Final

TAMPA BAY BLUE CARBON ASSESSMENT

Summary of Findings

Prepared for
Restore America's Esturaries

June 2016 - revised April 2017

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EXECUTIVE SUMMARY

Introduction

Coastal wetlands, including mangroves, tidal marshes, and seagrasses, are highly productive and valuable ecosystems that contribute an important part of regional and global carbon cycles. They have long been recognized for the many services and benefits that they provide, including sequestration of carbon, nursery, food sources, and feeding grounds for fisheries, water quality regulation, shoreline stabilization, and flood protection. These ecosystems, however, are under threat globally through the combined pressures of coastal population growth and migration as well as climate change.

Over the last 40 years, the United States has advanced coastal wetlands management involving wetlands restoration and conservation. In the 1970's, wetland restoration projects were small with ill-defined success criteria, but over time capacity and knowledge has grown such that programs incorporating over 24,710 acres (10,000 hectares) of wetlands recovery have been planned and executed[1]. Until recently, the goal has been to create vital multiuse landscapes, which balance nature and development needs. However, there is now recognition that we must not only adapt to pressures of climate change but also find mechanisms to reduce the drivers of climate change—principally, greenhouse gas (GHG) emissions (Crooks et al. 2014).

Globally, it is estimated that some 450 million tonnes[2] of carbon dioxide are released each year from stores of carbon in coastal wetland soils as human impacts drive wetland loss (e.g., diking and draining; Pendleton et al. 2012). Loss of wetlands also brings reduced, ongoing carbon sequestration, erosion of carbon stocks, and a decline in other ecosystem services. To combat these losses, there is a need for best practices in terms of: (1) habitat conservation and recovery in coastal settings, including urban estuaries; (2) quantification of the GHG exchange implications of strategies involving coastal wetland management; and (3) projections of how coastal landscapes will change as sea-level rises to inform forward looking planning decisions. Best practice approaches will vary from place to place, dependent upon cultural and landscape settings.

Tampa Bay provides an opportunity to explore the inclusion of coastal wetland carbon management within an urbanized estuary where the community has been very successful in planning and delivering environmental recovery. The region is particularly representative of

[1] Comprehensive Everglades Restoration Plan, Louisiana Coastal Master Plan, San Francisco Baylands Goal Project, and Puget Sound Nearshore Ecosystem Restoration Project
[2] Also referred to as metric tons (1,000 kg).

subtropical low-lying shoreline, largely devoid of major terrestrial sediment input, which is a key component of coastal wetland resilience to sea-level rise (Morris et al. 2016).

Project Setting

Tampa Bay has supported a thriving, European-settled, coastal community since at least the mid-1800s. Since that time, coastal development has expanded across the region with now more than 60% (446,307 ac) of upland and coastal land occupied by some level of development, with 14% (102,727 ac) under agriculture (SWFWMD, 2011). In the present day (2011 assessment), natural uplands and coastal wetlands represent only about 26% (190,165 ac) of the Bay shore.

Despite a fourfold increase in the population of the Tampa Bay region, water quality in Tampa Bay has been restored to conditions similar to those observed in the 1950s (TBEP 2012). In response, seagrass coverage is now higher than it has been in decades. Targets for seagrass recovery have been met and, as of 2015, exceeded. Additionally, significant progress toward achieving gains in salt marsh and salt barren habitats has been made since 1995 (Robison 2010).

However, future development patterns and an anticipated doubling of the current population by 2050 may threaten to further diminish both the economic and environmental integrity of Tampa Bay's coastal habitat resources. A challenge for the local municipalities around Tampa Bay will be management of urban development and environmental conservation in conjunction with pressures brought about by climate change, and in particular sea-level rise.

Efforts are under way to develop the science to support policies and management actions that recognize carbon cycling as an ecosystem service. In parallel, procedures that connect carbon markets and carbon finance to tidal wetlands restoration and protection activities are in development (Emmer et al. 2014, Emmer et al. 2015). The addition of climate mitigation benefits is expected to broaden the pool of potential funds for estuarine restoration, which could directly benefit ecosystem restoration efforts in Tampa Bay. Where carbon finance is not appropriate or feasible, recognition of the climate mitigation values of these ecosystems could help prioritize actions that improve and conserve these habitats in the context of climate adaptation.

Purpose of This Study

The goal of this Blue Carbon Assessment of Tampa Bay estuary is to determine the past and future climate mitigation benefits of ongoing and potential future coastal habitat restoration and conservation efforts. Additionally, the project identifies opportunities for enhanced ecosystem management that will provide agencies and community members in the region with information to support coastal management planning. The objectives of the project are to:

1 Determine the past and potential future climate mitigation benefits of coastal habitat restoration and conservation in Tampa Bay.

2 Identify opportunities for enhanced ecosystem management for climate change benefits, including guidance for priority conservation and restoration site selection.

3 Support increased capacity building for, and investment in, habitat restoration and coastal adaptation.

What Is Blue Carbon?

"Blue carbon" is a term or concept that has arisen to describe the carbon sequestration capabilities that marine systems provide. The concept of "coastal blue carbon" recognizes that improved management of marshes, mangroves, and seagrasses can result in protection of vulnerable stocks of sequestered atmospheric carbon dioxide (CO_2), now held in biomass and soils, and ongoing sequestration capacity. Particular focus has centered on wetlands, which occupy less than 2% of the ocean surface, but represent almost 50% of the ocean's transfer of carbon to burial in sediment sinks (Duarte et al. 2005). How these wetlands are managed will determine both the fate of carbon stocks that have accumulated over hundreds to thousands of years, as well as the gradual, ongoing process of future carbon sequestration from the atmosphere.

Wider Context

In December 2015 near Paris, France, 195 governments came together at the United Nations Framework Convention on Climate Change (UNFCCC) twenty-first Conference of Parties (COP21) to finalize an agreement by which all countries agree to act on climate change. At COP21, the role of improved forest and landscape management was recognized as being necessary to slow climate change. The Paris Agreement is a pivotal, driving, strong commitment toward restricting global warming to "well below" 2° Celsius.

Each country will determine how best to achieve the agreement through their own climate action plans (now called Nationally Determined Contributions), to be updated every 5 years. At COP21, connecting climate adaptation and mitigation was also recognized as important to achieving this goal. Quantifying the GHG impacts of management actions on landscapes will be critical to achieving success, as will the ability to monitor, report, and verify those outcomes.

To calculate GHG emissions and removals, the Intergovernmental Panel on Climate Change (IPCC) developed guidance on how to incorporate management of wetlands within national accounts of GHG emissions (IPCC 2014)[3]. The United States is one of the first to enact this guidance, and plans to include coastal wetlands within the 2017 U.S. National Inventory Report on GHG Emissions and Sinks. To improve this process moving forward, regionally specific quantification of coastal wetland carbon stocks and stock changes are required. In support, national scale science programs on blue carbon have been engaged, such as the NASA/U.S. Geological Survey (USGS)–funded Blue Carbon Monitoring Systems.

[3] The *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (Wetlands Supplement*) contains updated and new methodological guidance for GHG emissions and removals from drained inland and rewetted organic soils, specific human-induced changes in coastal wetlands and inland wetland mineral soils, and Constructed Wetlands for Wastewater Treatment. http://www.ipcc-nggip.iges.or.jp/public/wetlands/index.html

Mechanisms and procedures have also been developed to connect coastal wetland management to the carbon market, where appropriate[4]. At the locally relevant landscape level, a growing number of case studies are amassing to inform management agencies and policy developers on coastal wetland management and carbon finance markets[5].

What New Information Is Provided by This Study?

The Tampa Bay Blue Carbon Project is one of the first to link together modeled projections of coastal habitat change under various scenarios of sea-level rise, alternative wetland responses to sea-level rise, and the management scenarios of "holding the line" or moderate forms of "managed retreat." The modeling, expanded to include seagrasses for the first time in the estuary, includes an assessment of the impact on carbon sequestration stocks based upon field and laboratory analyses. Specific project elements included:

1. An updated Tampa Bay–wide spatial model of coastal wetland response to sea-level rise for Tampa Bay (Sheehan et al. 2016).
    a. This model incorporates seagrass meadow migration, as well as intertidal marsh and mangrove response to sea-level rise.
    b. Modeled projections forecast the extent of intertidal wetlands and seagrass meadows under low and high scenarios of sea-level rise under low and high accretion assumptions, recognizing sensitivity of intertidal wetlands to sediment supply.
    c. Modeled scenarios enable the exploration of policy decisions to "hold the line" on all development and agriculture, or to promote a "soft retreat" alternative wherein some uplands are allowed to convert to tidal wetlands areas.
2. Tampa Bay specific quantification of carbon stocks in biomass and soils at 17 sites covering a range of habitats including mangroves (natural and restored), salt marshes, brackish marsh, and salt barrens (Moyer et al. 2016).
3. Tampa Bay specific quantification of mangrove and marsh soil building over the past century, including carbon stock change, derived by radiometric Pb210 dating (Gonneea 2016).
4. An investigation of a potential unrecognized inorganic carbon sequestration pathway for seagrass meadows (Tomasko et al. 2015).
5. An assessment of the role of seagrass meadows and hydrogeomorphology in mitigating local ocean acidification (Tomasko et al. 2015).
6. Site prioritization for future intertidal wetland restoration using coastal blue carbon as an important decision criterion (Robison et al. 2016).

