to wetland systems and shoreline modifications during SLR. The five primary processes used to predict wetland fate with SLR are inundation, erosion, overwash, saturation and accretion. This model has been applied around the USA (Glick and Clough 2006), but several early applications used relatively low resolution (1.5 m contours) National Elevation Data (NED), which requires SLAMM to extrapolate elevations based on land cover data such as provided by the National Wetlands Inventory (NWI). Comparison of SLAMM results using inferred elevation information versus the recently available high resolution Light Detection and Ranging (LiDAR) elevation data revealed differences in predicted habitat distributions of up to 173% depending on the habitat type (Geselbracht et al. unpublished data).

During the period June 2010 through June 2013, we modeled SLR impacts on coastal wetland systems at five estuaries across the U.S. Gulf of Mexico (3 SLR scenarios at each site through the year 2100: 0.7 m, 1.0 m and 2.0 m), assessed impacts on the most vulnerable species, identified vulnerable infrastructure, historic and cultural resources, and held workshops with stakeholders at project sites to review the results of our research and develop locally relevant adaptation strategies. Our project sites included Corpus Christi Bay in Texas; Mobile Bay in Alabama; and Pensacola Bay, Southern Big Bend and Tampa Bay all in Florida (Figure 1). As an add on to our grant project we modeled the Alabama portion of Perdido Bay to complete the modeling around this bay system as the Florida portion of Perdido Bay is included with the Pensacola Bay results. We include the Alabama portion of Perdido Bay as a subarea under our Pensacola Bay results. In the following sections, the project sites, methods and results are provided as well as a discussion of our findings. Details of model inputs and results are provided in appendices as noted in the text of this report.

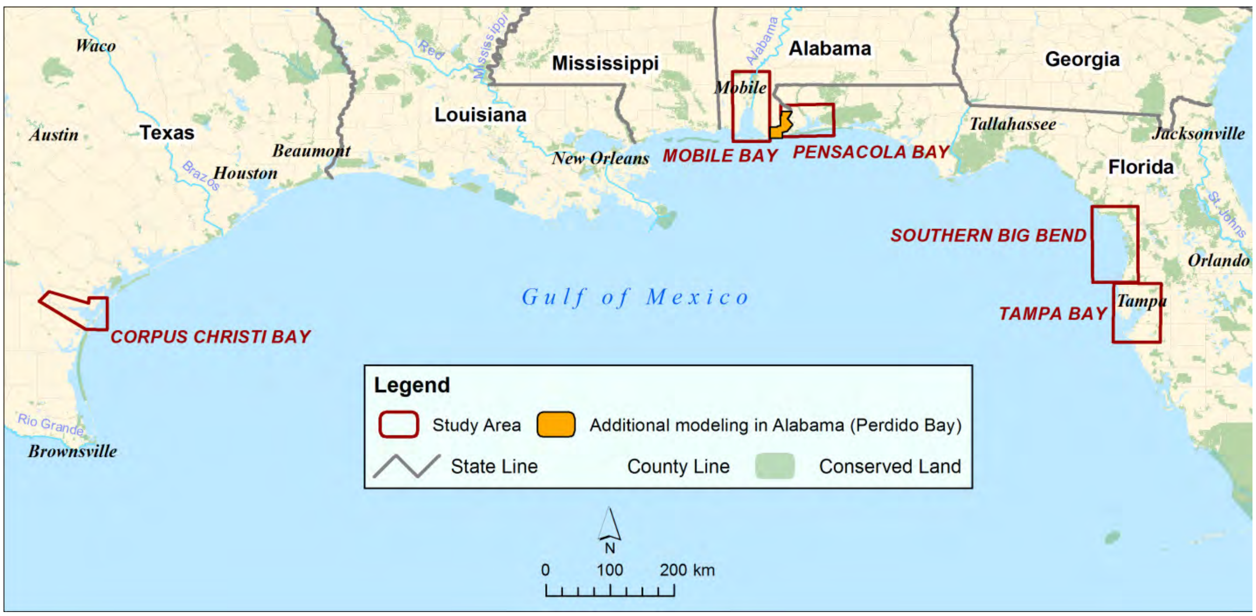


Figure 1. Project study areas are bounded in red. The Alabama portion of the Perdido Bay, added to the project to complete the Perdido Bay system, is shown in yellow.

Study Site and Methods

Study Sites

Throughout this report we discuss study areas in order from west to east. The Alabama portion of the Perdido By area is handled as a subarea of our Pensacola Bay site as it was added on to our EPA grant work and only SLR modeling was completed for this subarea.

Corpus Christi Bay, Texas

Our study site at Corpus Christi Bay, Texas (Figure 2) includes more than 23,600 ha of marshes, tidal flat, coastal forests and beaches. Corpus Christi Bay has a surface area of 497 km^2, an average daily freshwater inflow of 34 m^3/s, average depth of 3 m, and average salinity of 22 ppt (GulfBase 2013). The Nueces River is the major river that empties into Corpus Christi Bay via the much smaller Nueces Bay. Subtidal habitats present in the bay include both oyster reef and approximately 53 km^2 of seagrass meadows (GulfBase 2013; Sims et al. 2008). For the purposes of the modeling, we identified a study area of 543,052 ha, which entirely encompasses Corpus Christi Bay and includes most adjacent areas at or below 2 m elevation.

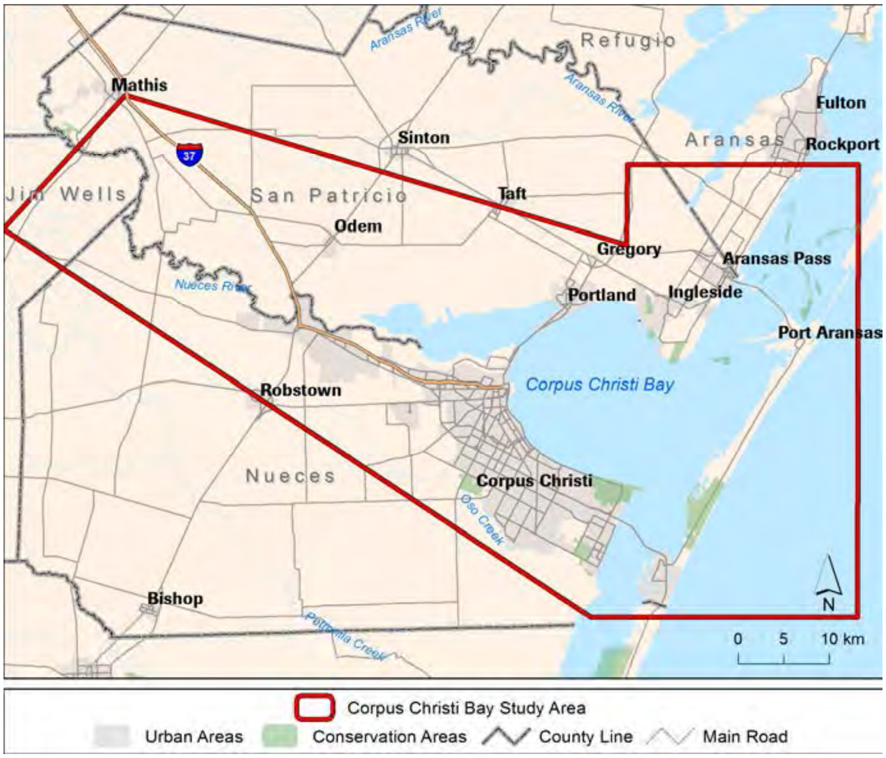


Figure 2. Corpus Christi Bay Study Area.

Mobile Bay, Alabama

Our study site at Mobile Bay, Alabama (Figure 3) includes nearly 99,000 ha of coastal forest, marshes, beaches, and tidal flat. Mobile Bay has a surface area of 1,059 km2, an average daily freshwater inflow of 2,246 m^3/s, average depth of 3 m, and average salinity of 19 ppt (GulfBase 2013). Five rivers form the delta at the head of Mobile Bay, the Mobile, Spanish, Tensaw, Apalachee and Blakeley rivers. Subtidal habitats in the bay include oyster reef and approximately 258 ha of submerged aquatic vegetation (USGS and USEPA 2004). For the purposes of the modeling, we identified a study area of 539,481 ha that entirely encompasses Mobile Bay and includes most adjacent areas at or below 2 m elevation.

Figure 3. Mobile Bay Study Area.

Pensacola Bay, Florida

Our study site at Pensacola Bay, Florida (Figure 4) includes more than 63,000 ha of marshes, coastal forests, tidal flats, cypress and tidal swamps, beaches and oyster reefs distributed from just below sea level to nearly 10 m NAVD88. Pensacola Bay has a surface area of 370 km^2, an average daily freshwater inflow of 328 m^3/s, average depth of 4 m and average salinity of 23 ppt (GulfBase 2013). The Escambia, Yellow and Blackwater rivers flow into the bay. Subtidal bay habitats include approximately 1800 ha of submerged aquatic vegetation (USGS and USEPA 2004) and oyster reef habitat of unknown extent. For the purposes of the modeling, we identified a study area of 351,679 ha that entirely encompasses Pensacola Bay and includes most adjacent areas at or below 2 m elevation.

Figure 4. Pensacola Bay Study Area.

Alabama portion of Perdido Bay

Our Pensacola Bay study site only included the Florida portion of Perdido Bay, a small bay system that spans the Florida-Alabama border. So as to model SLR impacts on the coastal wetlands surrounding all of Perdido Bay, we subsequently modeled the Alabama portion of coastal Perdido Bay (Figure 5). This area includes more than 11,000 ha of coastal forest, marshes and beaches. Perdido Bay has a surface area of 130 km^2, an average daily freshwater inflow of 62 m^3/s, average depth of 3 m, and average salinity of 15 ppt (GulfBase 2013). One river, the Perdido River, flows into Perdido Bay. Subtidal habitats in the bay include approximately 120 ha of submerged aquatic vegetation (USGS and USEPA 2004) and an unknown extent of oyster reef. For the purposes of the modeling, we identified a study area of 121,709 ha that encompasses the Alabama portion of the Perdido Bay and includes most adjacent areas at or below 2 m elevation.

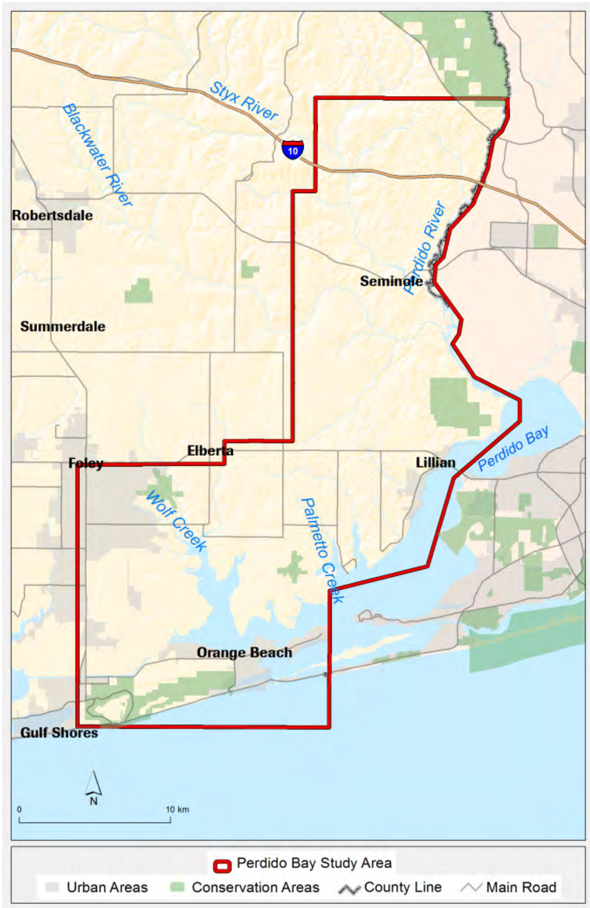


Figure 5. Alabama portion of Perdido Bay study area.

Southern Big Bend

Our study site in the Southern Big Bend Region of Florida (Figure 6) includes more than 90,960 ha of marshes, coastal forests, tidal flats, mangrove forests and beaches. While the Southern Big Bend region is not a typically shaped estuary it functions as one due to the extensive freshwater sheet flow that enters the Gulf of Mexico in this region. Average surface water salinity approximately 4 km offshore averages about 15 ppt (Fraser et al. 2002). Subtidal habitats in the region include oyster reef and a portion of one of the world's largest continuous seagrass bed. Two rivers flow into the Southern Big Bend Study Area, the Waccasassa and the Withlacoochee. For the purposes of the modeling, we identified a study area of 740,624 ha that includes most adjacent areas at or below 2 m elevation.

Figure 6. Southern Big Bend Study Area.

Tampa Bay, Florida

Our study site at Tampa Bay, Florida (Figure 7) includes more than 94,000 ha of marshes, coastal forests, tidal flats, coastal forests (including cypress and tidal), mangrove forests and beaches. These coastal wetland systems are distributed from just below sea level to over 40 m NAVD88, although 90% of them are below 18 m (50% are below 2 m). Tampa Bay has a surface area of 896 km^2, an average daily freshwater inflow of 68 m3/s, average depth of 3 m, and average salinity of 27 ppt (GulfBase 2013). The Hillsborough, Alafia, Manatee and Little Manatee rivers flow into Tampa Bay. Subtidal habitats present in the bay include both oyster reef (extent unknown) and approximately 121 km^2 of submerged aquatic vegetation (GulfBase 2013). For the purposes of the modeling, we identified a study area of 602,639 ha that entirely encompasses Tampa Bay and includes most adjacent areas at or below 2 m elevation.

Figure 7. Tampa Bay Study Area.

Methods

Simulation Modeling of SLR impacts on Coastal Wetland Systems

Model Inputs

SLAMM requires two types of inputs to simulate changes in coastal wetlands due to SLR: raster data and numeric site parameters. The raster data input requires three data sets: vegetation, elevation and slope. The numeric site parameters are habitat and site specific. They describe the site being modeled and represent the processes being simulated. In addition to the two types of inputs, the user specifies SLR scenarios and selects optional model switches that control various aspects of the simulation via the user interface. Table 1 lists the numeric input parameters and gives a brief definition of each. Detailed explanations of the model's processes and inputs are in the SLAMM Technical documentation (Clough et al., 2010) and user guide (Clough and Larson, 2010).

Table 1. Numeric input parameters required to run SLAMM.

SLAMM 6 Parameter	Description
NWI Photo Date (YYYY)	Date of vegetation input (ground condition)
Digital Elevation Model (DEM) Date (YYYY)	Date of the elevation input (ground condition)
Direction Offshore [n,s,e,w]	Site specific offshore direction
Historic Trend (mm/yr)	Historical sea level rise trend for the site being modeled
MTL-NAVD88 (m)	Correction factor (converts elevation to MTL datum used in the model)
Great Diurnal Tide Range (m)	Great Diurnal Tide (GT) range
Salt Elevation (m above MTL)	Elevation which is a inundated by salt water approximately once every 30 days
Marsh Erosion (horz. m /yr)	Marsh erosion rate
Swamp Erosion (horz. m /yr)	Coastal forest erosion rate
Tidal Flat Erosion (horz. m /yr)	Tidal Flat erosion rate
Reg. Flood Marsh Accretion (mm/yr)	Saltmarsh accretion rate
Irreg. Flood Marsh Accretion (mm/yr)	Brackish marsh accretion rate
Tidal Fresh Marsh Accretion (mm/yr)	Tidal Freshwater Marsh accretion rate
Beach Sedimentation Rate (mm/yr)	Beach and tidal flat sedimentation rate
Frequency of Overwash (years)	Frequency of overwash by large storms
Use Elevation Pre-processor [True,False]	Optional module for use with low-resolution elevation data

The accretion and overwash parameters have optional sub parameters that can be specified if detailed local information is available. The raster elevation data must use the NAVD88 datum and be of sufficient resolution to produce useful simulation results. Generally, this means elevation data derived from a LiDAR data source. Low resolution elevation data requires the use of the preprocessor module. From the elevation data, a slope raster dataset is derived. The raster vegetation data input into the simulation must be in SLAMM-specific vegetation categories. SLAMM was constructed to work with National Wetlands Inventory (NWI) data. The SLAMM technical documentation provides a table that translates NWI attribute codes to SLAMM categories. Any vegetation data source can be used as SLAMM input, but it must be crosswalked to the SLAMM vegetation categories. Additionally, the resolution of the vegetation should match the resolution of the elevation for better simulation results. The wetland vegetation data obtained for this project was in vector format. All crosswalks were done to the vector features. Any edits or attribute modifications were made to the vector features. Once all changes were made, the data was converted to a raster that aligned with the DEM.

Nomenclature

Throughout the document we use more commonly recognized wetland system names as opposed to the SLAMM category names as follows: saltmarsh in place of regularly flooded marsh, brackish marsh in place of irregularly flooded marsh, coastal forest in place of swamp, and transitional saltmarsh in place of scrub shrub. Some graphics in the document retain the SLAMM category names.

Subsites

The numeric parameters in Table 1 can be varied spatially across the study area by defining optional input subsites. Each input subsite can have its own set of numeric parameters, thus allowing for spatial variation to be modeled. Input subsites are entered by hand through the SLAMM user interface. This process is described in the SLAMM 6 user manual (Clough and Larson, 2010). Output sites can be defined in the same manner as input subsites. When an output subsite is defined, SLAMM results are produced for that area specifically, along with the results for the entire study area.

In addition to input and output subsites, a fresh flow site can be defined. The purpose of a fresh flow site is to account for habitat changes that occur when there is a large amount of freshwater flow in an area that would affect the typical vegetative response to SLR. This type of subsite does not vary numeric parameters. Within the boundary of a fresh flow site only the habitat switching algorithm is altered, changing the progression of one habitat type to another due to SLR (see Figure 8).

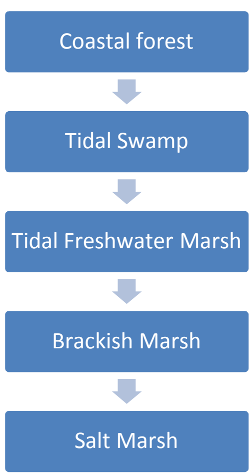


Figure 8. Sequence of vegetative response to inundation by salt water in a freshwater flow site.

Running the Model

At a minimum, via the model's user interface, the user selects the SLR scenario, a time-step at which to report results and an end year for the simulation (the default is year 2100). The output of the simulation is a table that shows the hectares of each SLAMM vegetation category at user-specified time-steps until the year 2100 (or user specified end date). In addition to the tabular output, there are optional outputs. The two main optional outputs are visualizations of vegetation at each time-step. This can be maps pasted into a Word document and/or GIS output (in the form of an ASCII file). The model keeps track of vegetation categories within a raster cell. The area totals in the model's tabular output include summing partial areas within a cell. Map and GIS output cannot depict multiple vegetation types within a cell, but are close spatial representations of the vegetation at the specified date.

Project Approach to Simulation Modeling

In this section, we describe the overall approach used to do the SLAMM modeling for this project. Each study area was treated separately, and availability of site-specific data varied. Site-specific variations from the methods described here are detailed in the site specific subsections below. SLAMM version 6.1 beta was used to do the modeling for all sites except Corpus Christi, which used a 64-bit version of SLAMM, version 6.2 beta, provided by the developer (Clough 2012). Esri ArcGIS software, ArcInfo versions 10 or 10.1, was used to do all geoprocessing needed to prepare raster inputs. Study area boundaries were established to encompass at least 2 meters of elevation, and in some cases to integrate with other projects. The source of raster data inputs, elevation and vegetation, varied by state.

SLAMM Inputs

Raster data inputs

All of the study areas modeled had LiDAR-derived DEMs available. In Florida, between 2006 and 2010, The Florida Division of Emergency Management (FDEM) collected coastal LiDAR data as part of a project to update the Sea, Lake, and Overland Surge from Hurricanes (SLOSH) models and the Regional Hurricane Evacuation Studies (RHES) for the entire state. FDEM collected existing LiDAR data and assessed it against the minimum technical specifications of the project (www.floridadisaster.org/gis/lidar/). To fill in coastal areas with gaps in acceptable LiDAR coverage, FDEM either collected data or worked with stakeholders to ensure new LiDAR projects would meet the FDEM project standards. The DEMs for the study areas in Florida, regardless of the source of the DEM, are derived from LiDAR data that was collected by a water management district or the FDEM. Elevation data for all sites was obtained as a DEM, not LiDAR points. Table 2 lists the source data that was used for each study area. Study areas are arranged from west to east.

Table 2. Sources of Digital Elevation Data used in the SLAMM simulations.

Study Area	DEM Source Dataset	DEM Source
Corpus Christi, TX	1/9 arc-second National Elevation Datasets: San Patricio County, Texas, 2007 Nueces County, Texas, 2011	USGS National Map website
Mobile, AL	AL_MOB_GCS_5m_NAVDm	NOAA
Pensacola, FL	2006 Escambia, Santa Rosa, and Walton Counties LiDAR	NOAA Coastal Services Center website
Alabama portion of Perdido Bay (a subarea of the Pensacola Bay study area)	1/9 arc-second National Elevation Datasets: Escambia County, Florida, 2006, Topobathymetric Data for Mobile Bay, Alabama and Jackson, Mississippi, 2001 - 2011	USGS National Map website
Southern Big Bend, FL	Tiled DEM data (from 2006-2007 LiDAR collections)	Southwest Florida Water Management District

Study Area	DEM Source Dataset	DEM Source
	Pasco County 2004-2008 FL Division of Emergency Management: Southwest Florida LiDAR	NOAA Coastal Services Center website
	NED 1/3 arc-second (small area to fill in missing marsh)	USGS National Map website
Tampa Bay, FL	TB_DEM_10m_m	Tampa Bay Estuary Program (TBEP)

*The Florida half of Perdido Bay is included in the Pensacola analysis. Only the modeling was completed for the Alabama portion of the Perdido Bay site, not other project elements as this was an add-on to the EPA grant funded project.

For each site, DEM's were mosaicked together (if needed), resampled to either 15 or 30 m cell size, re-projected to the site's coordinate system and clipped to the study area boundary. The third required raster input, a slope raster, was created from the final DEM using the Slope tool in the Spatial Analyst extension of ArcGIS.

In Mobile Bay and Corpus Christi Bay, the NWI was used to create the initial vegetation input for the modeling. SLAMM version 6.1 provides a crosswalk from NWI attributes to SLAMM categories as part of the download package of SLAMM v6.1 beta. This crosswalk was used to create the vegetation inputs. When an NWI attribute was encountered that was not in the crosswalk, the "NWI Classes to SLAMM 6 Categories" table provided in the SLAMM 6 technical documentation (Clough et al., 2010) was used to categorize the wetland feature. Since the NWI does not map uplands, additional datasets were used to identify developed dry land (Table 3).

Table 3. Sources for dry land and vegetation data input used for the SLAMM simulations.

Study Area	Land Cover Dataset	Land Cover Source
Corpus Christi, TX	NWI of Texas	NWI
	Phase 3 of Ecological Systems Classification of Texas (for Developed Dry Land category)	TPWD
Mobile, AL	NWI of Alabama	NWI
	NLCD 2006 (for Developed Dry Land category)	MRLC
Pensacola, FL	Cooperative Land Cover Map v1.1	FNAI
Perdido Bay, AL	NWI of Alabama	NWI
	NLCD 2006 (for Developed Dry Land category)	MRLC
Southern Big Bend, FL	Cooperative Land Cover Map v1.1	FNAI
Tampa Bay, FL	TB_veg_10m	TBEP

In Florida, a more comprehensive vegetation data set exists for the state, the Cooperative Land Cover Map v1.1 (CLCv1.1) (Florida Natural Areas Inventory, 2010). This dataset was used to create the vegetation inputs for the Florida sites. The final crosswalk between the CLCv1.1 and SLAMM vegetation categories is in Appendix 1.

SLAMM Numeric Parameters

Table 4 below lists the numeric parameters required for the SLAMM model, and the source of the value or the approach used to obtain it. Details and variations from the sources listed in the table are discussed in the site specific subsections that follow.

Table 4. General data sources for SLAMM simulation inputs.

SLAMM 6 Parameter	Data Source or Approach
NWI Photo Date (YYYY)	Date of vegetation input (ground condition)
DEM Date (YYYY)	Date of the elevation input (ground condition)
Direction Offshore [n,s,e,w]	Site specific
Historic Trend (mm/yr)	NOAA Tides and Currents website
MTL-NAVD88 (m)	NOAA's Vdatum software
Great Diurnal Tide Range (m)	NOAA Tides and Currents website
Salt Elevation (m above MTL)	Derived from NOAA Tides and Currents website
Marsh Erosion (horz. m /yr)	Literature search
Coastal Forest Erosion (horz. m /yr)	Literature search
Tidal Flat Erosion (horz. m /yr)	Literature search
Saltmarsh Accretion (mm/yr)	Literature search
Brackish Marsh Accretion (mm/yr)	Literature search
Tidal Fresh Marsh Accretion (mm/yr)	Literature search
Beach Sedimentation Rate (mm/yr)	Literature search
Frequency of Overwash (years)	Estimated by historical hurricane tracks (csc.noaa.gov/hurricanes/)
Use Elevation Pre-processor [True,False]	Not used

NOAA's Tides and Currents website provides a graphical interface for obtaining data from current and historical NOAA gauges. NOAA stations within the project study areas that had published tidal datums were used to obtain values for great diurnal tide (GT). SLR Historic Trend values were obtained from stations that are part of the National Water Level Observation Network (NWLON) and had published SLR rates. NOAA stations from which tidal values were retrieved are listed in Appendix 1.

To calculate salt elevation, data was downloaded from stations published on the NOAA tides and currents website that fell within or near a study area, and had 2 or 3 years of water level data available. A frequency distribution based on 3 years of tide data was used to identify the elevation at which inundation occurred no more than once a month (i.e., the salt elevation). The ratio of the salt elevation to MHHW was then used to estimate salt elevations at stations that did not have long-term water level data.

The MTL-NAVD88 parameter, the datum correction needed to align the NAVD88 elevation data with the model's internal MTL datum (i.e., the NAVD88 correction factor, can either be input as a numeric value or as a raster file that covers the entire site. For our project, the Vdatum program (vdatum.noaa.gov) was used to create a raster. For each study area, a regularly spaced grid of points was input into Vdatum. Valid Vdatum values that were over areas classified as water in the vegetation input were then used to create a raster of correction values with the Euclidean distance function in ArcGIS (Appendix 2).

Running the model

For each study area, three SLR scenarios were run: A1B maximum (0.7 m), 1 meter and 2 meter. All scenarios were run with 25 year time steps from (insert year) through the year 2100. GIS output was obtained for each time step with every scenario. Each scenario was run twice, once when developed and undeveloped dry land were both allowed to become inundated, and once when developed dry land was not allowed to change. The latter scenario simulated protecting existing development, a likely SLR adaptation. All scenarios were run using the optional connectivity algorithm. This option only allows dry land and freshwater wetlands to become inundated with saltwater if there is a connection to a saltwater source.

For each study area, the initial condition extent of wetland types was compared to the model's time zero (T0) extent. We established a project standard that considered model performance acceptable if the change of extent between initial condition and the model's time zero in all wetland types representing more than 1% of the study site was less than or equal to 10%. Appendix 3 shows the T0 percentage change for each study area.

SLAMM Simulations of Project Study Areas

Corpus Christi Bay Study Area

Recently available LiDAR-derived 1/9 arc-second DEM data downloaded from the National Map website was used to create the DEM for the Corpus Christi Bay study area (Figure 9). We used a DEM data of 2011 as nearly the entire study area was covered by a DEM with a date of 2011. Only the northern edges of the mainland study area and barrier islands were derived from 2006 data.

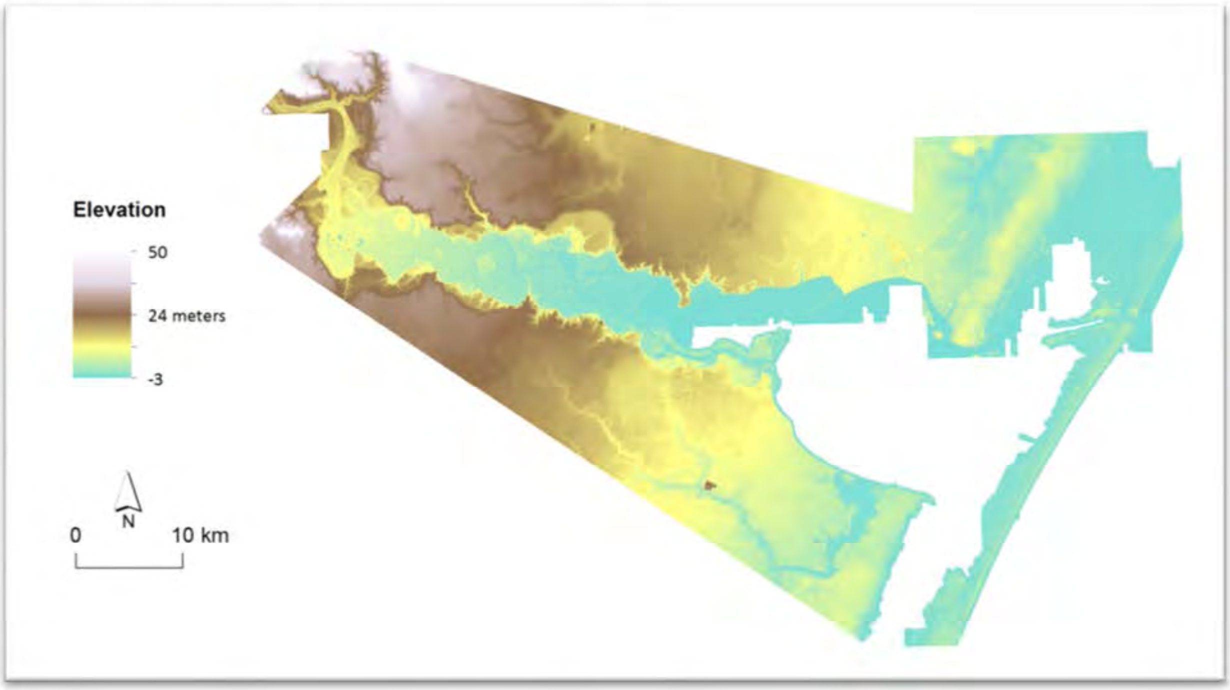


Figure 9. Corpus Christi Bay Study Area digital elevation model.

The NWI of Texas was crosswalked to SLAMM vegetation categories. In the SLAMM crosswalk, wetland code E2SS3N can either be crosswalked to mangrove or transitional saltmarsh. In our study area, mangroves are generally fringing marshes and/or sparse throughout. Therefore, E2SS3N was assigned to Transitional Salt Marsh. The elevation data used for the simulation modeling did not extend to all of the spoil islands and marshes in the Bay. These areas with no elevation data were not simulated by SLAMM, and are not shown in the vegetation layer or the simulated results. The NWI in our study had an image date of 2006.

The areas in the NWI with No Data values are uplands and were assigned the value for undeveloped dry land (2). A raster layer depicting Developed Dry Land was created from the Phase 3 of Ecological Systems Classification of Texas (http://www.tpwd.state.tx.us/gis/gallery/). Vegetation features categorized as Urban High Intensity or Urban Low Intensity were selected and converted to a raster. Any undeveloped dry land cell in the vegetation raster that overlapped a Phase III cell with an urban classification is assigned a one. Initial vegetation is shown in Figure 10.

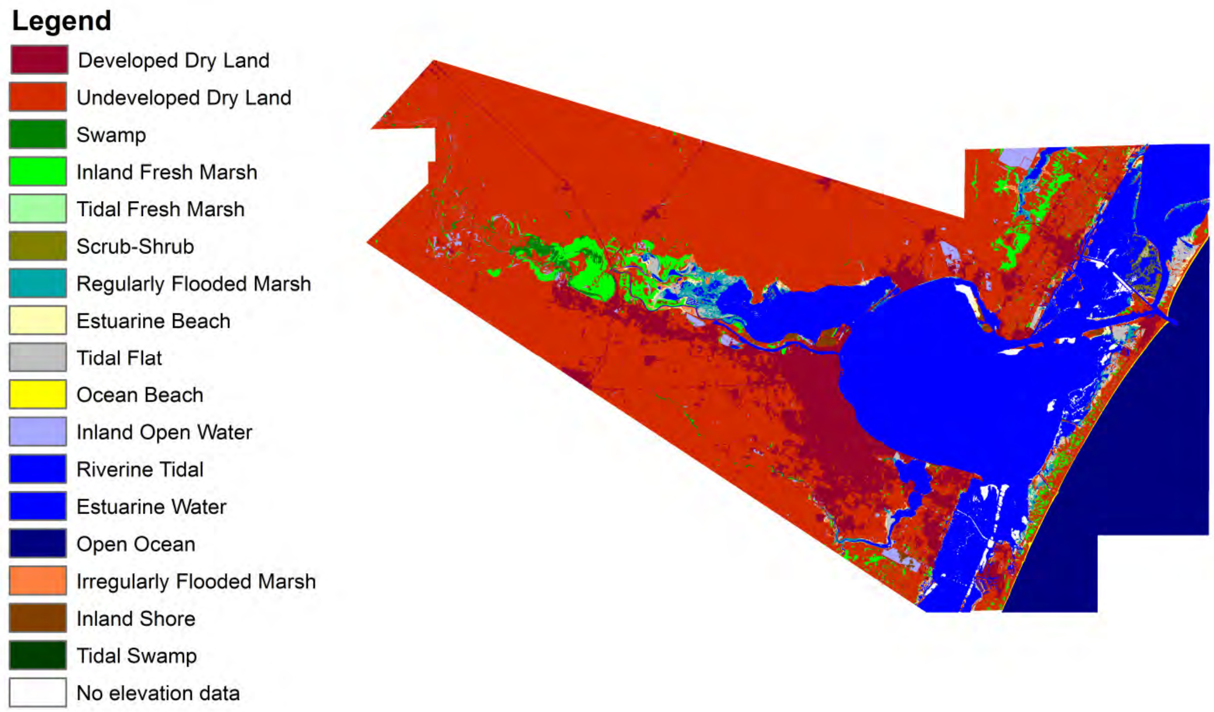


Figure 10. Corpus Christi Bay study area vegetation data used as the initial condition for the SLAMM simulation.

Nine subsites (Figure 11) were delineated to accommodate variations in erosion rates, salt elevation and difference in DEM dates. Three years of water level data was available for the Corpus Christi station and so a salt elevation was calculated directly. This value was used for the 2 Gulf-facing subsites (Table 5). Salt elevation at the other stations was estimated using ratio of the salt elevation to MHHW. The estimated salt elevations were averaged and this value was used for the remaining subsites.

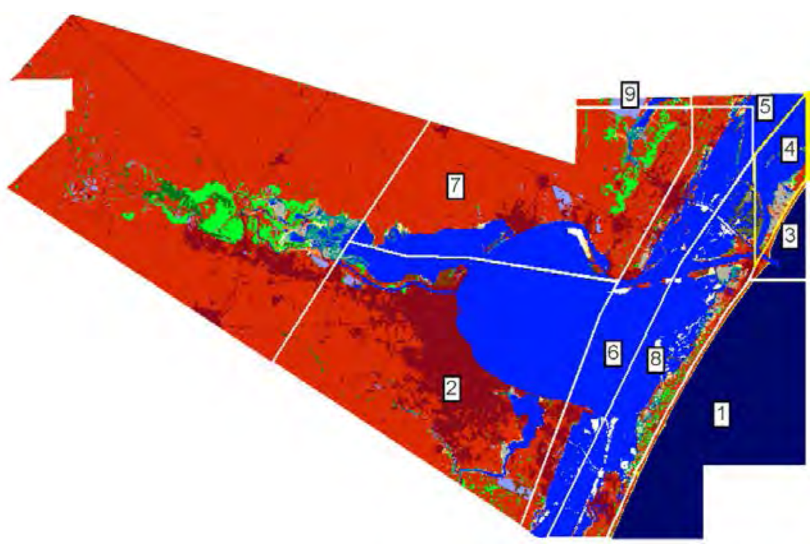


Figure 11. Corpus Christi Bay study area subsites.

Table 5. Numeric input parameters for the Corpus Christi Bay Area SLAMM simulation.

Parameter	Global	Subsite 1	Subsite 2	Subsite 3	Subsite 4	Subsite 5	Subsite 6	Subsite 7	Subsite 8	Subsite 9
NWI Photo Date (YYYY)	2006	2006	2006	2006	2006	2006	2006	2006	2006	2006
DEM Date (YYYY)	2011	2011	2011	2006	2006	2006	2011	2011	2011	2006
Direction Offshore [n,s,e,w]	East	East	North	East	West	East	East	South	West	North
Historic Trend (mm/yr)	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55
MTL-NAVD88 (m)										
GT Great Diurnal Tide Range (m)	0.2	0.48	0.2	0.48	0.2	0.2	0.2	0.2	0.2	0.2
Salt Elev. (m above MTL)	0.23	0.58	0.23	0.58	0.23	0.23	0.23	0.23	0.23	0.23
Marsh Erosion (horz. m /yr)	1.72	0.28	0.84	0.28	0.84	0.84	0.84	0.84	0.84	0.84
Coastal Forest Erosion (horz. m /yr)	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Tidal Flat Erosion (horz. m /yr)	1.72	0.28	0.84	0.28	0.84	0.84	0.84	0.84	0.84	0.84
Saltmarsh Accr (mm/yr)	3.81	3.81	3.81	3.81	3.81	3.81	3.81	3.81	3.81	3.81
Brackish Marsh Accr (mm/yr)	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Tidal Freshwater Marsh Accr (mm/yr)	4.86	4.86	4.86	4.86	4.86	4.86	4.86	4.86	4.86	4.86
Inland Freshwater Marsh Accr (mm/yr)	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
Mangrove Accr (mm/yr)	7	7	7	7	7	7	7	7	7	7
Tidal Swamp Accr (mm/yr)	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Coastal forest Accretion (mm/yr)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Beach Sed. Rate (mm/yr)	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
Freq. Overwash (years)	57	57	57	57	57	57	57	57	57	57
Use Elev Pre-processor [T,F]	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE

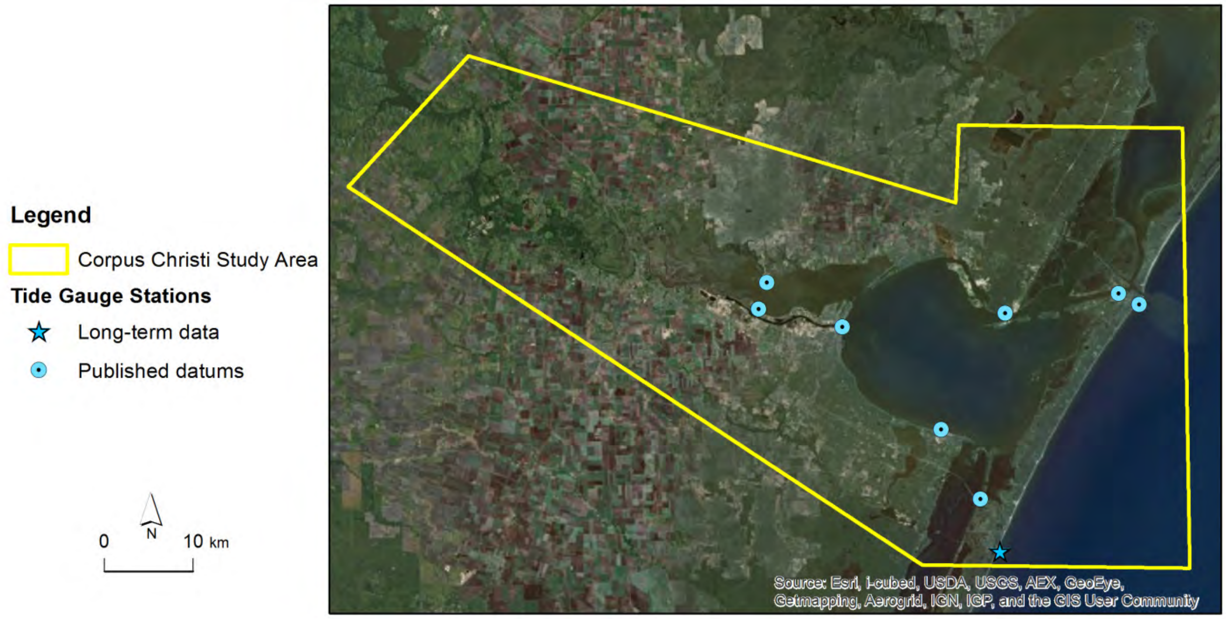


Figure 12. Corpus Christi Bay Study Area tide gauge stations used in the SLAMM analysis.

The historic trend for SLR was determined by averaging the values from the Rockport and Port Mansfield stations. This result was close to a rate published for Padre Island, 3.48 mm/yr (Paine et al. 2011). GT was a published value at 2 stations. These were averaged and the used for the 2 Gulf-facing subsites (Table 5). GT was calculated for the remaining stations (MHHW-MLLW). The resulting values were very close, so they were averaged and that value was assigned to the rest of the subsites.

Historical erosion rates were measured at transects throughout the Corpus Christi Bay area by Morton and Paine (1984). For marsh and tidal flat erosion rates, values from transects in representative areas (transects 16-23 and 35-48, years 1937-1982) were averaged. The Morton and Paine report did not provide enough detail to distinguish between tidal flat and marsh habitats. The representative areas are a mix of marsh and tidal flat, so the same erosion rate was assigned to both. More recent information on shoreline change for the Nueces River delta at 43 m of loss over 25 years (White et al. 2006) so the erosion rate for the global site was set at 1.7m/yr. The delta includes a mix of marsh and tidal flats, so the same erosion rate was used for both. There is little coastal forest in the study area, so coastal forest erosion rate was set at the erosion rate for Nueces County (City of Corpus Christi 2012).

Accretion rates were measured in our study area by Radosavljevic et al. (2012) on Mustang Island. They reported a accretion rates for marsh and flats of: high marsh, 1.30±0.09 mm yr-1; high flats, 1.29±0.01 mm yr-1; low marsh, 3.81±0.37 mm yr-1; low flats, 0.69±0.1 mm yr-1. From this, brackish marsh accretion was set to 1.3 mm/yr and saltmarsh accretion was set to 3.81 mm/yr. The beach sedimentation rate was set to 0.69 mm/yr.

Mobile Bay Study Area

At the time of the Mobile Bay study, a LiDAR-derived DEM suitable for modeling was not available via download from either the National Map or the NOAA CSC website. LiDAR data was collected by Mobile and Baldwin counties that bound Mobile Bay. These data were used by the NOAA Coastal Services Center to develop a DEM for their SLR viewer Web tool and were obtained for this project. In this DEM, high elevations are capped at 50m. Our SLAMM simulations did not track high elevations to save processing time.

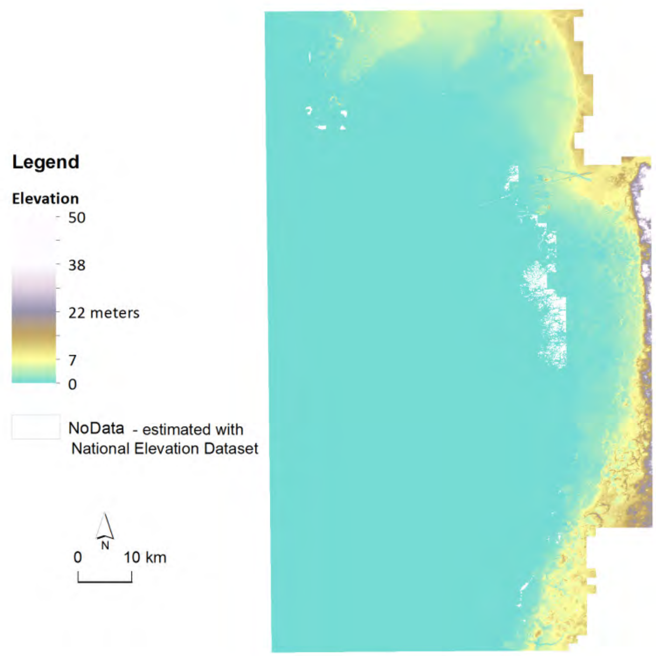


Figure 13. Mobile Bay Study Area digital elevation model used in the SLAMM analysis.

The NWI for Alabama was crosswalked to SLAMM categories to create the vegetation input for the Mobile Bay. The areas with NoData values are uplands and were assigned the value for undeveloped dry land (2). A raster layer depicting impervious surface was developed from the National Land Cover Data Set (NLCD) 2006. The NLCD 2006 Percent Developed Imperviousness raster dataset was clipped to the study area, resampled and aligned with the vegetation raster. Any undeveloped dry land cell in the vegetation raster that overlapped an NLCD cell with a value greater than zero is assigned a one. The result captured areas even with low imperviousness, such as suburban homes. However, a 2006 date for the impervious layer means that some recent development was not captured in the initial condition. The NWI photo date varied by county. Mobile County NWI image dates were almost entirely 2002 and Baldwin County was almost entirely 2001. Since Mobile County forms more of the study area, we selected the date 2002 for the photo date.

The Mobile Bay study area outlined in the thick yellow line is shown in Figure 14.

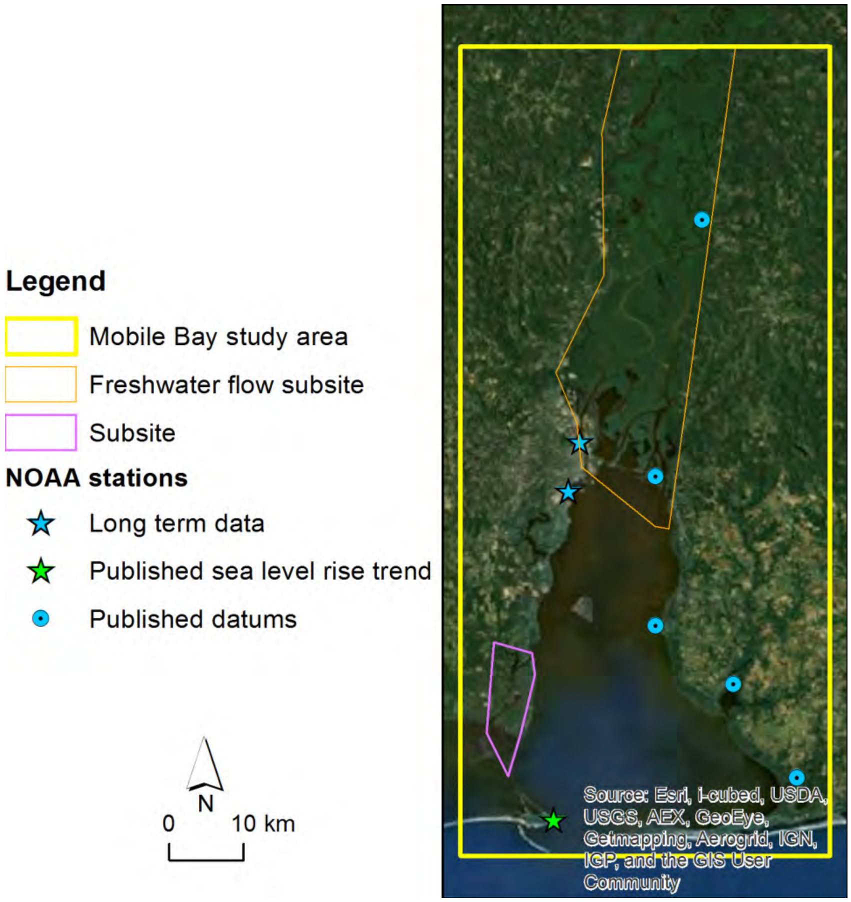


Figure 14. Mobile Bay Study Area subsites and NOAA stations used in the SLAMM analysis.

A small subsite was delineated to allow the marsh erosion rate to be lowered in the vicinity of Heron Bay because of the large extent of marsh. All other numeric parameters remained the same. A freshwater flow site was delineated for the Mobile-Tensaw river delta. The delta receives the drainage from the Mobile River Basin which encompasses both the Alabama and Tombigbee Rivers. Their combined average annual flow, at 62,100 cubic feet per second (cfs), is the fourth largest in the U.S. (O'Neil 2007). Numeric parameters for the Mobile Bay study area are shown in Table 6.

Table 6. Numeric input parameters for the Mobile Bay Area SLAMM simulation.

Parameter	Global	Subsite 1
NWI Photo Date (YYYY)	2002	2002
DEM Date (YYYY)	2002	2002
Direction Offshore [n,s,e,w]	South	South
Historic Trend (mm/yr)	2.98	2.98
MTL-NAVD88 (m)	-	-
GT Great Diurnal Tide Range (m)	0.471	0.471
Salt Elev. (m above MTL)	0.385	0.385
Marsh Erosion (horz. m /yr)	1.5	1
Coastal Forest Erosion (horz. m /yr)	1	1

Parameter	Global	Subsite 1
Tidal Flat Erosion (horz. m /yr)	0.8	0.8
Saltmarsh Accr (mm/yr)	11	11
Brackish Marsh Accr (mm/yr)	4.4	4.4
Tidal Freshwater Marsh Accr (mm/yr)	9	9
Beach Sed. Rate (mm/yr)	4.45	4.45
Freq. Overwash (years)	25	25
Use Elev Pre-processor [True,False]	FALSE	FALSE

Great diurnal tide (GT) range was averaged from published values from the NOAA stations. Salt elevation was calculated at 2 NOAA stations that had long term data. Both of these stations are in the same part of Mobile Bay, the northeast section (Figure 14). The calculated salt elevations, 0.63 (station 8737048) and 0.66 (station 8736897), and their ratio to MHHW, 2.07 and 2.08, were very similar. When these values were used to determine the salt elevation and entered into the model, the change at time zero (T0) change was very high and the simulation produced unrealistic results at year 2025. For this reason, salt elevation was estimated using a convention recommended on the SLAMM developer's forum http://warrenpinnacle.com/SLAMMFORUM/. The calculation 1.5 * (MHHW-MTL) was used to estimate the salt elevations at NOAA stations. The salt elevation is an average of these values.

Extremely detailed shoreline type mapping and horizontal erosion rates are available for Mobile Bay and surrounding bays as part of a 3 phase study conducted by the Geological Society of Alabama (GSA; Jones and Tidwell, 2011; Jones and Tidwell, 2012; Jones et al., 2009). The GSA study used the Digital Shoreline Analysis System version 4.0 (DSAS) to estimate horizontal erosion and accretion rates. The Mobile Bay study area has a highly variable shoreline, not only in terms of horizontal erosion and accretion, but in variety of shoreline types both man-made and natural.

General horizontal erosion rates for marsh and coastal forest input parameters were developed by examining DSAS transects in these habitat types. The Heron Bay area, a large marsh area in the study area, was estimated to have a slightly lower marsh erosion rate and so was delineated as a subsite. No site specific data for tidal flat erosion was found so the mean coastal erosion rate determined by the USGS national assessment of shoreline change (Morton, 2004) was used as the input parameter. Sedimentation and accretion rates were based on work conducted by Smith et al. (in review). Overwash frequency was set to 25 years.

Pensacola Study Area

Figure 15 shows the Pensacola Bay study area DEM. Any raster cells with a NoData value that fell under a SLAMM open water category were set to zero, so that the model's decision tree would operate on those cells. The western tip of Santa Rosa Island was missing from the DEM. This small area was filled in with licensed IfSAR-derived DTM data provided by the NOAA Coastal Services Center.

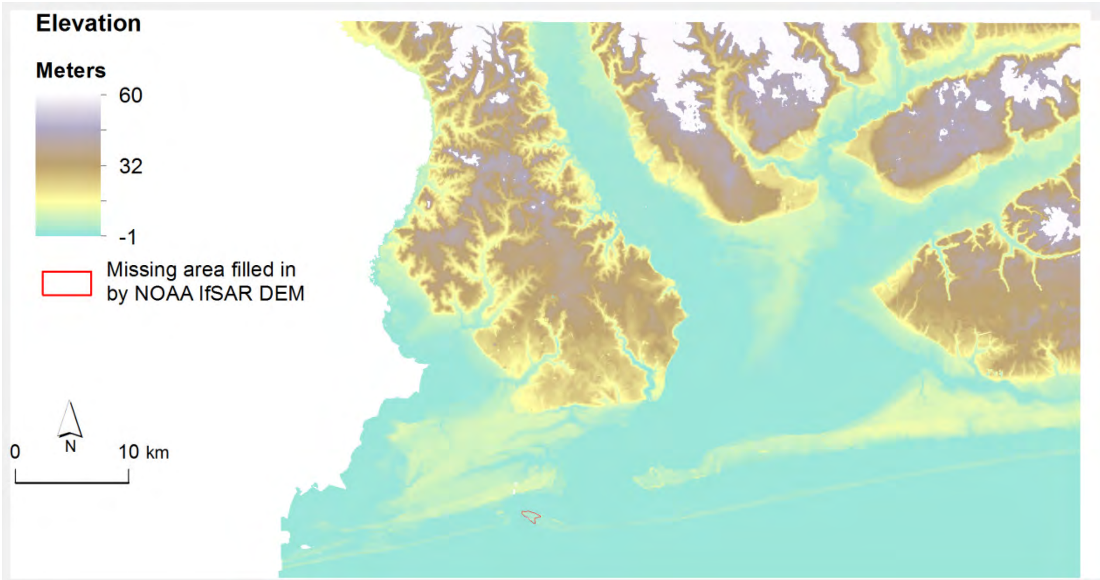


Figure 15. Pensacola Bay Study Area digital elevation model for the SLAMM analysis.

The vegetation layer used for the SLAMM simulation was the FNAI Cooperative Land Cover (CLC) version 1.1, modified by NWI information to better incorporate the water regime. Because we wanted to include brackish marsh and tidal swamp, NWI data for the study area were converted to SLAMM categories. Marsh and coastal forest areas between the 2 SLAMM coverages were compared. Edits to SLAMM assignments were made to the vector CLC data, before conversion to the raster input. The following rules were applied:

SLAMM category from CLC	SLAMM category from NWI	Input into simulation
Salt Marsh	Brackish Marsh	Brackish Marsh
Coastal Forest	Tidal Swamp	Tidal Swamp

A few feature shapes were slightly modified during the editing process based on comparing the land cover to aerial photography. A map of the initial vegetation is shown in Figure 16. Legend categories are interchangeable as follows: irregularly flooded marsh/brackish marsh, regularly flooded marsh/saltmarsh and coastal forest/swamp.

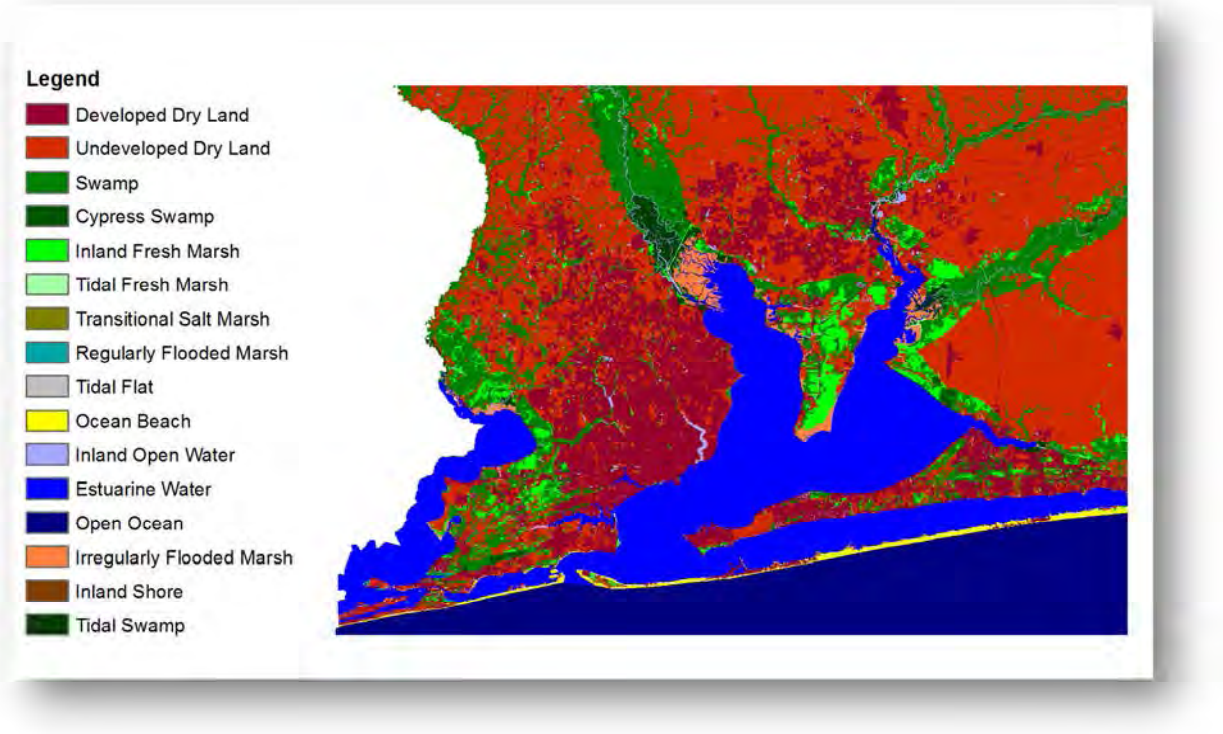


Figure 16. Pensacola Bay Study Area vegetation data used as the initial condition for the SLAMM simulation.

The NWI Photo Date represents the approximate date of the vegetation data. The CLC is a land cover merged from different sources. In the Pensacola Bay study area, most of the CLC data comes from the Northwest Florida Water Management District (NWFWMD) land use/land cover 2006-07, or was mapped as part of FNAI's Community Mapping in the range of 2003 -2010. In terms of simulation processing all these dates are relatively close, so the photo date parameter was set to 2006 (Table 7).

Two subsites were defined, and are shown in Figure 17. Only the Florida portion of Subsite 1 was modeled. Subsite 2 is also designated as a freshwater flow area due to the influx of freshwater from the Blackwater and Yellow Rivers.

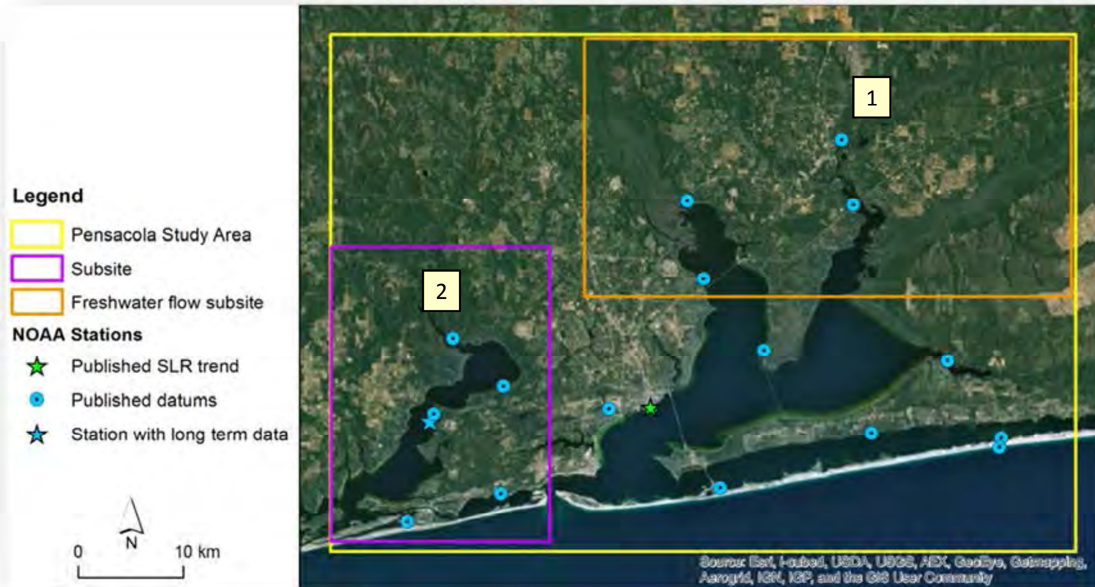


Figure 17. Pensacola Bay Study Area subsites and NOAA stations used in the SLAMM analysis.

Table 7. Numeric input parameters for the Pensacola Bay Area SLAMM simulation.

Parameter	Global	Subsite1	Subsite2
Land cover photo date	2006	2006	2006
DEM Date	2006	2006	2007
Direction Offshore [n,s,e,w]	South	South	South
Historic trend in sea level rise (mm/yr)	2.1	2.1	2.1
NAVD correction [MTL - NAVD88 (m)]	0.093	0.093	0.073
Great diurnal tide range (m)	0.408	0.465	0.383
Salt elevation (m above MTL)	0.542	0.467	0.570
Marsh erosion rate (horz. m/yr)	2	2	2
Coastal forest erosion rate (horz. m/yr)	1	1	1
Tidal flat erosion rate (horz. m/yr)	0.5	0.5	0.5
Saltmarsh accretion rate (mm/yr)	2.25	2.25	2.25
Brackish marsh accretion rate (mm/yr)	3.75	3.75	3.75
Tidal freshwater marsh accr. rate (mm/yr)	4	4	4
Beach sedimentation rate (mm/yr)	0.5	0.5	0.5
Frequency of overwash (years)	25	25	25
Used elevation pre-processor [True, False]	FALSE	FALSE	FALSE

Great diurnal tide (GT) values were averaged separately within each subsite and outside of the subsites to calculate the GT parameter. Because Pensacola Bay is strongly influenced by winds (Livingston 2006), salt elevation was calculated for the site using the method recommended by Jonathon Clough (pers. comm. 2011) where:

$$\text{Salt Elevation} = X(\text{TideRange}) + W$$

Salt Elevation = calculated estimate of the “sea water elevation” in meters above MTL;
X = unitless factor that accounts for the effect of local tide range on inundation;
W = constant effect of wind, not a function of tide range.

The salt elevation was calculated for 2 stations for which long-term (3 years) of data were available (Pensacola and Blue Angel Park). With the 2 derived elevations, we used Microsoft Excel Solver to find X and Win the above equation (Clough 2012). For each NOAA station, a salt elevation was calculated by entering the GT tide range into the equation. The resulting salt elevations were averaged by subsite.

Neither site-specific rates for Pensacola Bay for erosion, accretion and sedimentation nor rates from proximate sites were available at the time of modeling. The values used were the same used for an earlier application of SLAMM at the site (Clough 2006).

Alabama portion of Perdido Bay Area

Perdido Bay spans across Alabama and Florida. The Perdido Bay study area includes only the Alabama side of Perdido Bay, since the Florida side was modeled as part of the Pensacola Bay site, and extends to the east boundary of the Mobile study area. Elevation data was downloaded from the NED 1/9 arc-second dataset (Figure 18).

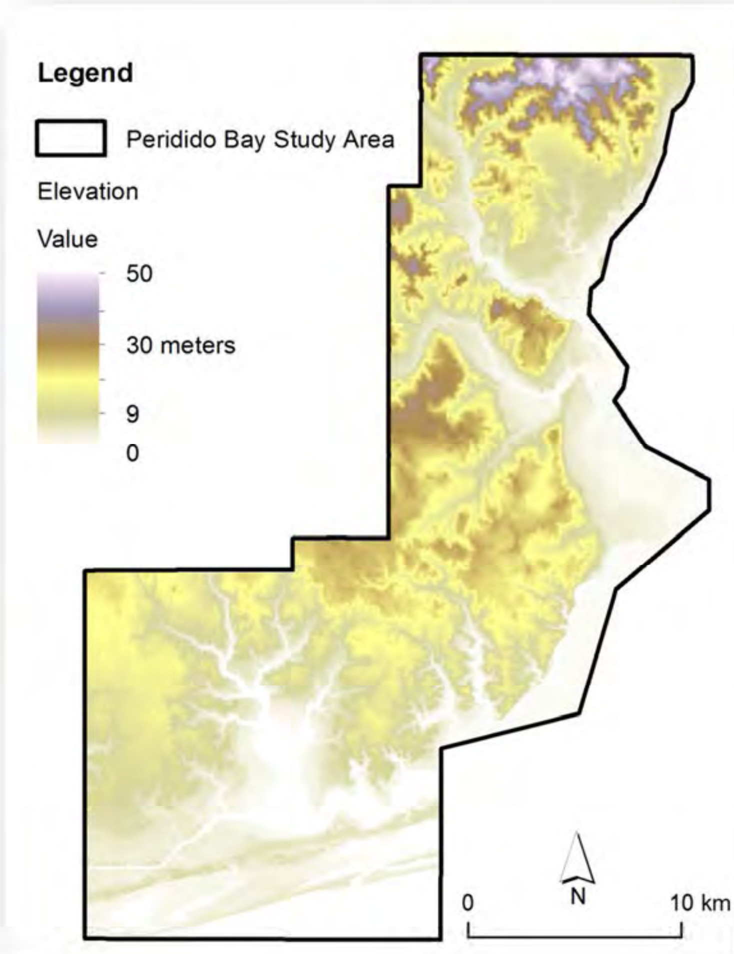


Figure 18. Alabama portion of Perdido Bay Study Area digital elevation model used in the SLAMM analysis.

The NWI for Alabama was crosswalked to SLAMM categories to create the vegetation input for Perdido Bay. The source date for the NWI data in the study area was 2001. The areas in the NWI with NoData values are uplands and were assigned the value for Undeveloped Dry Land (2). For the SLAMM category of Developed Dry Land, areas classified as developed in the NLCD 2006 were extracted. This includes four codes: 21-Developed Open Space, 22-Developed Low Intensity, 22-Developed Medium Intensity, 24-Developed High Intensity. Any undeveloped dry land cell in the vegetation raster that overlapped an NLCD developed cell is assigned a one. Figure 19 shows the initial condition vegetation data for Perdido Bay.

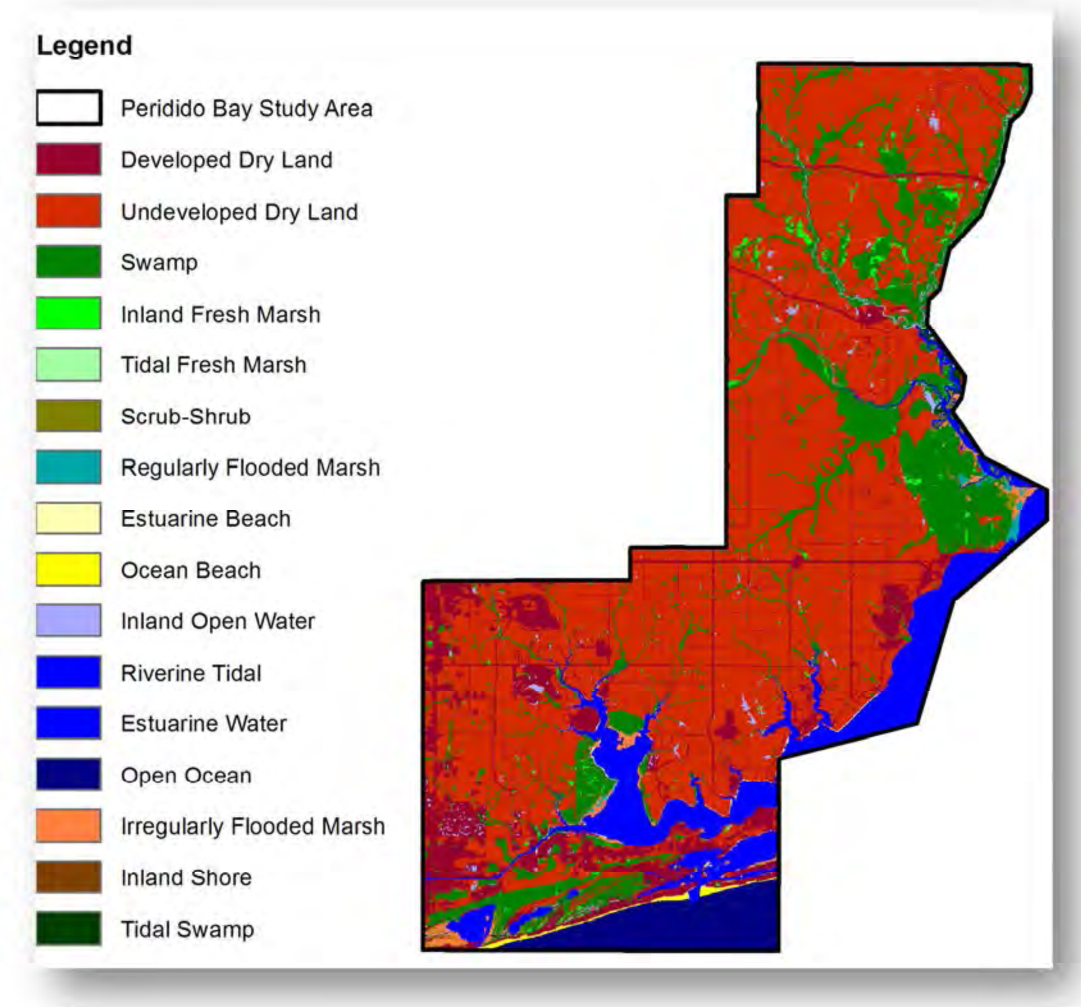


Figure 19. Alabama portion of Perdido Bay Study Area vegetation data used as the initial condition for the SLAMM simulation.

Numeric parameters for Perdido Bay were set to the values from subsite 2 of Pensacola Bay (Table 7), with the following exceptions: the DEM data around the Perdido Bay itself was from 2006. Outside of that, DEM data varied, generally from 2001 to 2011. Two subsites were defined to capture the 2 different dates (Figure 20). Subsite 1 has a DEM date of 2001 and subsite 2 has a date of 2011. The NAVD88 correction was set to a single value, 0.12, the value of MTL-NAVD from the Nix Point station in the center of Perdido Bay.

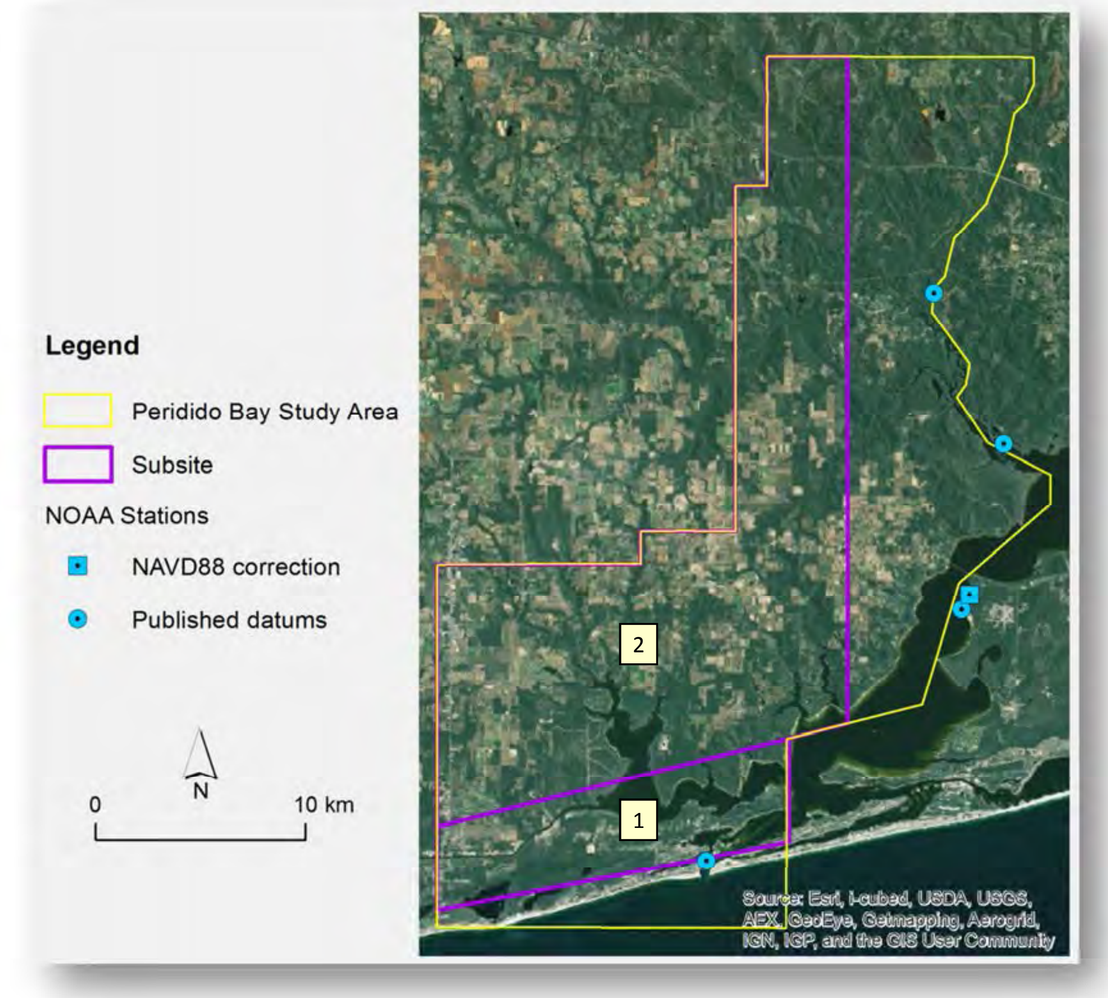


Figure 20. Alabama portion of Perdido Bay Study Area subsites and NOAA stations used in the SLAMM analysis.

Southern Big Bend Study Area

The Southern Big Bend study area DEM is illustrated in Figure 21. Any raster cells with a NoData value that fell under a SLAMM open water category were set to zero. After clipping to the study area, the DEM was multiplied by 0.3048 to convert the vertical elevation from feet to meters.

For some of the most seaward marsh areas, no LiDAR-derived elevation data was available (Figure 21). These marsh areas were not a priority for data collection since the primary use of the LiDAR data is municipal and not environmental. For these excluded areas, 1/3 arc-second data from the USGS NED was used in SLAMM's preprocessor module to get an estimate of change.

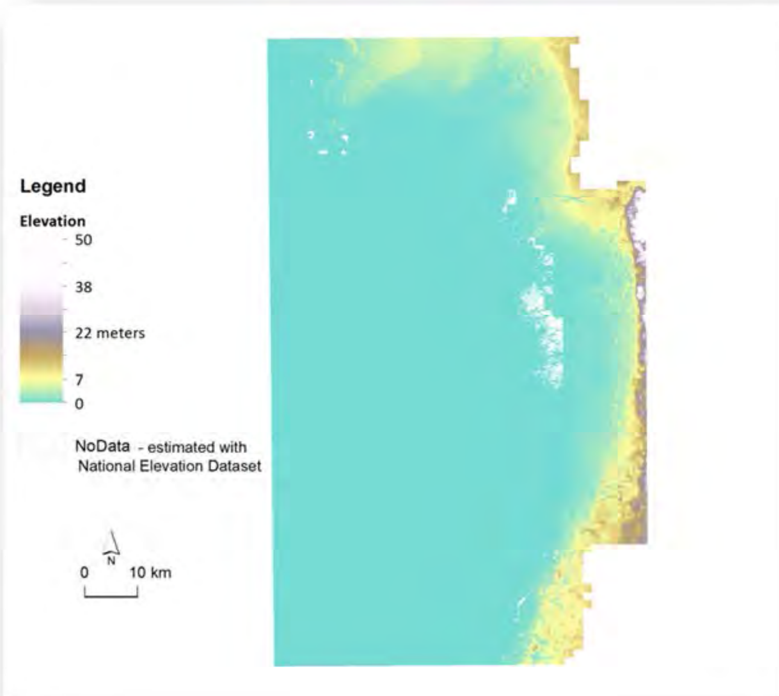


Figure 21. Southern Big Bend Study Area digital elevation model for the SLAMM analysis.

The vegetation layer used for the SLAMM simulation was the CLCv1.1 refined with other datasets. To better capture mangrove, the CLC data was compared to NWI vegetation crosswalked to SLAMM categories. When an entire vegetation feature was categorized as saltmarsh in the CLC and as mangrove in the NWI, we assigned the SLAMM category as mangrove. Within the extent of the CLC dataset, tidal flat features from benthic or seagrass studies replaced open water (FWC-FWRI 2009).

About 120 ha of tidal swamp were identified in the Crystal River Preserve State Park Unit Management Plan (FDEP 2004). In the NWI crosswalk to SLAMM categories, these areas were also assigned to tidal swamp. Therefore, CLC vegetation features that represented this area were coded as tidal swamp. Initial vegetation is shown in Figure 22.

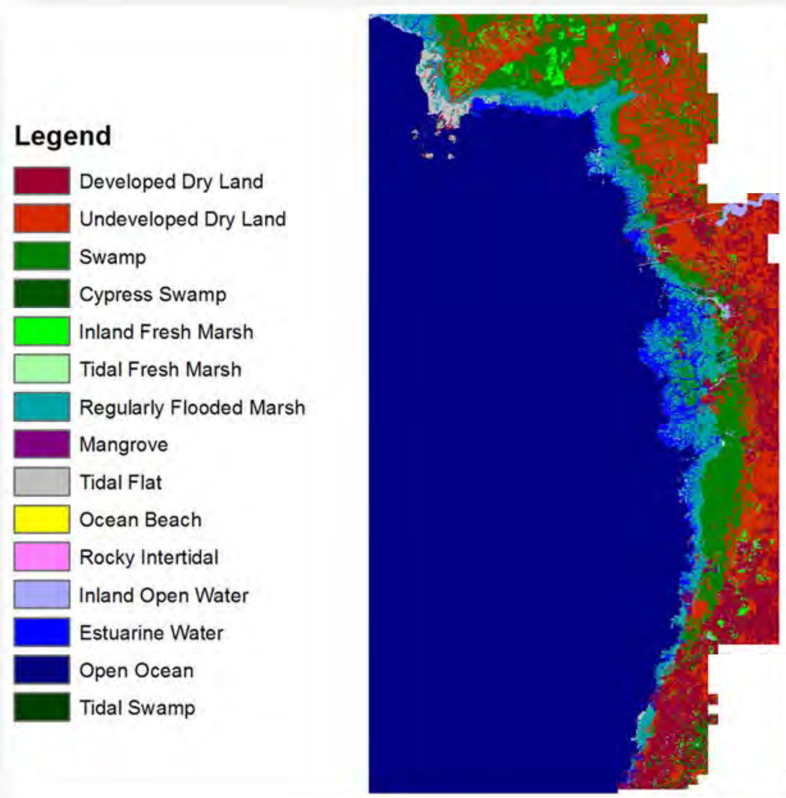


Figure 22. Southern Big Bend Study Area vegetation data used as the initial condition input into the SLAMM simulation.

The NWI photo date represents the approximate date of the vegetation data. The CLC is a land cover merged from different sources. In the Southern Big Bend study area, most of the CLC data comes from the Southwest Florida Water Management District (SWFWMD) land use/land cover 2008 or the Suwannee River Water Management District (SRWMD) 2005-2008. Remaining land cover included in the CLC dataset was generally mapped as part of natural community mapping efforts by FNAI or the Florida Park Service in the 2000's. The photo date parameter was set to 2008 for the study area.

Four subsites were defined and are shown in Figure 23 (subsites 1 – 4). Subsites 3 and 4 were created to encompass the portions of the study area that had no LiDAR-derived DEM data. In these subsites, the SLAMM preprocessor was used to estimate vegetation change using National Elevation Dataset (NED) 1/3 arc-second DEM data.

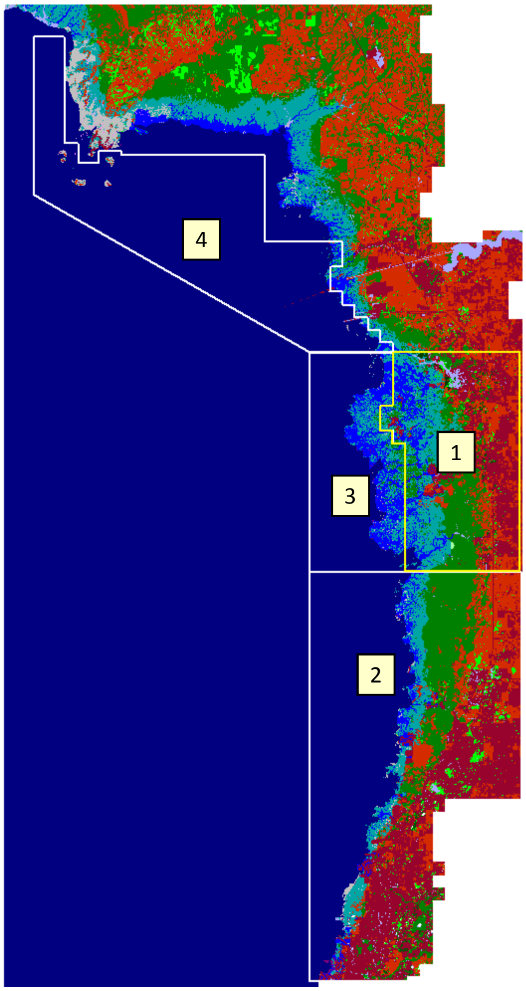


Figure 23. Southern Big Bend Study Area subsites used in the SLAMM analysis.