4 http://www.v-c-s.org/methodologies/methodology-tidal-wetland-and-seagrass-restoration-v10

5 These include an assessment of carbon sequestration with ongoing and potential future tidal marsh restoration in the Snohomish Estuary, Washington (Crooks et al. 2014); Implications of regional planning for tidal wetlands restoration in San Francisco Bay (Callaway, Crooks, Schile 2015); forecasting of the effects of coastal protection and restoration of the Mississippi Delta under the Louisiana Coastal Master Plan (Couvillion et al. 2013)); Analysis of impacts of coastal management in Southern California in response to sea-level rise under the Ventura Coast Resilience Project – Sea Level Rise and GHG Assessment (Vandebroek and Crooks, 2014); and the assessment of carbon project development of Cape Cod at the Herring River Estuary Restoration Project (in progress).

Analytical Approach

Predicting Coastal Habitat Responses to Sea-Level Rise

Over the past two decades, geospatial modeling tools have been developed to forecast changes in coastal wetland habitats in response to sea-level rise. The Environmental Protection Agency's Sea Level Affecting Marshes Model (SLAMM) simulates the dominant processes involved in coastal wetland migration and conversions with long-term sea-level rise. The basis of the model is a decision tree that maps out how quantified linkages between habitat response and sea-level rise will drive habitat locations across a landscape, considering the effects of coastal elevations, sea-level rise, accretion and erosion, and freshwater inflow. The model calculates habitat areas and maps habitat distribution over time based on inputs of existing vegetation, topography, accretion rates, and sea-level rise.

The evolution of wetland habitats in Tampa Bay has been modeled in SLAMM by three different groups: Glick and Clough in 2006, Sherwood and Greening in 2012 from the Tampa Bay Estuary Program (TBEP), and Geselbracht et al. in 2013 from The Nature Conservancy (TNC).

In the current blue carbon analysis, Environmental Science Associates (ESA) initially considered applying SLAMM or using the previous model results to calculate habitat acreages. A further look at the model showed that SLAMM does not accurately represent the full suite of habitat conversion processes that are important to Tampa Bay. For example, seagrasses are extremely important to the overall ecology of Tampa Bay, and understanding their response to sea-level rise is critical to developing future habitat management strategies. However, SLAMM does not include seagrass as a habitat category. Additionally, in tropical and subtropical locales, SLAMM predicts that virtually all habitat categories will convert to mangroves as the sea level rises, leading to an overestimate of mangrove dominance (all three previous studies showed large increases in mangrove habitat). This is because SLAMM does not adequately simulate the evolution of fringing high marsh and salt barrens created by irregular tidal inundation, or the migration of brackish Juncus roemarianus marshes maintained by localized freshwater inputs.

To improve predictions of habitat responses to sea-level rise, ESA developed a geographic information system (GIS)-based habitat evolution model specific to Tampa Bay as part of the overall study (Sheehan et al. 2016). The Tampa Bay Habitat Evolution Model (HEM) improves upon SLAMM by:

- Creating the flexibility to edit the habitat categories to facilitate cross-walks from site-specific vegetation mapping.
- Customizing the habitat evolution decision tree to incorporate more complex and locally specific topographic, hydrologic and biological relationships.
- Building a structure that allows for different "modules" to be added to or updated in the model in the future.

The HEM includes a habitat evolution decision tree specific to Tampa Bay habitats, elevations, tidal data, and climate conditions. In addition, the HEM incorporates a seagrass module that predicts the establishment of seagrasses in newly inundated subtidal areas.

Tampa Bay-Specific Accretion and Carbon Sequestration Data

Carbon aboveground biomass densities, soil sequestration rates, as well as emission rates of methane were collated for coastal Florida ecosystems, or their proxy along the Gulf of Mexico coast. Where possible, these values were gathered from published literature from studies in Tampa Bay, but, as necessary, values were also adopted from studies in the Everglades and other bays along the Gulf Coast. Land use categories for which emissions and removals were calculated include seagrass, mangroves, salt marsh, brackish (*Juncus spp.*) marsh, and freshwater marsh, as well as uplands habitats such as cropland and pastureland, tree crops, vineyards, grasslands, shrub and brushland, and upland forests.

To develop estuary-specific data, the USGS collected soil cores from around the Bay to quantify rates of sediment accumulation and carbon burial (Gonneea, 2016). Eight intertidal sites were sampled representing salt marsh, dominated by *Juncus roemarianus and Spartina alterniflora*, mangroves, including *Rhizophora mangle, Laguncularia racemosa* and/or *Avicennia germinans*, and young mangrove stands where wetlands were created within the last three decades. In addition, sediment samples were collected from a salt barren, but found not to be conducive to analysis. Gamma analysis was completed to determine accretion rates and dry bulk density, loss on ignition, and carbon and nitrogen quantities were determined as well.

USGS sampling locations were co-located with parallel research being undertaken by the Florida Fish and Wildlife Research Institute to quantify biomass and soil carbon stock at 17 intertidal locations (Moyer et al. 2016).

Data from Tomasko el al. (2015) was used to determine accretion and carbon sequestration rates for seagrass to use in the GHG framework. Tomasko et al. (2015) summarized the uncertainties that exist related to carbon sequestration rates for seagrass meadows, and compared bay-wide estimates of carbon sequestration against each other, using different assumptions available in peer-reviewed literature. The separately derived carbon sequestration estimates were compared against a bay-wide estimate of the potential amount of carbon assimilation via seagrass pathways throughout Tampa Bay. Tomasko et al. (2015) further discussed the discrepancies between an estimate of bay-wide carbon assimilation and various literature-derived carbon sequestration rates, and suggested techniques to address these differences.

Greenhouse Gas Accounting Framework

A GHG accounting framework was developed to quantify future changes in GHG fluxes due to sea-level rise and different coastal management strategies. Changes in CO_2 and methane (CH_4) fluxes[6] are estimated over time as habitats evolve as a result of sea-level rise. The framework uses locally and/or regionally appropriate values or estimates of biomass, soil carbon sequestration

[6] A GHG flux is the combination of emissions and removals of GHGs.

rates, and methane emission rates for each habitat type to estimate GHG fluxes based on land use changes. The values for biomass, soil carbon sequestration, and methane emissions were derived from the literature and include data collected in the field, which are specific to Tampa Bay (see following section; Tomasko et al. 2015, Moyer et al. 2016, Gonneea 2016).

The framework was used to evaluate changes in GHG fluxes for historic and future habitat areas, as well as for restoration projects implemented in Tampa Bay in the last 10 years. Historic and more recent habitats were based on data from TBEP and Southwest Florida Water Management District (SWFWMD) Land Use and Land Cover datasets, and from the reporting of restoration projects through the Government Performance and Results Act (GPRA). Future habitat areas were projected using the HEM.

Results

Habitat Evolution in Tampa Bay

HEM results indicate that habitat changes are most sensitive to differences in sea-level rise projections and accretion rates as opposed to differences in development protection scenarios. Table E-1 summarizes modeled habitat changes between 2007 and 2100 for the intermediate low (23.6 inches) and intermediate high (51.1 inches) sea-level rise scenarios, with low[7] and high[8] accretion rates applied to both.

In the lower sea-level rise scenarios (Runs 1 and 2), acreage increases are predicted for salt barren, high salt marsh, *Juncus roemarianus* marsh, and mangrove habitats, which are converted from uplands and freshwater marshes. However, in the higher sea-level rise scenarios (Runs 3 and 4), acreage decreases are predicted for high salt marsh. Under high sea-level rise and low accretion, *Juncus roemarianus* marsh and mangrove habitats, are replaced by open water, as well as, an approximately 15,000 acre increase in seagrass. These results underscore the sensitivity of coastal wetlands to variable sea-level rise and accretion rate scenarios, and indicate that under higher sea-level rise scenarios emergent wetlands could be replaced by subtidal seagrasses if accretion rates remain in the lower ranges typical of Tampa Bay coastal wetlands and water quality conditions remain favorable to seagrass expansion in the future.

7 Low accretion rates: 1.6 mm/yr salt marsh, 3.75 mm/yr *Juncus* marsh, and 1.6 mm/yr mangroves.
8 High accretion rates: 3 mm/yr salt marsh, 4 mm/yr *Juncus* marsh, and 5.0 mm/yr mangroves.