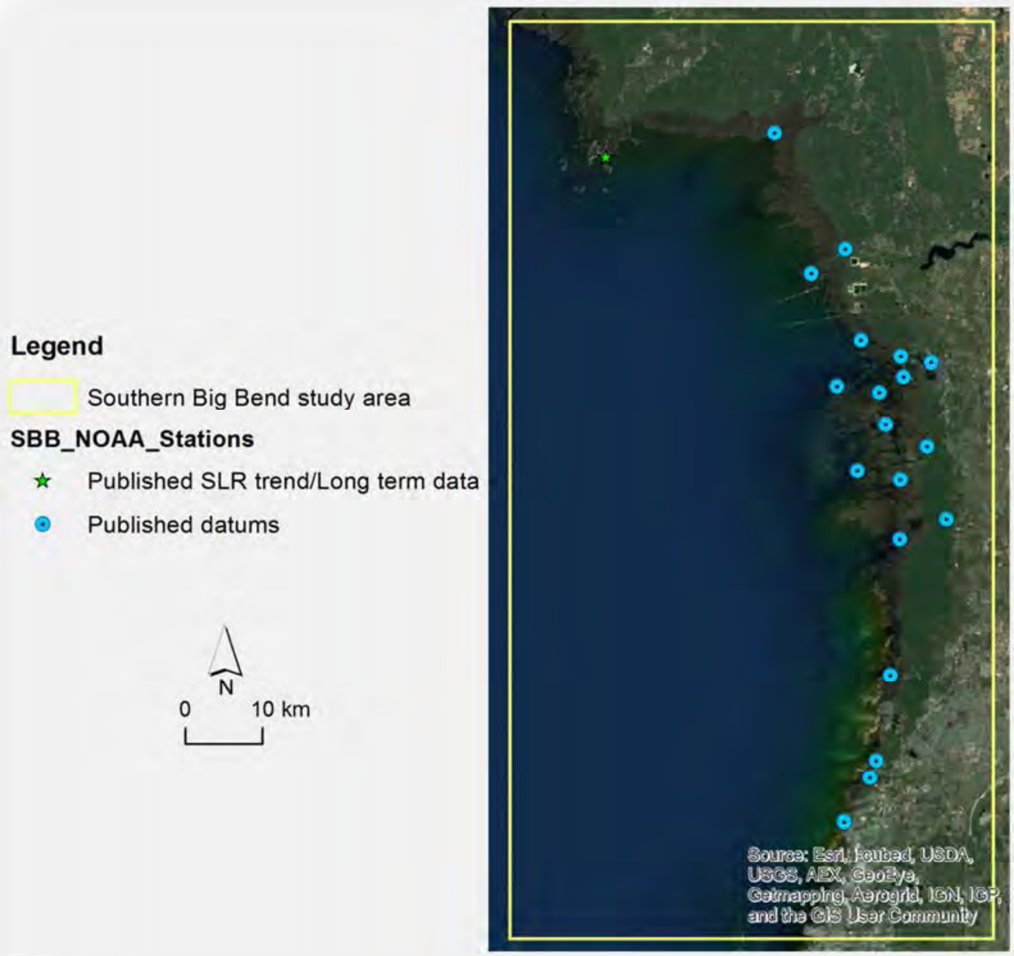


Figure 24. Southern Big Bend Study Area NOAA stations used in the SLAMM analysis.

To calculate tidal parameter values, data from NOAA stations were averaged separately within each subsite and outside of the subsites.

Table 8. Numeric input parameters for the Southern Big Bend Area SLAMM simulation.

Parameter	Global	Subsite 1	Subsite 2	Subsite 3	Subsite 4
NWI Photo Date (YYYY)	2008	2008	2008	2008	2008
DEM Date (YYYY)	2007	2007	2007	2007	2007
Direction Offshore [n,s,e,w]	West	West	West	West	West
Historic Trend (mm/yr)	1.8	1.8	1.8	1.8	1.8
MTL-NAVD88 (m)	-	-	-	-	-
GT Great Diurnal Tide Range (m)	1.187	0.594	0.917	0.594	1.187
Salt Elev. (m above MTL)	0.9	0.478	0.721	0.478	0.9

Marsh Erosion (horz. m /yr)	0.32	0.32	0.32	0.32	0.32
Coastal Forest Erosion (horz. m /yr)	0.32	0.32	0.32	0.32	0.32
Tidal Flat Erosion (horz. m /yr)	0.32	0.32	0.32	0.32	0.32
Saltmarsh Accr (mm/yr)	7.2	7.2	7.2	7.2	7.2
Brackish Marsh Accr (mm/yr)	7.2	7.2	7.2	7.2	7.2
Tidal Freshwater Marsh Accr (mm/yr)	7.2	7.2	7.2	7.2	7.2
Beach Sed. Rate (mm/yr)	0.5	0.5	0.5	0.5	0.5
Freq. Overwash (years)	25	25	25	25	25
Use Elev Pre-processor [True,False]	FALSE	FALSE	FALSE	TRUE	TRUE

The value of the input parameter for all three erosion rates (marsh, coastal forest and tidal flats) was 0.32 horizontal meters/year. This estimate is from research done by Hine and Belknap, 1986.

The value of the input parameter for all three accretion rates (saltmarsh, brackish marsh and tidal fresh marsh) was 7.2 mm/year. This estimate was derived from research by Leonard et al. (1995). The sedimentation rate is from Clough (2006). The frequency of overwash parameter, which represents the frequency of large storms, was set to 25 years.

Tampa Bay Study Area

The Tampa Bay Estuary Program (TBEP) previously ran SLAMM simulations as part of their long-standing mission to protect and restore Tampa Bay (Sherwood & Greening 2013). Their approach was slightly different from the approach describe for this study. To maintain consistency across our sites, we ran SLAMM simulations as well using some of the DEM and vegetation data provided to us by TBEP. Figure 25 shows the Tampa Bay study area DEM. The DEM was resampled from a 10m to a 15m cell size due to computer hardware constraints. A slope raster file was created from the resampled DEM.

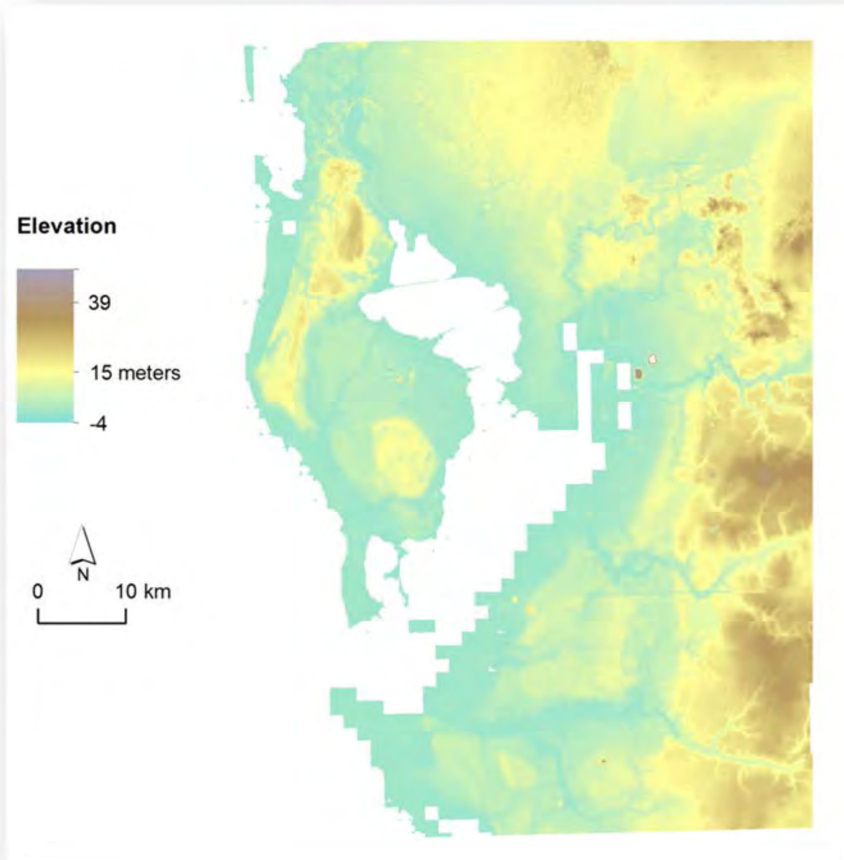


Figure 25. Tampa Bay Study Area digital elevation model for the SLAMM analysis.

Figure 26 shows the vegetation data provided the Tampa Bay Estuary Program. The vegetation raster was also resampled from a 10m to a 15m cell size. The elevation data used for the simulation modeling did not extend to all of the tidal flats delineated in Tampa Bay. Tidal flat areas with no elevation data were not simulated by SLAMM, and are not shown in the vegetation layer or the simulated results. The NWI photo date and the DEM date for the raster inputs were both 2007.

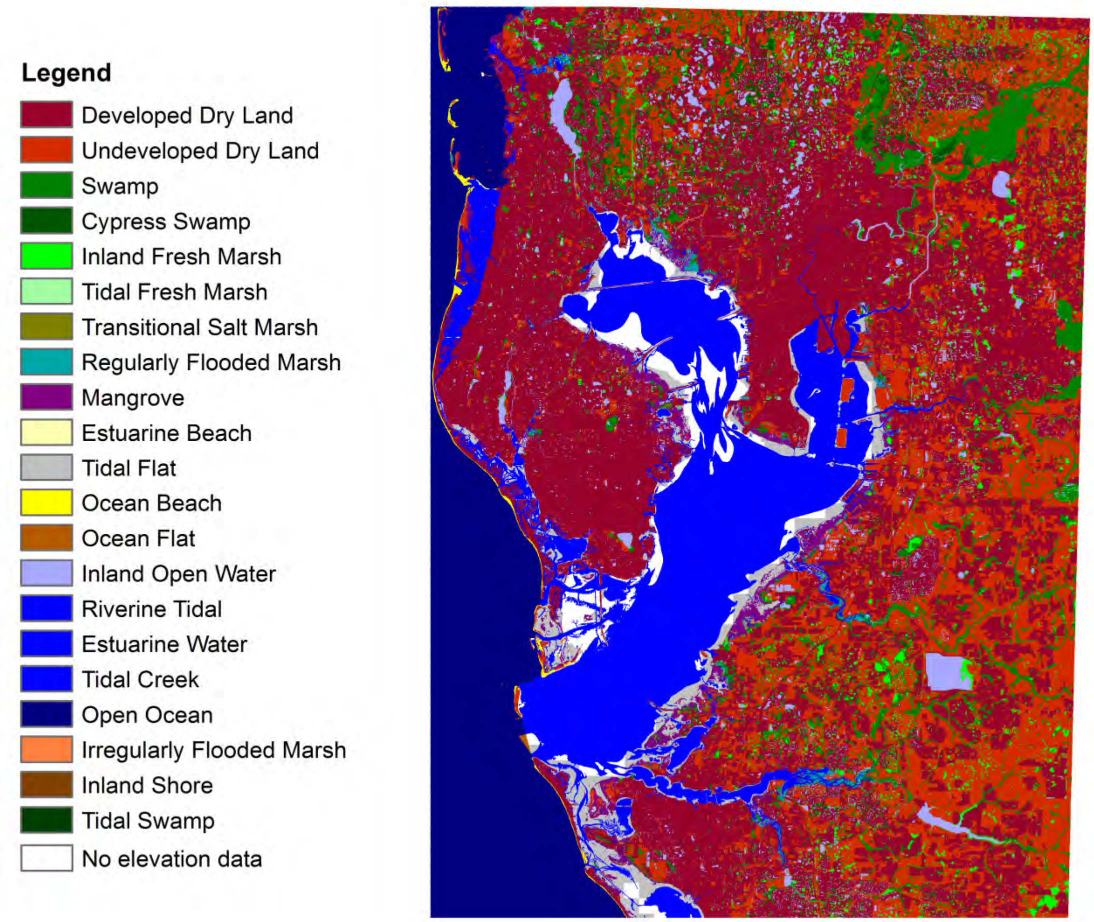


Figure 26. Tampa Bay Study Area vegetation data used in the SLAMM analysis.

Two subsites were defined and are shown in Figure 27, along with the NOAA stations that were utilized for tidal data. Five NOAA stations had long-term data with which to calculate salt elevations and their ratios to MHHW. The average salt elevation/MHHW of these 5 stations is 1.69. This ratio was used to estimate the salt elevation at the other stations. These values were averaged separately within each subsite and outside of the subsites to calculate the salt elevation parameters. GT values were averaged in the same way.

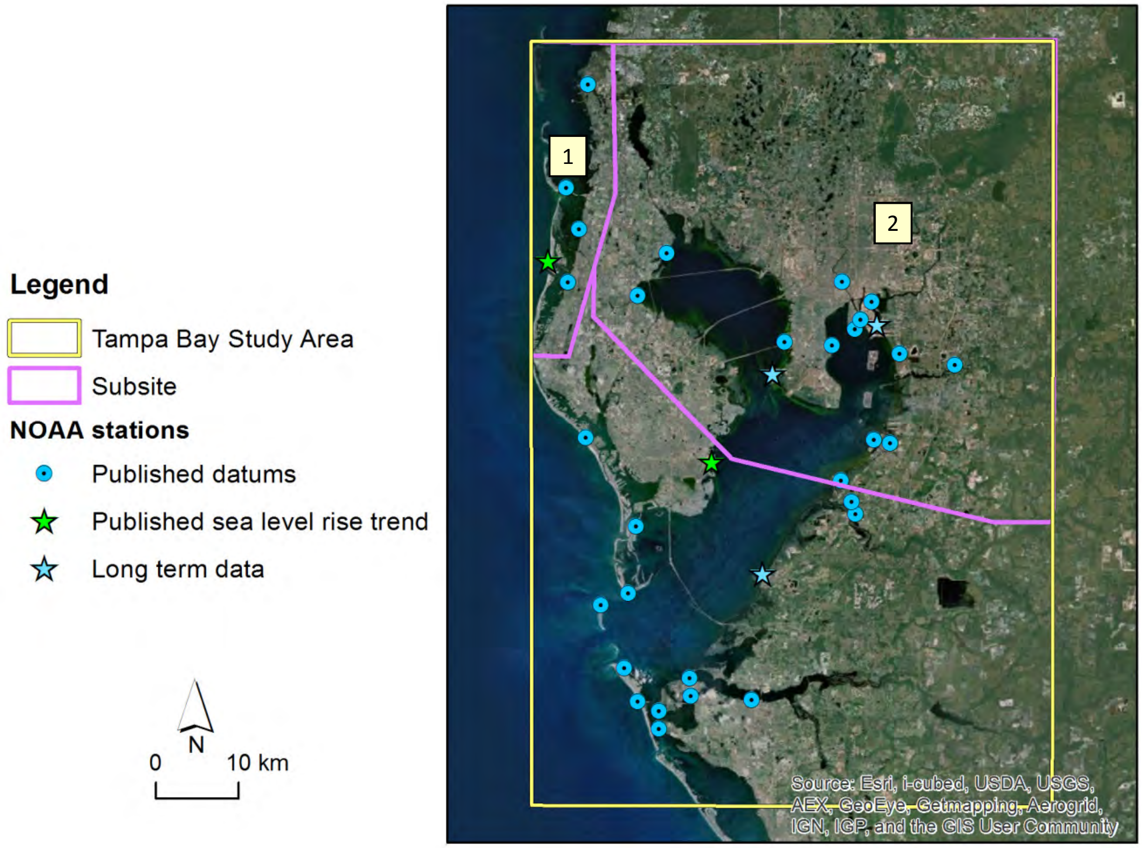


Figure 27. Tampa Bay Study Area subsites and NOAA stations used in the SLAMM analysis.

For this study area, a raster input for the MTL-NAVD88 parameter was not used. Applying the Euclidean distance function to a grid of point values from the Vdatum software resulted in outlier values being propagated over large portions of the study area. Instead, the point values were averaged by subsite, and entered as numeric parameters.

Site-specific erosion and accretion rates for Tampa Bay are from Clough (2006). Sedimentation rates in portions of the Tampa Bay study area were shown to be between 0.13 - 0.42 cm/yr (Brooks, 1989). The midpoint value of 2.75 mm/yr was input into the simulation. Frequency of overwash was set to zero, which turns off the function because the small cell size and land configuration produced unrealistic streaking in the results.

Table 9. Numeric input parameters for the Tampa Bay Area SLAMM simulation.

Parameter	Global	Subsite 1	Subsite 2
NWI Photo Date (YYYY)	2007	2007	2007
DEM Date (YYYY)	2007	2007	2007
Direction Offshore [n,s,e,w]	West	West	West
Historic Trend (mm/yr)	2.43	2.43	2.36

Parameter	Global	Subsite 1	Subsite 2
MTL-NAVD88 (m)	-0.14	-0.09	-0.08
GT Great Diurnal Tide Range (m)	0.67	0.87	0.79
Salt Elev. (m above MTL)	0.55	0.71	0.65
Marsh Erosion (horz. m /yr)	2	2	2
Coastal Forest Erosion (horz. m /yr)	1	1	1
Tidal Flat Erosion (horz. m /yr)	0.5	0.5	0.5
Saltmarsh Accr (mm/yr)	2.25	2.25	2.25
Brackish Marsh Accr (mm/yr)	3.75	3.75	3.75
Tidal Freshwater Marsh Accr (mm/yr)	4	4	4
Beach Sedimentation Rate (mm/yr)	2.7	2.7	2.7
Freq. Overwash (years)	0	0	0
Use Elev Pre-processor [True,False]	FALSE	FALSE	FALSE

Uncertainty Analysis

The numerical parameters for each study area's simulation were developed with data available at the time. For some sites, site specific parameter information was available for all numerical input parameters (e.g., saltmarsh accretion rate, beach sedimentation rate, etc.). For other sites, site specific parameter information was not available or only available for some of the numerical input parameters. The simulated results of the scenarios presented below have all the types of uncertainty inherent to simulation models (McKay et. al., 1999). Uncertainty and sensitivity in SLAMM v5.0 has been examined by Chu-Agor et. al. (2011) using a generic evaluation framework that is model-independent. To address the question of input uncertainty, an uncertainty analysis module was added to version 6 of SLAMM (Clough et al. 2010).

SLAMM's uncertainty analysis module was used to examine input uncertainty for selected parameters at each study area. The SLAMM uncertainty analysis module allows a user to specify a distribution for any input parameter, or multiple parameters, and performs a Monte-Carlo analysis. The user specifies the number of iterations using a random or non-random seed. Our uncertainty runs used a non-random seed. A limitation of SLAMM's uncertainty module is that the values drawn from the distribution are multipliers applied to a single value of the parameter in question. That is, the parameter value to which the multiplier is applied does not change even if that parameter changes across subsites.

The uncertainty analyses were also limited by computer resources. With small cell sizes of 15 or 30 meters and our available computer capacity, even 100 iterations could take 24 hours or more. As a result, we examined the effects of input uncertainty on 2 or 3 numeric parameters at each study site. The number of iterations was set to 100 for the 1 m SLR scenario. While 100 iterations can reveal trends, this number of iterations may not be enough to capture extremes. For the Pensacola and Corpus Christi study areas we ran the uncertainty module with a representative subset of the study area (Figure 28) to shorten the runtime of the 100 iterations. For Tampa Bay, three parameter distributions were included in the 100 model iterations. All uncertainty analyses were run on the 1 m SLR scenario with developed dry land allowed to transition.

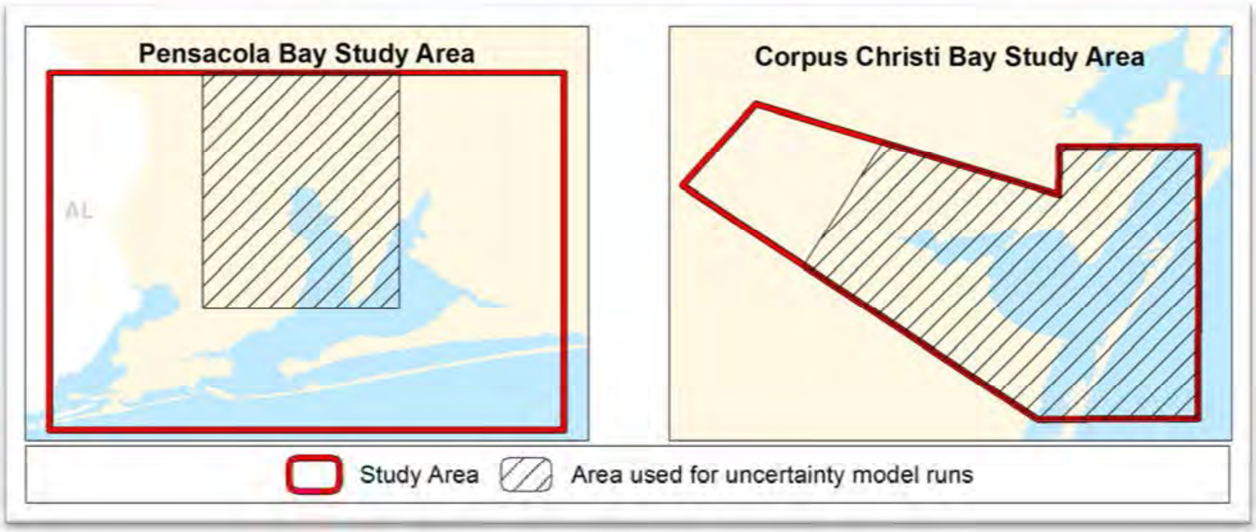


Figure 28. Study areas where only a portion of the site was used for uncertainty model runs.

We selected three parameters for uncertainty that appeared influential in simulation outcomes: marsh accretions, sedimentation and salt elevation. Generally, distributions used were plus or minus a likely spread from our input value based on values from the literature at nearby sites. Triangular distributions were used when there was a basis that a value for a parameter was more likely. In some cases, minimum and maximum values were chosen so that the distribution would encompass values from research that indicated a wider range as noted in Table 10. In Mobile Bay, coastal forest erosion was selected for the uncertainty analysis due to the large extent of coastal forest in the study area

Table 10. Parameters and their statistical distribution input into the SLAMM uncertainty analysis module. U= Uniform distribution (minimum, maximum); T=Triangular distribution (minimum, most likely, maximum).

Study Area	SLAMM Parameter	Input Value	Distribution
Pensacola	Saltmarsh Accretion (mm/yr)	2.25	T(0.9, 3.2, 8)*
Pensacola	Brackish marsh Accretion (mm/yr)	3.75	U(3,4)*
Southern Big Bend	Saltmarsh Accretion (mm/yr)	7.2	T(0.7, 7.2, 7.6)†
Southern Big Bend	Beach Sedimentation Rate (mm/yr)	0.5	U(0.375, 0.625)
Tampa Bay	Salt Elevation (m above MTL)	0.55	U (0.495, 0.605)
Tampa Bay	Saltmarsh Accretion (mm/yr)	2.25	T(0.9, 2.25, 8.0)*
Tampa Bay	Beach Sedimentation Rate (mm/yr)	2.7	T (0.01, 2.5, 5)*

Study Area	SLAMM Parameter	Input Value	Distribution
Mobile Bay	Salt Elevation (m above MTL)	0.385	U(0.11, 0.66)
Mobile Bay	Coastal Forest Erosion (horiz. m/yr)	1	U(0.8, 1.2)
Corpus Christi Bay	Beach Sedimentation Rate (mm/yr)	0.69	U (0.49, 1.3)††
Corpus Christi Bay	Salt Elevation (m above MTL)	0.23	U(0.115, 0.345)
Corpus Christi Bay	Inland Freshwater Marsh Accretion (mm/yr)	2.9	U(2.175, 3.625)

*distributions from Chu-Agor et. al. (2011). The area modeled for their analysis was adjacent to the Pensacola study area.

†values from Leonard et. al. (1995)

††values from Radosavljevic et. al. (2012)

Modeling Effects of SLR on Vulnerable Species and Communities

Species and natural community elements were selected for evaluation based on their global and state imperilment statuses, their dependence on study-area habitats vulnerable to SLR, and expert review. In addition to this modeling, three species from each study area with significant potential impacts from SLR were further assessed using the NatureServe Climate Change Vulnerability Index (CCVI; Young et al. 2012).

Habitat models were developed by FNAI for each target element. The habitat model was then used to examine both the initial condition of vegetation and the simulated vegetation at year 2100 of the 1 meter SLR scenario (with Developed Dry Land protected). Habitat change between the initial condition and the simulated result at year 2100 was then quantified.

Species modeling differed slightly between Florida and the other states because FNAI occurrence-based rare species habitat models were available only for Florida. These models are based on the Florida-specific Cooperative Land Cover Map and allowed development of "occupied habitat" maps for target elements. For SLAMM study areas in Alabama and Texas, "potential habitat" maps were created as occurrence-based habitat models were not available.

A habitat model for each target element was created based on the vegetation data input into SLAMM. Compatible SLAMM categories were assigned to each target element to model habitat. For each target element, relevant land cover classes were extracted and, in many cases, refined with auxiliary data. Both the determination of relevant land covers and the refinements were informed by some combination of documented element occurrences, biologist input, and scientific literature.

To assess impacts to target species, the area of overlap was calculated for each element's potential-habitat model with the current land cover dataset used for the SLAMM analysis the one-meter SLR SLAMM projected land cover (with maximum protection of developed dry land and no dikes). By comparing the amount of compatible land cover within each habitat model boundary at the initial condition with the amount of compatible land cover within each habitat model boundary in 2100 (1 m SLR scenario), the loss of habitat was calculated. Table 11 lists the target elements examined for all five study areas.

The Climate Change Vulnerability Index (CCVI) noted above can help identify plant and animal species that are particularly vulnerable to the effects of climate change. The Index is a Microsoft Excel based tool that requires the input of readily available information about a species' natural history, distribution and landscape circumstances to predict whether it will likely suffer a range contraction and/or population reductions due to climate change. Vulnerabilities assessed include potential barriers to migration, estimated dispersal capability, and estimated sensitivity to temperature and moisture changes. Information on the tool is available from https://connect.natureserve.org/science/climate-change/ccvi. Once the required information is added to the Index, an Index score (Table 12) is calculated and confidence level described. Index scores provide a relative measure of vulnerability to climate change. The Index is based on factors associated with climate change and so it is impossible to calculate numerical probabilities for decline. The Index does, however, separate species with numerous risk factors and a fast changing climate from those with fewer risk factors or characteristics that may cause them to increase. To estimate confidence in species information, the Index uses a Monte Carlo simulation.

Table 11. Target species and communities evaluated for the 5 SLAMM study areas: Corpus Christi Bay (CCB), Mobile Bay (MB), Pensacola Bay (PB), Southern Big Bend (SBB), and Tampa Bay (TB).

Scientific Name	Common Name	Group	Study Area
Acipenser oxyrinchus desotoi	Gulf sturgeon	Fish	PB
Ambrosia cheiranthifolia	south Texas ambrosia	Plant	CCB
Ambystoma bishopi	reticulated flatwoods salamander	Amphibian	PB
Ammodramus maritimus	seaside sparrow	Bird	CCB
Ammodramus maritimus peninsulae	Scott's seaside sparrow	Bird	SBB
Aphrissa statira	statira	Butterfly	TB
Bigelowia nuttallii	Nuttall's rayless goldenrod	Plant	TB
Calidris canutus	red knot	Bird	TB
Caretta caretta	loggerhead sea turtle	Reptile	TB, CCB
Charadrius alexandrinus	snowy plover	Bird	MB
Charadrius melodus	piping plover*	Bird	PB, MB, TB, CCB
Charadrius nivosus	snowy plover	Bird	TB
Charadrius wilsonia	Wilson's plover	Bird	TB

Scientific Name	Common Name	Group	Study Area
Chelonia mydas	green sea turtle	Reptile	CCB
Chrysopsis floridana	Florida goldenaster	Plant	TB
Chrysopsis godfreyi	Godfrey's golden-aster	Plant	MB
Echinodorus floridanus	Florida burrhead	Plant	PB
Egretta rufescens	reddish egret*	Bird	MB, CCB
Eretmochelys imbricata	Atlantic hawksbill sea turtle	Reptile	CCB
Eudocimus albus	white ibis	Bird	MB
Fallicambarus danielae	speckled burrowing crayfish	Crustacean	MB
Floridobia helicogyra	crystal siltsnail	Invertebrate	SBB
Fundulus jenkinsi	saltmarsh topminnow	Fish	PB
Glandularia tampensis	Tampa vervain*	Plant	TB
Graptemys ernsti	Escambia map turtle	Reptile	PB
Grindelia oolepis	plains gumweed	Plant	CCB
Haematopus palliatus	American oystercatcher	Bird	TB
Hasteola robertiorum	Florida Hasteola	Plant	SBB
Helianthus debilis ssp. tardiflorus	late flowering beach sunflower*	Plant	SBB
Helianthus debilis ssp. vestitus	hairy beach sunflower	Plant	TB
Hoffmannseggia tenella	slender rushpea	Plant	CCB
Hydric Hammock	n/a	Community	SBB
Lepidochelys kempii	Kemp's Ridley sea turtle	Reptile	CCB
Lindera subcoriacea	bog spicebush*	Plant	PB
Malaclemys terrapin	diamondback terrapin	Reptile	MB
Malaclemys terrapin littoralis	Texas diamondback terrapin	Reptile	CCB
Malaclemys terrapin macrospilota	ornate diamondback terrapin	Reptile	SBB
Microtus pennsylvanicus dukecampbelli	salt marsh vole	Mammals	SBB
N/A	coastal rookeries	Other Element	CCB
Najas filifolia	narrowleaf naiad	Plant	PB
Nerodia clarkii	Gulf saltmarsh snake*	Reptile	MB, CCB
Notropis melanostomus	blackmouth shiner*	Fish	PB
Pelecanus occidentalis	brown pelican	Bird	CCB
Peromyscus polionotus ammobates	Alabama beach mouse*	Mammals	MB
Peromyscus polionotus leucocephalus	Santa Rosa beach mouse*	Mammals	PB
Peromyscus polionotus trissyllepsis	Perdido Key beach mouse	Mammals	PB, MB
Phyllanthus leibmannianus ssp. platylepis	pinewood dainties	Plant	SSB
Plestiodon egregius insularis	Cedar Key mole skink	Reptile	SBB

Scientific Name	Common Name	Group	Study Area
Plestiodon egregius pop. 1	Egmont Key mole skink*	Reptile	TB
Potamogeton floridanus	Florida pondweed	Plant	PB
Procambarus leitheuseri	coastal lowland cave crayfish*	Crustacean	SBB
Pseudemys alabamensis	Alabama red-bellied turtle	Reptile	MB
Pseudobranchus striatus lustricolus	Gulf hammock dwarf siren	Amphibian	SBB
Rhododon angulatus	Tharp's rhododon	Plant	CCB
Rhynchospora crinipes	hairy-peduncled beakrush*	Plant	MB
Ruellia noctiflora	night-flowering wild-petunia	Plant	MB
Rynchops niger	black skimmer*	Bird	TB
Salicornia bigelovii/ salicornia virginiana-batis maritima series	glasswort-saltwort series	Community	CCB
salt flat	salt flat	Habitat	MB
Sarracenia leucophylla	white-top pitcherplant	Plant	PB, MB
Scrub	n/a	Community	SBB
Spigelia loganioides	pinkroot*	Plant	SBB
Sternula antillarum	least tern	Bird	TB
Thurovia triflora	three flower broomweed*	Plant	CCB
Troglocambarus maclanei	North Florida spider cave crayfish	Crustacean	SBB
Uniola paniculata-panicum amarum series	sea oats-bitter panicum series	Community	CCB
Xyris stricta var. obscura	Kral's yellow-eyed grass	Plant	PB

*Species assessed with the NatureServe Climate Change Vulnerability Index (CCVI)

Table 12. Climate Change Vulnerability Index Definitions of Index Scores

Climate Change Vulnerability Index Definitions of Index Scores	
Extremely Vulnerable:	Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.
Highly Vulnerable:	Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.
Moderately Vulnerable:	Abundance and/or range extent within geographical area assessed likely to decrease by 2050.
Not Vulnerable/Presumed Stable:	Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.
Not Vulnerable/Increase Likely:	Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.
Insufficient Evidence:	Available information about a species' vulnerability is inadequate to calculate an Index score.

Stakeholder Workshops

We convened workshops at each site to engage local stakeholders in the development of SLR adaptation strategies. The one-day workshops brought together natural areas land managers, natural resource managers, planners, water resource managers, non-governmental organization staff, elected officials, community leaders, research scientists and cultural resource professionals to discuss SLR impacts and actions that could be taken in the near term for their local communities to adapt to SLR. One workshop was held at each of the project sites on the dates below.

Study Area	Location	Workshop Date
Pensacola Bay	Pensacola, FL	June 16, 2011
Southern Big Bend	Crystal River, FL	October 13, 2011
Tampa Bay	St. Pete Beach, FL	March 14, 2012
Mobile Bay	Mobile, AL	June 13, 2012
Corpus Christi Bay	Corpus Christi, TX	January 29, 2013

For each workshop, we invited local participants from a variety of governmental and non-governmental institutions that had been suggested by local TNC staff, partners and local land managers. Invitations were distributed and invitees could also suggest colleagues.

Registered invitees were emailed an agenda and a four question pre-workshop survey and asked to submit the survey prior to the workshop. The pre-workshop survey was also available at the beginning of the workshop for any who had not yet completed it. This pre-workshop survey (Appendix 4) provided a basis for comparing participant views on SLR effects and adaptations prior to the workshop to their thoughts afterwards.

The workshop agenda was the same for each meeting as follows:

Welcome and Introductions
Overview of Workshop
Presentations:

- Overview of TNC's SLR modeling and results
- Species vulnerability assessment
- Vulnerable infrastructure, cultural and historic sites

Break
Presentation:

- Concept of adaptation strategies

Participant Roundtable:

- Development of Adaptation Strategies

Next Steps
Post-workshop survey

Workshop Description

The workshop was divided into two sessions. The morning session was devoted to a presentation of results of the modeling and likely impacts to habitats, species, and infrastructure. This material provided the basis for the local adaptation strategies developed by the participants in the afternoon discussion session. Following a brief overview of the project and workshop, a synthesis of the results from the SLAMM simulations and habitat modeling was presented. Although SLAMM was applied to 3 SLR scenarios, the presentation focused on the results of the 1m SLR by year 2100 scenario to keep the presentation succinct. Figures from all 3 SLR scenarios were posted on the walls for viewing by the participants. Presentation of the SLAMM results was followed by a presentation on the Vulnerable Species Analysis. This analysis was conducted by the Florida Natural Areas Inventory and was presented by an FNAI staff.

The infrastructure and cultural resources presentation provided an overview of the study area's landscape and development patterns and presented maps of existing infrastructure, and historical and cultural resources. Site-specific elements within the study area with the potential to be affected by SLR were presented to the audience. Low-lying areas particularly vulnerable to SLR were highlighted. Presentations and maps varied from site to site because they were tailored to the characteristics of the study area. The basic topics covered were essentially the same: urban areas and transportation infrastructure; potential pollution sources; water and site-specific key infrastructure; and cultural resources.

The data used for the infrastructure and cultural resources presentations were downloaded from publically available websites. State agencies were a good source of infrastructure data, however, the availability of data varied from state to state. The Geographic Names Information System (GNIS) is the national database of names and locations of physical and cultural features. The Census Bureau website was used to obtain demographic data and maps. The National Register of Historic Places was used to identify significant cultural resources in all the study areas. In addition, the State of Florida has extensive archaeological and historical data maintained by the Division of Historical Resources. The division maintains an active Master Site File of spatially explicit (GIS data) archeological and historical data. We presented the Master Site File data for each Florida study area at the workshops, but the data use agreement with the division precludes publishing it in this document. Texas has a similar archeological database at the Texas Archaeological Research Laboratory (www.utexas.edu/research/tarl/default.php), but it was not accessed for the workshop as it is only available to archeology researchers. For the Corpus Christi Bay, Texas and Mobile Bay, Alabama study areas, sites on the National Register of Historic Places or other publicly available data were shown at the workshops. Appendix 5 contains maps from all of the infrastructure and cultural resources presentations as well as the sources of the data.

Adaptation Discussions

Following a mid-day break, we presented the concept of adaptation strategies and provided participants with a framework for adaptation strategies and examples of the different types:

- Land use planning and building regulation
- Emergency/Disaster response planning
- Tax and Market-based approaches
- Conservation of species
- Land protection
- Conservation of natural areas
- Conservation of marine life
- Water supply and delivery; water resources
- Transportation and infrastructure
- Beaches, beach and shoreline management
- Research needs
- Miscellaneous/General Comments
- Education, outreach and communication

The goal of the workshop was to elicit from the participants SLR adaptation strategies relevant to the locality. To achieve this, the facilitators called upon each attendee in turn to suggest an adaptation strategy. The main idea of the participant speaking was recorded by the facilitators on a flip chart. This round table process was repeated until all participants felt they had communicated their ideas. Discussion of ideas and questions to the group occurred throughout the process and main points were recorded.

A post-workshop survey was handed out during the afternoon. This three question survey (Appendix 4) provided a way for participants to share how their ideas about SLR adaptation had been changed or informed by the workshop.

Results

In this section, we present the results of the SLAMM runs for the 3 SLR scenarios, the results of the vulnerable species analyses and the results of the workshops. Results are organized by project site. Only a selection of the SLAMM graphical results is provided in the body of this report. Results of additional model runs are presented in Appendix 7 and full results for all scenarios are available upon request.

Sea Level Rise Modeling Results

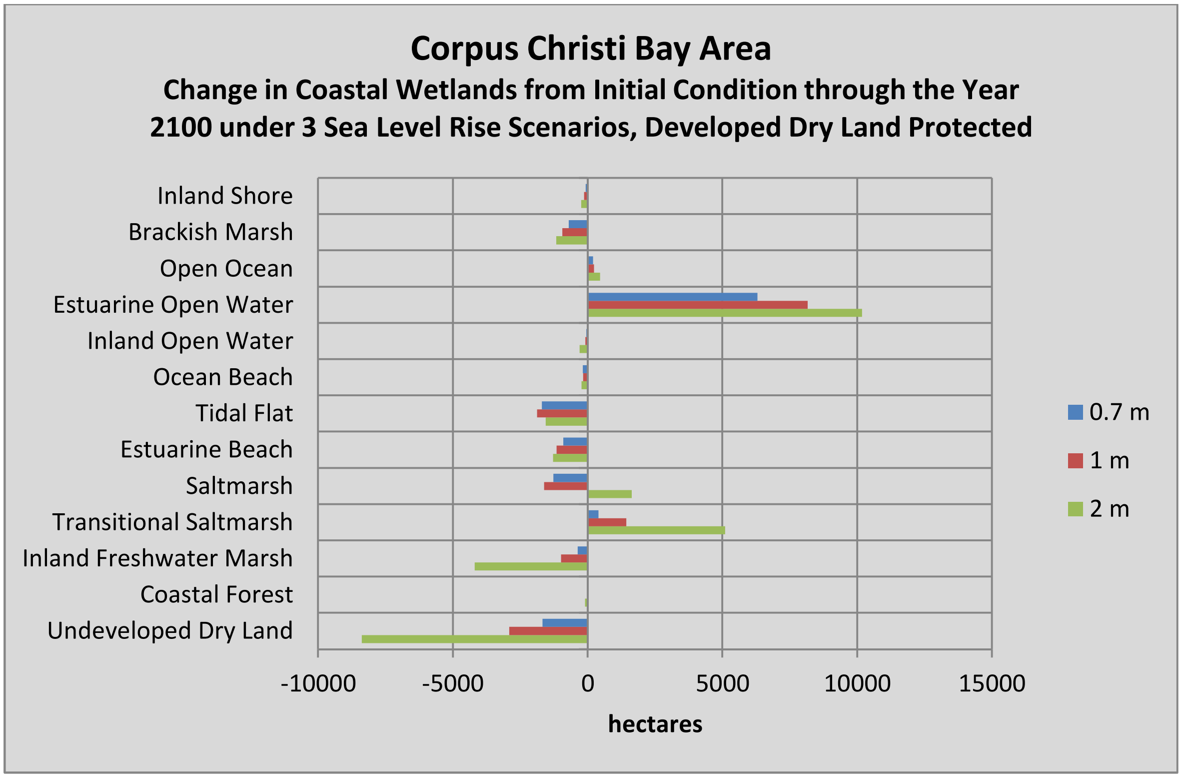
Corpus Christi Bay

The composition of coastal wetlands in the Corpus Christi Bay system will change substantially (defined as >1000 ha and > 10% change) even under the most conservative SLAMM simulation (0.7 m of SLR) by the year 2100 (developed dry land protected. Under all 3 SLR scenarios, substantial change was predicted for saltmarsh and tidal flat (Table 13 and Figure 30). Under the 1 m SLR scenario, substantial change was also predicted for transitional saltmarsh and estuarine beach and under the 2 m SLR scenario, inland freshwater marsh and brackish marsh also reached our defined threshold for substantial change. Saltmarsh is lost under the 0.7 m and 1 m scenarios, but is predicted to increase in extent under the 2 m scenario. The change map for the 1 m SLR scenario (Figure 30), illustrates that predicted wetland changes primarily take place in the Nueces River delta and on the barrier island (Mustang Island).

Under the SLAMM scenarios with developed dry land allowed to transition, SLAMM simulates losses of developed dry land at 2%, 3%, and 8% with the 0.7 m, 1 m and 2 m scenarios, respectively (Table 7-1, Appendix 7). The direction and magnitude of change simulated for coastal wetlands are similar to the developed dry land protected scenarios with the exception that simulated gains of transitional saltmarsh are larger, simulated losses inland freshwater marsh are smaller and the simulated changes in saltmarsh vary in magnitude depending on the SLR scenario.

Table 13. Corpus Christi Bay area SLAMM results under 3 SLR Scenarios through the Year 2100, developed dry land protected from change.

Corpus Christi Bay Area SLAMM Results: Developed Dry Land Protected from Changing										
Scenario		**0.7 m protected**			**1 meter protected**			**2 meter protected**		
Units are in hectares.	Initial Condition (IC)	2100	2100-IC	% Change	2100	2100 - IC	% Change	2100	2100 - IC	% Change
Developed Dry Land	27367	27367	0	0.0%	27366	0	0.0%	27366	0	0.0%
Undeveloped Dry Land	141861	140195	-1666	-1.2%	138954	-2907	-2.0%	133489	-8372	-5.9%
Coastal Forest	1464	1459	-4	-0.3%	1457	-6	-0.4%	1370	-94	-6.4%
Inland Freshwater Marsh	8042	7673	-369	-4.6%	7055	-987	-12.3%	3858	-4184	-52.0%
Tidal Freshwater Marsh	3	2	-1	-36.3%	1	-2	-80.6%	0	-2	-84.0%
Transitional Saltmarsh	596	1001	405	67.9%	2032	1436	240.9%	5702	5106	856.4%
Saltmarsh	3242	1969	-1274	-39.3%	1632	-1611	-49.7%	4879	1637	50.5%
Estuarine Beach	1382	480	-902	-65.3%	238	-1144	-82.8%	100	-1283	-92.8%
Tidal Flat	3210	1510	-1700	-53.0%	1336	-1874	-58.4%	1657	-1553	-48.4%
Ocean Beach	425	246	-179	-42.1%	256	-169	-39.8%	206	-219	-51.5%
Inland Open Water	2915	2873	-42	-1.4%	2835	-80	-2.8%	2623	-292	-10.0%
Riverine Tidal Open Water	10	10	0	-3.8%	9	-1	-7.7%	7	-3	-27.3%
Estuarine Open Water	74079	80376	6297	8.5%	82248	8169	11.0%	84268	10189	13.8%
Open Ocean	34886	35095	209	0.6%	35123	237	0.7%	35351	465	1.3%
Brackish Marsh	1193	493	-700	-58.7%	258	-935	-78.3%	31	-1162	-97.4%
Inland Shore	909	836	-73	-8.0%	783	-126	-13.8%	679	-230	-25.3%
Tidal Swamp	11	11	0	-2.0%	11	-1	-5.9%	8	-3	-29.3%



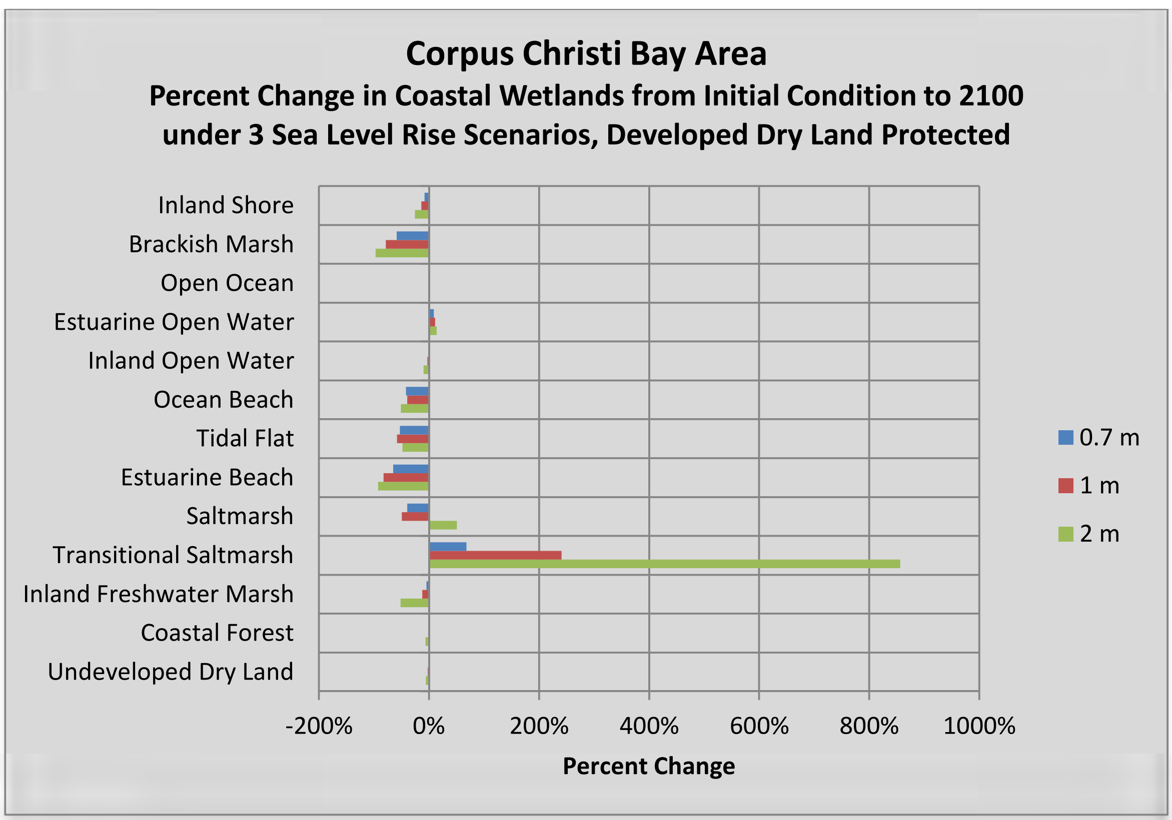


Figure 29. Corpus Christi Bay Study Area SLAMM results under 3 SLR scenarios through the year 2100, developed dry land protected.

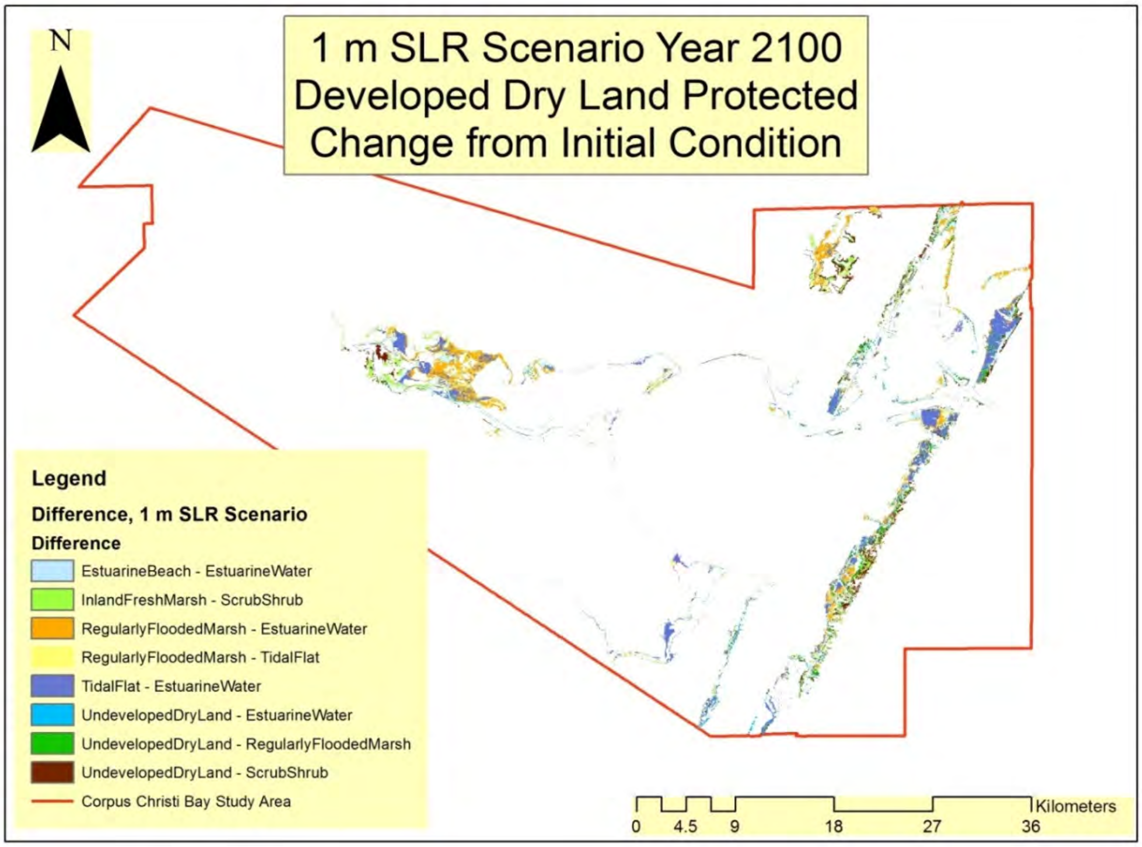


Figure 30. Corpus Christi Bay Area SLAMM Results – change in coastal wetland systems under a 1 m SLR scenario.

Uncertainty Analysis

The uncertainty analysis for the Corpus Christi Study Area was conducted on only a portion of the study area (254,396 ha versus 543,052 ha) due to the extremely long runtime of the analysis on the entire site. The uncertainty results were characterized by subtracting the minimum output from the maximum output values (Table 14) We created a scale to simplify characterization of the uncertainty results as follows:

none	< 1
lowest	1 - 100
modest	100 - 1000
moderate	1000 - 10000
highest	>10,000

The uncertainty analyses run on the three selected input parameters, inland freshwater marsh accretion, salt elevation and saltmarsh accretion rate found only small to modest changes in the coastal wetland 2100 results with changes to marsh accretion rates. However, small to moderate variations in coastal wetland and dry land types resulted when salt elevation was varied. The largest of these changes was seen with undeveloped dry land. The histogram of change (Figure 31) illustrates that when salt elevation was varied, undeveloped dry land results ranged from a low of 94,374 ha to a high of 95,643 ha, a difference of 1,269 ha or 1%. Based on this analysis, uncertainty in our results for the above identified coastal wetland systems at this site is low.

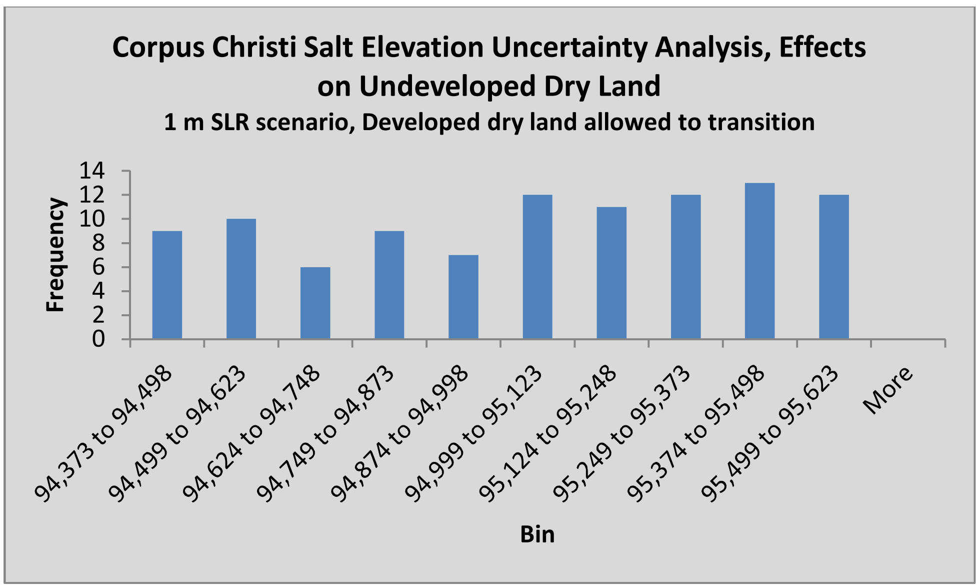


Figure 31. Corpus Christi Bay Study Area uncertainty analysis on salt elevation and its effects on undeveloped dry land under the 1 m SLR scenario.

Table 14. Corpus Christi Bay Study Area uncertainty analysis for 3 input parameters, inland freshwater marsh accretion rate, salt elevation and saltmarsh accretion rate.

Distribution Type	Uniform	Uniform	Uniform-75runs
Distribution Parameter	Inland Fresh Marsh Accr	Salt Elevation	Reg. Fld. Marsh Accr
Variable Name	Max-Min	Max-Min	Max-Min
Developed Dry Land	8.5	260.7	1.1
Undeveloped Dry Land	44.1	1242.1	0.5
Coastal Forest	0.1	6.1	0.0
Cypress Swamp	0.0	0.0	0.0
Inland Freshwater Marsh	530.9	702.1	0.0
Tidal Freshwater Marsh	0.0	0.2	0.0
Transitional Salt Marsh	394.5	939.6	1.5
Saltmarsh	137.7	613.7	170.7
Mangrove	0.0	0.0	0.0
Estuarine Beach	0.0	5.0	0.0
Tidal Flat	43.7	304.4	362.2
Ocean Beach	0.2	33.6	0.0
Ocean Flat	0.0	0.0	0.0
Rocky Intertidal	0.0	0.0	0.0
Inland Open Water	6.5	32.4	0.0
Riverine Tidal Open Water	0.0	1.6	0.0
Estuarine Open Water	13.8	345.0	533.5
Tidal Creek	0.0	0.0	0.0
Open Ocean	0.4	1.4	0.0
Brackish Marsh	0.0	0.4	0.0
Inland Shore	0.1	5.3	0.0
Tidal Swamp	0.0	0.4	0.0

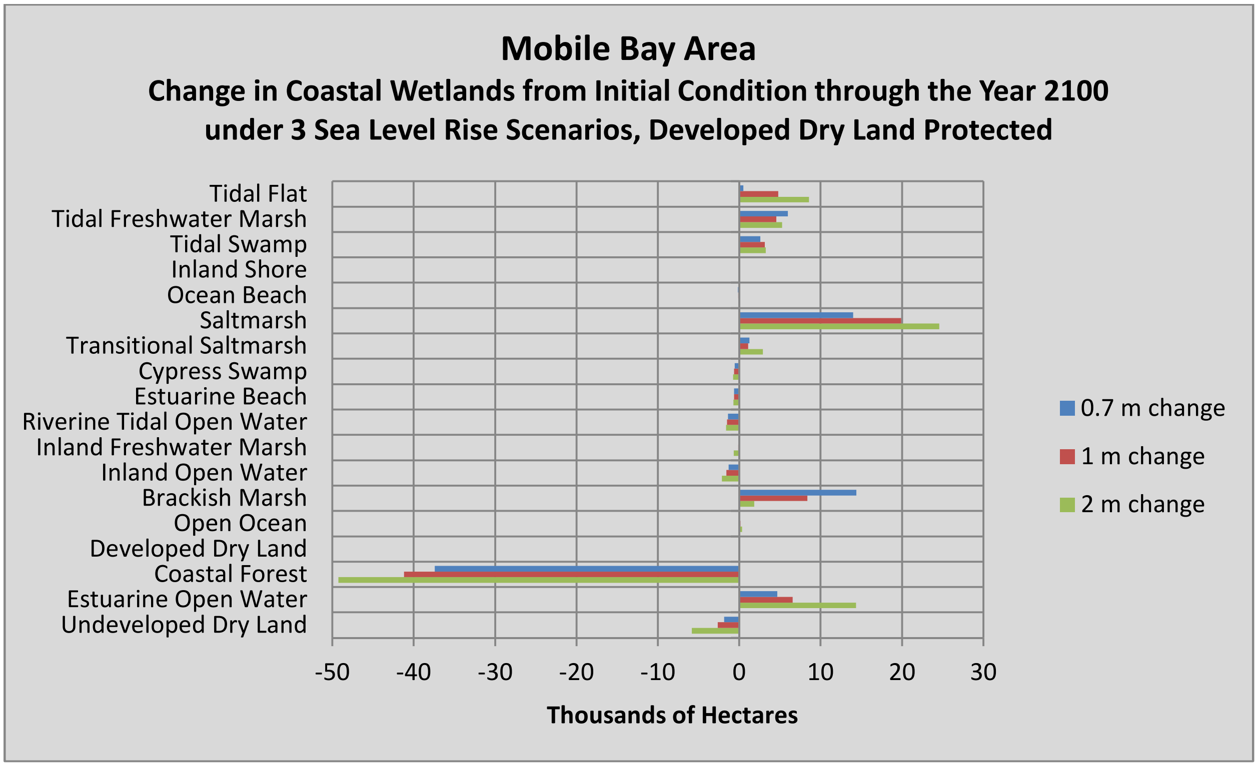
Mobile Bay

Even under the most modest SLR scenario modeled, coastal wetlands in the Mobile Bay study area change substantially (defined here as >1000 ha and > 10% change). The most dramatic change predicted is the loss of coastal forest, ranging from -37,436 ha to -49,250 ha (-45% to -59%) depending on the scenario (Table 15, Figure 32). Coastal forest is the only coastal wetland system predicted to experience a net loss under the three SLR scenarios examined as it transitions to a variety of other marsh types (Figure 33). All marsh types were predicted to experience a substantial gain under all three SLR scenarios. In addition, a substantial increase in tidal flat occurs under the higher rates of SLR modeled (1 m and 2 m).

Under the SLAMM scenarios with developed dry land allowed to transition, SLAMM simulates losses of developed dry land at 1%, 2%, and 6% with the 0.7 m, 1 m and 2 m scenarios, respectively. The direction and magnitude of change simulated for coastal wetlands are similar to the developed dry land protected scenarios with the exception that simulated gains of transitional saltmarsh, saltmarsh and tidal flat are larger and simulated losses estuarine beach and ocean beach are smaller Table 7-2 in Appendix 7).

Table 15. Mobile Bay Area SLAMM Results under 3 SLR Scenarios through the year 2100, Developed Dry Land Protected from Changing.

Mobile Bay Area SLAMM Results: Developed Dry Land Protected from Changing										
Scenario		0.7 m			1 meter			2 meter		
SLAMM Category	Initial Condition (ha)	2100	2100-IC	Percent Change	2100	2100-IC	Percent Change	2100	2100-IC	Percent Change
Undeveloped Dry Land	235804	233935	-1868	-0.8%	233146	-2658	-1.1%	229975	-5828	-2.5%
Estuarine Open Water	121109	125798	4688	3.9%	127663	6554	5.4%	135458	14348	11.8%
Coastal Forest	83845	46409	-37436	-44.6%	42658	-41187	-49.1%	34595	-49250	-58.7%
Developed Dry Land	51707	51691	-16	0.0%	51689	-18	0.0%	51690	-17	0.0%
Open Ocean	13423	13532	109	0.8%	13583	160	1.2%	13747	324	2.4%
Brackish Marsh	7970	22354	14385	180.5%	16323	8353	104.8%	9803	1834	23.0%
Inland Open Water	6282	4962	-1320	-21.0%	4695	-1587	-25.3%	4145	-2137	-34.0%
Inland Freshwater Marsh	3087	3017	-70	-2.3%	2946	-141	-4.6%	2400	-687	-22.3%
Riverine Tidal Open Water	2088	704	-1383	-66.3%	577	-1511	-72.4%	476	-1612	-77.2%
Estuarine Beach	927	292	-635	-68.5%	273	-654	-70.5%	221	-706	-76.2%
Cypress Swamp	814	245	-569	-69.9%	193	-621	-76.3%	49	-764	-93.9%
Transitional Salt Marsh	717	1964	1247	174.1%	1795	1078	150.5%	3599	2883	402.3%
Saltmarsh	570	14550	13979	2450.7%	20475	19905	3489.5%	25150	24579	4309.0%
Ocean Beach	298	145	-153	-51.3%	162	-136	-45.7%	235	-63	-21.0%
Inland Shore	253	246	-8	-3.1%	244	-9	-3.7%	237	-16	-6.4%
Tidal Swamp	250	2819	2569	1029.1%	3380	3130	1253.8%	3521	3271	1310.3%
Tidal Freshwater Marsh	182	6155	5973	3285.6%	4743	4562	2509.1%	5441	5260	2893.0%
Tidal Flat	24	531	507	2071.1%	4804	4780	19524.3%	8606	8582	35055.9%



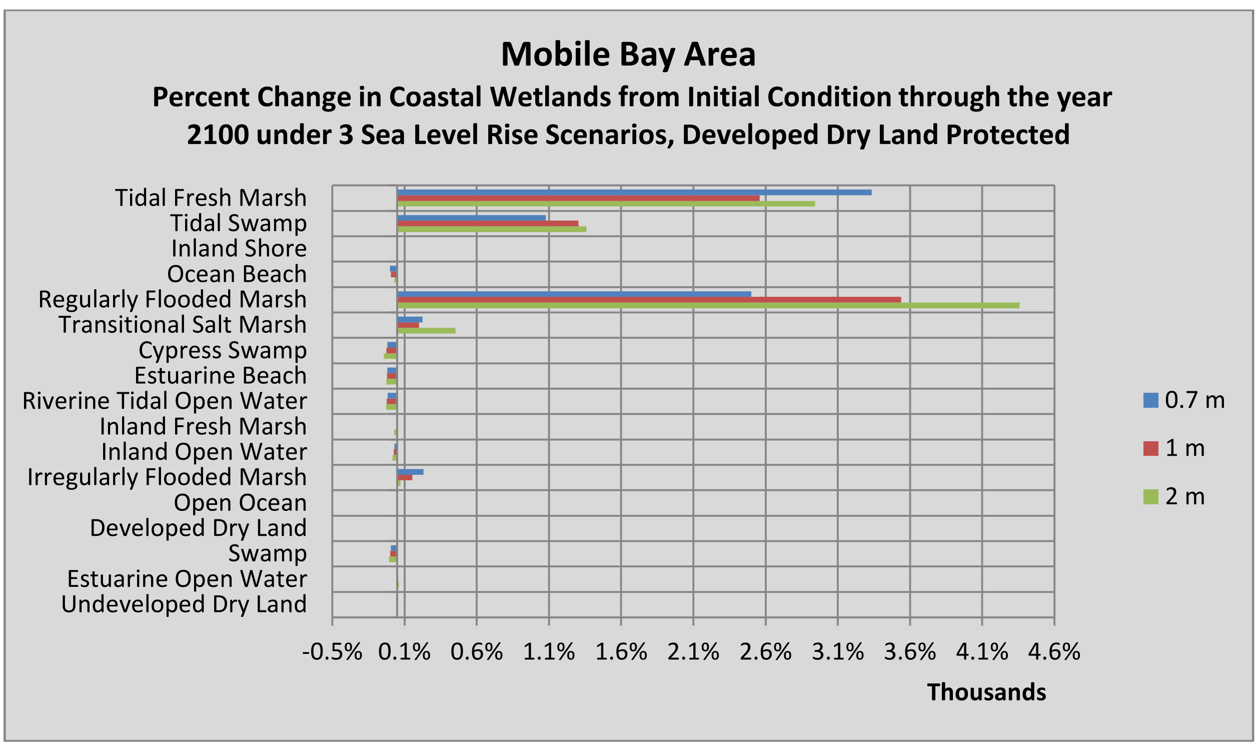


Figure 32. Mobile Bay area SLAMM results under 3 SLR scenarios through the year 2100, developed dry land protected.

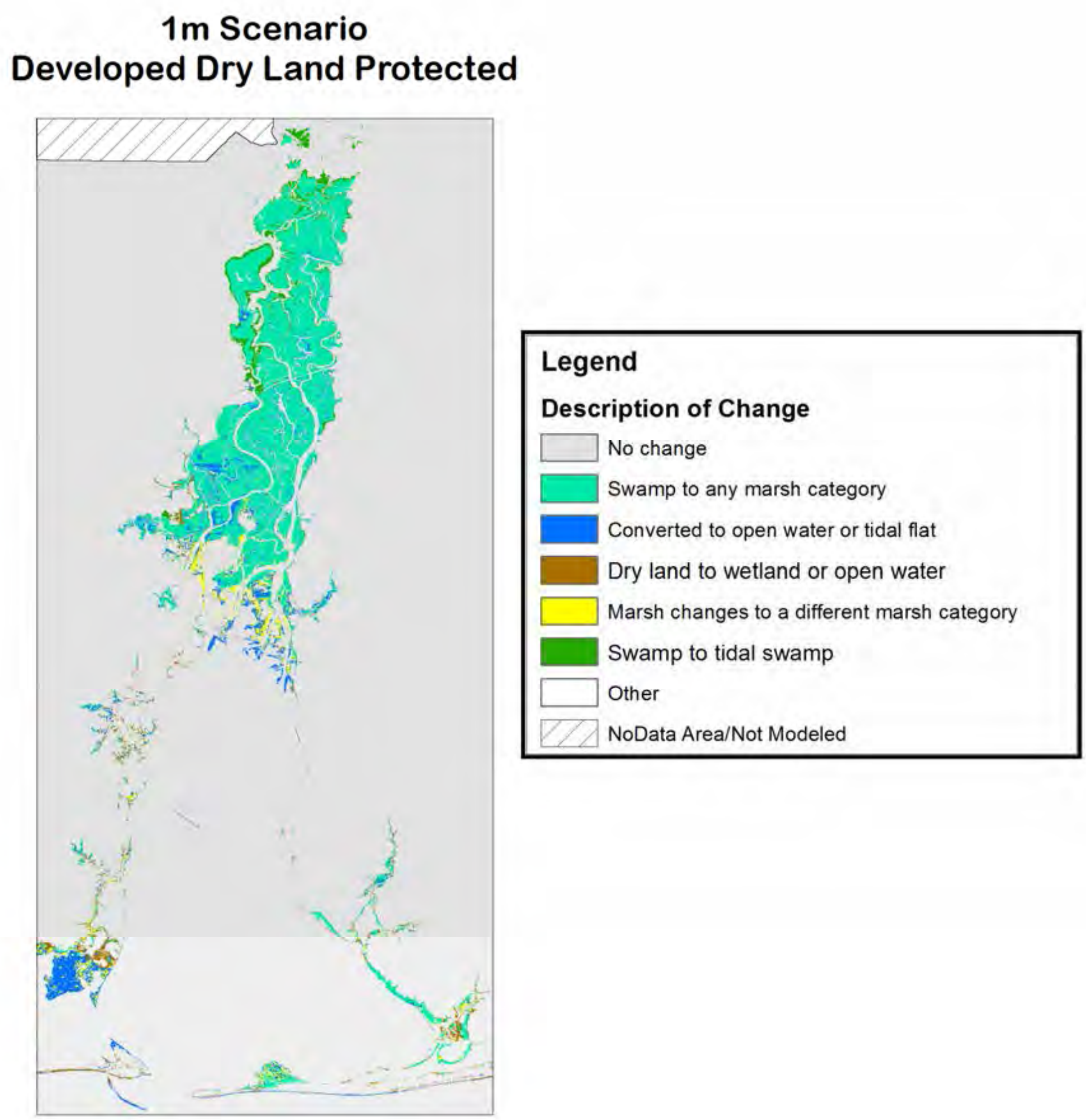


Figure 33. Change map for Mobile Bay study area under the 1 m SLR scenario (developed dry land protected) from initial condition to the year 2100.

Uncertainty Analysis Results

Uncertainty results were characterized by subtracting the minimum output from the maximum output values (Table 16). We created a scale to simplify characterization of the uncertainty results as follows:

None	< 1
Lowest	1 - 100
Modest	100 - 1000
Moderate	1000 - 10000
Highest	>10,000

The uncertainty analyses run on the two selected input parameters, salt elevation and coastal forest erosion rate, revealed only a few small changes in coastal wetland 2100 results with changes to the coastal forest erosion rate as illustrated in Table 16. However, small to large variations in coastal wetland and dry land types resulted when salt elevation was varied. The largest changes were seen with saltmarsh and tidal freshwater marsh. The histogram of change for tidal freshwater marsh (Figure 34) illustrates that when salt elevation was varied, tidal freshwater marsh varied from a low of 3,990 ha to a high of 18,101 ha with 77% of the results in the 3,990 to 8,224 ha range (SLAMM predicted 4,743 ha). The histogram of change for saltmarsh (Figure 35) illustrates that when salt elevation was varied, saltmarsh results varied from a low of 5,848 ha to a high of 25,448 ha with 48% of the returns on values in the 24,449 to 25,488 ha range (SLAMM predicted 20,896 ha). Based on these results, uncertainty in our results for saltmarsh and tidal freshwater marsh is high. These results indicate that tidal freshwater marsh and saltmarsh are sensitive to salt elevation. Having accurate salt elevation data for the site is critical for improving projections of how SLR will affect these coastal marsh systems in the study area.

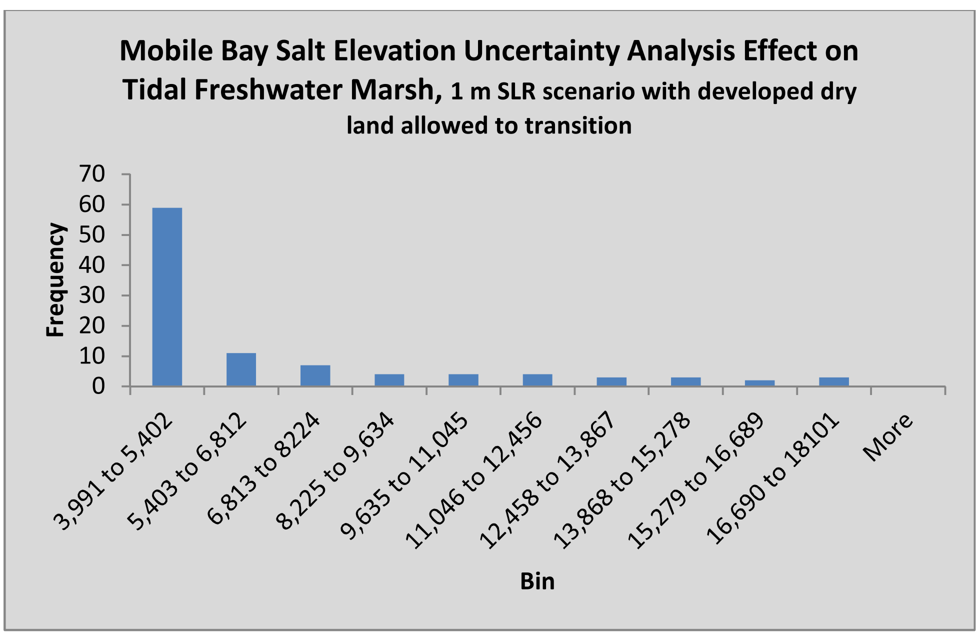


Figure 34. Mobile Bay Study Area uncertainty analysis on salt elevation and its effect on tidal freshwater marsh.

Table 16. Mobile Bay Study Area uncertainty analysis results for two input parameters, salt elevation and coastal forest erosion.

Distribution Type	Uniform	Uniform
Distribution Parameter	Salt Elevation	Coastal forest
Variable Name	Max-Min	Max-Min
Developed Dry Land	983.2	0.0
Undeveloped Dry Land	1577.6	0.0
Coastal Forest	6221.7	0.4
Cypress Swamp	92.4	0.0
Inland Freshwater Marsh	255.4	0.0
Tidal Freshwater Marsh	14106.9	0.0
Transitional Salt Marsh	1674.1	0.1
Saltmarsh	19593.9	1.4
Mangrove	0.0	0.0
Estuarine Beach	162.7	0.0
Tidal Flat	692.5	0.7
Ocean Beach	167.5	0.0
Ocean Flat	0.0	0.0
Rocky Intertidal	0.0	0.0
Inland Open Water	947.5	0.0
Riverine Tidal Open Water	472.5	0.0
Estuarine Open Water	1737.4	1.4
Tidal Creek	0.0	0.0
Open Ocean	2.8	0.0
Brackish Marsh	9116.2	0.0
Inland Shore	0.0	0.0
Tidal Swamp	1139.0	0.0

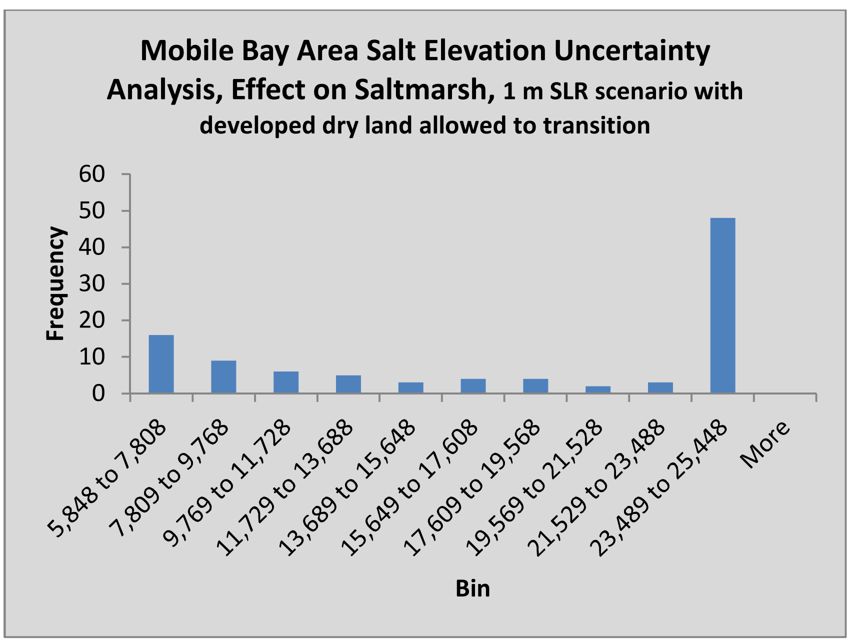


Figure 35. Mobile Bay Study Area uncertainty analysis on salt elevation and its effect on saltmarsh.

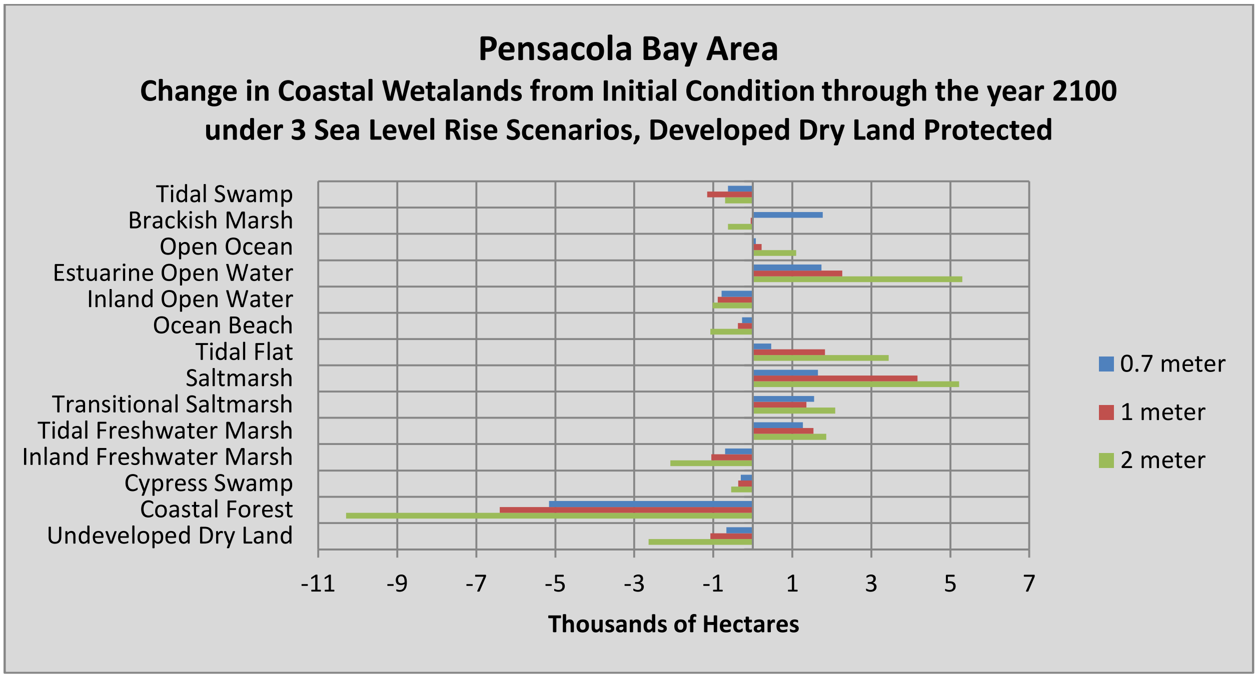
Pensacola Bay

The composition of coastal wetlands in the Pensacola Bay system (including the Florida portion of Perdido Bay) are predicted to change substantially (defined here as >1000 ha and > 10% change) under all 3 of the SLR scenarios modeled by the year 2100 (model assumes that developed dry land will be protected). Under these scenarios, a substantial loss of coastal forest, and a substantial gain of saltmarsh, transitional saltmarsh and tidal freshwater marsh were predicted (Table 17). Under the 0.7 m scenario, substantial change was also predicted for brackish marsh and tidal swamp. For the 1 m SLR scenario, substantial change was also predicted for inland freshwater marsh and tidal flat. The same coastal wetland systems change under the 2 m scenario as under the 1 m scenario, but at a greater magnitude. Under the 1 m SLR scenario, most of the changes are predicted to take place in river deltas and lower flood plains (Figure 37).

Under the SLAMM scenarios with developed dry land allowed to transition, SLAMM simulates losses of developed dry land at 1%, 2%, and 5% with the 0.7 m, 1 m and 2 m scenarios, respectively. The direction and magnitude of change simulated for coastal wetlands are similar to the developed dry land protected scenarios with the exception that simulated gains of transitional saltmarsh, saltmarsh and tidal flat are larger and simulated losses tidal freshwater marsh and ocean beach are smaller (Table 7-3 in Appendix 7).

Table 17. Pensacola Bay Area SLAMM Results under 3 SLR scenarios through the year 2100, developed dry land protected from changing.