TABLE E-1
CHANGES IN TAMPA BAY HABITAT ACREAGE FOR DIFFERENT ACCRETION RATES

		Modeled Acreage in 2100									
		Int. Low Sea-Level Rise				Int. High Sea-Level Rise					
Run	**Modeled Acreage in 2007**	**Run 1 (Low Accretion)**		**Run 2 (High Accretion)**		**Run 3 (Low Accretion)**		**Run 4 (High Accretion)**		**Difference (Run 2 –Run 1)**	**Difference (Run 4 –Run 3)**
Developed Upland - Hard	461,640	461,640	(0)	461,640	(0)	461,640	(0)	461,640	(0)	0	0
Developed Upland - Soft	210,310	210,310	(0)	210,310	(0)	210,310	(0)	210,310	(0)	0	0
Undeveloped Upland	230,600	227,370	(-3,230)	227,370	(-3,230)	222,870	(-7,730)	222,870	(-7,730)	0	0
Freshwater Marsh	81,390	79,260	(-2,130)	79,260	(-2,130)	77,590	(-3,800)	77,590	(-3,800)	0	0
Salt Barrens	1,520	2,870	(+1,350)	2,870	(+1,350)	2,280	(+760)	2,280	(+760)	0	0
High Salt Marsh	2,290	2,500	(+210)	2,910	(+620)	1,090	(-1,200)	1,460	(-830)	410	370
Juncus Marsh	4,250	4,530	(+280)	4,730	(+480)	2,430	(-1,820)	4,270	(+20)	200	1,840
Mangroves	13,990	16,040	(+2,050)	15,980	(+1,990)	4,870	(-9,120)	18,260	(+4,270)	-60	13,390
Mudflat	0	0	(0)	0	(0)	840	(+840)	830	(+830)	0	-10
Beach	70	30	(-40)	30	(-40)	10	(-60)	10	(-60)	0	0
Seagrass	33,310	33,550	(+240)	33,010	(-300)	48,280	(+14,970)	32,680	(-630)	-540	-15,600
Open Water	338,710	339,960	(+1,250)	339,960	(+1,250)	345,880	(+7,170)	345,880	(+7,170)	0	0
Total Intertidal Wetland[1]	20,530	23,070	(+2,540)	23,620	(+3,090)	8,390	(-12,140)	23,990	(+3,460)	(550)	(15,600)

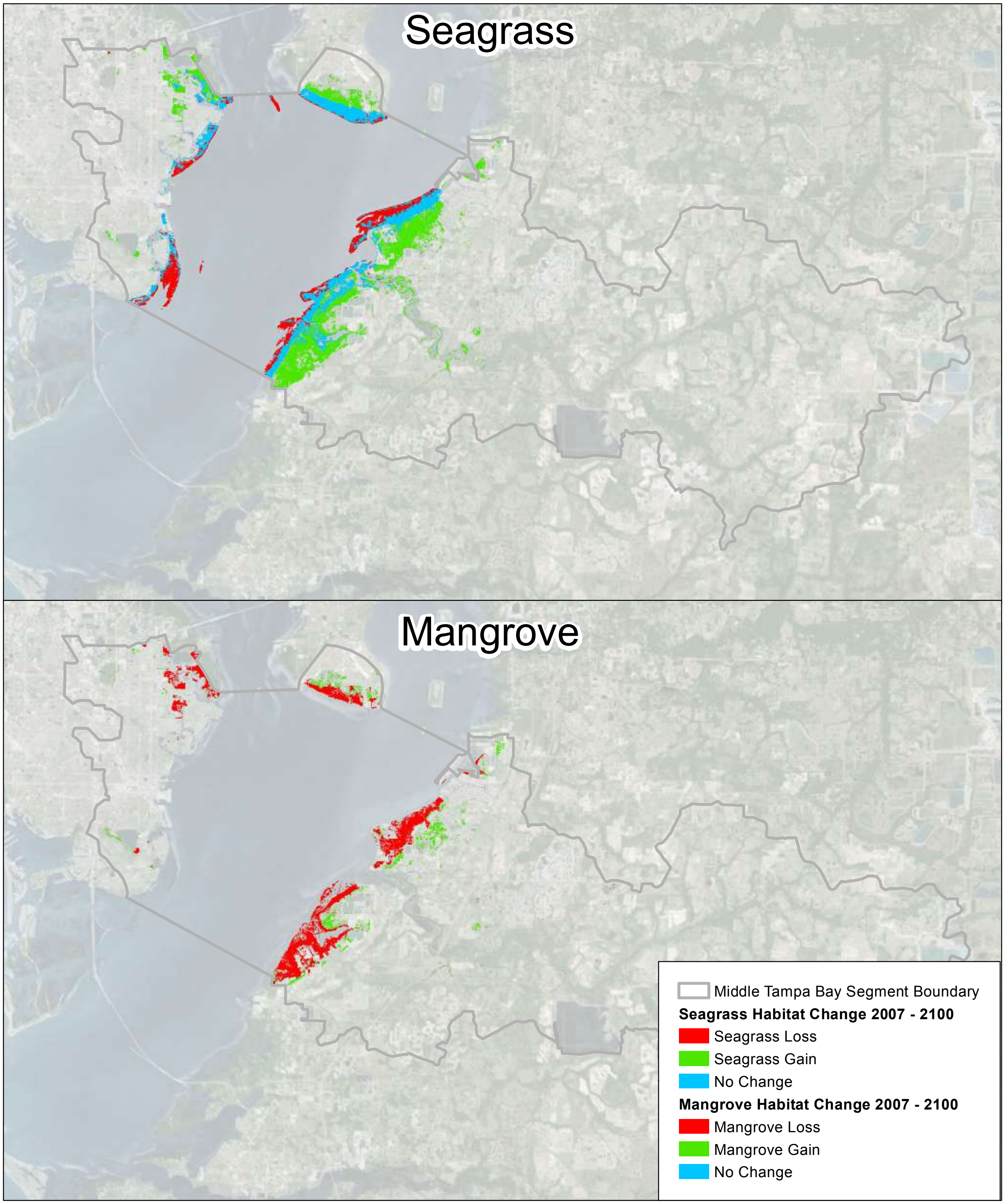
[1] Includes High Salt Marsh, Juncus Marsh, and Mangroves

The HEM output can be exported to GIS and graphically displayed to show areas of gain, loss, or no change, for particular habitat types between two time periods for various sea-level rise scenarios. Figure E-1 shows examples of graphical output for mangrove and seagrass habitat changes in the Middle Tampa Bay segment for the intermediate high sea-level rise (51.1 in.) and low accretion rate model scenario (Run 3). These results indicate that many existing, large contiguous stands of mangroves could be sufficiently inundated by sea-level rise in 2100 to convert to shallow subtidal zones suitable for landward seagrass expansion. However, existing seagrass beds at deeper elevations could be drowned out by reduced light penetration caused by a deeper water column associated with sea-level rise.

Within Tampa Bay, black needle rush (*Juncus roemerianus*) marshes are spatially restricted to lower-salinity zones found in tidal rivers and creeks, even though this species can tolerate a wide salinity range (Stout, 1984). This spatial restriction may make *Juncus* marshes in Tampa Bay particularly vulnerable to sea-level rise. The largest remaining stands of *Juncus* marsh in the Tampa Bay estuarine system are located in the Manatee River bay segment, where both the Manatee River and the Braden River are impounded for public water supplies. Rising sea levels in these truncated tidal rivers could result in substantial losses to the remaining stands of *Juncus* marsh located there. Figure E-2 (top panel) shows HEM simulation of *Juncus* marsh in the Middle Tampa Bay segment for the same intermediate high sea-level rise (51.1 in.) and low accretion rate model scenario (Run 3). The losses depicted in this graphic would likely be even greater if freshwater inflows to these systems were further reduced.

Figure E-2 (bottom panel) shows wetland habitats over time for Tampa Bay from 1900 to 2100. The HEM model forecasts that irrespective of assumptions about the rate of sea-level rise or sediment supply, the total extent of intertidal habitat changes little through time, decreasing slightly by 2100 for high rates of sea-level rise. However, as the rate of sea-level rise accelerates in the latter half of the century, the capacity of the wetlands to accrete vertically becomes sensitive to the availability of mineral sediments to support soil building. While there is potential for mangroves to transgress into salt and freshwater wetland areas, the model projects a decline of mangrove area under the low sediment availability scenarios (Run 3 and Run 5). Although intertidal habitat is projected to decline through the coming century, this loss is offset by an increase in area of subtidal seagrasses should water quality be maintained.