Pensacola Bay Area SLAMM Results: Developed Dry Land Protected from Changing										
		0.7 meter			1 meter			2 meter		
	Initial Condition (IC)	2100	2100-IC	Percent Change	2100	2100-IC	Percent Change	2100	2100-IC	Percent Change
Developed Dry Land	47506	47504	-1	0.0%	47500	-6	0.0%	47469	-36	-0.1%
Undeveloped Dry Land	101097	100430	-668	-0.7%	100022	-1075	-1.1%	98457	-2640	-2.6%
Coastal Forest	35695	30535	-5160	-14.5%	29286	-6408	-18.0%	25394	-10301	-28.9%
Cypress Swamp	1311	1006	-305	-23.2%	941	-370	-28.2%	762	-548	-41.8%
Inland Freshwater Marsh	9733	9034	-699	-7.2%	8685	-1048	-10.8%	7647	-2086	-21.4%
Tidal Freshwater Marsh	46	1314	1268	2750.5%	1583	1536	3332.6%	1908	1862	4039.4%
Transitional Salt Marsh	31	1579	1548	4991.9%	1388	1357	4376.0%	2119	2088	6735.1%
Saltmarsh	120	1764	1644	1368.5%	4286	4166	3468.1%	5345	5225	4349.2%
Estuarine Beach	0	6	6		17	17		29	29	
Tidal Flat	90	555	465	514.2%	1917	1826	2021.0%	3529	3438	3805.0%
Ocean Beach	2241	1971	-270	-12.1%	1866	-376	-16.8%	1165	-1076	-48.0%
Inland Open Water	2772	1981	-791	-28.5%	1885	-888	-32.0%	1752	-1021	-36.8%
Estuarine Open Water	58162	59900	1738	3.0%	60425	2263	3.9%	63467	5305	9.1%
Open Ocean	41667	41746	78	0.2%	41888	221	0.5%	42762	1095	2.6%
Brackish Marsh	3121	4894	1773	56.8%	3063	-58	-1.9%	2490	-631	-20.2%
Inland Shore	4	4	0	-3.2%	3	-1	-23.4%	2	-3	-61.9%
Tidal Swamp	2637	2012	-625	-23.7%	1481	-1157	-43.9%	1936	-701	-26.6%



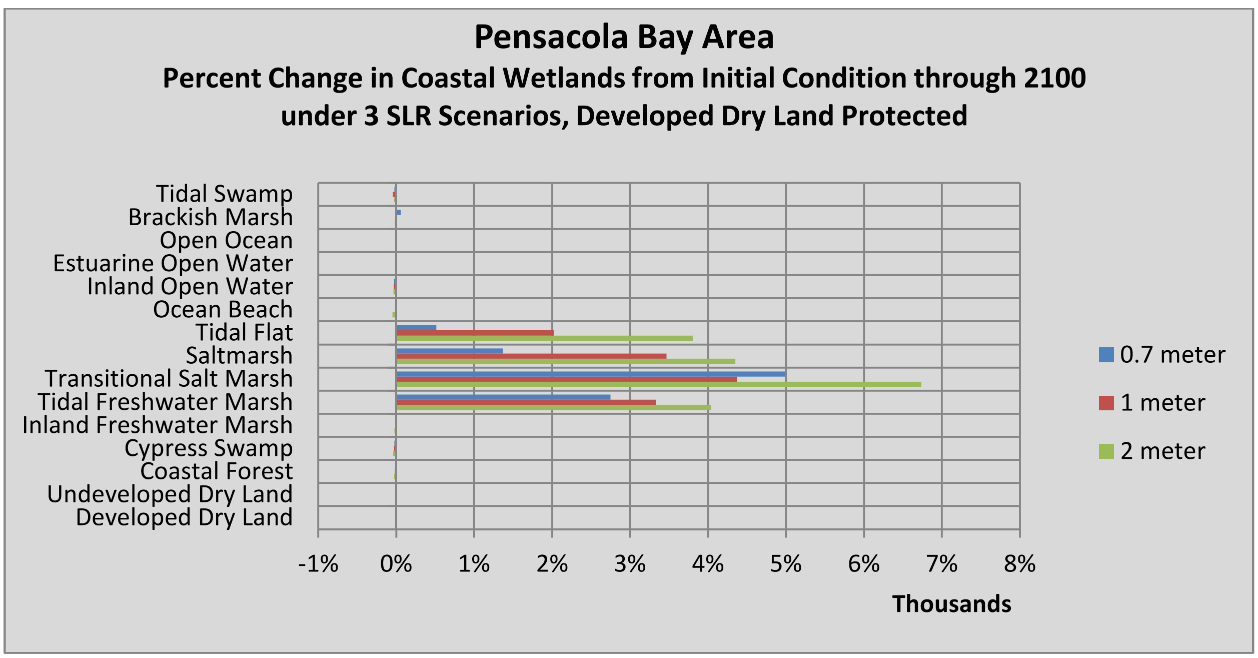


Figure 36. Pensacola Bay Area SLAMM results under a 1 m SLR scenario shown as loss/gain of coastal wetland systems. Units are in hectares.

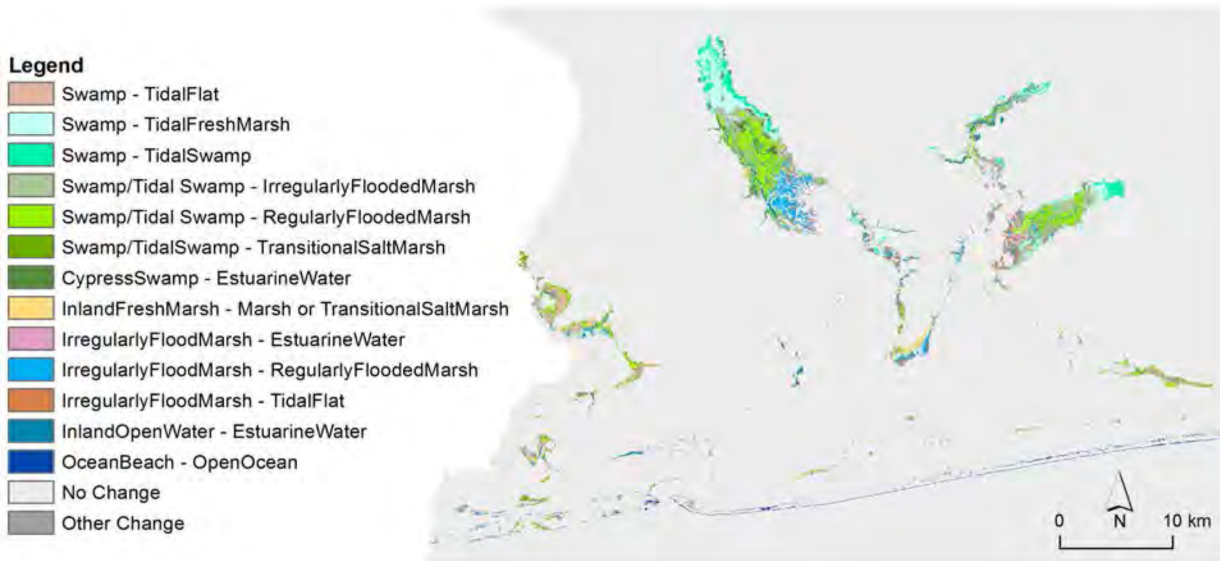


Figure 37. Pensacola Bay Area SLAMM Results – Change in wetland type under a 1 meter SLR scenario, developed dry land protected.

Uncertainty Analysis

The uncertainty analysis for the Pensacola Bay Study Area was conducted on only a portion of the study area (87,796 ha versus 351,679 ha) due to the extremely long runtime of the analysis on the entire site. Uncertainty results were characterized by subtracting the minimum output from the maximum output values (**Error! Reference source not found.**). We created a scale to simplify characterization of the uncertainty results as follows:

none	< 1
lowest	1 - 100
modest	100 - 1000
moderate	1000 - 10000
highest	>10,000

The uncertainty analyses run on the two selected input parameters, brackish marsh accretion and saltmarsh accretion, revealed only small to modest changes in the 2100 results for the various wetlands types with changes to the parameters as illustrated in **Error! Reference source not found.**. Based on these results, uncertainty in the results at this site is low.

Table 18. Pensacola Bay Study Area Uncertainty Analysis Results for two parameters, brackish marsh accretion and saltmarsh accretion.

Distribution Type	Uniform	Triangular
Distribution Parameter	**Irreg. Fld. Marsh Accr**	**Reg. Fld. Marsh Accr**
Variable Name	**Max-Min**	**Max-Min**
Developed Dry Land		0.1
Undeveloped Dry Land		0.0
Coastal Forest		0.0
Cypress Swamp		0.0
Inland Freshwater Marsh	1.2	0.0
Tidal Freshwater Marsh	0.0	0.0
Transitional Saltmarsh	103.2	0.7
Saltmarsh	144.5	297.1
Mangrove	0.0	0.0
Estuarine Beach	1.3	0.0
Tidal Flat	186.3	158.0
Ocean Beach	2.2	0.0
Brackish Marsh	333.7	0.0
Inland Shore	0.0	0.0
Tidal Swamp	0.0	0.0

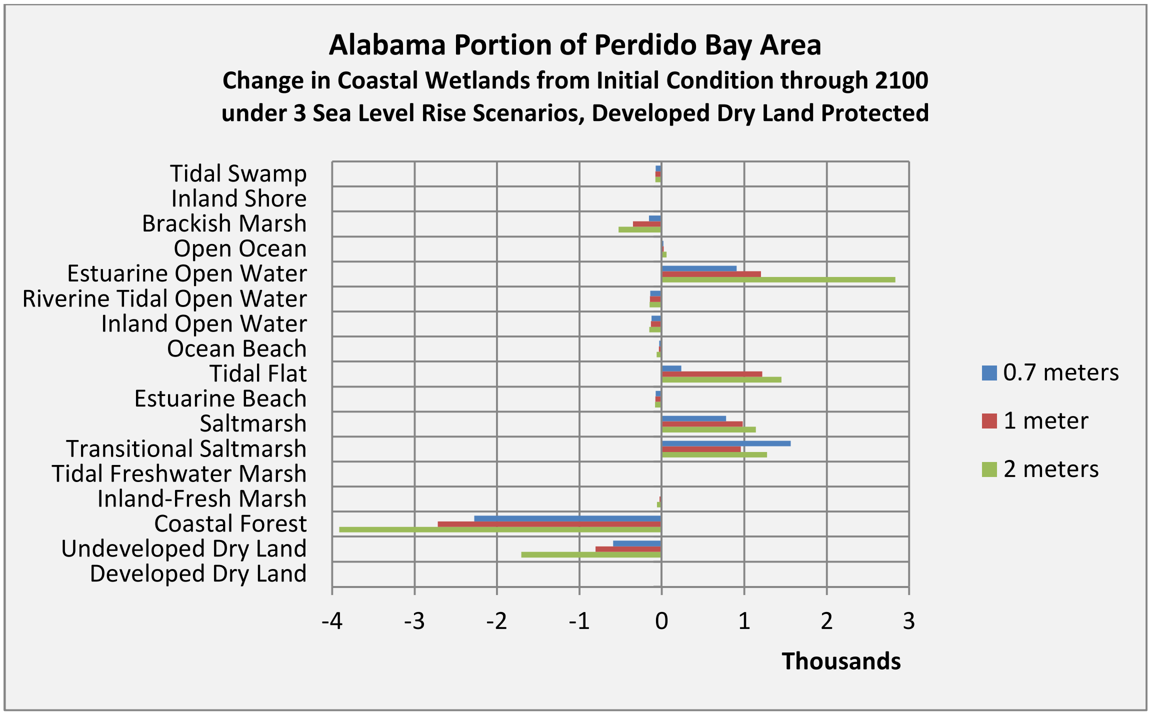
Alabama portion of Perdido Bay

The composition of coastal wetlands in the Alabama portion of the Perdido Bay system are predicted to change substantially (defined here as >1000 ha and > 10% change) under all 3 of the SLR scenarios modeled by the year 2100 (model assumes that developed dry land will be protected). Under all three scenarios, a substantial loss of coastal forest was predicted (-24% to -41%; Table 17; Figure 38. Under the 0.7 m and 2 m scenarios, substantial change was also predicted for transitional saltmarsh (+855% and +698%, respectively). Tidal flat changes substantially under the 1 m and 2 m scenario with gains of 1,217 ha and 1,448 ha, respectively. Only under the 2 m scenario was saltmarsh predicted to change substantially (+934%). Under the 1 m SLR scenario, most of the changes are predicted to take place in river deltas and lower flood plains (Figure 39).

Under the SLAMM scenarios with developed dry land allowed to transition, SLAMM simulates losses of developed dry land at 3%, 5%, and 12% with the 0.7 m, 1 m and 2 m scenarios, respectively. The direction and magnitude of change simulated for coastal wetlands are similar to the developed dry land protected scenarios with the exception that under the 1 m SLR scenario, transitional saltmarsh and saltmarsh meet our threshold for substantial change (+642% and + 865%, respectively; Table 7-4 in Appendix 7).

Table 19. Perdido Bay (Alabama portion only) SLAMM Results under 3 SLR Scenarios through the year 2100, Developed Dry Land Protected from Changing.

Alabama Portion of Perdido Bay Area SLAMM Results: Developed Dry Land Protected from Changing										
		0.7 meters			1 meter			2 meters		
	Initial Condition (IC)	2100	2100-IC	Percent Change	2100	2100-IC	Percent Change	2100	2100-IC	Percent Change
Developed Dry Land	6,883	6,883	0	0.0%	6,883	0	0.0%	6,883	-1	0.0%
Undeveloped Dry Land	36,207	35,614	-594	-1.6%	35,403	-805	-2.2%	34,502	-1,705	-4.7%
Coastal Forest	9,552	7,275	-2,277	-23.8%	6,834	-2,718	-28.5%	5,636	-3,916	-41.0%
Inland Freshwater Marsh	492	473	-19	-3.9%	463	-29	-5.8%	431	-61	-12.4%
Tidal Freshwater Marsh	3	0	-2	-99.1%	0	-3	-100.0%	0	-3	-100.0%
Transitional Salt Marsh	183	1,745	1,562	855.2%	1,139	957	523.6%	1,457	1,274	697.5%
Saltmarsh	122	901	779	637.1%	1,103	981	802.8%	1,264	1,141	933.8%
Estuarine Beach	87	11	-76	-87.9%	7	-80	-92.1%	2	-85	-98.0%
Tidal Flat	0	235	235	na	1,217	1,217	na	1,448	1,448	na
Ocean Beach	178	146	-33	-18.4%	142	-37	-20.5%	115	-64	-35.7%
Inland Open Water	582	456	-126	-21.6%	447	-134	-23.1%	427	-155	-26.6%
Riverine Tidal Open Water	159	17	-141	-89.1%	14	-144	-90.9%	10	-149	-93.9%
Estuarine Open Water	5,927	6,835	908	15.3%	7,128	1,201	20.3%	8,759	2,832	47.8%
Open Ocean	2,465	2,483	18	0.7%	2,487	22	0.9%	2,521	56	2.3%
Brackish Marsh	530	372	-158	-29.8%	180	-350	-66.1%	6	-525	-99.0%
Inland Shore	22	22	0	-1.4%	22	-1	-2.4%	14	-8	-37.9%
Tidal Swamp	84	8	-76	-90.4%	6	-78	-92.6%	3	-81	-96.4%



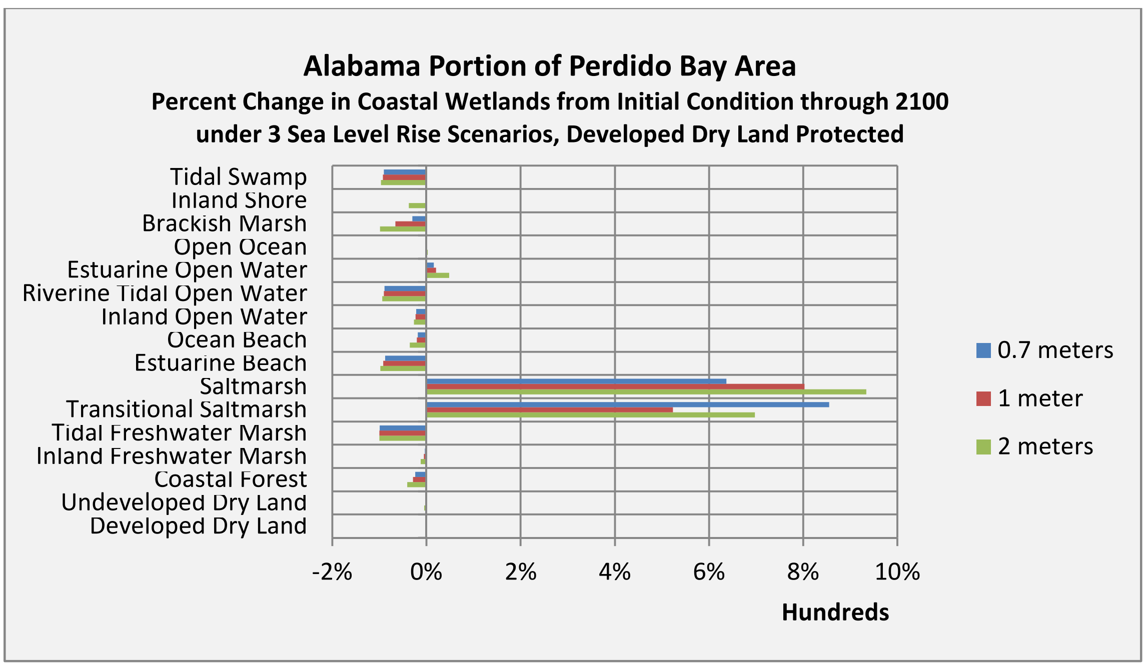


Figure 38. Perdido Bay Area (Alabama portion only) SLAMM results under a 1 m SLR scenario shown as loss/gain of coastal wetland systems. Units are in hectares

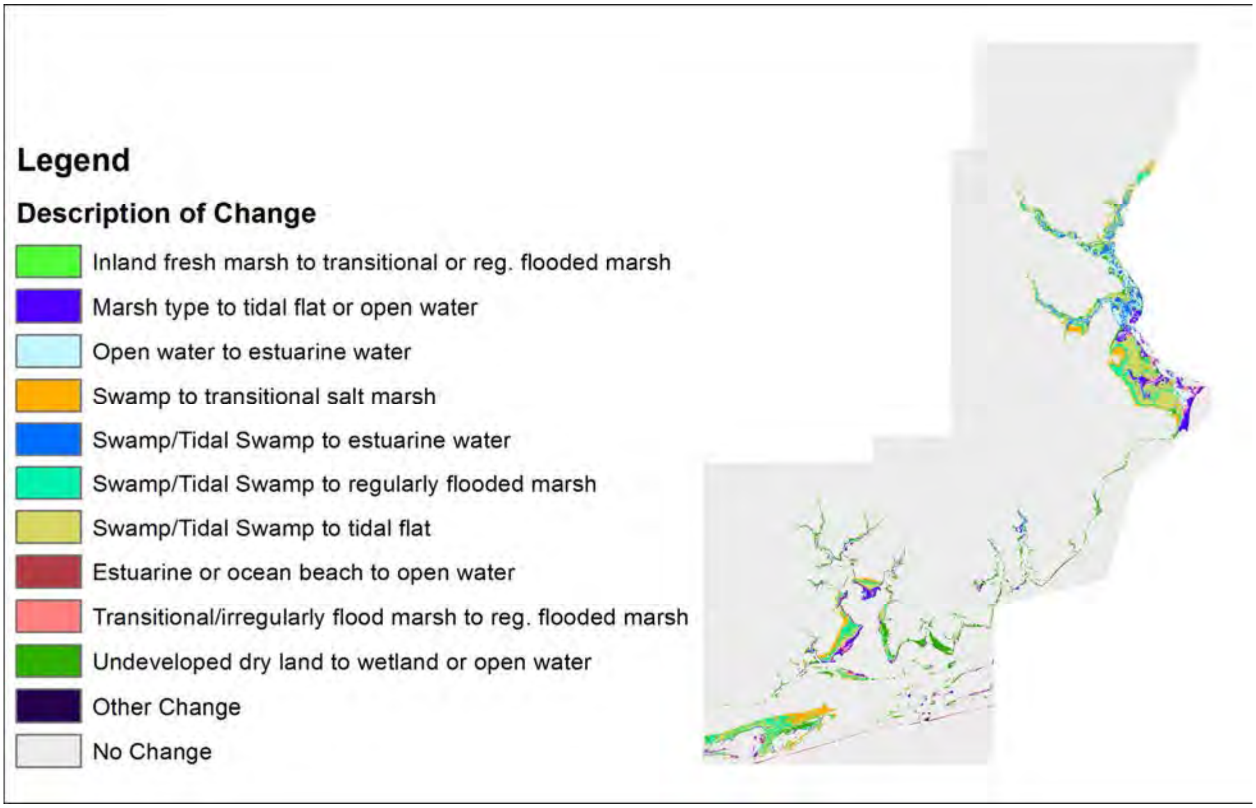


Figure 39. Alabama portion of Perdido Bay Area SLAMM Results - Change in wetland type under a 1 meter SLR scenario, developed dry land protected.

Southern Big Bend

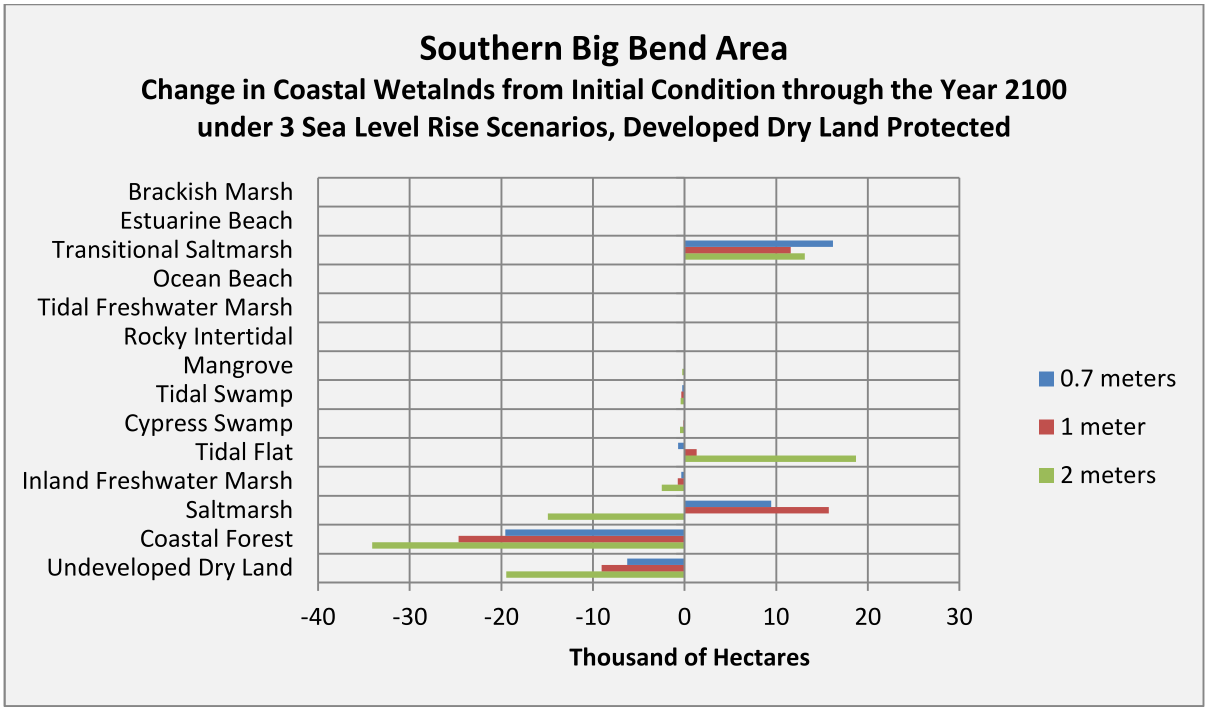
Under the SLR scenarios modeled (0.7 m, 1 m and 2 m) with developed dry land protected from changing, several coastal wetland systems in the Southern Big Bend area change substantially (defined here as >10% and >1000 ha) by the year 2100 (Table 20; Figure 40). The largest predicted loss of a coastal wetland system is coastal forest, which loses from 19,568 ha to 34,112 ha by the year 2100 depending on the scenario. Over the same time period, the largest gains predicted are with transitional saltmarsh (16,186 and 11,592 ha) and saltmarsh (9,458 and 15,736 ha) under the 0.7 m and 1 m SLR scenarios, respectively. Under the highest rate of SLR modeled (2 m), a substantial amount of saltmarsh is predicted to be lost (14,933 ha) and a substantial amount of tidal flat is predicted to be gained (18,710 ha). Substantial changes in undeveloped dry land are also predicted to occur under the 2 highest SLR scenarios modeled with 9,066 ha predicted to be lost under the 1 m scenario and 19,465 ha under the 2 m scenario.

Coastal forest primarily transitions to saltmarsh (17,022 ha), but also transitional saltmarsh and tidal flat along most of the coast of the Southern Big Bend study area under the SLR scenarios modeled as shown in Figure 40 (only 1 m scenario illustrated). The transition of undeveloped dry land to saltmarsh and transitional saltmarsh is also widely distributed in the study area, but most prevalent in the northern portion of the study area, primarily around the large bay system (Waccasassa Bay). The transition of saltmarsh to estuarine open water and tidal flat is widely dispersed across the coastal portion of the study area, whereas the transition of tidal flat to estuarine water is concentrated in the Cedar Key area (point of land at the northern end of the study area).

Under the SLAMM scenarios with developed dry land allowed to transition, SLAMM simulates loss of developed dry land at 5%, 7%, and 16% with the 0.7 m, 1 m and 2 m scenarios, respectively. For wetland systems, the direction of magnitude of change simulated are similar to the developed dry land protected scenarios with the following exceptions: changes in mangrove forest are larger and there are larger simulated gains in ocean beach and transitional saltmarsh under the 0.7 m and 1m scenarios. Under the 1 m scenario there is a greater gain of estuarine beach, saltmarsh and tidal flat, and under the 2 m SLR scenario, there is a loss of saltmarsh and gain of tidal flat, ocean beach, transitional saltmarsh and estuarine beach (Table 7-5 in Appendix 7).

Table 20. Southern Big Bend Area SLAMM Results under 3 SLR scenarios through the year 2100, developed dry land protected from changing.

Southern Big Bend SLAMM Results: Developed Dry Land Protected from Changing										
		0.7 meters			1 meter			2 meters		
SLAMM Category (hectares)	Initial Condition (IC)	2100	2100 - IC	Percent Change	2100	2100 - IC	Percent Change	2100	2100 - IC	Percent Change
Open Ocean	456,652	456,713	61	0.0%	456,726	73	0.0%	456,767	114	0.0%
Undeveloped Dry Land	67,217	60,949	-6,269	-9.3%	58,151	-9,066	-13.5%	47,752	-19,465	-29.0%
Coastal Forest	49,873	30,305	-19,568	-39.2%	25,218	-24,655	-49.4%	15,760	-34,112	-68.4%
Developed Dry Land	45,486	45,457	-29	-0.1%	45,457	-29	-0.1%	45,453	-33	-0.1%
Saltmarsh	31,754	41,212	9,458	29.8%	47,490	15,736	49.6%	16,821	-14,933	-47.0%
Estuarine Open Water	15,327	17,931	2,604	17.0%	22,771	7,444	48.6%	56,843	41,516	270.9%
Inland Freshwater Marsh	7,552	7,183	-369	-4.9%	6,794	-758	-10.0%	5,059	-2,493	-33.0%
Tidal Flat	3,870	3,162	-708	-18.3%	5,203	1,333	34.4%	22,580	18,710	483.5%
Inland Open Water	3,603	2,453	-1,151	-31.9%	2,423	-1,180	-32.8%	2,343	-1,260	-35.0%
Cypress Swamp	1,521	1,450	-71	-4.7%	1,381	-140	-9.2%	1,028	-493	-32.4%
Tidal Swamp	443	186	-256	-57.9%	90	-353	-79.7%	3	-440	-99.3%
Mangrove	280	237	-43	-15.3%	158	-121	-43.5%	25	-255	-91.2%
Rocky Intertidal	68	21	-47	-69.3%	1	-67	-98.7%	0	-68	-100.0%
Tidal Freshwater Marsh	31	29	-2	-6.1%	19	-12	-37.4%	0	-31	-100.0%
Ocean Beach	18	52	33	183.3%	58	40	216.5%	51	33	181.7%
Transitional Saltmarsh	1	16,186	16,186	1618628.9%	11,592	11,592	1159232.7%	13,121	13,121	1312124.9%
Estuarine Beach	1	60	60	6030.7%	57	57	5702.3%	52	52	5236.0%
Brackish Marsh	1	110	110	11016.8%	107	107	10667.7%	36	36	3560.6%



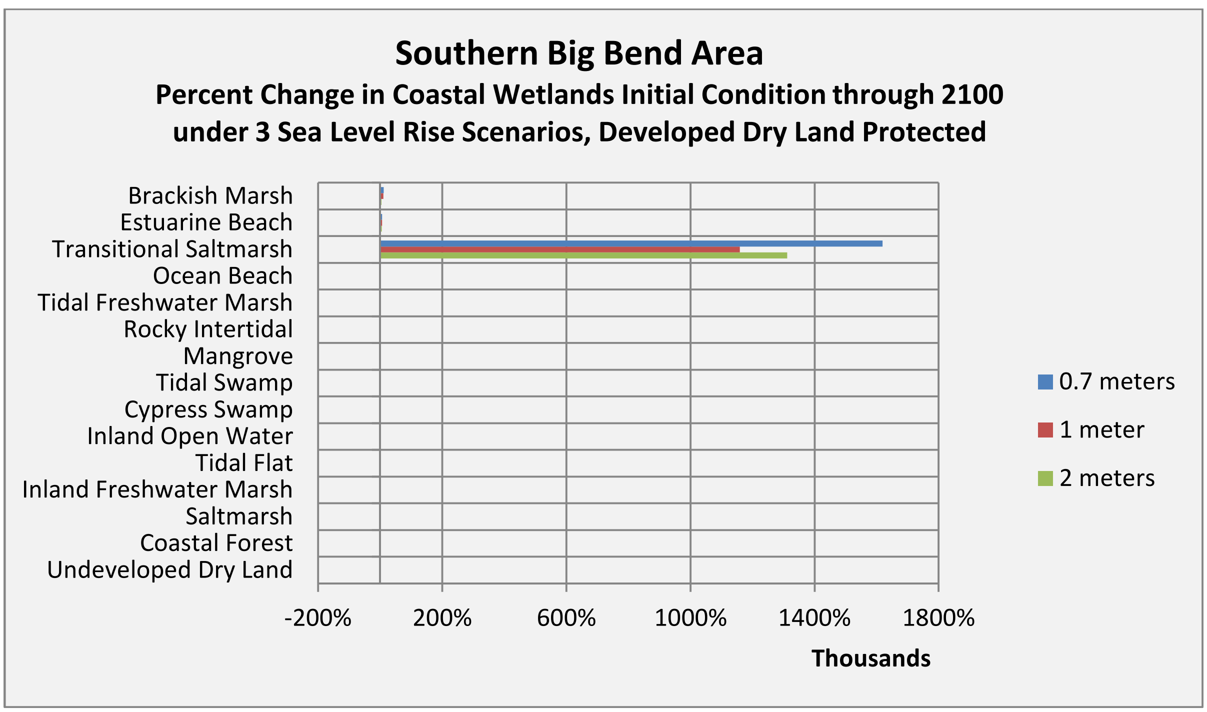


Figure 40. Southern Big Bend Area Results under 3 SLR Scenarios through the year 2100 with developed dry land protected. Change and percent change graphs are illustrated

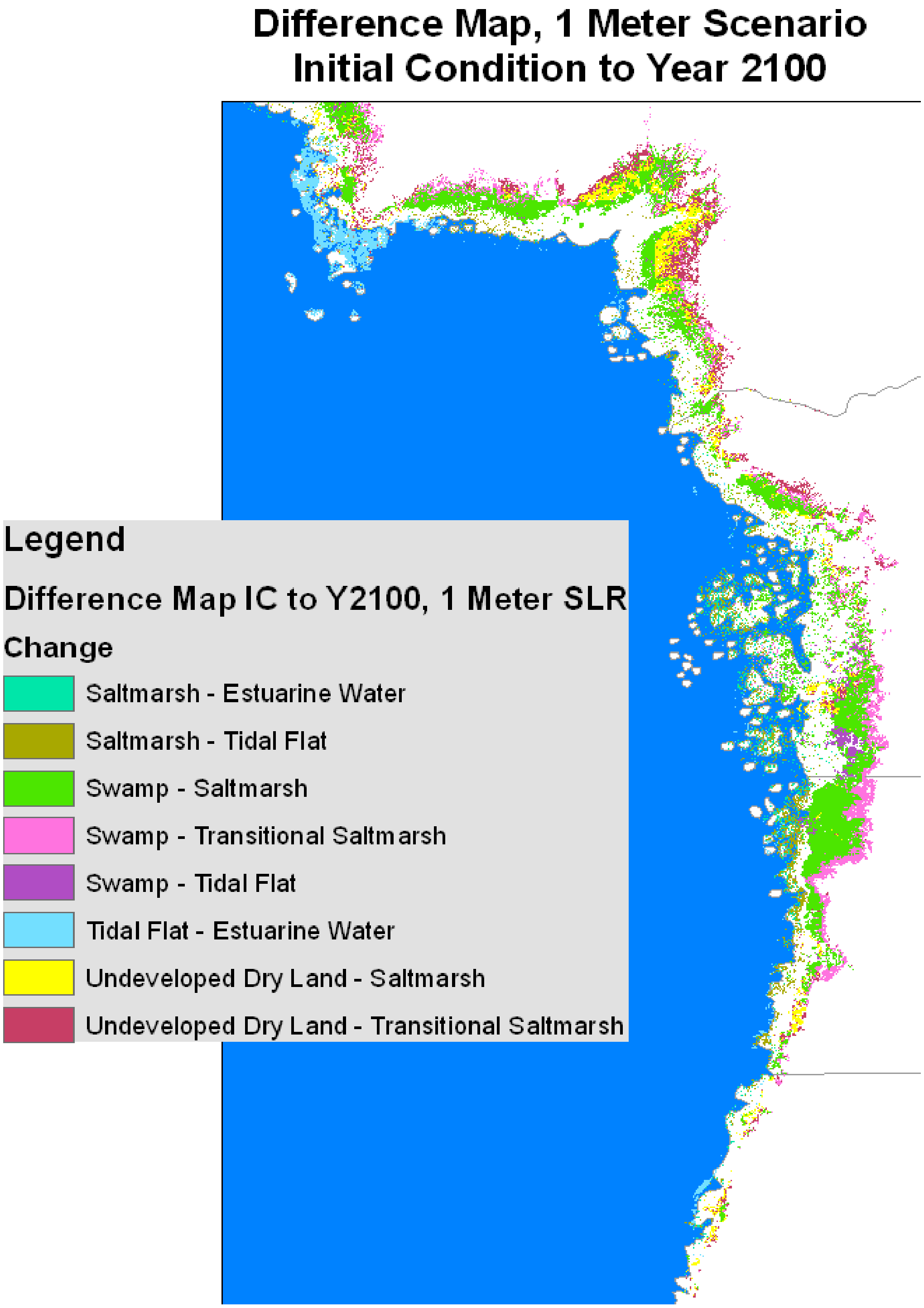


Figure 41. Southern Big Bend Study Area map of coastal wetland system change under a 1 meter SLR scenario, developed dry land protected. Swamp is another name for coastal forest.

Uncertainty Analysis Results

Uncertainty results were characterized by subtracting the minimum output from the maximum output values (Table 21). We created a scale to simplify characterization of the uncertainty results as follows:

none	< 1
lowest	1 - 100
modest	100 - 1000
moderate	1000 - 10000
highest	>10,000

The uncertainty analyses run on the two selected input parameters, saltmarsh accretion and sedimentation rate, revealed only small to modest changes in the 2100 results for the various wetlands types with changes to the sedimentation rate as illustrated in Table 21. However, large variations in saltmarsh and tidal flat results resulted when saltmarsh accretion rate was varied. When saltmarsh accretion rate was varied, saltmarsh varied from a low of 22,216 ha to 48,686 ha with a greater frequency of return at the higher end of the range (SLAMM predicted 48,584 ha; Figure 42). Tidal flat results also returned high variation when an uncertainty analysis was run on saltmarsh accretion rate. Tidal flat varied from a low of 5,616 ha to 22,396 ha with a greater frequency of return at the lower end of the range (SLAMM predicted 5,345 ha; Figure 43). Based on these results, uncertainty in our results at this study area for saltmarsh and tidal flat is high. Not surprisingly, these results indicate changes in saltmarsh and tidal flat are sensitive to saltmarsh accretion rate. Having empirically derived saltmarsh accretion rates for the site is crucial for improving projections of how SLR will affect coastal wetlands in this study area.

Table 21. Southern Big Bend Study Area uncertainty analysis results for two input parameters, saltmarsh accretion and sedimentation rate.

Distribution Type	Triangular	Uniform
Distribution Parameter	Reg. Fld. Marsh Accr	Sedimentation
Variable Name	Max-Min	Max-Min
Developed Dry Land	0.8	0.8
Undeveloped Dry Land	0.6	0.3
Coastal Forest	2.4	0.6
Cypress Swamp	0.0	0.0
Inland Freshwater Marsh	0.0	0.0
Tidal Freshwater Marsh	0.0	0.0
Transitional Saltmarsh	9.1	0.7
Saltmarsh	26462.5	1.4
Mangrove	0.1	0.0
Estuarine Beach	32.2	2.4
Tidal Flat	16775.0	126.6
Ocean Beach	1.2	2.4
Ocean Flat	0.0	0.0
Rocky Intertidal	0.0	0.0
Inland Open Water	0.0	0.0
Riverine Tidal Open Water	0.0	0.0
Estuarine Open Water	9715.0	126.7
Tidal Creek	0.0	0.0
Open Ocean	0.7	3.0
Brackish Marsh	0.0	0.0
Inland Shore	0.0	0.0
Tidal Swamp	0.0	0.0

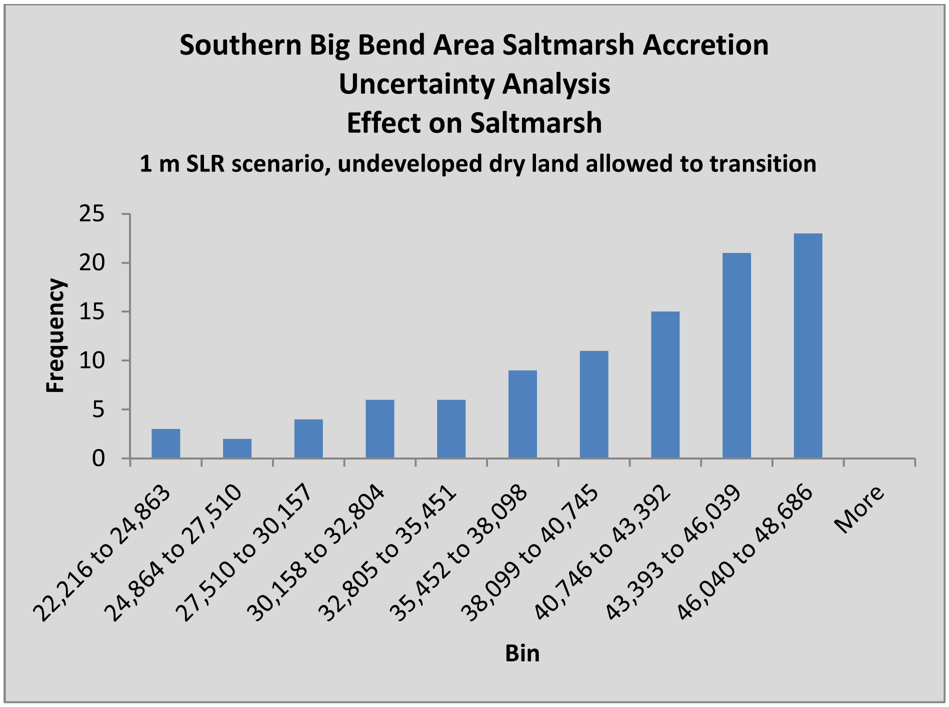


Figure 42. Southern Big Bend Study Area uncertainty analysis on saltmarsh accretion and its effect on saltmarsh.

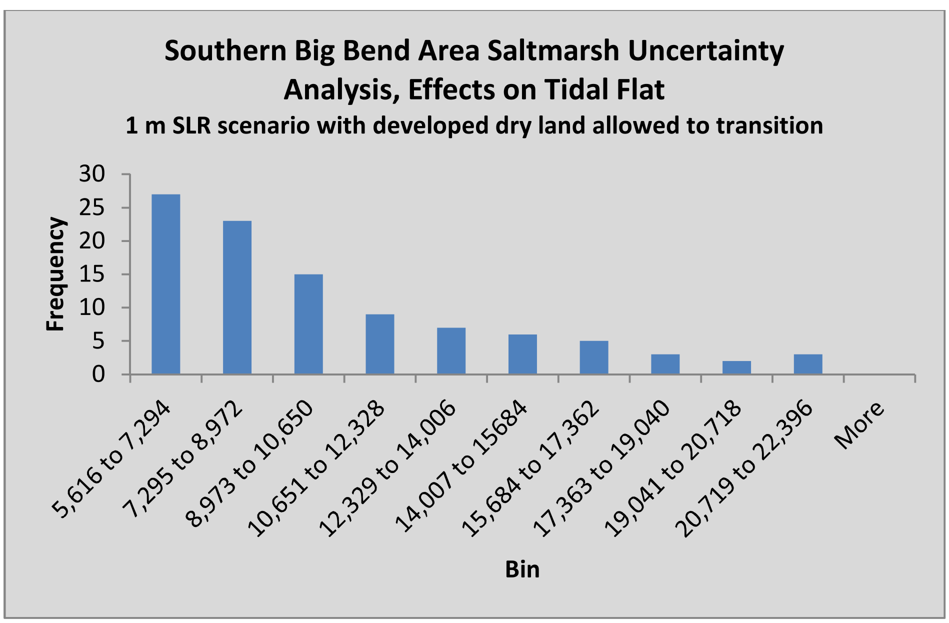


Figure 43. Southern Big Bend Study Area uncertainty analysis on saltmarsh accretion and its effect on tidal flat.

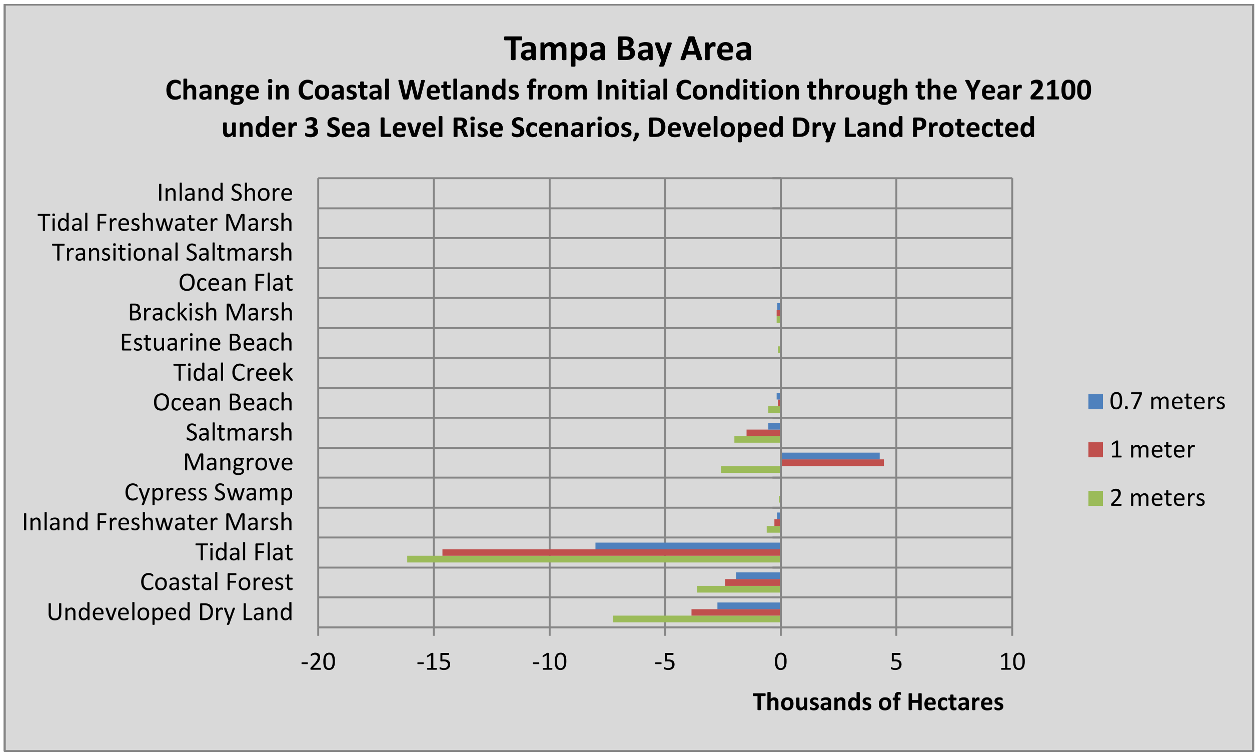
Tampa Bay

The composition of coastal wetlands in the Tampa Bay system is predicted to change substantially under all 3 of the SLR scenarios evaluated. Substantial change (defined here as >10% and >1000 ha) was predicted for tidal flat and mangrove forest under all 3 SLR scenarios (Table 22; Figure 44) with substantial gains of mangrove forest predicted under the two lower rates of SLR, but a substantial loss predicted under the highest rate evaluated (2 m by the Year 2100). Nearly all tidal flats are lost under the 1 and 2 meter scenarios. Elevation data was not available for 10,290 ha of tidal flats in our study area. Table 1 values for tidal flats are adjusted so that they do not include these areas, which remained unchanged in the simulation. However, it is realistic to assume these areas would also be inundated. Under the two highest rates of SLR evaluated (1 m and 2 m SLR by the Year 2100), a substantial loss of saltmarsh is predicted. Several of the lowest elevation wetland types transition into tidal flat. Coastal forest and undeveloped dry land convert to mangrove forest and some mangrove forest is lost to shallow subtidal habitat.

Under the SLAMM scenarios with developed dry land allowed to transition, approximately 2%, 4%, and 11% of developed dry land is predicted to be lost under the 0.7 m, 1 m and 2 m scenarios, respectively (Table 7-6 in Appendix 7). The direction and magnitude of change simulated for coastal wetlands are similar to the developed dry land protected scenarios with the exception that simulated changes in mangrove forest are much larger (Appendix 7). In the 0.7 m and 1.0 m SLR developed dry land protected scenarios, mangrove forest is predicted to increase by 4,273 ha and 4,452 ha, respectively. Whereas under the 0.7 and 1.0 m SLR developed dry land allowed to transition scenarios, mangrove forests are predicted to increase by 8,581 and 11,912 ha, respectively. Under the highest rate of SLR modeled (2 m by 2100) with developed dry land protected from changing, 2,598 ha of mangrove forest is predicted to be lost whereas under the same SLR scenario, but where developed dry land is allowed to transition, mangrove forest is predicted to increase by 10,011 ha.

Table 22. Tampa Bay Area SLAMM Results for 3 SLR Scenarios through the Year 2100, Developed Dry Land Protected.

Scenario		A1B Max (0.7 meters) Protected			1 meter Protected			2 meter Protected		
SLAMM Category (Hectares)	Initial Condition (IC)	2100	2100-IC	%Change	2100	2100-IC	Percent Change	2100	2100-IC	%Change
Developed Dry Land	217,894	217,894	0.0	0.0%	217,894	0.0	0.0%	217,894	0.0	0.0%
Undeveloped Dry Land	109,902	107,158	-2,744.4	-2.5%	106,034	-3,867.9	-3.5%	102,639	-7,262.8	-6.6%
Estuarine Open Water	78,438	90,402	11,964.0	15.3%	99,661	21,223.3	27.1%	114,157	35,719.1	45.5%
Open Ocean	68,510	68,748	238.5	0.3%	68,818	307.7	0.4%	69,369	858.8	1.3%
Coastal Forest	32,018	30,084	-1,934.7	-6.0%	29,605	-2,413.3	-7.5%	28,393	-3,625.2	-11.3%
Tidal Flat	15,706	7,683	-8,022.5	-51.1%	1079	-14,627.4	-93.1%	110	-15,596.0	-99.3%
Inland Open Water	18,216	17,542	-673.5	-3.7%	17,399	-816.6	-4.5%	16,944	-1,271.9	-7.0%
Inland Freshwater Marsh	12,573	12,398	-174.5	-1.4%	12,297	-276.0	-2.2%	11,965	-607.9	-4.8%
Cypress Swamp	8,388	8,359	-28.4	-0.3%	8,352	-35.6	-0.4%	8,300	-87.3	-1.0%
Mangrove	7,054	11,327	4,273.2	60.6%	11,506	4,452.7	63.1%	4,465	-2,589.0	-36.7%
Riverine Tidal Open Water	4,129	2,120	-2,009.1	-48.7%	2,085	-2,044.2	-49.5%	2,044	-2,084.6	-50.5%
Saltmarsh	2,047	1,501	-546.4	-26.7%	556	-1,490.6	-72.8%	41	-2,006.4	-98.0%
Ocean Beach	1,052	875	-177.0	-16.8%	922	-130.2	-12.4%	507	-544.8	-51.8%
Tidal Creek	421	421	0.0	0.0%	421	0.0	0.0%	421	0.0	0.0%
Estuarine Beach	195	188	-7.1	-3.6%	170	-24.5	-12.6%	70	-125.0	-64.1%
Brackish Marsh	195	45	-150.0	-77.0%	15	-179.7	-92.3%	6	-189.0	-97.1%
Transitional Saltmarsh	83	115	31.6	38.0%	69	-13.8	-16.5%	120	37.1	44.6%
Tidal Freshwater Marsh	43	6	-37.1	-85.6%	3	-40.7	-93.7%	1	-42.6	-98.2%
Inland Shore	11	10	-0.9	-7.7%	8	-2.9	-25.5%	8	-3.1	-26.9%



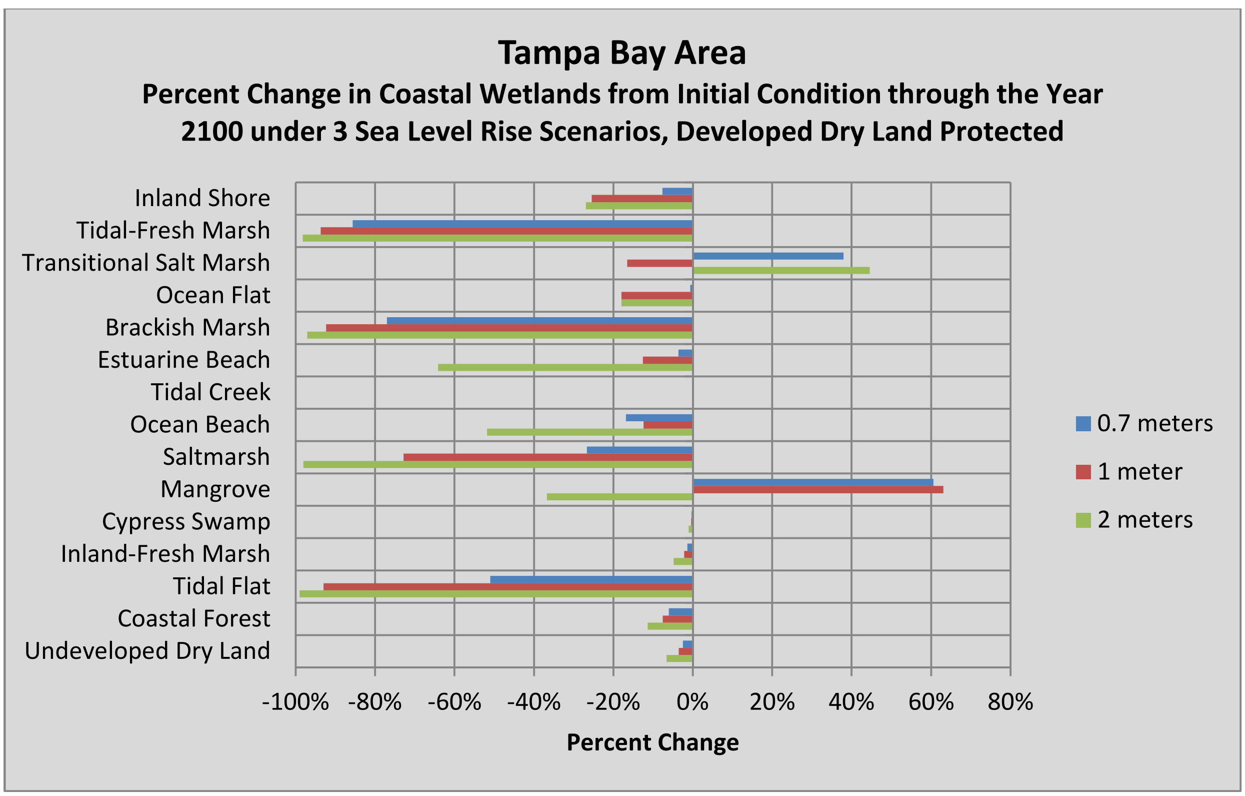


Figure 44. Tampa Bay Area SLAMM Results under 3 SLR Scenarios through the year 2100 with developed dry land protected. Change and percent change graphs are illustrated.

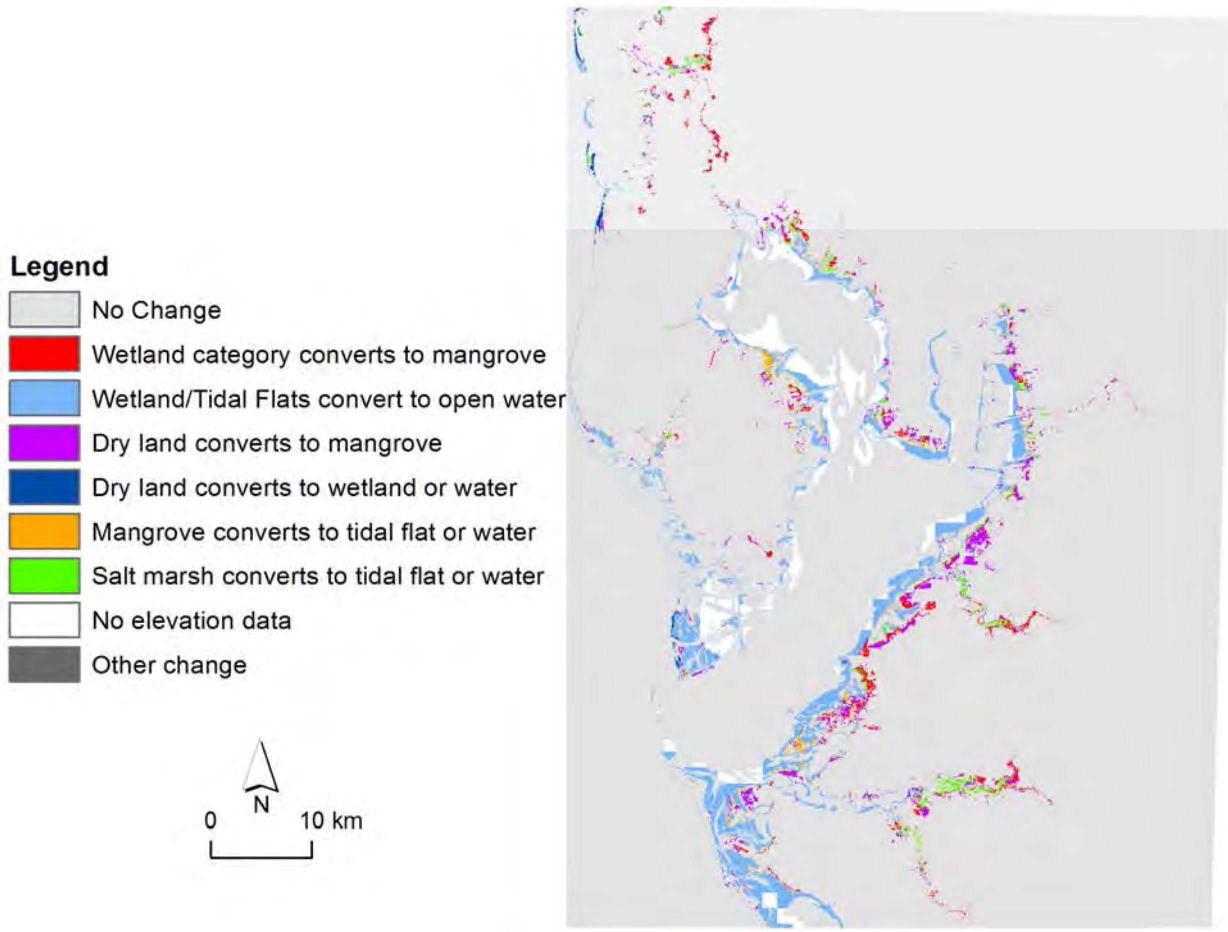


Figure 45. Tampa Bay Study Area SLAMM results - change in coastal wetland cover under a 1 meter SLR scenario, developed dry land protected from changing.

Uncertainty Analysis Results

Uncertainty results were characterized by subtracting the minimum output from the maximum output values. We created a scale to simplify characterization of the uncertainty results as follows:

none	< 1
lowest	1 - 100
modest	100 - 1000
moderate	1000 - 10000
highest	>10,000

The uncertainty analyses run on the three selected input parameters, salt elevation, saltmarsh accretion rate and beach sedimentation rate, revealed small to moderate changes in the 2100 results for the various wetland and dry land types with changes to the selected input parameters as illustrated in Table 23. Based on these results, uncertainty in our results at this site are modest. These results indicate that having accurate saltmarsh accretion, beach sedimentation and salt elevation data available for the site is helpful for improving projections of how SLR will affect coastal wetlands in the study area.

Table 23. Tampa Bay Study Area uncertainty analysis results for salt elevation, saltmarsh accretion rate and beach sedimentation rate.

Distribution Type	Multi
Distribution Parameter	Multi
Variable Name	Max-Min
Developed Dry Land	2035.1
Undeveloped Dry Land	483.7
Coastal Forest	195.2
Cypress Swamp	1.7
Inland Freshwater Marsh	51.8
Tidal Freshwater Marsh	0.9
Transitional Saltmarsh	28.4
Saltmarsh	1554.6
Mangrove	2591.5
Estuarine Beach	53.8
Ocean Beach	222.0
Ocean Flat	0.0
Rocky Intertidal	0.0
Inland Open Water	189.8
Riverine Tidal Open Water	31.6
Estuarine Open Water	1166.3
Tidal Creek	0.0
Open Ocean	112.5
Brackish Marsh	0.0
Inland Shore	0.0
Tidal Swamp	0.0

SLAMM Results, All Sites

Overall results for the five study areas predict that coastal forest (aka coastal forest) and undeveloped dry land will face the greatest loss in cover by the year 2100 (-74,670 ha and -19,570 ha, respectively). The largest gains in cover are predicted for saltmarsh (36,157 ha), transitional saltmarsh (15,301 ha), brackish marsh (7,727 ha) and tidal freshwater marsh (6,039 ha; Table 24 and Figure 46). While the five study areas represent only a portion of Gulf of Mexico estuaries, the results provide an indication of which coastal wetland systems are likely to experience the greatest change and the direction of the change (gain or loss) in this region by the year 2100. Of the five study areas, Mobile Bay and Southern Big Bend were predicted to experience the greatest change in coastal wetland systems as coastal forest and, in the case of Southern Big Bend undeveloped dry land, transition into various marsh types (Figure

47). Collecting data for the extent and elevation of tidal flats is often problematic. LiDAR elevation data for tidal flats is difficult to obtain, not only due to their ephemeral nature, but also due to the limitations of collecting topographic LiDAR in areas covered with water. Tidal flat results in our simulations are not as reliable as other vegetation categories.

Table 24. Change in coastal wetland systems and adjacent dry land across the 5 study areas under the 1 m scenario, developed dry land protected.

Study Areas	Corpus Christi Bay	Mobile Bay	Pensacola Bay	Southern Big Bend	Tampa Bay	TOTAL Hectares
Coastal Forest	-6	-41,187	-6,408	-24,655	-2,413	-74,670
Undeveloped Dry Land	-2,907	-2,658	-1,071	-9,066	-3,868	-19,570
Tidal Flat	-1,874	4,780	1,770	1,333	-14,628	-8,619
Inland Freshwater Marsh	-987	-141	-1,048	-758	-276	-3,210
Estuarine Beach	-1,144	-654	17	57	-24	-1,748
Cypress Swamp	0	-621	-370	-140	-36	-1,166
Ocean Beach	-169	-136	-386	40	-130	-782
Inland Shore	-126	-9	-1	0	-3	-139
Tidal Swamp	-1	3,130	-983	-353	0	1,793
Mangrove Forest	0	0	0	-121	4,453	4,331
Tidal Freshwater Marsh	-2	4,562	1,532	-12	-41	6,039
Brackish Marsh	-935	8,353	381	107	-180	7,727
Transitional Saltmarsh	1,436	1,078	1,208	11,592	-14	15,301
Saltmarsh	-1,611	19,905	3,617	15,736	-1,491	36,157

Table 25. Percent change in coastal wetland systems and adjacent dry land across the 5 study areas under the 1 m scenario, developed dry land protected. Substantial habitat changes are in bold (>1,000 ha and >10% change). Ocean beach changes are considered substantial even though <1,000 ha due to essential requirement of this habitat for many species.

Study Areas	Corpus Christi Bay	Mobile Bay	Pensacola Bay	Southern Big Bend	Tampa Bay
Coastal Forest	0%	**-49%**	**-18%**	**-49%**	-8%
Undeveloped Dry Land	-2%	-1%	-1%	**-14%**	-4%
Tidal Flat	**-58%**	**19524%**	**2021%**	**34%**	**-93%**
Inland Freshwater Marsh	-12%	-4%	**-11%**	-10%	-2%
Estuarine Beach	**-83%**	-71%	-----	5702%	-13%
Cypress Swamp	-----	-76%	-28%	-9%	0%
Ocean Beach	**-40%**	**-46%**	**-17%**	**217%**	**-12%**
Inland Shore	-14%	-25%	-23%	-----	-26%
Tidal Swamp	-6%	**1254%**	**-44%***	-80%	-----
Mangrove Forest	------	-----	-----	-44%	**63%**
Tidal Freshwater Marsh	-81%	**2509%**	**3333%**	-37%	-94%
Brackish Marsh	**-78%***	**105%**	-2%	10668%	-92%
Transitional Salt Marsh	**241%**	**151%**	**4376%**	**1159233%**	-17%
Saltmarsh	**-50%**	**3490%**	**3468%**	**50%**	**-73%**

*Listed as substantial because close to the cutoff and large percent loss from system.

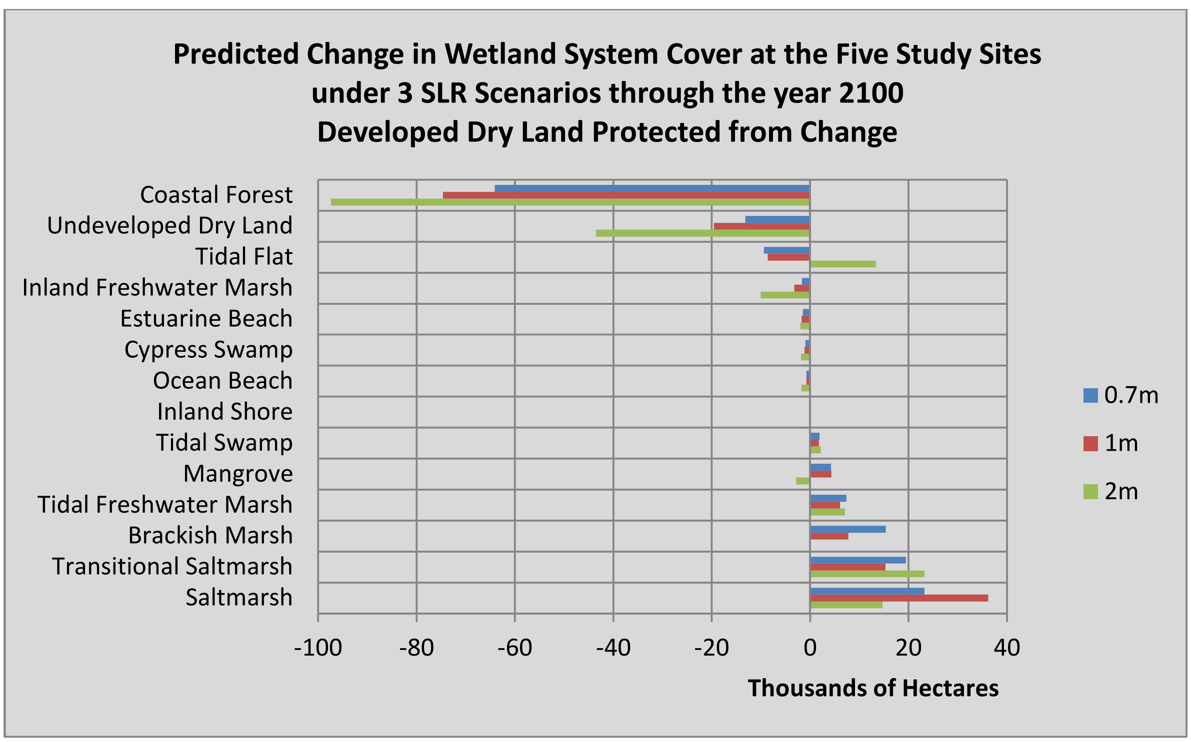


Figure 46. Change in coastal wetland type cover for all sites summed, 3 SLR scenarios (0.7m, 1m, 2m) with developed dry land protected from change.

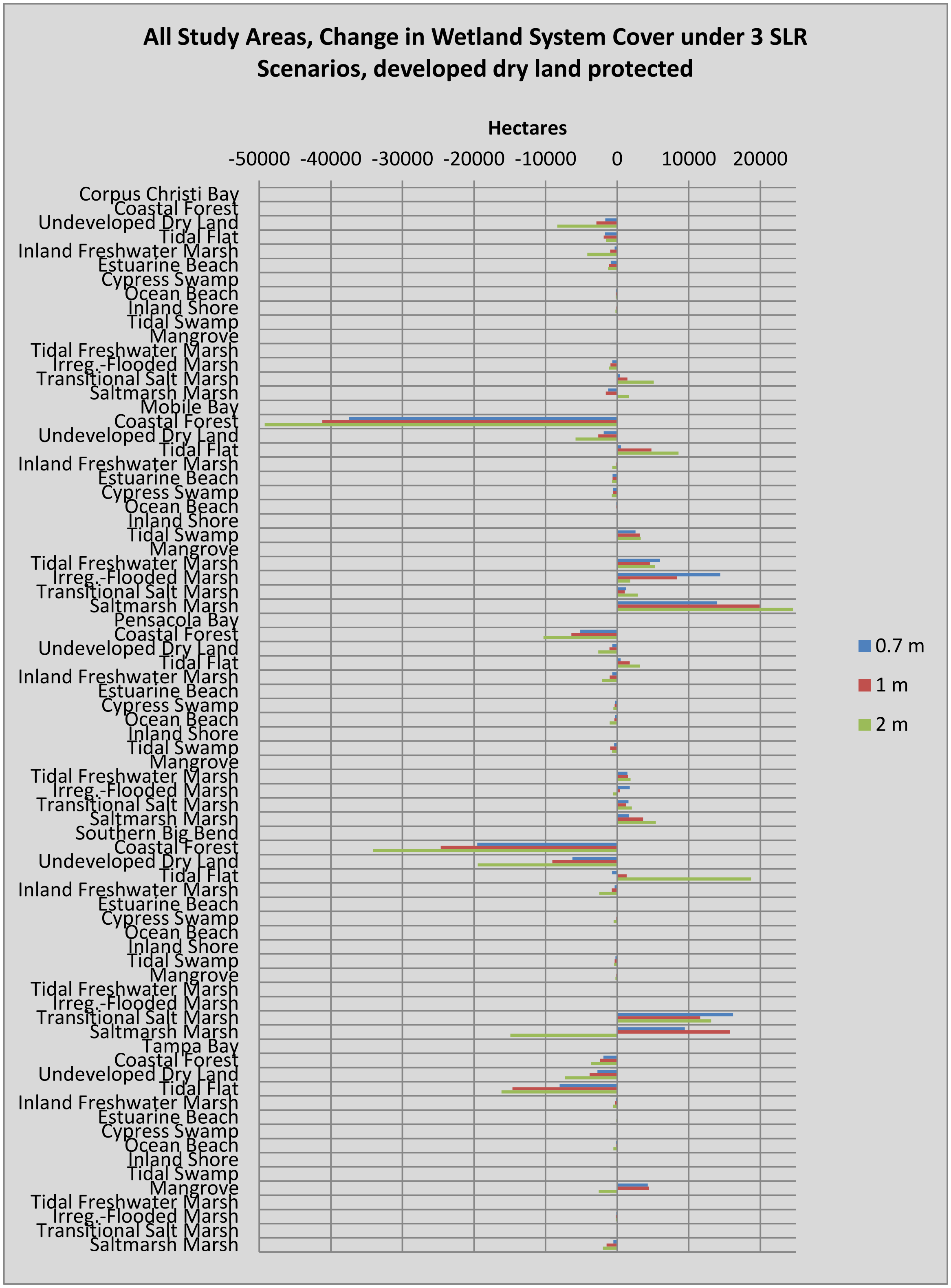


Figure 47. All Modeled Sites – Change in Coastal Wetland Systems under the 1 m SLR Scenario.

Results of Vulnerable Species Analysis

Corpus Christi Bay Study Area

As indicated above, we estimated loss of potential habitat for each species based on overlap with incompatible land cover classes present in the 1 meter SLAMM scenario (Table 11). Estimates of habitat loss were based solely on projected SLR-driven changes. That is, we assumed no losses due to other land cover conversions (e.g., natural areas to development or agriculture).

Before examining the results, it should be pointed out that gaps exist in the SLAMM land cover datasets and that these gaps may skew our results slightly. SLAMM can only make projections for areas where high-resolution digital elevation data exist. In our DEM, several of the spoil islands in Corpus Christi and Redfish Bays and Madre Lagoon lack such data and therefore could not be evaluated by SLAMM. The map below represents these data gaps in red. (The orthogonal gaps at the northeast and southeast edges of the study area are not important for this analysis.)

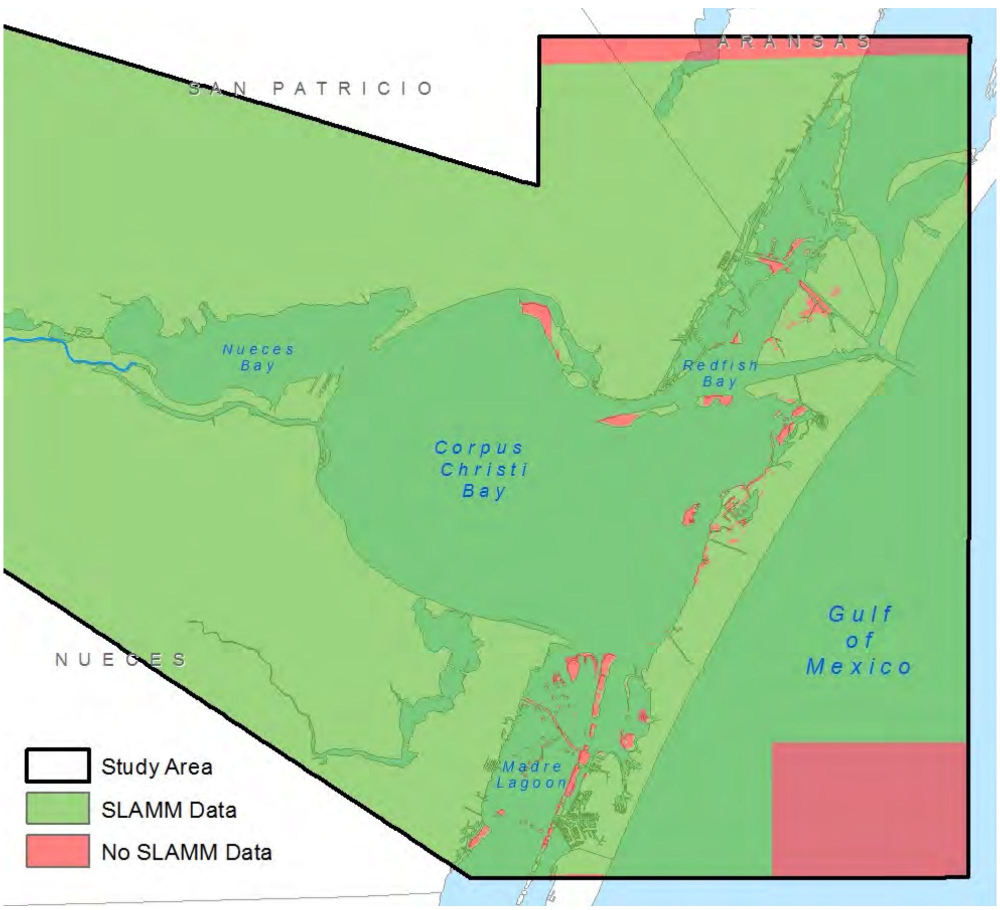


Figure 48. Corpus Christi Study Area gaps in high resolution LiDAR elevation data where SLAMM was not applied.

Because these gaps include many low-elevation and island areas, we believe they may cause the SLAMM analysis to slightly understate the loss of some land covers, including estuarine beach, inland shore, and salt marsh. As Gibeaut et al. (2010) point out in their discussion of projected sea level rise-driven land cover changes in this region, certain coastal land cover classes such as salt marsh exist in very narrow elevation ranges, meaning that SLR of only a half meter or so could significantly change the land cover in these data-gap areas. While Gibeaut et al. do not quantify these changes, their report includes a series of maps showing land cover within some of our data gaps transitioning from salt marsh and tidal flat to open water.

Species reliant on these data-gap areas, such as piping plover and reddish egret, may therefore experience a somewhat greater loss of habitat area than our analysis suggests. We calculated that about 12% of piping plover habitat and 10% of reddish egret habitat lie within the data gaps, meaning that we are evaluating land cover change for about 88% and 90% of their current habitat areas, respectively. In our view these reduced sample sizes do not disqualify the results.

The predicted changes in coastal wetland systems are projected to impact many of the target elements of this study (Table 26). The greatest projected loss of total habitat area is seen for reddish egret and Texas diamond back terrapin (both projected to lose 7,158 hectares) and gulf saltmarsh snake (projected to lose 6,005 hectares). In terms of percentage of habitat, the largest projected losses are for piping plover (80% loss), seaside sparrow (77% loss), and the glasswort-saltwort natural community (75% loss). The least impacted elements include the sea oats-bitter panicum natural community (74 ha; 15% loss), Tharp's rhododon (431 ha; 3% loss), and brown pelican (800 ha; 1% loss). Maps comparing current and predicted future habitat are provided in Appendix 8. In terms of types of impacts, the influx of estuarine waters are expected to impact the current habitat of piping plover (Fig. 8-1), reddish egret, saltmarsh snake (Fig. 8-2), three flower broomweed (Fig. 8-3), and seaside sparrow (Fig. 8-4), as well as the glasswort-saltwort natural community (Fig. 8-5). The latter two elements will also see impacts from a shift in tidal flats. Rising ocean waters will also impact the beach habitat of piping plover and sea turtles (Fig. 8-6). We should note that several of these species, particularly those found in salt marsh, tidal flat, and beach habitats, will also see an inland shift in habitat to varying degrees beyond their current habitat extent (noted in Table 26, last column). While these shifts in potential habitat were not explicitly modeled in this project, they would likely result in a smaller net loss of habitat overall. However, none of the target species is expected to see a net gain in habitat in this study area.

Finally, three species – reddish egret, Gulf saltmarsh snake, and three flower broomweed – were further assessed using the NatureServe Climate Change Vulnerability Index (CCVI; Table 27). All three species were found to be Moderately Vulnerable to climate change. See Table 12 for index score definitions. The reddish egret and saltmarsh snake are vulnerable due to the reduction and shift in habitat caused by SLR; in both cases the degree of vulnerability depends on the species' ability to respond to this habitat shift. The three flower broomweed is vulnerable due to the expected changes in the hydrology and salinity of its habitat substrate, again due to SLR.

Table 26. Corpus Christi Bay Study Area projected impacts to species habitat with SLAMM 1-meter SLR scenario, developed dry land protected. Projected potential habitat represents only current habitat minus areas projected to be unsuitable in the SLAMM scenario.

Scientific Name	Common Name	Current Potential Habitat (hectares)	Projected Potential Habitat (hectares)	Habitat Lost (hectares)	Habitat Lost (percent)	Substantial Shift in Habitat likely
Ambrosia cheiranthifolia	south Texas ambrosia	39,102	38,258	844	2	
Ammodramus maritimus	seaside sparrow	4,752	1,077	3,675	77	yes
Charadrius melodus	piping plover*	5,689	1,145	4,544	80	yes
Egretta rufescens	reddish egret*	10,015	2,857	7,158	71	yes
Grindelia oolepis	plains gumweed	35,606	34,762	844	2	
Hoffmannseggia tenella	slender rushpea	35,660	34,816	844	2	
Malaclemys terrapin littoralis	Texas diamondback terrapin	52,686	45,528	7,158	14	yes
Nerodia clarkii	Gulf saltmarsh snake*	14,585	8,580	6,005	41	yes
Pelecanus occidentalis	brown pelican	137,337	136,337	800	1	yes
Rhododon angulatus	Tharp's rhododon	12,894	12,463	431	3	
salicornia virginiana-batis maritima series	glasswort-saltwort series	6,486	1,658	4,828	74	yes
Thurovia triflora	three flower broomweed*	7,003	5,904	1,099	16	
Uniola paniculata-panicum amarum series	sea oats-bitter panicum series	487	413	74	15	
coastal rookeries	coastal rookeries	23,853	20,356	3,497		
sea turtle group	sea turtle group	429	199	230	54	yes

Table 27. Corpus Christi Bay Study Area assessment of climate change vulnerability for three species using the NatureServe Climate Change Vulnerability Index.

Common Name	Range in Study Area	Vulnerability Index	Confidence	Primary Factors
Reddish egret	center of range	Moderately Vulnerable	Low	SLR would shift/reduce habitat – depends on response to disturbance
Gulf saltmarsh snake	west edge of range	Moderately Vulnerable	Low	SLR would shift/reduce habitat – depends on response to disturbance
Three flower broomweed	Southern edge of range	Moderately Vulnerable	Moderate	SLR & substrate hydrology/salinity

Mobile Bay Study Area

As indicated above, we estimated loss of potential habitat for each species based on overlap with incompatible land cover classes present in the 1 meter SLAMM scenario. Estimates of habitat loss were based solely on projected sea-level-rise-driven changes. That is, we assumed no losses due to other land cover conversions (e.g., natural areas to development or agriculture).

These (and other) land cover changes in the study region will likely translate into significant potential-habitat losses for many--but not all--target elements (Table 28). Our calculations suggest that the piping and snowy plovers and salt flat will lose more than half of their potential habitat. Losing between 15 and 36 percent of their potential habitat will be the hairy-peduncled beakrush, Alabama redbelly turtle, and Godfrey's golden-aster. Somewhat less impacted will be the reddish egret, speckled burrowing crayfish, white-top pitcherplant, Alabama beach mouse, and night-flowering wild petunia; these five elements will lose between six and 11 percent of their potential habitat. The white ibis, gulf salt marsh snake, and diamondback terrapin are all projected to lose less than two percent of their potential habitat.

As would be expected, the most heavily impacted elements are associated with the most dynamic land cover classes. The plovers are heavily dependent on estuarine and ocean beach, both of which are projected to see significant decreases in area by 2100 (69% and 45% respectively). Salt flat also correlates with estuarine beach but might be even more impacted by the shift of brackish marsh from the study region's southern to central reaches. The hairy-peduncled beakrush and Alabama redbelly turtle are associated with coastal forest, whose area is expected to decrease by about 45%.

Maps of each element's potential-habitat changes appear in Appendix 8. In these maps, potential habitat typically encompasses certain portions of compatible land cover classes (see Potential-Habitat Modeling Process); these are colored green. Other portions of compatible land cover classes appear in white, while land cover classes considered incompatible are colored beige. Note that some elements appear to have ample refuge among inland compatible land cover classes. While we did not model potential range shifts, we caution against assuming that elements will be able to easily shift to inland compatible land cover classes. Some elements, for example Godfrey's golden-aster and the Alabama beach mouse, depend on a very specific subset of their compatible land cover classes. More importantly, without extensive further analysis, the ability of elements to migrate at all can only be guessed at.

Finally, three species--piping plover, Alabama beach mouse, and hairy-peduncled beakrush--were further assessed using the NatureServe Climate Change Vulnerability Index (CCVI). Two, the piping plover and Alabama beach mouse, were found to be "highly vulnerable", while the beakrush was found to be "moderately vulnerable". Confidence in all three results is very high (Table 29). See Table 12 for index score interpretation.

Table 28. Mobile Bay Study Area projected impacts to species habitat with SLAMM 1-meter SLR scenario, developed dry land protected. Projected potential habitat represents only current habitat minus areas projected to be unsuitable in the SLAMM scenario.

SCIENTIFIC NAME	COMMON NAME	CURRENT POTENTIAL HABITAT (hectares)	PROJECTED POTENTIAL HABITAT (hectares)	POTENTIAL HABITAT LOST (hectares)	POTENTIAL HABITAT LOST (percent)	S RANK	G RANK
Charadrius alexandrinus	snowy plover	491.5	184.7	306.8	62.4%	S1B, S2N	G4
Charadrius melodus	piping plover	1,248.8	316.3	932.6	74.7%	S1N	G3
Chrysopsis godfreyi	Godfrey's golden-aster	1,895.2	1,612.8	282.4	14.9%	S1	G2
Egretta rufescens	reddish egret	7,630.8	6,799.4	831.4	10.9%	S1B	G4
Eudocimus albus	white ibis	96,717.9	94,863.5	1,854.3	1.9%	S2B, S3N	G5
Fallicambarus danielae	speckled burrowing crayfish	54,943.5	49,307.4	5,636.0	10.3%	S1	G2
Malaclemys terrapin	diamondback terrapin	43,018.0	43,014.6	3.4	0.0%	S2	G4
Nerodia clarkii clarkii	Gulf salt marsh snake	13,737.4	13,724.1	13.3	0.1%	S2	G4T3
Peromyscus polionotus ammobates	Alabama beach mouse	784.2	711.0	73.2	9.3%	S1	G5T1
Pseudemys alabamensis	Alabama redbelly turtle	90,011.7	74,264.5	15,747.2	17.5%	S1	G1
Rhynchospora crinipes	hairy-peduncled beakrush	31,493.4	20,220.9	11,272.5	35.8%	S1	G2
Ruellia noctiflora	night-flowering wild petunia	13,208.4	12,396.8	811.6	6.1%	S1	G2
Sarracenia leucophylla	white-top pitcherplant	54,943.5	49,307.4	5,636.0	10.3%	S3	G3
salt flat	salt flat	3.2	1.3	1.9	58.3%	N	G4

Table 29. Mobile Bay Study Area assessment of climate change vulnerability for three species using the NatureServe Climate Change Vulnerability Index.