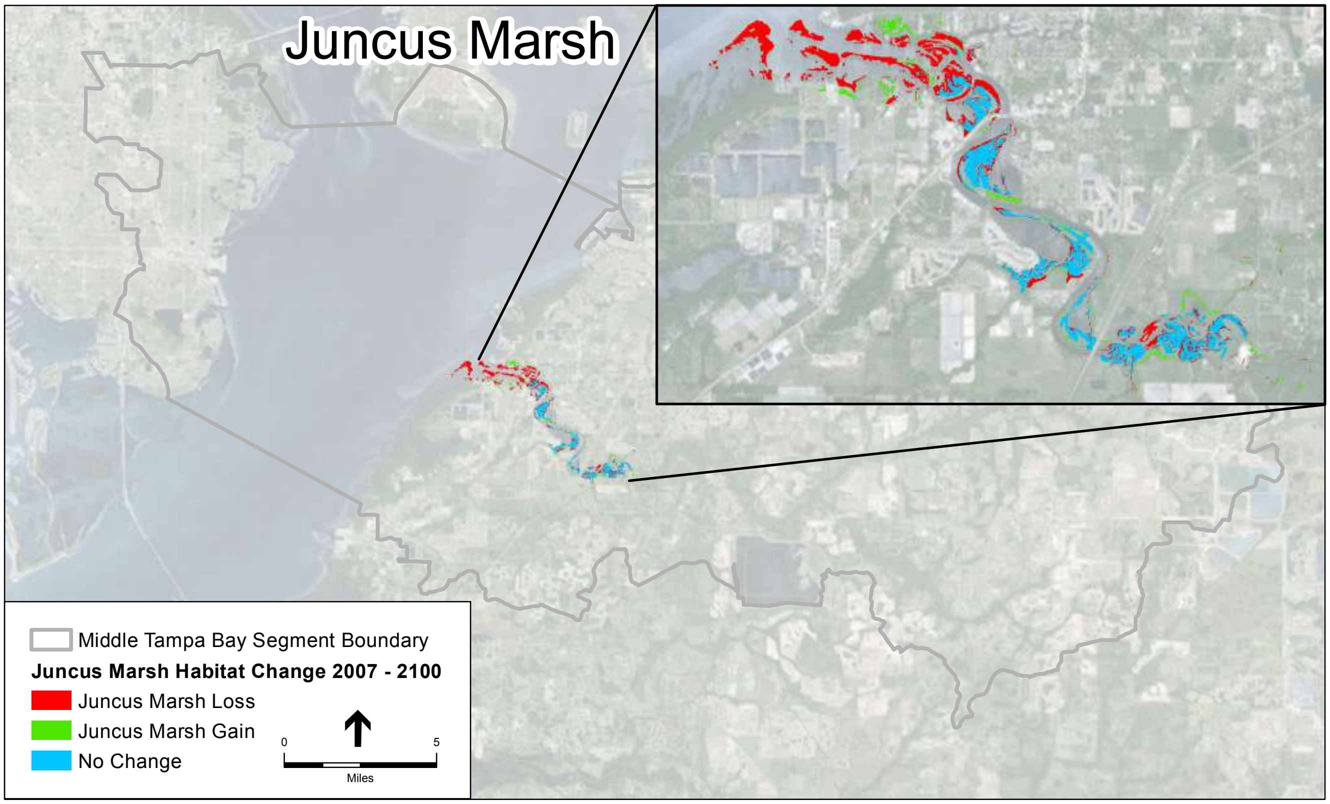
Despite advancements in modeling tools and techniques for simulating changes in coastal wetland habitats in response to sea-level rise, there are still uncertainties in the modeled predictions. Small differences in the rates of sea-level rise and sediment/organic matter accretion can result in very large differences in predicted habitat changes. The actual evolution of coastal wetland habitats in Tampa Bay will almost certainly be further affected by localized changes in rainfall patterns, freshwater inflows, nutrient loading, flushing and circulation patterns, dredge and fill, restoration actions, and urban development activities. Sea levels are on the rise, and recent evidence suggests that the rate of sea-level rise is increasing (Watson et al. 2015). Tampa Bay coastal wetland habitats will continue to dynamically respond to sea-level rise for centuries to come.

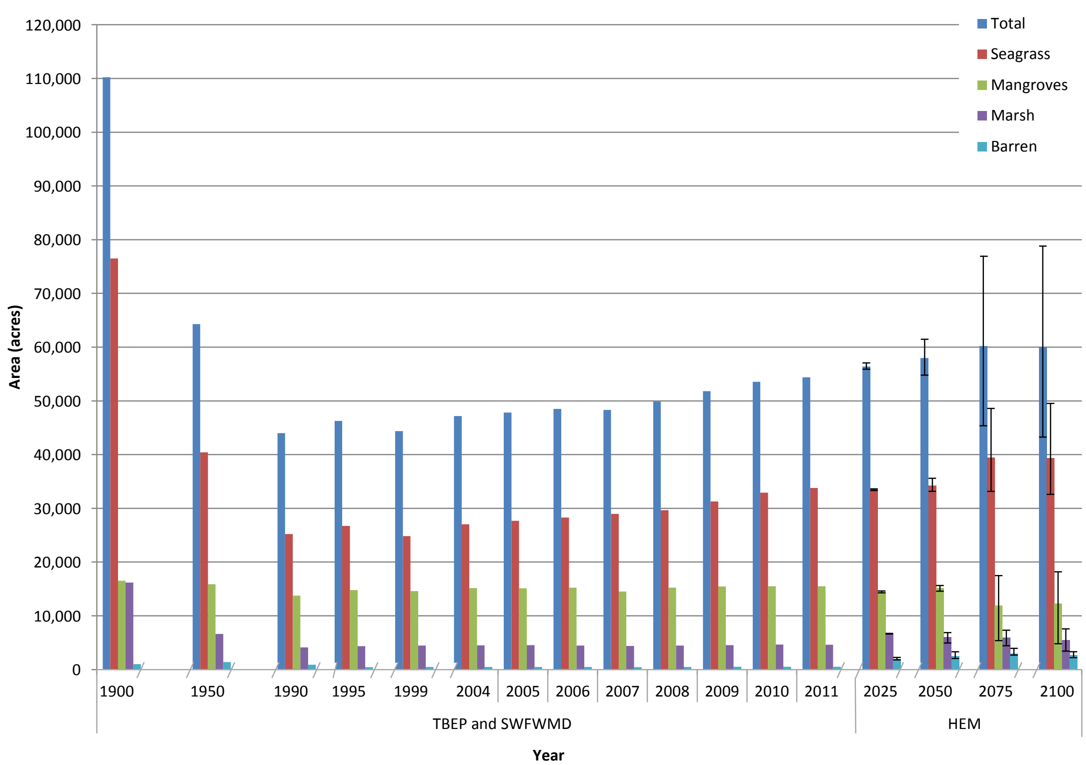


SOURCE: ESRI, SFWFMD, FDEM, ESA

ESA

Figure E-1
HEM Simulation of Seagrass and Mangrove Changes Between 2007 and 2100 in Middle Tampa Bay





SOURCE: ESA, ESRI, FDEM, SWFWMD, TBEP

Figure E-2
HEM Simulation of Juncus Marsh Changes Between 2007 and 2100 in Middle Tampa Bay (top) and Wetland Habitats Over Time (bottom)

Historic and Future Bay Wide Changes in GHG Fluxes and Carbon Sequestration

Based on the HEM results (Section 3.2.3), Tampa Bay coastal habitats are expected to remove between 73,415,000 and 74,317,000 tonnes of CO_2 from the atmosphere by 2100, the equivalent of removing approximately 15.5 million fossil-fueled vehicles from the roads (EPA, 2016).

The HEM runs give some insight to potential management strategies to maintain carbon sequestration. Runs showed increased sedimentation resulted in more wetland habitats and more carbon sequestration, especially with higher rates of sea-level rise. Management strategies that focus on allowing more sediment from the watershed (e.g. preventing new impoundments) to reach the wetlands would help sustain the habitats and continue carbon sequestration for longer. Additionally, results showed that allowing wetlands to migrate into “soft” development (e.g., agricultural areas near the coast) would create more habitat and increase carbon sequestration. Coastal managers can use the HEM results to prioritize areas for restoration. Even greater benefits could be gained by identifying “harder” developed areas that would be highly susceptible to future inundation, and target these areas for restoration activities as well. Further, lower sea-level rise will allow habitats to be preserved longer and sequester more carbon. Strategies that reduce emissions to limit climate change will have a positive effect on Tampa Bay habitats and their ability to sequester carbon in the future.

Restoration projects have removed 217,000 tonnes CO_2 equivalents[9] since 2006. While this number is small compared to the substantial total amount of carbon sequestration occurring within existing habitats in Tampa Bay, protecting and restoring habitats, especially those bordering upland transgressional areas, will be key to maintaining strong rates of carbon sequestration into the future. The HEM results indicate that areas of existing intertidal wetland habitat will decline by 2100 (see discussion in Section 4.1.4), with the exception of seagrass habitat. This indicates the importance of taking a continuing approach to wetland restoration, recognizing landscape change through time. There are opportunities throughout the Bay for wetland habitats to migrate inland into undeveloped or slightly developed lands. As such, coastal managers can use these results to identify areas of “soft” development to target for future acquisitions and restoration.

Management Implications

The communities around Tampa Bay have made impressive strides in reversing the twentieth century decline in wetland area, with recovery of seagrass extent to 1950s levels and a significant number of water quality improvement and habitat restoration projects. The HEM predicts that if water quality is maintained, seagrasses will thrive, and, under conditions of high sea-level rise rates, will move into newly-submerged areas vacated by displaced mangroves. Maintaining a balance of habitat including marsh and salt barren, which, based on the HEM, will particularly decline in extent, will require creation of space for wetlands in upland areas that will be flooded by future sea-level rise.

9 Accounting for warming impacts of methane emissions.

A community-wide discussion is needed to map out continuing priorities moving forward, including agreement and goals for:

- Identification and protection of essential existing infrastructure and development. Protective measures include living shorelines, shoreline armoring, levees and pumps, and elevated structures, roadways and other critical infrastructure.
- Restriction of new infrastructure and development in coastal flood prone areas. Restrictive measures include a range of regulatory and planning tools to curtail new development in coastal areas subject to tidal flooding.
- Public acquisition of developed parcels depreciated by coastal flooding. Strategies include the dedication of funding sources to acquire developed coastal parcels depreciated by nuisance tidal flooding and/or damaged by hurricane storm surge.
- Conservation of undeveloped coastal parcels threatened by sea-level rise. Strategies include the development of incentives and disincentives for private owners of undeveloped coastal parcels to maintain their properties as open lands suitable for accommodating future tidal inundation and habitat migration. The concept of “rolling easements” to “reserve” coastal uplands for future habitat migration (Titus 2011) is a promising legal mechanism that should be further explored.

The Southeast Florida Regional Climate Change Compact (http://www.southeastfloridaclimatecompact.org/) provides a model for Tampa Bay area local governments to follow. This type of local government collaboration will be needed to effectively manage sea-level rise, for both the built and natural environments.

Although a near-term increase in sea-level rise and nuisance tidal flooding may be unavoidable, there are still many uncertainties with regard to the long-term trajectory of sea-level rise. To slow the rate of sea-level rise, and enable coastal communities to adapt in affordable and manageable ways, emissions of GHGs must be reduced now. Given their ability to sequester and store large quantities of atmospheric carbon, ensuring the sustainability of coastal blue carbon habitats should be a component of the overall climate change adaptation strategy for the greater Tampa Bay area.