SCIENTIFIC NAME	COMMON NAME	RANGE VS. STUDY AREA	VULNERABILITY INDEX	CONFIDENCE	PRIMARY FACTORS
Charadrius melodus	piping plover	southern edge of range	highly vulnerable	very high	SLR (loss of beach area)
Peromyscus polionotus ammobates	Alabama beach mouse	western edge of range	highly vulnerable	very high	more-frequent, more-intense storms; barriers to migration
Rhynchospora crinipes	hairy-peduncled beakrush	center of range	moderately vulnerable	very high	requires freshwater streams and rivers

Pensacola Bay Study Area

We estimated loss of occupied and potential habitat for each species based on overlap with incompatible land cover resulting from the 1 m SLAMM scenario (Table 30). We assumed no losses due to other sources of land conversion (e.g., development and silviculture). In addition to the overlap calculations, we developed maps for a subset of species to illustrate the most prominent issues related to potential impacts of SLR in this region, as described below. Maps are provided in Appendix 8.

The conversion of freshwater wetlands to estuarine wetlands results in a high percentage of habitat loss for bog spicebush (Fig. 8-22) and Florida burrhead (Fig. 8-23) and considerable acreage loss for white-top pitcherplant (Fig. 8-23). The two beach mouse species, which are endemic to the barrier islands they occupy, are impacted by conversion of their habitat to estuarine water and open ocean (see Perdido Key beach mouse, Fig. 8-25). Escambia map turtle, narrowleaf naiad, Florida pondweed, and blackmouth shiner are all impacted by loss of freshwater stream habitat to estuarine systems, although these impacts are more significant for the latter two species whose habitat is likely restricted to the lower Blackwater River (see map turtle, Fig. 8-26 and blackmouth shiner, Fig. 8-27).

Species with minimal habitat loss include the reticulated flatwoods salamander and Kral's yellow-eyed grass, both of whose habitat is largely inland from open water or salt marsh intrusion. Piping plover also shows surprisingly low habitat loss within the study area due to the relatively high relief of barrier islands in the western panhandle. However, SLAMM modeling does not take into account the dynamics of barrier island formation and shift and how these might be impacted by SLR. Substantial shifts could take place that could impact habitat for plover and the two beach mice species.

Because gulf sturgeon is found in both freshwater and saltwater, our method of assessing habitat loss shows no impact to this species. Impacts to sturgeon are more likely to be seen in changes to flow rates, turbidity, and specific substrate preferences that are not captured in this form of land cover-based habitat analysis.

The habitat loss figures for salt marsh topminnow (Table 30; Fig. 8-28) are misleading, because they only include land cover changes within the current extent of the species' habitat. SLAMM modeling projects substantial increases in salt marsh beyond current areas, so it is likely that this fish would move into these areas and likely expand its extent within the study area.

Table 30. Pensacola Bay Study Area projected impacts to species habitat with SLAMM 1-meter SLR scenario, developed dry land protected. Projected potential habitat represents only current habitat minus areas projected to be unsuitable in the SLAMM scenario.

Species*	Occupied Habitat (acres)	Occupied Habitat Projected Loss (acres)	Occupied Habitat Percent Lost	Buffer Habitat (acres)	Buffer Habitat Projected Loss (acres)	Buffer Habitat Percent Lost	Potential Habitat (acres)	Potential Habitat Projected Loss (acres)	Potential Habitat Percent Lost	Endemic to Study Area
Reticulated flatwoods salamander	7,220	304	4%	n/a	n/a	n/a	17,458	981	6%	
Piping plover	5,759	239	4%	n/a	n/a	n/a	6,069	249	4%	
Florida burrhead	237	200	84%	n/a	n/a	n/a	319	272	85%	Likely
Bog spicebush	135	60	44%	n/a	n/a	n/a	278	208	75%	
Santa Rosa beach mouse	4,007	648	16%	n/a	n/a	n/a	n/a	n/a	n/a	
Perdido Key beach mouse	1,221	174	14%	n/a	n/a	n/a	n/a	n/a	n/a	Mostly
White-top pitcherplant	37,743	3,239	9%	n/a	n/a	n/a	95,004	10,875	11%	
Kral's yellow-eyed grass	1,991	40	2%	n/a	n/a	n/a	7,652	666	9%	
Gulf sturgeon	119,500	0	0%	58,570	97	0.2%	n/a	n/a	n/a	
Saltmarsh topminnow	4,919	1,127	23%	26,000	156	0.6%	4,647	1,605	35%	
Escambia map turtle	1,300	639	49%	33,500	13,600	41%	n/a	n/a	n/a	
Narrowleaf naiad	375	232	62%	2,289	707	31%	829	552	67%	
Blackmouth shiner	329	298	91%	3,160	1,319	42%	n/a	n/a	n/a	Likely
Florida pondweed	313	242	77%	3,684	1,482	40%	891	608	68%	Yes

*Scientific names are provided in Table 11 above.

Finally, three species – bog spicebush, blackmouth shiner, and Santa Rosa beach mouse – were further assessed using the NatureServe Climate Change Vulnerability Index (CCVI; Table 31). Bog spicebush and blackmouth shiner were found to be Moderately Vulnerable, while Santa Rosa beach mouse was found to be Highly Vulnerable. See Table 12 for interpretation of the vulnerability index scores. A primary factor for all three was SLR, as demonstrated by the habitat analysis described above. Bog spicebush and blackmouth shiner were also considered vulnerable due to having a relatively specific hydrological niche that could be impacted by changes in temperature, precipitation, and/or sea level. Santa Rosa beach mouse was also considered highly vulnerable due to the obvious barrier that the barrier island presents to range shifts to more suitable locations.

Table 31. Pensacola Bay area assessment of climate change vulnerability to 3 species using the NatureServe Climate Change Vulnerability Index.

Common Name*	Range in Study Area	Vulnerability Index	Confidence	Primary Factors
Bog spicebush	center of range	Moderately Vulnerable	Very High	SLR; hydrological niche
Blackmouth shiner	eastern edge	Moderately Vulnerable	Very High	SLR; hydrological niche
Santa Rosa beach mouse	center of range	Highly Vulnerable	Very High	SLR; barriers to range shift

*Scientific names are provided in Table 11**Error! Reference source not found.** above.

Southern Big Bend Study Area

We estimated loss of occupied and potential habitat for each species based on overlap with incompatible land cover resulting from the 1 m SLAMM scenario (Table 32). Estimates of habitat loss were based solely on sea-level rise conversions; we assumed no losses due to other land conversions (e.g., development and silviculture).

Based on SLAMM projections, this study area is likely to experience two primary types of land cover changes due to SLR that would have the most substantial impacts on the species considered: conversion of hydric hammock to salt marsh as rising sea level pushes the marshes inland; and inundation of sandy beaches on small keys by estuarine and open ocean (in this case Gulf) waters. The migration of salt marsh would impact both species dependent on salt marsh, Scott's seaside sparrow and the ornate diamond back terrapin. (Fig. 8-29; Fig. 8-30;Table 32) and species dependent on hydric hammock and other coastal forested wetlands (Florida hasteola, pinewood dainties – Fig. 8-31, Gulf Hammock dwarf siren, pinkroot – Fig. 8-32, as well as the hydric hammock itself – Fig. 8-33). Inundation of sandy beaches would impact the Cedar Key mole skink (Fig.8-34) and late flowering beach sunflower (Fig. 8-35). The figures referenced above can be found in Appendix 8.

Impacts to salt marsh-dependent species are difficult to assess, as salt marsh is actually projected to expand in overall area in this region. For example, while Scott's seaside sparrow is projected to lose 19%

of its current salt marsh habitat, it could potentially see a net gain of 48% as salt marsh expands inland. Likewise, salt marsh vole is projected to lose seven percent of current habitat, but potentially gain 65% over current. Whether the new salt marsh communities will be of the same composition and habitat quality with respect to those species' needs cannot be assessed through SLAMM.

Potential impacts of SLR on coastal cave species are less clear. The crystal siltsnail is found in a freshwater aquatic cave predicted to convert to estuarine water (Fig. 8). While not connected to coastal waters at the surface, caves occupied by the coastal lowland cave crayfish and North Florida spider cave crayfish could still be affected by subterranean estuarine waters.

The remaining focal element – scrub – is not projected to see substantial losses in the southern Big Bend study area. The scrub in this region is far enough inland and at high enough elevation that only four percent is expected to be converted to other land cover types.

Finally, three species – beach sunflower, coastal lowland cave crayfish, and pinkroot – were further assessed using the NatureServe Climate Change Vulnerability Index (Table 33). The late flowering beach sunflower and pinkroot were found to be Moderately Vulnerable, while the coastal lowland cave crayfish was found to be Presumed Stable. See Table 12 for interpretation of the Index scores. The sunflower's vulnerability is primarily due to the impacts of SLR as outlined in this study, namely the overwash of sandy beaches on small keys. Pinkroot served to some extent as a surrogate for the impacts of hydric hammock in the region, and in this case vulnerability was due to the influx of salt marsh into hydric hammock due to SLR. The primary climate-change-related threat to coastal lowland cave crayfish is the influx of saline water into freshwater caves inhabited by this species. The caves are known to be tidally influenced so it is likely that they will experience an increase in salinity as sea level rises. That issue was included in the CCVI inputs, but did not rise to the level of vulnerability based on the CCVI system. Impacts to coastal aquatic cave species may not be adequately addressed in the current CCVI model.

Table 32. Southern Big Bend Study Area projected impacts to species habitat and natural communities with SLAMM 1-meter SLR scenario, developed dry land protected. Projected potential habitat represents only current habitat minus areas projected to be unsuitable in the SLAMM scenario.

Common Name	Occupied Habitat (hectares)	Occupied Habitat Projected Loss (hectares)	Occupied Habitat Lost (percent)	Potential Habitat (hectares)	Potential Habitat Lost (hectares)	Potential Habitat Lost (percent)	Occupied Habitat Percent of Potential	Endemic to Study Area?
Scott's seaside sparrow	31,814	5,885	18	n/a	n/a	n/a	100	
Cedar Key mole skink	29	12	42	42	20	47	68	yes
Crystal siltsnail	308	133	43	n/a	n/a	n/a	100	yes
Florida hasteola	903	0	0	4,701	1,480	31	19	
Late flowering beach sunflower*	11	6	55	36	28	76	30	
Ornate diamondback terrapin	n/a	n/a	n/a	34,704	85	0	n/a	
Salt marsh vole	1,991	141	7	8,340	757	9	24	yes
Pinewood dainties	4,387	928	21	36,655	13,637	37	12	
Coastal lowland cave crayfish*	153	0	0	n/a	n/a	n/a	100	yes
Gulf hammock dwarf siren	1,569	0	0	26,705	12,420	47	6	mostly
Pinkroot*	3,450	1,513	44	38,733	21,711	56	9	mostly
North Florida spider cave crayfish	56	0	0	n/a	n/a	n/a	100	
Scrub	3,409	137	4	n/a	n/a	n/a	100	
Hydric Hammock	43,535	22,817	52	n/a	n/a	n/a	100	

Table 33. Southern Big Bend Study Area assessment of climate change vulnerability to three species using the NatureServe Climate Change Vulnerability Index.

Species	Range in Study Area	Vulnerability Index	Confidence	Primary Factors
Late Flowering Beach Sunflower	southern edge	moderately vulnerable	very high	SLR: overwash of sand beaches on small keys
Pinkroot	eastern edge	moderately vulnerable	very high	SLR: influx of saltmarsh into hydric hammock
Coastal Lowland Cave Crayfish	entire range	presumed stable?	low	SLR: influx of saline water into freshwater caves

Tampa Bay Study Area

Late in the analysis phase of this project, TNC staff discovered that portions of the Tampa Bay Study Area were modeled incorrectly in the SLAMM analysis due to problems with the DEM data. While the analysis was corrected in the SLAMM results section, we did not have time to completely revise the vulnerable species analysis for this study area. The problematic areas were located predominately on barrier islands, including the entirety of Egmont Key. We compared these "No Data" areas with our species habitat models, and all but one species showed at least some degree of overlap (Table 34). Although we were unable to make fundamental corrections within the project time frame, we believe the results for most species are still useful for interpretation and we are presenting them with error estimates. The one exception is Egmont Key mole skink, whose entire habitat was within the No Data zone. Rather than present statistics for this species, we will characterize expected impacts below, as well as through the results of the CCVI assessment.

We estimated loss of occupied and potential habitat for each species based on overlap with incompatible land cover resulting from the one meter SLAMM scenario (Table 35). Estimates of habitat loss were based solely on sea-level rise conversions; we assumed no losses due to other land conversions (e.g., development and agriculture). Projected potential habitat represents only current habitat minus areas projected to be unsuitable in the SLAMM scenario. Plus/minus figures in Table 35 indicate the range of potential error due to No Data zones in SLAMM results. Due to complete overlap with No Data zones, no statistics are reported for Egmont Key mole skink.

Based on SLAMM projections, this study area is likely to experience two primary types of land cover changes due to SLR that would have the most substantial impacts on the species considered: shifting of mangrove coastal forest inland overtaking salt marsh, freshwater wetlands, and uplands; and inundation of sandy beaches on small keys by estuarine and open ocean (in this case Gulf) waters. Some species would be impacted by both trends, including statira (Table 35; Fig. 8-37; Figures referenced below can be found in Appendix 8), Tampa vervain (Fig. 8-39) and nesting shorebirds (Fig. 8-40). Mangrove expansion would also impact Nuttall's goldenrod (Fig. 8-41), while inundation of beaches and dunes by estuarine or gulf waters would also impact the loggerhead (Fig. 8-42), beach sunflower (Fig. 8-43), and wintering shorebirds (Fig. 8-44). Egmont Key mole skink would likely also see loss of coastal upland habitat to inundation from the Gulf. Finally, mangrove coastal forest itself is likely to see a net expansion of area as it shifts inland due to SLR (Fig. 8-45). The 1 m SLAMM scenario projects a net increase of about 11,000 hectares of mangrove coastal forest in the Tampa Bay study area.

Of the species examined in this analysis, only Florida goldenaster is projected to see little or no impact to its habitat in the region. This species prefers upland scrub habitat which is far enough removed from impacted areas (in distance and/or elevation) to be unaffected in the 1 meter SLR scenario.

Finally, three species – Egmont Key mole skink, Tampa vervain, and black skimmer – were further assessed using the NatureServe Climate Change Vulnerability Index (CCVI; Table 36). The Egmont Key mole skink was found to be Moderately Vulnerable, while the Tampa vervain and black skimmer were found to be Presumed Stable. See Table 12 for information on interpreting the Index scores. The mole skink's vulnerability is primarily due to the impacts of SLR as outlined in this study, namely the expected overwash of sandy beaches on Egmont Key. Tampa vervain faces some concern due to the fact that much of its current habitat is surrounded by development, limiting its ability to shift locations in response to climate change. Black skimmer (along with other shorebirds) faces possible constraints due to development along the shoreline that may limit the dynamics of beach formation and shifting as sea level rises.

Table 34. Tampa Bay Study Area percent overlap of species' habitat with areas of no data in the SLAMM Results

Common Name	Occupied Habitat	Potential Habitat
Statira	0.20%	*
Nuttall's rayless goldenrod	0.02%	0.02%
Loggerhead sea turtle	9%	*
Florida goldenaster	0%	1%
Tampa vervain*	0%	0%
Hairy beach sunflower	20%	13%
Egmont Key mole skink*	99%	*
Wintering shorebirds	9%	9%
Nesting shorebirds	15%	8%

*Occupied the same as Potential habitat.

Table 35. Tampa Bay Study Area projected impacts to species habitat and communities with SLAMM 1-meter SLR scenario, developed dry land protected.

Common Name	Occupied Habitat (hectares)	Occupied Habitat Projected Loss (hectares)	Occupied Habitat Lost (percent)	Potential Habitat (hectares)	Potential Habitat Projected Lost (hectares)	Potential Habitat Lost (percent)	Occupied Habitat Percent of Potential	Endemic to Study Area?
Statira	407	46 +/-1	11		n/a	n/a	100	
Nuttall's rayless goldenrod	166	35	21	188	35 +/-0.4	19	88	mostly
Loggerhead sea turtle	522	240 +/-49	46+/-9		n/a	n/a	100	
Florida goldenaster	1,104	1	0	3,022	6 +/-40	0+/-1	37	mostly
Tampa vervain*	664	118	18	2,655	265	10	25	
Hairy beach sunflower	340	80 +/-67	23+/-20	572	120 +/-74	27+/-7	59	mostly
Egmont Key mole skink*	68	n/a	n/a		n/a	n/a	100	yes
Wintering shorebirds	1,111	554 +/-105	50+/-10	1,762	800 +/-166	45+/-9	63	
Nesting shorebirds	353	132 +/-52	38+/-15	864	297 +/-71	34+/-8		

Table 36. Tampa Bay Study Area assessment of climate change vulnerability to three species using the NatureServe Climate Change Vulnerability Index.

Species	Range in Study Area	Vulnerability Index	Confidence	Primary Factors
Egmont Key mole skink	Entire range	moderately vulnerable	very high	SLR: overwash of sandy beaches on Egmont Key
Tampa vervain	center of range	presumed stable	high	SLR and urban barriers to range shift
Black skimmer	center of range	presumed stable	very high	SLR and urban barriers to beach dynamics

Results of Stakeholder Workshops

In this section, we detail the results of the stakeholder workshops held at each study area site by providing information on attendees and what adaptation strategies they recommended for their study area. We organized the adaption strategies into 13 categories to facilitate summary and comparison. The 13 categories of adaption strategies we utilized are provided in Table 37.

Table 37. Categories used to organize adaptation strategies.

Adaptation Strategy Category
Land use planning and building regulation
Emergency/disaster response planning
Tax and Market-based approaches
Conservation of species
Land protection
Conservation of natural areas
Conservation of marine life
Water supply and delivery; water resources
Transportation and infrastructure
Beaches, beach and shoreline management
Research needs
Miscellaneous/General Comments
Education, outreach and communication

Corpus Christi Study Bay

The Stakeholder Workshop for the Corpus Christi Bay study area was held on January 9, 2013 in Corpus Christi, Texas with 27 people in attendance. Attendee affiliations included state agencies and programs, a local planning organization, federal agencies and programs, non-profit organizations, academic institutions, research institutions, a port authority and an aquarium (Table 9-1, Appendix 9).

Adaptation Strategies Developed at the Workshop

Although stakeholders developed a diversity of adaptation strategies (Table 38) from each of our identified categories in Table 37, strategies having to do with education, outreach and communication by far dominated the recommendations with 39 individual strategies. Other frequently identified categories of adaptation strategies for these stakeholders included conservation of natural areas (n=11), tax and market based approaches (n=10) and land use planning and building regulation (n=9).

Table 38. Corpus Christi Bay Study Area locally relevant adaptation strategies developed by workshop participants.

Type and Number of Adaptation Strategies Developed at the Corpus Christi Bay Area Sea Level Rise Adaptation Workshop	
Adaptation Type	**Recommended Strategies**
Land use planning and building regulation (n=9)	Business as usual regarding wetland mitigation won't work; Need to build in additional flexibility.
	Consider the effects of SLR when issuing permits for new septic tanks in new developments and for wastewater outfalls.
	Incorporate SLR into land use planning.
	Conduct full cost analysis of development proposals under current and future SLR conditions. Understand the economic impacts today and into the future.
	Design for the future. Design for retreat.
	Revise building codes to allow for innovative ideas.
	Urban designers think in 3-D. Allow them to design for SLR.
	Plan for future impacts and implement responses approved by the community.
	Require Erosion Response Plans that would provide incentives for setbacks on Gulf facing areas and tie to funding; State certifies, local government approves. Look at long-term shoreline change rates (which SLR accelerates).
Emergency/disaster response planning (n =2)	Create emergency evacuation routes for people in vulnerable areas.
	State emergency operations center surge threats and SLR impacts needed helpful cities, counties regional disaster committees - incident command structure to funnel information.
Tax and Market-based approaches (n=10)	Engage in policy, tax and market-based. Incentivize development in less risky areas.
	Create programs that provide financial incentives for acquiring important parcels.
	Institute a rolling easement program that creates incentives for landowners to sell their land.
	Eliminate flood insurance subsidies in high risk areas.
	Reform flood insurance, especially in repetitive loss areas. TO what extent are we willing to subsidize coastal properties?
	Link tax abatement to geohazards map.
	Model insurance subsidies that include ecosystem values. Use public funds to develop the methodology. At what subsidy level do non-coastal residents benefit?
	Factor carbon credits into restoration to encourage industry to invest in restoration. If they conduct restoration, they get carbon credits.
	Create incentives for managed retreat. For example, provide tax incentives to move away from beaches and other coastal areas.

	Abandon or move structures, and demolish and dispose of remains.
	Use a percentage of flood insurance payments to restore lands, conduct environmental cleanup and mitigate damages.
Conservation of species (n =3)	Construct new islands as necessary for colonial shorebirds.
	Bring science of individual species working group into SLR science to fully understand impacts.
	Research how to reconstruct tidal flat habitat (for the piping plover for example).
Land protection (n=4)	Protect marsh advancement areas (areas where marshes will migrate as sea level rises).
	Acquire conservation easements and protect land in areas that will be changing.
	Use mitigation funds from coastal development to acquire marsh advancement areas.
	Use CIAP funds for land acquisition.
Conservation of natural areas (n=11)	Manage based on acreage targets within bay systems; where is the money coming from?
	Conduct regional sediment management planning.
	Change sediment management: ACOE is holding lots of sediment behind dams. Remove some dams? Our shorelines are sediment starved Change river management.
	Incorporate adaptation strategies into the next revision of the Texas costal management plan.
	Maintain fish habitat and restore habitat that will be lost. Maintain reefs and bird island rookeries.
	Take care of the full suite of habitats. However, using habitat as a proxy for species loss is a problem.
	Strive for a no net loss of habitats using SLR projections to protect future habitat and to make current protection and management decisions.
	Identify and protect areas that will be future wetlands. Prioritize protection areas based on SLR projections and types of land (habitat and species).
	Influence ACOE policies for adaptation management to accept mitigation where in-kind is not the only criteria to consider. Look at source of problem to mitigate or diff. habitat to restore than impacted habitat. Be flexible in mitigation solutions. Change policy at national and local level to allow offsite, out of kind for mitigation under some circumstances.
	Develop regional plan by community to direct mitigation to specific needs including ACOE planning. The acquisition and restoration plan is on the Coastal Bays and Estuaries (Texas) NEP website.
	Create a mechanism to manage lands once acquired. Include money for endowments.

Water supply and delivery; water resources (n=1)	Protect freshwater sources from saltwater intrusion and consider human and wildlife needs
Transportation and infrastructure (n=5)	Conduct transportation planning taking into consideration SLR.
	Research how to protect existing structures and evaluate the options for the future, "protect or adapt?"
	Partner with industry to accomplish coastal protection. - green versus grey infrastructure.
	Prioritize and act on protecting critical infrastructure vulnerable to SLR, e.g., stormwater outfalls and roads.
	Design life - extend beyond the typical 20-50 year timeframe.
Beaches, beach and shoreline management (n=9)	The Texas Open Beaches Act is now in flux (HR 54). Support legislation to bring OBA back to the original intent (rolling easement).
	Influence public policy to keep OBA at its original intent. We need political influence at the local level.
	Beaches in the area have changed. They used to be much wider. Get photography over time on the beach.
	SLR will exacerbate vessel induced scouring of waterways.
	Prioritize and repair armoring in vulnerable areas.
	Perhaps let some of these areas erode to create new marsh.
	Living shoreline and impediments: Require land office coastal bound survey (LSLS certification) that sets pre- and post- project boundaries. Make this requirement exempt for small projects, e.g., single landowner, as incentive to promote the installment of living shorelines over hardened ones.
	Support Texas open Beaches Act (affects Gulf shores only)
	There is a dune setback regulation in place now in Corpus Christi. Adopt a similar policy/regulation for bay coastlines.
	Create incentives for living shorelines. Streamline the permitting process, as a good alternative to bulkheads.
Research needs (n=8)	Conduct research on what habitats are providing in terms of ecosystem services and what is likely to be lost as SLRs. Society might decide to protect those providing the services they most value.
	Conduct greater research into erosion and accretion rates, etc. including bathymetry, sediment supply.
	Identify areas susceptible to change. (This is what TNC's modeling results do.)
	Collect data/information on the impact of SLR on navigation and maritime traffic.
	Improve our understanding of the ecological and economic impacts to fisheries.
	Assess vulnerability better to SLR impacts in addition to SLR; cumulative; climate and no-climate stressors when/where are impacts to priority actions/decisions.

	Understand cumulative impacts to species impacted by SLR, e.g., changes to tides and currents.
	Use dynamic versus bathtub models for tidal flats to understand true SLR effects. Use a uniform tidal datum.
Miscellaneous/General Comments (n=6)	Offshore rigs, etc. are being torn down. They play a role for some species. Can artificial structures replace the role of natural structure?
	TNC, NERR, City of Corpus Christi, Coastal Resilience Index; What will make the city more resilient? Document with many good approaches.
	Civil engineering planning - plan life vs. natural resources planning.
	Texas Windstorm Insurance (TWI) is the insurance of last resort.
	The University of Texas Energy Institute has produced white papers on habitat and socio-economic impacts of SLR, and is bringing recommendations on adaptation strategies to the state legislature.
	Develop a SLR plan for the state.
Education, outreach and communication (n=38)	Create a web-portal that provides address/parcel specific information on the likelihood of inundation (i.e., flood risk)
	Create tools for identifying areas where marshes might migrate.
	Create a curriculum for distance learning. For example, there is a program on vulnerable species at the Aquarium.
	Get the message across to suits and boots that they have the power to make and or pay for what's needed. Send them a uniform message.
	Need next steps to distribute information, succinct 1-2 sentences.
	Train decision makers in the use of tools that will identify hazards, SLR, etc.
	Bridge the gap between science and what happens at city hall. Translate science for general audiences. Translate ideas into policy, Help general public think about future impacts of SLR.
	Easily understood visual tools are critical to getting SLR understood by general public. For example, a topographic relief map of the area that can be inundated at different levels of SLR or 3-D computer simulations.
	Communicate ecosystem services valuation to policy makers and the general public.
	Educate about how important planning is. For example, with respect to wastewater treatment planning, how do we avoid compromising the integrity of the system? Talk in terms of dollars.
	Conservationists should hire communications, public relations and marketing firms to bring important messages to target audiences.
	Require policy makers to have some science training.
	Train/educate scientists how to communicate messages.
	Get into situations where you will reach new audiences. Stop preaching to the choir.
	Get funding agencies and other supporters to pay for marketing and communications.

	Use Sea Grant model to reach new audiences, those that should use the information.
	Get insurers/reinsurers to use the web tools, also suits and ties.
	Workshop participants should continue the conversations on SLR.
	Identify message and scenario.
	Educate state legislators regarding why coastal resources matter to all in state and country.
	The SLR debate is still on whether it is happening. Collect local evidence on SLR, get information out to schools, etc.
	Oral history of long-time residents to document how the environment is being seriously impacted.
	Communities other than scientists use stories not PowerPoint. Develop stories to get our points across.
	On Google Earth create a line that shows where beaches have migrated over time.
	Wetlands provide carbon sequestration, get the message out.
	USDOI - Idle iron - decommissioning steel structures - revisit.
	Get a Public Service Announcement ready to go for release during storm events with parallel PSA on climate change and SLR impacts.
	Develop responses to papers, call to action.
	Create messages that illustrate how natural resources have an impact on people's lives.
	Show more immediate impacts (100 year time horizon) that people can comprehend and services provided by natural systems that could be lost.
	As an education tool, stakeout in the city where 2100 SLR projections will affect land, e.g., create SLR/surge markers as an art project.
	With respect to disaster response, communicate the importance of natural resources as a protective barrier and make connections with the available data.
	Link ecosystem services to SLR with people and stakeholders, e.g., fisheries. Target fishable population areas. Use as education tool vested interest in ecosystem services, ex. CCA advocacy.
	Link charismatic species (ex. Whooping crane) with ecosystem services and habitat function; link to species survival. As educational messaging.
	Create a poster to promote adaptation strategies, for example zoning changes.
	Develop an effective campaign (ex. Smokey the Bear) to change the way people think about SLR impacts.
	Emblematic species represent SLR along the Gulf Coast; also recycling campaigns anti-otter were very effective in changing our attitudes and behaviors.

	Develop PSAs for storm smart communities. Funding is needed to develop commercials to change perceptions and actions.

Pre and Post Workshop Survey Results

Below we provide a summary of the pre- and post-workshop survey results as well as an overall assessment based on the pre- and post-workshop surveys. Complete surveys and responses are provided in Appendix 9.

Summary of Pre-Workshop Survey Responses

The respondents have a good general sense of what may happen to coastal wetlands in the Corpus Christi Bay area in the next 100 years as a result of SLR. They understand that SLR will bring direct as well as indirect effects and that no areas will be unaffected. Regarding species impacts, respondents are particularly concerned about 4 species of coastal birds: black skimmer, piping plover, snowy plover, Wilson's plover; as well as birds nesting on rookery islands. In addition, they are concerned about sea turtles nesting in the area, a common saltmarsh grass, *Spartina alterniflora*, and humans. Respondents recommended a variety of adaptation strategies. The most frequently identified strategies they recommended were keeping new development in areas less vulnerable to SLR, protecting infrastructure, and minimizing barriers to upslope migration of coastal wetlands.

Summary of Post-Workshop Survey Responses

Some respondents were surprised at the types and magnitude of change in wetland distribution with SLR. Other new information provided by the workshop as identified by respondents included the number of vulnerable species and pollution sites. Some respondents changed their perceptions of what species were most vulnerable to SLR in the study area and some did not. As with the pre-workshop survey, coastal birds received the most mention. Respondents also expressed concern for estuarine dependent species such as terrapin and fish, also shrimp. As with the pre-workshop survey, respondents identified a range of adaptation strategy types. Unlike the pre-workshop survey, education, outreach and communication topped the list of recommendations. Other frequently identified strategy types included conservation of natural areas, protecting beaches and shorelines, and tax & market based approaches.

Workshop Influence Based on Survey Results

While prior to the workshop, respondents had a good general sense of what would happen to the coastal wetlands in the study area in response to SLR over the next 100 years, they were not aware of the types and magnitude of predicted change. Regarding potential species impacts, respondents had a good sense that coastal birds were vulnerable and this perception did not change although they added concern for other estuarine dependent species. After learning about the specific types of changes predicted to be brought about by SLR, respondents adjusted their recommendations for the types of adaptation strategies needed. In summary, the workshop appears to have influenced the participants responding to the surveys both in what they understand about the consequences as well as what they believe are the most appropriate actions to take to better adapt to SLR.

Mobile Bay Study Area

The Stakeholder Workshop for the Mobile Bay study area was held on June 13, 2012 in Mobile, Alabama with 29 people in attendance. Attendee affiliations included state agencies and programs, local governments, House of Representatives, federal agencies and programs, and non-profit organizations, (Table 9-2, Appendix 9).

Adaptation Strategies Developed at the Workshop

Stakeholders developed a diversity of adaptation strategies from each of our identified categories (Table 37) except emergency response planning and conservation of marine life (Table 39), strategies having to do with education, outreach and communication dominated the recommendations with 37 individual strategies. Other frequently identified categories of adaptation strategies for these stakeholders included research (n=20) and land use planning and building regulation (n=14).

Table 39. Mobile Bay Study Area locally relevant adaptation strategies developed by workshop participants.

Type and Number of Adaptation Strategies Developed at Mobile Bay Area Stakeholder Workshop	
Adaptation Type	**Recommended Strategies**
Land use planning and building regulation (n=14)	Limit development in overlay planning area
	Create Coastal Protection Areas. Use FEMA FIRM maps as a guide, especially in the most vulnerable areas to protect the greater good.
	Improve mapping of riparian areas; NWI – FEMA need updated
	Map critical components, e.g., water quality is affected by erosion.
	Identify how human migration will affect the environment.
	Focus more on adaptation rather than resiliency. Make progress on active retreat.
	Establish state level set back requirements to take the pressure off local governments which find it difficult to say “no” to development.
	Change municipal zoning ordinances (subdivision regulations; plats) to state that city streets will not be (re)built in flood prone and high hazard areas – must be (re)built and maintained by homeowners.
	Avert the weakening of the Coastal Barrier Resources System (CBRS).
	Create/enhance planning programs that can integrate science and research.
	Revise comprehensive plans to accommodate SLR with re-zoning, etc. Change future land use locations.
	When revising the comprehensive plan, hire a consultant that will take into account SLR and other proactive environmental changes.

	Put the requirement to address SLR right into the RFP.
	Change permitting rules to require that SLR is addressed if project is below a certain elevation.
	Adapt existing policies to incorporate SLR planning and adaptation (rather than make new ones)
Tax and Market-based approaches (n=5)	Let repetitive loss happen without compensation to drive people out of areas.
	Tell homeowners who buy in highly vulnerable areas what they are facing. If there is no legal public obligation to rebuild roads and provide services don't. Require residents to finance their own improvements in highly vulnerable areas.
	Remove incentives that encourage development in coastal areas.
	Create incentives for coastal homeowners' to implement adaptation strategies.
	Have state/feds create incentives for smaller communities to develop adaptation strategies.
Conservation of species (n=2)	Protect refuge locations for rare species inshore and upland, and corridors to connect to protected areas.
	May have to stop focusing on species that will not do well with SLR (i.e., chance of persisting very low). Focus Instead on species that like oysters that will do well with SLR.
Land protection (n=3)	Create programs to purchase lands in low-lying areas
	Get GIS layers into hands of local government
	Reauthorize Alabama's Forever Wild – Educate the public to pass program reauthorization; great tool to deal with SLR; SLR not specifically addressed in decision-making; Add SLR to scoring criteria.
Conservation of natural areas (n=5)	Increase protection measures for freshwater wetlands by requiring mitigation by watershed and migrate mitigation areas further up into the watershed.
	Focus on restoration sites that meet multiple objectives.
	Incorporate SLR issues into statewide restoration plan.
	Hold firm on mitigation areas. Do not let them be repurposed for development as sea level rises.
	Demonstration projects are good – keep it in front of people. For example, oyster reef as shoreline stabilization – protects both infrastructure and coastal ecosystems.
Water supply and delivery; water resources (n=2)	Create a statewide strategy for water management; Flows by basin. What is the policy for moving water or water withdrawals . The Department of Economic and Community Affairs is just beginning to tackle this.
	Need a water resources policy for the state of Alabama.
Transportation and infrastructure (n=8)	Create and implement an infrastructure adaptation plan now.
	Map the roads that may become inundated.

	Deal now with Thee Mile Creek, an unmaintained landfill with contamination close to high tide.
	Turn the causeway into a bridge to benefit both the human and natural environment, a win-win strategy.
	Develop economic hooks to get people interested in SLR; Docks, Port Authority, Coast Guard. Inquire with them how they are dealing with SLR.
	Prioritize pollution facilities at risk and create a program to deal with these threats. There are potentially huge impacts near tidal waters.
	Incorporate SLR into infrastructure planning and restoration projects.
	Update roadways that are vulnerable to SLR. Prioritize based on transportation needs, e.g., causeway, Dauphine Island Causeway, etc.
Beaches, beach and shoreline management (n=5)	Improve communication between agencies regarding the beneficial use of dredge materials and beach renourishment. Both provide a storm buffer for human and natural communities.
	Develop a plan for the beneficial use of dredge material now. Develop criteria and have projects ready to go and pre-approved now by agencies for use post disaster.
	Use of band aid strategies in the near term is okay. For example, keep barrier islands in place a while longer (20 year time frame?).
	Pass a dredge material beneficial use law that requires ecologically beneficial use as first choice.
	Relate beach renourishment to SLR.
Research needs (n=20)	Develop an adaptive monitoring tool and SOP for all agencies for SLR.
	Monitor riparian areas for SLR change.
	Hire a resource economist to calculate the resource values that will be lost with SLR: stormwater attenuation, oysters, fishery losses, etc. Examine how the breakwaters and causeways are exacerbating these changes as well.
	Is there a legal obligation for local and state governments to rebuild in highly vulnerable areas post disaster?
	Conduct research on disturbance ecology in coastal areas.
	Create funding mechanisms to pay for monitoring of ecosystem changes.
	Use information from models to determine where we can have the greatest impact (i.e., the greatest benefit for the community). Link economic gains and losses.
	There is a wealth of monitoring done now – figure out how to use it for SLR benefit.
	Conduct more restoration research.
	USE SLR modeling to locate monitoring locations.

	Map out low lying areas including riparian and adjacent areas. Map out high erosion areas. There are currently a lot of inaccuracies in the NWI and FEMA maps.
	Have a resource economist value the value of the habitat lost and the fisheries and oyster values that will be lost.
	What are the ecosystem service adjustments after a major coastal surge event? What if we disrupt coastal surges with development? How does this change the system ecology?
	Improve our understanding of incremental SLR. How will meteorologically extreme events affect us?
	Conduct monitoring research to document changes.
	Where will vulnerable fishing communities in vulnerable coastal areas relocate to? For example, the communities in Bayou Le Batter? Where will marinas move to?
	How will native fish communities move?
	Monitor water quality attributes to better predict where they will move.
	Value ecosystem services to better understand how SLR will change these values.
	Look into where the fishing boats and marinas should be relocated.
Miscellaneous/General Comments (n=2)	Identify a handful of strategies that affect multiple industries, etc. and focus on strategies that provide the greatest benefits, ex. Dune restoration protects property, some species, infrastructure, maybe water resources, etc.; Have projects ready to go; Get diverse stakeholders to promote for implementation.
	Continue to adapt our adaptation strategies.
Education, outreach and communication (n=37)	Map fossilized oyster reefs as educational tool, to show how they have moved up the bay.
	Figure out ways to make SLR matter to politicians.
	Create user-friendly models that can be used by planners, e.g., decision support tools and modeling tools.
	Improve communication among entities dealing with SLR planning; improve communication with elected officials
	Improve education about SLR implications at all age groups.
	Educate elected officials as a separate group without press. Targeted stakeholder meetings.
	Educate the Governor’s Office about the protective benefits of beach renourishment and beneficial use of dredged materials.
	Educate high level state staff on the above issues as they are not on a short-term political cycle.
	Compile compelling information that makes the case that we should implement adaptation strategies sooner rather than later.
	Educate about changes in sea level over the last 15,000 years. Look to the geological history. Barrier islands and river flood plains are a

	bad place to build. Teach people how to read tope maps.
	Educate planning staff about the historic rise of sea level especially the long-term view.
	Support education (environmental education) on SLR and its impacts. Make SLR impacts part of the state environmental science curriculum.
	Grassroots education campaign, because people will demand it of their politicians.
	Hold elected officials accountable through grassroot approaches; Raise awareness in the community as a way to effect change.
	Make discussion of SLR more personal/more direct.
	Keep the discussion of SLR in front of the public and public officials, e.g., impacts on utilities, sewers, gas lines, etc.
	Encourage the press to keep discussing SLR.
	Place markers or other visuals, e.g., where the water was 50 years ago.
	Hold an ecological symposium for county commissioners. Work through scenarios with them. For example, How will ecological services change?
	Get SLR discussions integrated into school curriculum.
	Develop an application for SLR education.
	Use impacts to fishing communities and other industries as a mechanism for engaging these communities in education campaigns, e.g., "This is how SLR will affect your insurance rates, your job, etc."
	Form a national coalition of stakeholders to focus on SLR; Have conferences; Develop strategies to take to the politicians.
	Have diverse group of stakeholders state what is important to them so that you have something ready to present to politicians.
	Hold a contest "What is the legal coastal community?"; What policies should be in place?
	Create a Sim City climate change and/or SLR version.
	Distribute T-shirts "Death, Taxes and SLR"
	Use social media to spread the word about SLR – work it into a competition/rivalry
	Create websites that deliver tools and information on SLR.
	Look at North Carolina and make sure we don't make the same mistake silencing state employees with respect to considering accelerated rates of SLR.
	Use interactive web GIS technology to try and show the real-time and recent past SLR, visually for the lay people; Make relevant to local areas.

	Create a business coalition on the coast that demands adaptation to SLR. e.g., LA-1 coalition – oil industry creating adaptation strategies to continue operation in the face of SLR.
	Facilitate shift in thinking from why Global CC exists to what we do about it.
	USE NEPS to continue discussion on and implementation of adaptation strategies.
	Add SLAMM result layers to the habtools.org
	Don't leave regional planning commissions out of the loop; educate them and include them in SLR forums.
	Enhance communication regarding the cost effectiveness of beach renourishment. The alternative is much greater FEMA dollars spent.

Pre- and Post-Workshop Survey Results

Below we provide a summary of the pre- and post-workshop survey results as well as an overall assessment based on the pre- and post-workshop surveys. Complete surveys and responses are provided in Appendix 9.

Summary of Pre-Workshop Survey Results

Most respondents have a good sense of what is happening to coastal wetlands in the Mobile Bay area and some have very specific ideas on what will happen. While a few respondents were unable to identify specific areas that will be unaffected by SLR, several did and a few specified that no areas would be unaffected. Respondents identified a diversity of species that would be vulnerable to SLR impacts. The greatest number of responses concerned shorebirds, in particular the piping plover and snowy plover as well as other shorebird species that nest in the area. In addition, respondents noted concern for submerged aquatic vegetation, oysters, terrapins, and beach mice among other vertebrates, invertebrates and plants. Respondents recommended a variety of adaptation strategies. The most frequently identified strategies were keeping new development in areas less vulnerable to SLR; education, outreach and communication; keeping infrastructure operational; and managing beaches and shorelines more appropriately.

Summary of Post-Workshop Survey Results

Regarding new information learned at the workshop, several respondents were surprised at the types and magnitude of predicted change in wetland distribution with SLR, but one was not. Other respondents were surprised by or hadn't thought about impacts to infrastructure, the economy and native species. Several respondents changed their perceptions of what species were most vulnerable to SLR in the study area, a few did not and a few did not answer the question. Those that changed their responses focused on those species included in the vulnerable species analysis presented as part of the workshop (red-bellied turtle, beach mouse, saltmarsh snake and plovers). As with the pre-workshop survey, respondents identified a range of adaptation strategy types. Unlike the pre-workshop survey, education, outreach and communication dominated the list of recommendations. Another frequently identified strategy type included land use planning and building regulation.

Workshop Influence Based on Survey Results

Prior to the workshop, respondents displayed a good level of knowledge about what would happen to the coastal wetlands in the study area in response to SLR over the next 100 years. However, they were not as aware of the specific types and magnitude of predicted change. Regarding potential species impacts, respondents identified a number of species that could be vulnerable. Their perceptions changed somewhat after the workshop with several respondents specifically identifying the vulnerable species that had been discussed in a workshop presentation. After learning about the specific types of changes predicted to be brought about by SLR, respondents somewhat adjusted their recommendations for the types of adaptation strategies needed. While education, communication and outreach and land use planning and building regulations still dominated their responses, in the post-workshop survey respondent adaptation recommendations were more heavily weighted towards the former. In summary, the workshop appears to have influenced the participants responding to the surveys both in what they understand about the consequences as well as what they believe are the most appropriate actions to take to better adapt to SLR in their area.

Pensacola Bay Study Area

The Stakeholder Workshop for the Pensacola Bay study area was held on June 16, 2011 in Gulf Breeze, Florida with 36 people in attendance. Attendee affiliations included state agencies and programs, local governments, Florida House of Representatives, federal agencies and programs, Air Force, Navy, non-profit and civic organizations and a planning council (Table 9-3, Appendix 9).

Adaptation Strategies Developed at the Workshop

Stakeholders developed a diversity of adaptation strategies from each of our identified categories except conservation of species (Table 40). Strategies having to do with research had the most recommendations (17). Other frequently identified categories of adaptation strategies for these stakeholders included and use planning and building regulation (n=7), emergency/disaster response planning (n=8) and education, outreach and communication (n=7).

Table 40. Pensacola Bay Study Area locally relevant adaptation strategies developed by workshop participants.

Adaptation Type	Strategy Recommendations
Land use planning and building regulation (n=7)	Change the local development permitting process for shoreline armoring and construction.
	Develop state policy to identify conditions under which differently designated public lands can or should armor their shorelines.
	Redefine the use of "eminent domain".
	Take advantage of new authority to designate "Adaptation Action Areas" that are at risk for coastal flooding and in which different rules can be developed.
	Change regulatory/mitigation/permitting language that requires maintenance of conditions that will change with SLR to at least recognize SLR in the permit and perhaps create a special condition for altered implementation.
	Revise Florida statutes to require coastal wetland buffers as needed to protect adjacent developed areas from SLR and storm surge. Sovereign state lands would change, and what you can do on them would change.
	Through permitting decisions, discourage development in areas projected to be affected by SLR over the next 100 years.
Emergency/Disaster Response Planning (n=8)	Revise FEMA policies to require that recovery funds be allocated to the "best" location for rebuilding rather than to the original footprint.
	Expand FEMA's ability and authorization to map future hazards.
	Increase funding for flood mitigation assistance programs, FEMA, and other hazard mitigation programs so counties can afford to implement adaptation strategies.
	Require FEMA to hold on to land acquired after a disaster rather than turn it over to local government unless local government agrees not to sell the property without a conservation easement.
	Use post-disaster recovery plans to identify developed land that should become conservation land.
	Modify the Post-disaster Recovery Plan to target areas for acquisition after their infrastructure has been destroyed in a storm or flooding event.
	Require that FEMA pay-offs are linked to agreement for a rolling easement.
	Require FEMA programs to provide funding to local governments to maintain/manage property once they get it.
Tax and Market-based approaches (n=4)	Incentivize both movement from the coast and freshwater flow and sediment management upstream by having downstream beneficiaries compensate for the upstream management – thus rewarding upstream management and making coastal living even

	more expensive.
	Buy-out property owners with emergency funding allocated post-disaster rather than fund them to rebuild.
	Amend flood control policy to use flood insurance to disincentivize building in SLR and storm surge vulnerable areas and use the funding instead to support retreat from the coastline rather than rebuilding.
	Develop dynamic flood insurance maps that support incentives to abandon areas with high probability of repeated flooding.
Land protection (n=5)	Protect the ability of systems to migrate inland – through protection of the eastern shore of East Bay and parts of the Escambia and Yellow Rivers and Garcon Point.
	Protect land that will allow dispersal of threatened species.
	Maintain connectivity for species both inland and across barrier islands.
	Use the SLR modeling results to prioritize upland sites for protection before development migrates to those sites..
	Increase budget for Sea Grant acquisition program so they can protect coastal land.
Conservation of natural areas (n=5)	Convene a panel to develop restoration guidelines for incorporating future SLR into projects.
	Increase seagrass plantings and living shorelines to increase resilience to SLR.
	Identify the gaps in connectivity of the system and evaluate with respect to SLR and vulnerability to development
	Co-locate wellfields with habitat connectors.
	Manage fire and invasive species and restore wetlands on conservation lands to increase their resilience to SLR Be vigilant on newly created wetlands to foster growth of native versus invasive, non-native species.
	Triage sites for management, focusing on those that will not be converted to other habitats and those that need restoration so new habitats will be functional (e.g., restoring freshwater flows).
Conservation of marine life (n=3)	Remove infrastructure before inundation if it will threaten viability of coastal systems /or species.
	Address potential threats from superfund sites, deep injection wells, and other facilities that will pollute new coastal habitat as it forms.
	Require interstate coordination on habitat management for regional fisheries (e.g., shrimp and crab).

Water supply and delivery; water resources (n=5)	Assist homeowners with reducing reliance on individual wells by providing access to a regional water supply.
	Regionalize water supply on the barrier island Gulf Breeze Peninsula, and on the mainland.
	All homes in the study area should be on central sewer systems.
	Restore and maintain freshwater flows, taking care not to mobilize pollutants or allow their movement to new areas.
	Prevent diversion of freshwater flows from the Yellow and Shoal Rivers to reservoirs.
Transportation and infrastructure (n=2)	Engage industrial and commercial maritime industries and the business community to identify how SLR will impact them.
	Require that the National Seashore Coastal Road be constructed out of a substance that does not impede dune formation when fragmented by storm events.
Beaches and beach management (n=4)	Require planting of dune vegetation if it allows movement of beach mice even across areas adjacent to development.
	Prohibit beach renourishment material from being mined from Aquatic Preserves.
	Restore living shorelines without threatening other values (e.g., sturgeon habitat) at : 1) mid-upper Garcon Point; 2) conservation areas; 3) properties of large land-owners.
	Deposit dredge material from Pensacola Bay in strategic areas rather than dumping the material offshore.
Research (n=17)	Develop a sediment budget for the region.
	Investigate the effects of salt intrusion and ground water level on infrastructure.
	Monitor sea grass restoration in Pensacola Bay. Determine whether restoration guidelines developed for Tampa Bay that take SLR into account will apply here.
	Reanalyze water movement patterns and pollutants under sea water intrusion scenarios.
	Identify the habitat(s) that serve as movement corridors for beach mice.
	Identify sensitive areas – current and with additional SLR.
	Develop case study on the failed activated septic system policy to understand why the approach failed.
	Evaluate wetland buffer zones
	Assess the economic value of resources threatened by SLR
	Use hydrologic flow path analysis with a groundwater model to identify the best places for hydrological restoration
	Conduct storm surge modeling with projected SLR and hurricane effects

	Quantify ecosystem services from new coastal systems relative to protected lands (that will become coastal).
	Conduct appropriately scaled cost/benefit analysis on shoreline hardening and other responses to SLR
	Identify policies/programs that are currently mandated into which SLR can be incorporated
	Identify where upstream development would negatively impact downstream communities and habitats so they can be protected through comprehensive plans and land/water protection.
	Use coastal and marine spatial planning methods to identify where SLR will impact current maritime industries and businesses.
	Conduct cost/benefit analyses by type of public land (park, aquatic preserve, etc.) for shoreline armoring.
Miscellaneous/general comments (n=1)	Take advantage of post-hurricane window to emphasize and promote SLR adaptations.
Education, outreach and communication (n=7)	Develop artist renderings of likely SLR changes in landscapes that resonate with the public.
	Educate the public about the dynamism of natural systems so they support policy that can also adapt as needed to SLR changes.
	Conduct outreach to local governments on how to address SLR.
	Educate state policy-makers on the need to amend permitting to avoid SLR impacts and costs.
	Use Florida Association of Counties meetings as an opportunity to educate county commissioners that SLR considerations need to be comprehensive plans and land development codes.
	Use education, outreach, and social marketing to develop and informed public willing to act on SLR.
	Implement adaptation demonstration on federal sites.

Pre- and Post-Workshop Survey Results

Summary of Pre-Workshop Survey Results

Thirty-one workshop attendees participated in the survey. Most respondents had a very good idea of what is likely to happen to coastal wetlands in the Pensacola Bay area. Several respondents identified areas that are likely to be unaffected by SLR and several specified that no areas would be unaffected. Respondents identified a diversity of species that would be vulnerable to SLR impacts. The greatest number of responses concerned birds (shorebirds, migratory birds, wading birds, sea birds, piping plover and snowy plover; n=14), the beach mouse (n=13), marsh plants (specifically *Spartina* and *Juncus*; n=11) and sea turtles (n=8). Respondents recommended a variety of adaptation strategies. The most common strategies identified were land protection (n=15); land use planning and regulation (n=12); tax and market-based approaches (n=7); and beaches, beach and shoreline management (n=7).

Summary of Post-Workshop Survey Results

Twenty-four workshop participants completed the post-workshop survey. Several of these respondents were surprised at the types and magnitude of change in wetland distribution with SLR. Other respondents were surprised by the location of the change and the impacts on the species that rely on coastal wetlands for habitat. Only half of the respondents (n=12, changed their perceptions of what species were most vulnerable to SLR in the study area. Those that changed their responses noted the beach mouse, shorebirds, freshwater coastal forest species (e.g., cypress), fish and a variety of others. As with the pre-workshop survey, respondents identified a range of adaptation strategy types. After the workshop, respondents focused to a much greater extent on adaptation strategies involving education, outreach and communication (n=19). Other common strategy types included land protection (n=9); emergency/disaster response planning (n=7); land use planning and building regulation (n=6); and conservation of species (n=5).

Workshop Influence Based on Survey Results

Prior to the workshop, respondents displayed a very good level of knowledge about what would happen to the coastal wetlands in the study area in response to SLR over the next 100 years. However, they were not as aware of the specific types and magnitude of predicted change. Regarding potential species impacts, respondents identified a number of species they felt were vulnerable to SLR impacts. Following the workshop, only half of the respondents changed what species they felt were most vulnerable to SLR, Most changes reflected the species most identified by respondents prior to the workshop. After learning about the specific types of changes predicted to be brought about by SLR, respondents substantially adjusted their recommendations for the types of adaptation strategies needed. While land protection strategies dominated responses in the pre-workshop survey, the most frequently identified type of adaptation strategy selected in the post-workshop survey was education, communication and outreach. Land protection strategies remained frequently cited, but land use planning and building regulation strategies lost appeal following the workshop. In summary, the workshop influenced the participants responding to the surveys both in what they understand about the consequences as well as what they believe are the most appropriate actions to take to better adapt to SLR in their area.

Southern Big Bend Study Area

The Stakeholder Workshop for the Southern Big Bend study area was held on October 13, 2011 in Crystal River, Florida with 35 people in attendance. Attendee affiliations included state agencies and programs, local government agencies, elected officials, federal agencies and programs, non-profit organizations and planning organizations (Table 9-4, Appendix 9).

Adaptation Strategies Developed at the Workshop

Stakeholders developed a diversity of adaptation strategies from each of our identified categories (Table 41). Strategies having to do with research had the most recommendations with 23 individual strategies. Other frequently identified categories of adaptation strategies for these stakeholders included land use planning and building regulation (n=11); water supply and delivery; water resources (n=8); and education and outreach (n=8).

Table 41. Southern Big Bend Study Area locally relevant adaptation strategies developed by workshop participants.

Adaptation Type	Strategy Recommendations
Land use planning and building regulation (n=11)	Develop critical areas of concern and require an advanced wastewater treatment plant to service these areas. Upgrade local areas that are not now on sewer.
	Adjust the current Department of Health sewage treatment line that requires secondary treatment within one mile of the coast taking SLR into account.
	Incorporate SLR into the language of comprehensive plans, both coastal and interior plans.
	Streamline the permitting requirements for living shorelines.
	Define an adaption area in comprehensive plans and adopt FWC's wildlife friendly subdivision design.
	Never waste a crisis, be ready with policy. For example, create policies that identify areas where we will not build bridges or repair a sewer system. See http://www.floridahabitat.org/wildlife manual and BMPs for Florida communities and landowners.
	Maintain and enhance Florida's existing land use planning efforts.
	Adaptation –UF Law – looked at this relevant to properties. Some reports to this effect. Incorporate into local planning and to home purchase process.
	Local governments should add SLR risk into deeds and zoning before development is permitted/re-zoned. Improve coordination between agencies and local government.
	Develop comprehensive plan policies to protect caves, which are karst windows into the aquifer and can be critical to understanding climate change.
	Place a "Notice of Proximity" on property in danger zones. Add something into people's deeds "You're buying coastal forestland in Florida".
Emergency/disaster response planning (n=2)	Integrate strategies for natural infrastructure into pre and post disaster agency plans as a response to SLR.
	See the UF Law Department drafts of comp plan amendments that accommodate different types of hazard areas.
Tax and market based approaches (n=5)	Create a buyout program for coastal property owners. Address at the state level (legislative fix) and in the best interest of all.
	Raise insurance rates in coastal areas at high risk of inundation/ flooding to prohibitively high levels. Don't let insurance of highly vulnerable lands be pooled with less vulnerable lands.
	Revise the insurance and reinsurance industries to take into account the full cost accounting of coastal properties.
	Use tax increment financing of cultural resource projects, a tool used by our resource development agencies to eliminate blight. Establish a base rate for taxes.
	Realistically value coastal property taking into consideration higher insurance needs, sewage, shoreline stabilization, etc.

Conservation of species (n=2)	Promote assisted migration for selected species and habitats. Focus on common species with narrow habitat requirements (rather than the most imperiled that may not survive).
	Identify critical wildlife linkages that will be flooded in the future and identify upland alternatives. See UF/Noss/FNAI work. For example, Chassahowitzka to Green Coastal forest critical wildlife linkage, Caber Coastal Connector (part of the Florida ecological greenways linkage), Goethe to Waccasassa to Rainbow connections.
Land protection (n=1)	Identify and protect coastal scrub that is not already in public ownership, especially in Levy County.
Conservation of natural areas (n=4)	Establish greenways (fee simple and conservation easements) to link core habitats. Identify and prioritize where the critical linkages are to direct funding.
	Design restoration projects to accommodate coastline migration at the site and regional scale.
	Conserve/restore natural habitats that act as natural storm buffers.
	Ensure that future conservation efforts incorporate SLR impacts. What resources are we potentially losing? How do we protect underserved species and habitats?
Conservation of marine life/habitat (n=2)	Restore oyster reefs in inshore areas to mitigate erosion, provide habitat and protect natural and human coastal communities from storm impacts.
	Monitor the deep edge of seagrass beds in relationship to water depth. Is seagrass moving shoreward as SLR progresses?
Water supply and delivery; water resources (n=8)	Don't permit new development without first determining whether water supply is available to meet the needs of the new development.
	Move or alter septic and sewer systems that are likely to be inundated.
	Protect freshwater flows from springs to protect manatees.
	Eliminate all landform alterations that inhibit freshwater flow to the Gulf. Catalog and prioritize these to direct funding. Example: Restore culverts to ambient grade.
	Restore priority freshwater flow alteration structures to restore/maintain freshwater flows to estuaries.
	Maintain and enhance Florida's existing water planning efforts (WMD authority).
	Establish a valid SLR component to MFL decisions.
	Establish MFLs that meet historic levels by reducing pumpage, establishing conservation measures and reducing impervious surface (modeling suggests 1% of the impact).
Transportation and infrastructure (n=2)	Replace septic wastewater and stormwater treatments systems that are going to be inundated to a higher elevation.
	Make value/area of infrastructure at risk available so it's understood that good planning saves money.
Research needs (n=23)	Need more information on vegetative response to climate change. Where the tipping point is for that community. Conduct vulnerability assessments for species/communities.

	Identify SLR trigger points at which specific SLR measures are implemented.
	Study offshore sandbars and oyster bars to better understanding how they function to enhance restoration.
	Determine what ecosystem services would be affected by SLR and how this information could be used to help preservation of coastal wetlands. Examine if a payment system would be effective.
	Examine the consequences of limerock mining in terms of impacts on hydrology and natural communities.
	Identify trigger points of SLR at which specific adaptation strategies are implemented. Use rate rather than level and evaluate annually. The thresholds should be locally determined, but the guidelines should be identified at the regional or statewide scale.
	Apply SLOSH modeling to identify where septic tanks will be inundated due to storm surge and SLR.
	Improve our understanding of land economics at the local level in terms of how insurance influences development and land use behavior.
	Determine what the trend is towards human migration inland and what pressure this puts on resources inland. Project these types of human impacts. Identify areas that should go into conservation. Are there newly vulnerable species related to these new threats?
	Determine what visual materials are easily understood in rural communities. (SLR visualization approaches for rural communities. GIS maps are not it).
	Further develop our understanding of the dynamic between coastal ecologies and archaeological resources.
	Enhance our understanding of how much water is coming out of the aquifer and where. Improve our understanding of natural fluxes and location of saltwater wedge over time. Improve our understanding of aquifer flow through karst.
	Examine where the conservation areas are now and which habitats and species will be underserved in the future. What habitats and species do we value?
	Conduct a spatial analysis of how historic landform alterations have impacted water flow.
	Research oyster restoration structure development in Suwannee Sound.
	Work SLAMM and SLOSH together to identify comprehensive risks to areas. (Integrate SLAMM And SLOSH together (HAZUS).
	Study traditionally disadvantaged coastal communities to preserve cultural heritage.
	Evaluate the dynamic between past people and development patterns and their impact on natural systems and vise-versa to understand the future.
	Collect better data on which to base models (Accretion and sedimentation map).
	Conduct a spatial analysis of how historic landform alterations have impacted water flow.
	Use the 2 m SLR levels that recognize episodic erosion through surges.
	Improve our understanding of vegetative response to SLR and other climate

	change in terms of composition.
	Identify how offshore reefs/ features act like barrier islands and how they could be enhanced/mimicked.
Miscellaneous/ General Comments(n=6)	Inventory archaeological sites to prioritize for excavation.
	Establish the roll of subsidence in coastal modeling.
	Develop useful metrics for evaluation adaptation strategies.
	Focus adaptation on surge impacts and accelerated rates of SLR due to surge.
	Identify, inventory and prioritize archaeological sites. Excavate important archaeological sites prior to inundation.
	Better differentiate on maps difference between brackish and salt marsh.
Education and Outreach (n=8)	Target data for specific audiences in terms of content and distribution methods.
	Improve networking to enhance coordinated decision-making.
	Public outreach and education should reach beyond environmental issues alone and should include information on quality of life and our children's future. Children will become our new advocates.
	Enhance public education and outreach beyond the environmental community to reach non-specialists and non-technically oriented. Don't preach to the choir.
	Implement a SLR curriculum for schools (so that parents learn too).
	Develop exercises and experiments for local schools to better understand SLR and its impacts.
	Define who our target groups should be and package our data so that they can use it. It needs to mean something to them for effective distribution of the data. Ex. ACOE talked about land acquisition in the high impact zones. People got defensive, felt like their land was going to be taken away.
	Educate people moving into Florida about wet and dry seasons, etc.

Pre- and Post-Workshop Survey Results

Summary of Pre-Workshop Survey Results

Sixteen workshop attendees participated in the pre-workshop survey. Many respondents had informed ideas about what is likely to happen to coastal wetlands in the Southern Big Bend area as a result of SLR (full results in Appendix 9). When asked what areas would be unaffected by SLR, several respondents answered that no areas would be unaffected (n=5) and several did not know (n=4). Those that did identify areas likely to be unaffected by future SLR specified high areas (n=3), inland areas (n=2) and marsh habitat (n=2). Most respondents identified a diversity of species that would be vulnerable to SLR impacts. A few respondents weren't sure or didn't know (n=4) which species would were vulnerable to SLR impacts. Of the species identified as vulnerable, the most mentioned were oysters (n=5), sabal/cabbage palm (n=4) and red cedar (n=3). Other species mentioned more than once include cypress (n=2), clams (n=2), manatees (n=2) and the diamondback terrapin (n=2). Respondents recommended a variety of adaptation strategies for SLR, most of which can be implemented at the local level. The most frequently identified strategies noted fell into the following categories land use planning and regulation (n=8); land protection (n=4); and education, outreach and communication (n=4).

Summary of Post-Workshop Survey Results

Twenty-nine workshop attendees participated in the post-workshop survey. Most respondents learned a variety of new information from the workshop with a few mentioning the SLAMM results (full results in Appendix 9). A couple of respondents answered that the information presented at the workshop was nothing new to them. Those that did learn something from the workshop learned not only from the formal presentations, but from each other. Approximately half of the respondents (n=15) changed their perceptions of what species were most vulnerable to SLR in the study area, five did not change their perception and the rest did not answer the question or provided general comments. Those that changed their responses noted oysters (n=3), hydric hammock species (n=3) and the mole skink (n=2). As with the pre-workshop survey, respondents recommended a range of adaptation strategy types. However after the workshop, respondents focused to a much greater extent on adaptation strategies involving education, outreach and communication (n=22). Other frequently identified strategy types included water supply and delivery/water resources (n=9); tax and market-based approaches (n=8); conservation of natural areas (n=7) research needs (n=7) and transportation and infrastructure (n=5).

Workshop Influence Based on Survey Results

Prior to the workshop, respondents displayed a very good level of knowledge about what would happen to coastal wetlands in the study area in response to SLR over the next 100 years. However, they were not as aware of the specific types and magnitude of predicted change. Regarding species most vulnerable to SLR impacts, about half of the respondents changed what which ones felt were most vulnerable to SLR. After learning about the specific types of changes predicted to be brought about by SLR, respondents substantially adjusted their recommendations for the types of adaptation strategies needed. While land protection strategies were most selected by respondents in the pre-workshop survey, the most frequently identified type of adaptation strategy selected in the post-workshop survey was education, communication and outreach. While water supply and deliver/water resource type strategies were not frequently identified in the pre-workshop survey (n=3), identification rate rose in the post-workshop survey (n=9). Conversely, land use planning and building regulation type strategies were frequently identified in the pre-survey (n=8) but lost favor in the post survey (n=2). In summary, the workshop influenced the participants responding to the surveys both in what they understand about the consequences as well as what they believe are the most appropriate actions to take to adapt to SLR in their area.

Tampa Bay Study Area

The Stakeholder Workshop for the Tampa Bay study area was held on March 14, 2011 in St. Pete Beach, Florida with 35 people in attendance. Attendee affiliations included state agencies and programs, local government agencies, State House of Representatives, federal agencies and programs, non-profit organizations and planning organizations (Table 9-5, Appendix 9).

Adaptation Strategies Developed at the Workshop

Stakeholders developed a diversity of adaptation strategies from each of our identified categories except conservation of species; conservation of marine life; and water supply, delivery and water resources (Table 42). Strategies having to do with research had the most recommendations with 21 individual strategies. Other frequently identified categories of adaptation strategies for these stakeholders included education and outreach (n=13) and land use planning and building regulation (n=8).

Table 42. Tampa Bay Study Area locally relevant adaptation strategies developed by the workshop participants.

Adaptation Type	Strategy Recommendations
Land use planning and building regulation (n=8)	Add SLR specific adaptation actions the local mitigation strategy and hurricane evacuation study.
	Integrate planning across local governments and counties.
	Create a land use category "build at your own risk" for transportation, housing, etc.
	Identify for the public both unwise development areas and areas to which people might retreat.
	Create a SLR land use category that would allow for increasing densities
	Direct development away from coastal high hazard areas.
	Manage retreat from the coast for hazardous materials. Have restrictions on facilities that can be located in the coastal high hazard areas.
	Incorporate SLR elements into Pinellas Sustainable Neighborhood Program like living shorelines.
Emergency/disaster response planning (n=4)	Create a robust program for post-Hurricane mitigation that helps us understand the changes being brought about by SLR. For example, an affected homeowner must build to current standards if more than 50% of structure is damaged.
	Ensure SLR adaption strategies are incorporated into the Local Mitigation Strategy so that they become eligible for mitigation funds.
	Identify "proposed conditions" that would be used by FEMA in vulnerable areas (educational benefits, local implementation). For example, builders would become liable if you illustrate that something will happen under a specified time period. Builders would have to disclose this to the buyer. Important to identify "proposed conditions" through the comprehensive land development approval process. Implement the proposed conditions level for SLR impacts. Educate the public (indirectly), e.g., Satellite Beach built up an additional 2 feet. Updating the coastal flood insurance rate maps. Because of endangered species, FEMA must integrate the program. Get local buy in, then go to Board of Realtors and say potential loss is X, and an additional Y feet of freeboard must be provided.
	Prohibit development on the ground level on barrier islands. Require new homeowners to sign a letter acknowledging risks if in evacuation or flood zone. Stick an endorsement on the deed saying it is encumbered and must be elevated, or that it is vulnerable to increasing sea levels over the next 100 years.

Tax and market-based approaches (n=5)	Work with the private insurance industry to anticipate rate changes and how to use as an incentive. There is an avenue through the re-insurance industry and FEMA coastal hazard program.
	Create a disincentive for redeveloping in high risk areas after a damaging event occurs, i.e., in repetitive loss areas.
	Incentivize movement to low hazard areas.
	Work with the insurance industry to recognize the value of natural systems for minimizing storm surge and flooding risks.
	Work with insurance companies to influence the right land use/regulatory decisions (not focus only on profit).
Land protection (n=2)	Identify and map priority built environment areas and apply appropriate regulatory protections.
	Identify the private lands needed for habitat migration in the face of SLR. Involve private citizens or large private land holders. Look at land buying opportunities now through easements, fee simple, life estates, etc.
Conservation of natural areas (n=6)	Consider using beach renourishment to protect natural systems at the Refuge.
	Identify priority areas, especially sensitive habitats and acquire properties around it. Identify areas to retreat to.
	Institute active seagrass restoration projects and minimize direct disturbances to newly submerged areas to allow seagrass to colonize. Build into ACOE, DEP, WMD and NOAA regulatory programs/ permitting.
	Strategically use appropriate dredge material for restoration, e.g., spoil areas. ACOE section 404. Redo dredge material master plan?
	Incorporate SLR into use of BP settlement dollars.
	Address SLR in the NPDES county permitting process. Talk about water quality. Make a government agency responsible, for example the public works dept.
Transportation and infrastructure (n=4)	Target vital service infrastructure and transportation with mitigation plans to accommodate risks related to SLR.
	Adapt stormwater infrastructure to mitigate for saltwater intrusion incorporating sufficient quality controls.
	Identify graduated risks associated with underground storage tanks as sea level rises.
	Move incompatible infrastructure out of soon-to-be and newly submerged areas.
Beaches, beach and shoreline management (n=5)	Facilitate City, County and WMD permitting of Living Shorelines to incentivize homeowners to install in place of hardened shorelines.
	Build wave attenuating living shorelines (e.g., oyster reefs) at shoreline of large land holders (TECO, Mosaic and Progress Energy) where 110 acres of mangroves are currently present. Keep buying land to allow for the upslope migration of habitats with SLR (N. of Cockroach Bay and south part of Tampa Bay).
	Replace sea walls and other hard structures with Living Shorelines. Alternatively, put mangroves and oyster reefs in front of seawalls.
	Encourage and facilitate the permitting and construction of living shorelines

	vs. armored shorelines. For example, Project Green Shores in Pensacola Bay promotes a community that is resilient and adaptive to storm surge
	City, Counties and WMDs facilitate permitting of living shorelines, even installing for homeowners.
Research needs (n=21)	Assess the economic impact of SLR to tourism.
	Evaluate and monitor vulnerable species/species of concern and their habitats.
	Better quantify how/whether natural systems can be used for adaptation.
	Put a monetary value on protected areas. For example, we will lose 36% of a type of habitat, what does that translate into in terms of value? Characterize the ecosystem services and put a dollar value on it.
	Determine messaging that is effective for specific audiences and improve the communication of science.
	Better understand how the ecosystems services that habitats provide will be influenced by SLR (EPA in Gulf Breeze, ecosystems services valuation study in Tampa Bay)
	Evaluate political and social acceptability of adaptation strategies and prioritize strategies with results.
	Better quantify how habitats will protect the shoreline.
	How will the local impacts of SLR impact streams, Lake Tarpon and Lake Seminole? How will storm-water be impacted? What will be the pollution impacts of SLR so that we may mitigate the environmental impacts.
	How will natural systems react to SLR? What are the error bars associated with this problem?
	Include subsidence in SLR modeling. Also, withdrawal of freshwater exacerbates the effects.
	Model SLR impacts on built environment with groundwater rise.
	Develop economic value data for natural systems in simple terms that are comparable to property values. Quantify the ecosystem services of surge attenuation, etc.
	Conduct a risk assessment on facilities in coastal areas to identify the facilities that we should versus shouldn't invest in, and where changes will be necessary (e.g., water treatment facilities).
	Identify community in this system and conduct a social vulnerability assessment. Determine why they care about this area. Identify communities that are favorable to this, e.g., the beach communities. Neighborhood associations get leverage. Council of Neighborhood Associations (CONA) could amplify a story in the area.
	Institute a monitoring program of climatic changes. Support the funding of it.
	Look at what effects non-native invasive species will have on habitats in affected areas and what we do about those.
	Identify the risks associated with chemical contamination in vulnerable areas.
	Research how to address infrastructure, waste sites, etc. that would remain as people retreat from the coast.
	Track storm frequency to identify whether frequency is changing.

	Conduct a study on chemical contamination after storm surge, e.g., on ports.
Miscellaneous/general comments (n=1)	Projects will be much better in 10 years, but need to identify which decisions need to be made now.
Education, outreach and communication (n=13)	Create a public relations campaign that effects change (ex. Smokey the Bear). Highlight charismatic fauna and ecosystem services; include people (snorkeling through house).
	Translate linear increase in SLR (8 inches) into a number that would motivate risk incorporation into policy and regulatory decisions (e.g., storm surge increase). Monitoring would provide stronger evidence of an increase in the rate of SLR.
	Create more compelling arguments with the data we have.
	Involve the community in research on local natural areas to build education and constituency. For example, there is an existing citizen science project to monitor phenological changes.
	Create an example project of sustainable development in a highly visible place such as downtown Tampa or the St. Pete waterfront (whether a government building or private structure). Elevated off the ground, living shoreline, etc. Use as an opportunity to have better community.
	Tap more fully the substantial experience in the Tampa Bay area. Educate the older generation, leverage for policy change at the national level, and apply what we already know.
	Don't base education on fear; there is a cost to overstating the problem.
	Develop messaging that can effectively overcome an active misinformation campaign discrediting the validity of climate change, e.g., the Smarter/Safer Campaign.
	Coalesce web-based information/ Create a coastal areas climate change web page (see USF and TBRPC).
	Build scientific understanding through educational systems.
	Programs like Tampa Bay Regional Planning Council and One Bay should create education programs.
	Hold workshops for area planners, HOAs and inform them about SLR and Living Shoreline options. Get public works involved, maritime construction companies and permit staff.
	Encourage and facilitate the understanding of living shorelines vs. armored shorelines. There are case studies out there that are decades old. We need to get the info out to homeowners.

Pre- and Post-Workshop Survey Results

Summary of Pre-Workshop Survey Results

Eleven workshop attendees participated in the pre-workshop survey. The majority of respondents were well informed about what is likely to happen to coastal wetlands in the Tampa Bay area as a result of SLR (See Appendix 9 for full survey results). The majority of respondents identified specific areas or types of areas that would be unaffected by SLR (n=7) and two answered that no areas would be unaffected. Those that did identify areas likely to be unaffected by future SLR specified higher elevation areas and inland areas. Respondents identified a diversity of species that would be vulnerable to SLR impacts. Some identified broad categories of species associated with particular habitats. Birds were the most mentioned species group (n=3). Respondents recommended a variety of adaptation strategies, most of which can be implemented at the local level. The most frequently identified strategies were land use planning and regulation (n=14); and education, outreach and communication (n=5).

Summary of Post-Workshop Survey Results

Thirteen workshop attendees participated in the post-workshop survey. Most respondents expressed that they had learned something new in the workshop and those that did noted the SLAMM results. A couple of respondents answered that they were knowledgeable about prospective wetland impacts in the area and one had seen similar modeling results. Approximately half of the respondents (n=6) changed their perceptions of what species were most vulnerable to SLR in the study area and approximately half did not (n=6). One was unsure. Those that changed their responses identified shorebirds (n=3), sea turtles (loggerhead; n=3), seagrass, humans and at least one species included in the vulnerable species analysis (Egmont Key mole skink). The adaptation strategies listed by respondents post-workshop were slightly more diverse than in the pre-workshop survey. In addition, respondents focused to a much greater extent on adaptation strategies involving education, outreach and communication (n=13) and less so on land use planning and building regulation strategies (n= 3) . Other strategies types identified more frequently included beaches, beach and shoreline management (n=5); land protection (n=3); research needs (n=3); and land use planning and building regulation (n=3).

Workshop Influence Based on Survey Results

Prior to the workshop, most respondents were knowledge about what would happen to coastal wetlands in the study area in response to SLR over the next 100 years. Even so, the majority acknowledged that they learned something new about the type, magnitude and location of predicted changes. Regarding species most vulnerable to SLR impacts, about half of the respondents changed which ones they felt were most vulnerable to SLR after the workshop with the highest recognition given to shorebirds and sea turtles. After learning about the specific types of changes predicted to be brought about by SLR, respondents substantially adjusted their recommendations for the types of adaptation strategies needed. While land use and building regulation strategies were most selected by respondents in the pre-workshop survey, the most frequently identified type of adaptation strategy selected in the post-workshop survey was education, communication and outreach. Furthermore, while beaches, beach and shoreline management were not frequently identified in the pre-workshop survey (n=1), identification rose in the post-workshop survey (n=5). In summary, the workshop influenced the participants responding to the surveys both in what they understand about the consequences as well as what they believe are the most appropriate actions to take to adapt to SLR in their area.

Conclusions

The analyses detailed in this report show that coastal wetland systems will likely change substantially as a result of SLR and that these changes will increase in magnitude as SLR progresses. SLAMM is a useful tool for characterizing these changes in a quantitative, spatial and temporal manner. By applying SLAMM, we found that some habitats will steadily gain spatial extent, others will steadily lose spatial extent, and some will gain spatial extent during one time period and lose spatial extent in subsequent time periods. The changes to coastal wetland systems brought about by SLR will affect some species more than others, with some being substantially affected. SLR will also adversely affect the human communities at our study sites in a variety of ways including impacts to infrastructure (e.g., roads, bridges and water treatment facilities), cultural and historical resources, and increased vulnerability to storms and flooding. Improving our understanding of these changes improves our ability to predict how, when and where vulnerable species and human communities will be impacted. These quantitative, spatial and temporal data will help us develop, refine and implement adaptation strategies to minimize the impacts of SLR on these natural systems and human communities. For example, the spatial results can be used to identify promising locations for restoration based on where coastal wetlands are likely to become open water, where coastal forests are likely to become marshes, and where undeveloped dry land is likely to become wetlands. Vulnerable developed areas can be identified in the scenarios allowing developed dry land to transition with SLR.

The workshops surveys identified that informed members of the study area communities were not always familiar with how coastal wetland systems and human communities were likely to be affected by SLR. Specific quantitative, spatial and temporal information about coming changes can be used to educate all sectors of the study area communities and will help planners, natural resource managers, elected officials and other community members develop specific, locally relevant strategies to minimize the impacts to natural systems and the built environment. The quantitative, spatial and temporal information on coastal wetland change produced by this study can also be used to assist in the development of monitoring programs to signal when on-the-ground change is happening and at what rate. The modeling results and uncertainty analyses conducted on a selection of input parameters, can be used to pinpoint the input parameters that are most important for focused data collection (e.g., marsh accretion) and which ecosystem responses are most important to monitor (e.g., transition of coastal forest to marsh).

Improving our understanding of SLR impacts on coastal wetland systems also improves our understanding of impacts to dependent species and adjacent human communities. Although SLR is just one impact of global climate change, examining how coastal wetland systems will change provides insights into how species dependent on these systems might be impacted. This information will be useful in the prioritization of species that should be monitored more closely than others. The change in coastal wetlands adjacent to human communities will also affect their vulnerability to coastal storms and flooding. Knowing what these changes are likely to be, where they will occur and the timing of these changes can inform the development and implementation of adaptation strategies.

The adaptation strategies developed by the stakeholders participating in project workshops point to the actions communities can take now to minimize the long-term impacts of SLR. For example:

- Reducing the rebuilding of vulnerable structures in high risk areas by altering insurance and other compensation (subsidies) that currently incentivize re-building following storm and flooding damage (e.g., using disaster relief dollars to relocate to less vulnerable areas rather than paying people to rebuild in vulnerable sites.)
- Protecting undeveloped upland and wetland buffers now will allow for coastal wetlands migration with SLR rather than expensive efforts to protect structures and infrastructure built on those vulnerable sites.
- Assisting species experiencing temporary habitat bottle necks rather than allowing them to be extirpated from an area.
- Taking into account SLR as vulnerable infrastructure is replaced, repaired or relocated over the next 85 years which will be less expensive and reduces service interruptions than responding to an emergency infrastructure need.
- Educating people of all ages in every sector of society about the issues and predicted consequences so that they can take and urge informed action.
- Improving communication about SLR vulnerability and potential solutions among and between private and government sectors and the community to expedite proactive response to SLR.

This study provides the seeds of many promising ideas for helping human communities and natural systems adapt to SLR. It is up to local stakeholders from each study area community to further refine and implement these strategies. Our hope is that other GOM communities where SLR has been modeled will be inspired to develop and implement adaptation strategies of their own. Implementing adaptation strategies now will be the most cost-effective and safest response to the environmental changes that we know are coming.

Electronic results including geospatial files are available upon request to the project PI, Laura Geselbracht (lgeselbracht@tnc.org). For those unfamiliar with the use of geospatial files, or the sake of convenience, spatial results can be viewed on The Nature Conservancy's Coastal Resilience 2.0 website available at www.coastalresilience.org. The SLR modeling results can be found under the Future Habitats app.

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