Implications for Blue Carbon Science and Policy

This study highlights the substantial contribution that coastal wetlands provide to removing carbon dioxide from the atmosphere and storing carbon as biomass and in the soil. By 2100 Tampa Bay’s blue carbon ecosystems will remove 74,000,000 tonnes of CO_2.

Management actions that conserve and restore blue carbon ecosystems and build in resilience to sea-level rise in Tampa Bay, and Florida more generally, will have a positive benefit for long term carbon sequestration and storage.

Over the past centuries, the bay has seen a gradual expansion of mangroves, expanding across marshes and intertidal flats. This has resulted in an increase in biomass and soil carbon storage. In absence of increasing rates of sea-level rise, this gradual displacement of marshes by mangroves will continue along with soil carbon enrichment.

Blue carbon stocks in Tampa Bay were found to be relatively insensitive to the loss of intertidal wetlands with greater levels of sea-level rise post-2050. If water quality is maintained, a decline in mangrove area and associated displacement in biomass and soil carbon is offset by the expansion of seagrass and building of submarine carbon stocks. This is somewhat of a surprising result because of the lower soil carbon densities in seagrass sediments than mangroves. This result was driven in part by the shallowness of mangrove soil (typically less than 50 cm thick) and by the inclusion in this assessment of a reasonable assumption that 40% of mobilized carbon stocks are buried elsewhere within the coastal system and not returned to the atmosphere[10].

Maintaining water quality and creating space for wetland landward migration will be important to maintaining the extent of blue carbon ecosystems and carbon sequestration with sea-level rise.

This report also highlights the need to understand the inorganic carbon pathway in carbon sequestration and storage. Inclusion of seagrass mediated bicarbonate production effectively doubles the total carbon sequestration potential of seagrass meadows. Further research is needed before inorganic carbon pathways can be included within blue carbon sequestration estimates.

[10] Based upon Blair and Aller 2012

1. INTRODUCTION

Worldwide efforts to mitigate greenhouse gas (GHG) emissions, including through biological carbon sequestration, have increased throughout the early twenty-first century. To date, much of the science and practice of biological carbon sequestration and the development of associated carbon offset projects have focused on forestry, and the science and tools necessary to calculate GHG benefits are fairly well developed for forestry practices.

More recently, national and international organizations, as well as state and federal agencies, have become increasingly interested in exploring the carbon storage and sequestration capacities of wetlands, especially salt marsh, mangroves, and seagrass. Peer-reviewed scientific literature has demonstrated the great significance of these ecosystems for both carbon uptake and storage—the process of capturing carbon dioxide from the atmosphere and storing it over time in plant materials and sediments (e.g., Pendleton et al. 2012 and references within). The carbon sequestration associated with coastal ecosystems has been referred to as “blue carbon.”

Globally, these coastal ecosystems are being lost at an alarming rate, and the diminishing carbon sequestration capacities associated with such losses has been the focus of many studies. However, Tampa Bay may be an example where carbon sequestration is increasing over time, rather than decreasing. Recent increases in habitat extent are potentially positive for coastal ecosystem carbon sequestration in Tampa Bay. Despite a four-fold increase in the population of the Tampa Bay region, water quality appears to be similar at present to what it was in the 1950s (Tampa Bay Estuary Program [TBEP] 2012). In response, seagrass coverage is now higher than it has been in decades. Between 2008 and 2010, an additional 3,250 acres of seagrass were added in Tampa Bay, an increase of 11 percent (TBEP 2012). The current seagrass coverage, an estimated 40,295 acres, is 86% higher than the 21,647 acres mapped in 1982. The Bay now supports as much seagrass as was present in the 1950s.

In addition to seagrass recovery, there has been an increase of 1,056 acres of emergent tidal wetlands between 1995 and 2011 (adapted from TBEP 2012; SWFWMD 2011). Combined, the increase in seagrass coverage and coastal wetlands represents a potentially significant increase in ecosystem-based carbon sequestration associated with estuarine restoration.

However welcome this news may be, these hard fought gains in ecosystem health could be at risk under various sea-level rise and climate change scenarios. If sea-level rise or climate change stresses these ecosystems, then not only could they be lost, partially or in full, but their loss could be part of a positive feedback loop wherein initial losses make further losses more likely.

1.1 Goal and Objectives

The goal of the Coastal Blue Carbon Assessment of the Tampa Bay Estuary project is to determine the past and future climate mitigation benefits of ongoing and potential future coastal habitat restoration and conservation efforts in Tampa Bay. Additionally, the project strives to identify opportunities for enhanced ecosystem management that will provide agencies and community members in the region with information to support coastal management planning. The objectives of the project are to:

1 Determine the past and potential future climate mitigation benefits of coastal habitat restoration and conservation in Tampa Bay.

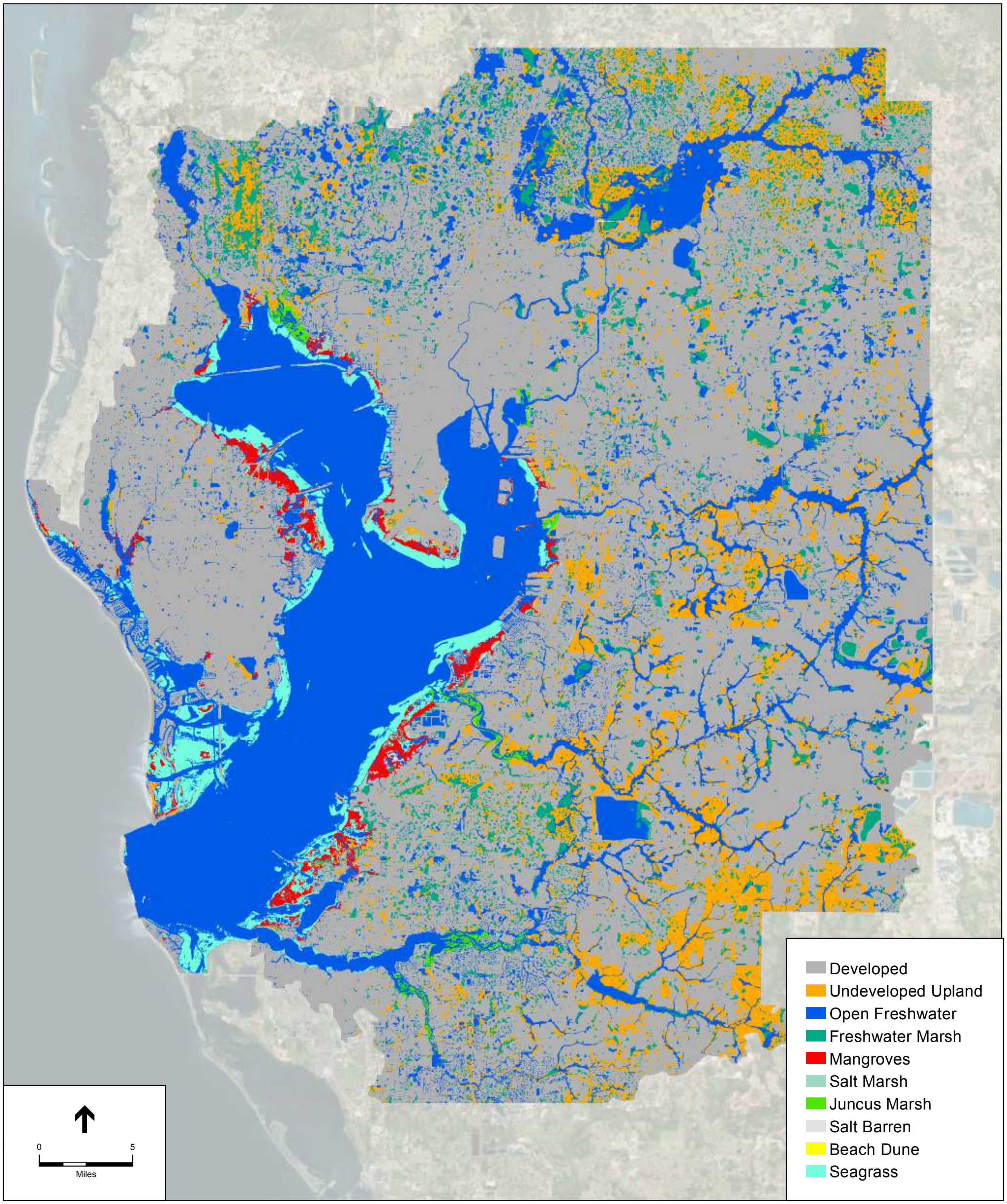
2 Identify opportunities for enhanced ecosystem management for climate change benefits, including guidance for priority conservation and restoration site selection.

3 Support increased capacity building for, and investment in, habitat restoration and coastal adaptation.

1.2 Project Background

Tampa Bay has supported a non-aboriginal coastal community since at least the mid-1800s. Since that time, coastal development patterns to expand industrial, commercial, and residential land uses within the watershed have negatively impacted critical coastal habitats to varying degrees (Simon 1974). Beginning in the 1950s, the most significant impacts to emergent tidal and subtidal habitats started to occur. Large-scale dredge and fill activities to create shoreline residential and commercial development opportunities resulted in the burial or removal of many of Tampa Bay's critical coastal habitats (LES and CE 1996). It was not until the 1970s through the 1980s that more stringent development regulations and environmental standards were implemented to prevent further loss of Tampa Bay's coastal habitats and help foster water quality improvement. Since that time, Tampa Bay resource managers have had mixed success in restoring some of these habitats, which include seagrass, mangrove forests, salt marshes, and salt barrens.

As of 2011, greater than 60% (180,614 ha) of the upland and coastal land cover within 15 km of Tampa Bay's shoreline was urban and suburban development (SWFWMD 2011; Figure 1). An additional 13.8% (41,572 ha) has been developed for agricultural purposes within this buffer area. The remaining natural uplands, wetlands, or restored lands (as of 2011) only total about 25.6% (76,957 ha) of this fringing coastal area of Tampa Bay's shore. Habitats contained within this 15 km coastal buffer have been recognized for their importance to the life history of specific estuarine species guilds (LES and CE 1996; TAS 1999).



Source: SWFWMD 2011

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Figure 1
Tampa Bay 2011 Land Use

Despite these significant, historic conversions of coastal habitats to developed land uses, Tampa Bay continues to support a thriving estuarine ecosystem. In turn, the ecosystem services provided by the Bay's coastal habitats support and directly contribute toward a substantial regional economy (Tampa Bay Regional Planning Council 2015). About half of the regional employment is dependent upon the Bay itself, and in total, one in five jobs in the region depends on a "healthy" Tampa Bay.

However, future development patterns and an anticipated doubling of the population between 2016 and 2050 may threaten to further diminish both the economic and environmental integrity of Tampa Bay's coastal habitat resources. Not only does expanding development create significant potential issues, but new, emerging climate change pressures may also work synergistically to alter the extent, distribution, quality, and ecosystem services provided by the remaining critical coastal habitats in Tampa Bay. As such, regional managers have been looking to develop new incentives and policies to promote the protection and expansion of these important estuarine habitats.

Efforts are under way to develop the tools and refine the science needed to bring carbon markets and carbon finance to bear on tidal wetlands restoration and protection activities. The National Oceanic and Atmospheric Administration's (NOAA's) National Estuarine Research Reserve System Science Collaborative, Entergy, and TBEP provided funding to Restore America's Estuaries (RAE). RAE is working with a team of estuarine restoration, climate change, and carbon market experts to develop a methodology for tidal wetlands and seagrass restoration GHG offsets, and is working on a methodology for conservation of intact wetlands. The addition of climate mitigation benefits is expected to broaden the pool of potential funds for estuarine restoration, which could directly benefit ecosystem restoration efforts in Tampa Bay. Where carbon finance is not appropriate, recognition of the climate mitigation values of these ecosystems could help prioritize actions that improve and conserve these habitats in the context of climate adaptation.

While the high carbon storage and sequestration values of coastal systems are fairly well recognized, a translation of these carbon values to an estuary restoration and protection setting needs to be developed. Such a translation could provide a demonstration of the added value of wetland carbon storage potential to achieving estuary-specific restoration and protection goals, as well as the climate mitigation benefits of past actions.

This project will focus on Tampa Bay, which offers a variety of tidal wetland habitats, past restoration actions, and future restoration and management needs, including salt marsh, seagrass, and mangrove habitats. There is carbon sequestration potential in the suite of ongoing and proposed ecosystem restoration projects, as well as a significant body of estuary-specific data on land-use changes, sea-level rise projections, and detailed site-specific restoration plans. In addition, by incorporating sea-level rise predictions, this project will provide the added benefit of determining the resiliency of carbon storage and sequestration processes given the dramatic changes predicted in the near- and long-term due to climate change impacts.

1.3 Project Partners

1.3.1 Restore America's Estuaries

RAE is a national alliance of 10 coastal conservation groups that stretch from Rhode Island to Washington State. Local projects restore coastal wetlands, improve water quality, open fish passages, build living shorelines, replant salt marshes, and restore shellfish habitat.

RAE provides a united voice for coastal conservation in the nation's capital and advances the science and practice of protecting and restoring estuaries through on-the-ground projects, groundbreaking science, high-level meetings, and the power of convening people. RAE is dedicated to the protection and restoration of bays and estuaries as essential resources to the nation.

1.3.2 Environmental Science Associates

Environmental Science Associates (ESA) is a nationally recognized environmental planning firm with 45 years of experience that provides innovative approaches to complex water resource problems for clients throughout the Western and Southeast United States and abroad. ESA's work integrates rigorous science with practical engineering solutions to address a range of problems affecting environments from the headwaters to the coast. ESA specializes in the planning and design of multi-objective projects that combine ecologic, economic, flood protection, recreational, and other social benefits.

ESA is at the cutting edge of blue carbon science and coastal wetland management. ESA has been engaged since the beginning of the blue carbon concept and provides technical advice at all levels of government and community. ESA staff have been personally invited to aid national delegations at the Climate Change Negotiations, contribute to Intergovernmental Panel for Climate Change (IPCC) documents, and aid in demonstration of blue carbon projects at the local level. ESA staff serve as principal investigators for NASA projects and are invited as co-chairs of science panels for committees and advisory groups, including the International Blue Carbon Scientific Working Group and Global Environmental Facility Blue Forest (Mangrove) Project.

1.3.3 Tampa Bay Estuary Program

TBEP's mission is to build partnerships to restore and protect Tampa Bay through implementation of a scientifically sound, community-based management plan. TBEP was created by Congress in 1991 to assist the community in restoring and protecting Florida's largest open-water estuary. As a designated "estuary of national significance," Tampa Bay is the economic and environmental centerpiece of a rapidly growing region supporting more than 2.3 million people.

1.3.4 Tampa Bay Watch

Tampa Bay Watch is a nonprofit organization dedicated to the protection and restoration of the Tampa Bay estuary through scientific and educational programs. Tampa Bay Watch is working to preserve the delicate ecological balance that exists in Tampa Bay. Established in 1993, Tampa Bay Watch performs a variety of habitat restoration and protection activities throughout the year, using thousands of volunteers to help the Bay recover from its environmental problems. Individuals of all ages from community groups, scout troops, schools, and other organizations participate in salt marsh plantings, storm drain markings, oyster bar creation, coastal cleanups, and wildlife protection each year, demonstrating environmental stewardship in its purest form.

1.4 Study Approach

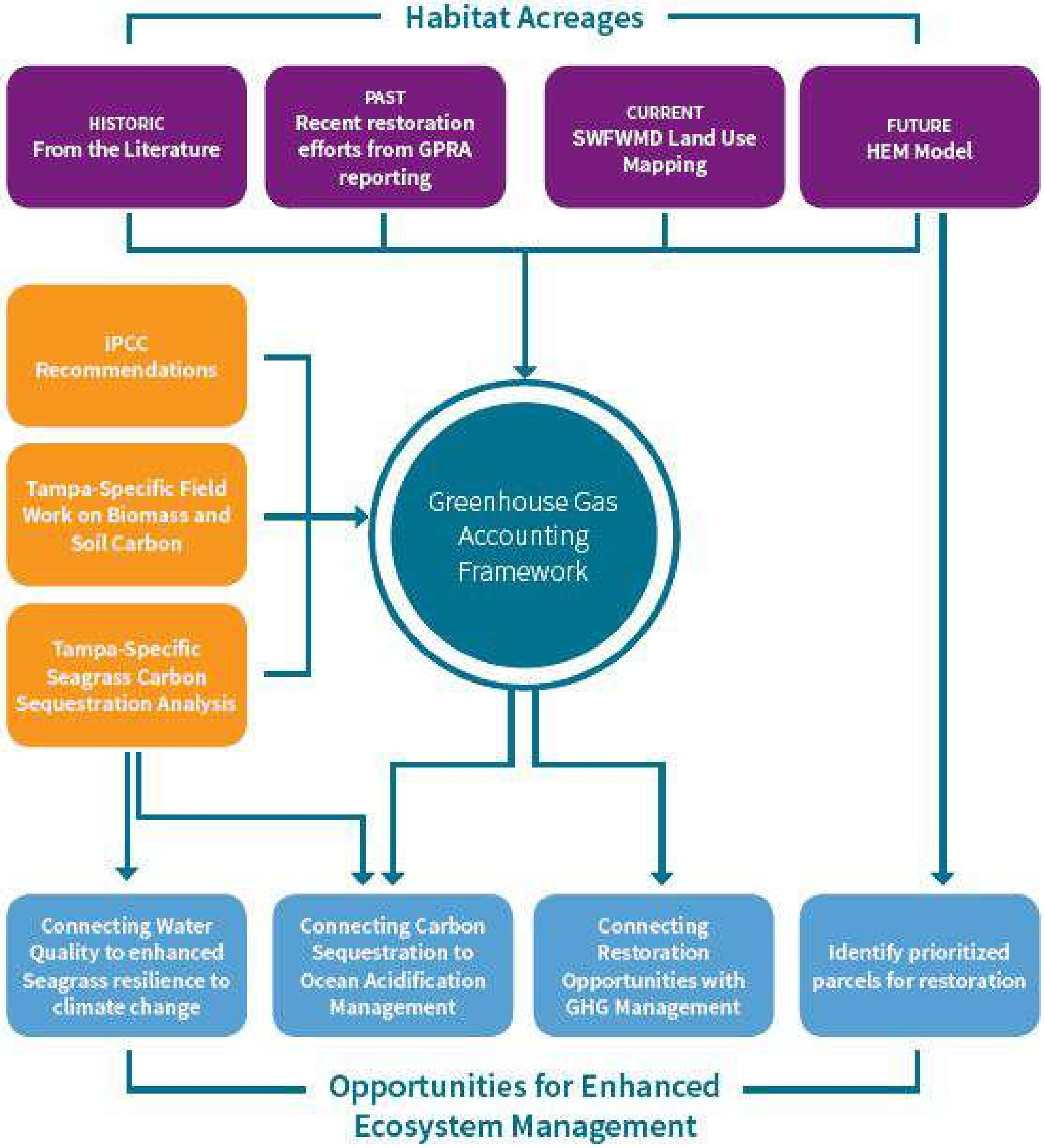
The study approach began with developing a conceptual model of Tampa Bay habitats and processes to better understand the system (Figure 2, Section 3.1). Using this conceptual model, habitat areas were quantified for Tampa Bay in the past, present, and future (Section 3.2). Historic habitat acreages were taken from the literature, while data for the more recent past was derived from the Southwest Florida Water Management District (SWFWMD) Land Use/Land Cover maps and the reporting of restoration projects through the Government Performance and Results Act (GPRA). Future habitat acreages were projected using a custom-built geographic information system (GIS) model specific to Tampa Bay, referred to as the Habitat Evolution Model (HEM).

The resulting habitat acreages were then input to an IPCC-based, GHG framework (Section 3.3). The framework uses locally and/or regionally appropriate values or estimates of biomass, soil carbon sequestration rates, and methane emission rates for each habitat type to estimate GHG fluxes based on land use changes. The values for biomass, soil carbon sequestration, and methane emissions were derived from the literature and include data collected in the field and specific to Tampa Bay (Tomasko et al. 2015, Moyer et al. 2016, Gonneea 2016).

The HEM analysis included different management options, such as “holding the line” (protecting development), or allowing marshes to migrate into “soft” development (e.g. agriculture, recreational lands). Results from the HEM and GHG framework analyses provide insight into which management scenarios are most effective. Additionally, the HEM results were used to identify and prioritize parcels for restoration within Tampa Bay. These results can be used to inform future elements of adaption planning around Tampa Bay.

1.5 Report Organization

This report is organized into four chapters beyond the introduction. Chapter 2 lays out the planning context and previous work done toward achieving the project goal and objectives (Section 1.1). Chapter 3 discusses the analytical approach as summarized in Section 1.4. Chapter 4 presents the results of the analysis and Chapter 5 discusses the management implications of the results. References used in this study are presented in Chapter 6.



Source:

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Figure 2
Study Approach

2. Planning Context and Previous Work

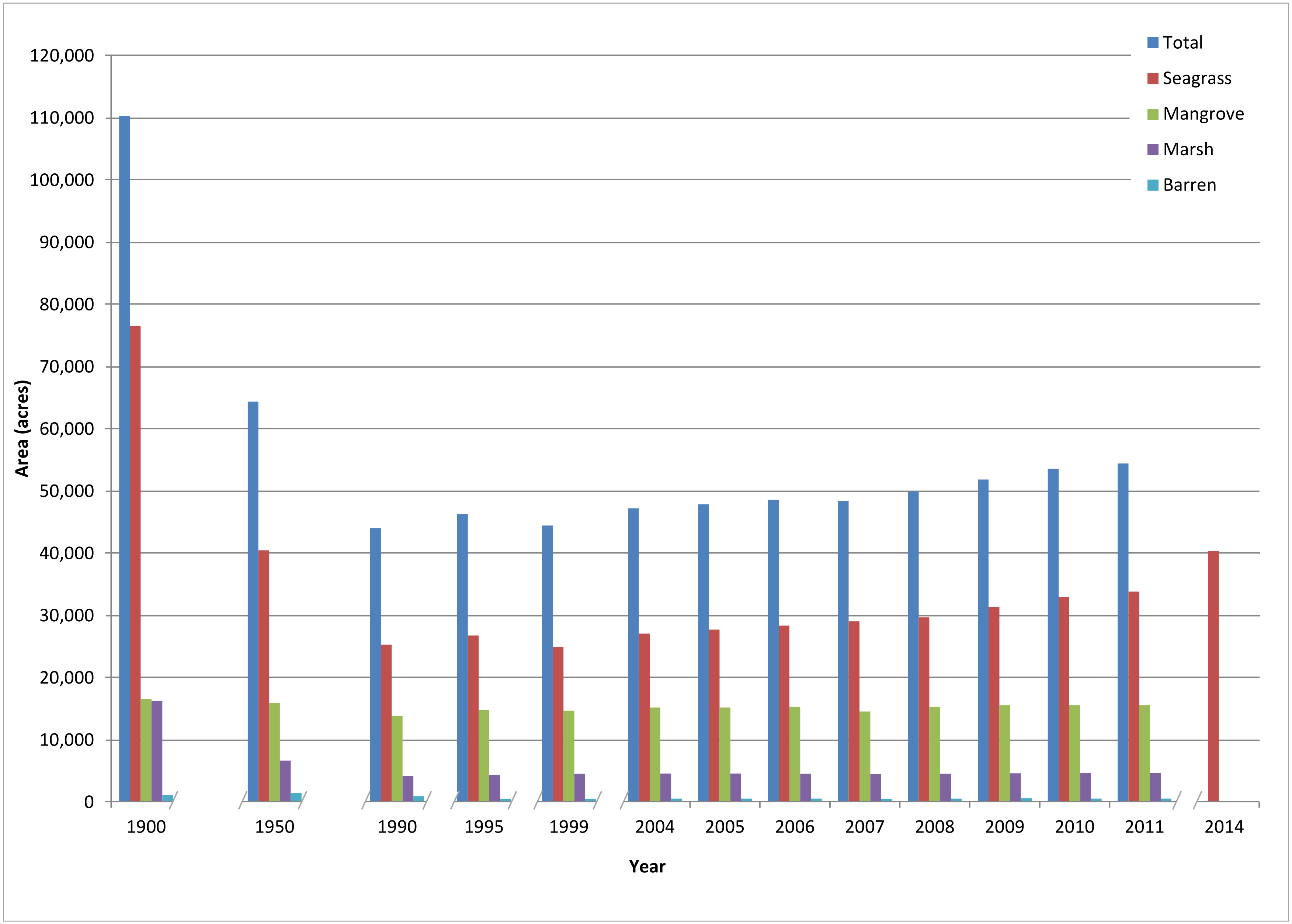
2.1 Wetland Conservation and Restoration in Tampa Bay

Most recent estimates of Tampa Bay wetland habitats show general declines in coverage between the 1900s and early 1990s due to rampant land development (Figure 3). Since then, land acquisition and habitat restoration activities undertaken primarily by public agencies, but also by for-profit and non-profit entities, has led to modest gains in coastal habitat acreages.

Historically, Tampa Bay tidal wetland habitats were composed of a mosaic of mangroves, salt marshes, and salt barrens. Since the nineteenth century, mangroves have become more dominant, although the extent of the change still remains a question of interest[11] (Raabe et al. 2012). However, significant progress toward achieving gains in salt marsh and salt barren habitats has been made since 1995 (Robison 2010). Additionally, seagrass restoration has been hugely successful in Tampa Bay with an increase of approximately 18,645 acres since 1982 as a result of improved wastewater and stormwater treatment as well as checks on dredging and filling activities (adapted from Robison 2010; Sherwood et al. 2015).

As depicted in Figure 3, seagrass coverage increased more rapidly than mangrove coverage since the 1990s. Salt marsh acreage remained relatively steady from 1995 to 2007 (Table 1). Salt barren acreage has experienced a small increase, and is now roughly a third of the extent that was estimated in the 1950s. Note that the land cover classifications used for the 1950s data vary somewhat from the Florida Land Use, Cover, and Forms Classification System categories. See Yates and Raabe (2011) for a full explanation of methods for estimating coastal wetland extent in 1900. Land use was first mapped by SWFWMD in 1990, thus there are variable methodologies used during this year (see Robison 2010). SWFWMD did not systematically map salt barren habitat types until after 1999; however, Robison (2010) estimated salt barren habitat extent for 1995 and 1999 from color photography. Table 1 presents changes in saltwater vegetation acreage over various time periods in Tampa Bay.

[11] Raabe et al. compared maps from the 1870s with present day to determine changes in marsh habitat types. However, some of the maps from the 1870s show questionable data and should be considered accordingly.



SOURCE: ca. 1900 1950; adapted from LES & CE 1996; years 1990-2014 from SWFWMD 2014

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Figure 3

Estimated Area of Tampa Bay Blue Carbon Habitats over Time

TABLE 1
TAMPA BAY WETLAND HABITAT ACREAGES OVER TIME

	1900	1950	1990	1995	1999	2005	2011
Salt Barren	1,000	1,400	880	450	470	490	500
Salt Marsh	16,200	6,600	4,100	4,300	4,500	4,500	4,600
Mangroves	16,500	15,900	13,800	14,800	14,600	15,100	15,500
Seagrass	76,500	40,400	25,200	26,700	24,800	27,700	33,800
Total	110,200	64,400	44,000	46,300	44,400	47,800	54,400

2.2 Modeling Habitat Response to Sea-Level Rise

Changes in wetland habitats in Tampa Bay caused by sea-level rise have been modeled by three different groups (Glick and Clough 2006, Sherwood and Greening 2012, Geselbracht et al. 2013). All three studies used the Environmental Protection Agency's model, Sea Level Affecting Marshes Model (SLAMM), to look at the effects of sea-level rise, accretion and erosion, and freshwater inflow on different coastal habitats. The model calculates habitat areas and maps habitat distribution over time based on inputs of existing vegetation, topography, accretion rates, and sea-level rise.

Glick and Clough (2006) modeled sea-level rise and framed the results in the context of impacts on coastal habitats and species, particularly saltwater fishery species. Modeling of sea-level rise was conducted over nine sites on the Florida coastline, including Tampa Bay. For Tampa Bay specifically, the model projected the greatest overall habitat gain for mangroves, expected to approximately double in acreage by 2100. The greatest overall habitat loss was for tidal flats, a reduction of 96%, followed closely by salt marsh, with an 86% decrease. The barrier islands were projected to experience significant inundation— roughly 10% of dry land would be impacted. These results translate to high risk for species, including flounder, permit, redfish, sheepshead, snook, spotted seatrout, and tarpon.

Sherwood and Greening (2012) focused on Tampa Bay and updated the estimates of Glick and Clough using more contemporary sea-level rise information from the IPCC. As in Glick and Clough's study, Sherwood and Greening found an estimated decline in overall critical coastal habitat acreage by 2100. The study notes that these results are projected regardless of implementation of two, divergent adaptation strategies. The results of Sherwood and Greening's model estimate, similarly to Glick and Clough's results, that mangrove habitat acreage would increase from 74% of critical coastal habitat acreage to a maximum of 89%. This would translate to loss of other critical coastal habitats. The results showed coastal freshwater wetland is expected to experience the greatest acreage loss, followed closely by salt marsh and salt barren. These acreage changes would negatively impact species dependent on all three habitat types experiencing acreage loss, particularly those associated with salt marsh and salt barren.

Geselbracht et al. (2013) used SLAMM to examine five estuarine systems in the Gulf of Mexico, including Tampa Bay. As found in Glick and Clough's as well as Sherwood and Greening's results mangroves are expected to increase most substantially by 2100. The most significant habitat losses were projected to be tidal flat, coastal forest, and salt marsh, in order of largest to smallest acreage loss. The most impacted species are reported to be Statira (*Aphrissa statira*), Nuttall's rayless goldenrod (*Bigelowia nuttallii*), Tampa vervain (*Glandularia tampensis*), and Hairy beach sunflower (*Helianthus debilis* spp. *vestitus*).

In the current blue carbon analysis, ESA initially considered applying SLAMM or using the previous model results to calculate habitat acreages. However, a further look at the model showed that SLAMM does not accurately represent the full suite of habitat conversion processes that are important to Tampa Bay. For example, for tropical locations such as Tampa Bay, almost all of the habitat categories convert to mangroves as sea-level rise drowns the existing habitat in SLAMM. This leads to an overestimate of the area of mangroves predicted for the future (all three studies above showed large increases in mangrove habitat). Similarly, none of the habitats convert to irregularly flooded marsh/brackish marsh, a category that would include salt barrens, so the prediction shows an underestimate of the area of brackish marsh or salt barren habitat (all three studies showed significant loss in salt barren habitat). To address these differences, ESA developed a GIS HEM that recreated some of the features of SLAMM and added in other processes that were important to the system in Tampa Bay. Section 3.2.3 describes the new model used for this study.

Additionally, while it should be intuitive that new shallow subtidal areas will be created by sea-level rise, as acknowledged by Sherwood and Greening (2013), SLAMM is not able to simulate seagrass responses to sea-level rise. Seagrasses are extremely important to the overall ecology of Tampa Bay, and understanding their response to sea-level rise is critical to developing future habitat management strategies. The HEM adds subtidal seagrass expansion to the model to evaluate changing habitats over time.

2.3 Prioritizing Future Wetland and Adjacent Uplands Restoration and Conservation

Based on previous modeling (Sherwood and Greening 2012), Sherwood and Greening (2013) compared the habitat projections to established restoration goals within Tampa Bay. Based on these evaluations, they proposed recommendations for future protection and restoration of critical coastal habitats. They developed a GIS-based Tampa Bay Sea-Level Rise Visualization Tool (http://www.tampabay.wateratlas.usf.edu/TB_SLRViewer/) to be applied to land use planning and habitat restoration efforts. In their study, Sherwood and Greening (2013) concluded that the paradigm of "Restoring the Balance" of critical coastal habitat may need to be reconsidered, based on the projection that mangrove habitat will overtake most other wetland habitats. They recommend continuing efforts to restore large-scale ecosystems with a mosaic of habitats and to consider lands upslope of the previously identified priority restoration areas to provide sea-level rise accommodation space.

3. ANALYTICAL APPROACH

3.1 Conceptual Model of Tampa Bay Processes, Habitats, and Greenhouse Gas Fluxes

The first part of the blue carbon analysis looks at the habitat acreages in Tampa Bay historically, currently, and in the future. To project future habitat evolution and the resulting habitat acreages, an understanding of the Bay's existing processes is needed. The habitat projection model described in Section 3.2.3 is based on the understanding that Tampa Bay habitats change over the long-term in response to multiple processes, including tides, accretion, freshwater inflow, sea-level rise, and ecology. These biological and physical processes are described in Section 3.1.1.

The second part of the analysis considers how GHG fluxes have changed and will further change over time. To quantify these changes, an understanding of stocks and emissions is necessary. Section 3.1.2 discusses carbon stocks, methane emissions, nitrous oxide emissions, and how these combine to calculate net GHG flux.

3.1.1 Tampa Bay Natural Processes

3.1.1.1 Tides

Salt marsh and intertidal habitats establish within zones corresponding to tidal inundation. Tides and tidal inundation within the Bay are therefore important processes affecting habitats within the Bay. The Tampa Bay tides are driven by ocean tides that propagate through the bay mouth and which affect tidal heights in the Bay relative to tidal heights in the ocean (e.g., through tidal muting or damping).

The Florida Gulf coast experiences mixed semidiurnal tides, with two high and two low tides of unequal heights each day. In addition, the tides exhibit strong spring-neap tide variability; spring tides exhibit the greatest difference between high and low tides while neap tides show a smaller than average range. Tidal datums for the different gages in Tampa Bay, as well as a gage at Clearwater Beach, which is just up-coast of the Bay and measures the Gulf of Mexico tides, are summarized in Table 2.

Tides propagate through Lower and Middle Tampa Bay back into Boca Ciega Bay, Terra Ceia Bay, Manatee River, Old Tampa Bay, and Hillsborough Bay. Since there are no tide gages in Boca Ciega Bay, Terra Ceia Bay, and Manatee River, the tides are assumed to match those in Lower Tampa Bay. In the two back bays, the tide range is 0.3 – 0.6 feet greater than in Lower and Middle Tampa Bay. However, the overall tide range is muted compared to the tides in Gulf of

Mexico, as represented at Clearwater Beach. Figure 4 shows the gage locations, while Figure 5 shows the tides within the different Bay segments.

TABLE 2
NOAA TIDAL DATUMS FOR TAMPA BAY

	Port Manatee *Lower Tampa Bay*		St. Petersburg[1] *Middle Tampa Bay*		Old Port Tampa[2] *Old Tampa Bay*	McKay Bay Entrance *Hillsborough Bay*		Clearwater Beach *Gulf of Mexico*	
Tidal Datum	**ft MLLW**	**ft NAVD**	**ft MLLW**	**ft NAVD[1]**	**ft MLLW**	**ft MLLW**	**ft NAVD**	**ft MLLW**	**ft NAVD**
Highest Astronomical Tide (HAT)	3.06	1.51	3.12	1.66	3.46	3.67	2.01	3.71	1.94
Mean Higher High Water (MHHW)	2.19	0.65	2.26	0.80	2.46	2.67	1.00	2.76	0.99
Mean High Water (MHW)	1.92	0.37	1.98	0.52	2.14	2.33	0.66	2.42	0.65
North American Vertical Datum of 1988 (NAVD)	1.55	0.00	1.45	0.00	-	1.67	0.00	1.77	0.00
Mean Tide Level (MTL)	1.15	-0.40	1.18	-0.27	1.29	1.42	-0.25	1.46	-0.31
Mean Sea Level (MSL)	1.16	-0.38	1.20	-0.25	1.28	1.44	-0.22	1.48	-0.29
Mean Low Water (MLW)	0.37	-1.18	0.38	-1.07	0.45	0.51	-1.16	0.51	-1.26
Mean Lower Low Water (MLLW)	0.00	-1.55	0.00	-1.45	0.00	0.00	-1.67	0.00	-1.77

1. NOAA did not have a published NAVD conversion for St. Petersburg. However, the gage did have one benchmark with an NAVD value, so that is used to create the conversion.
2. A conversion of 1.56 ft MLLW = NAVD was used for Old Port Tampa based on an average of St. Petersburg and McKay Bay gages.

3.1.1.2 Topography and Accretion

The elevation of an area determines the frequency of tidal inundation and salinity, which then influences the type of vegetation that will establish. If the topography changes as a result of accretion (or restoration/grading), the habitat types can change in response.

Sediments are delivered to the Bay via tributary inflows, and through the internal deposition of decaying organic matter. Therefore, tidal wetland accretion rates are controlled by both external inputs of inorganic sediments (e.g., mineral sand, silt, and clay) from the watershed, as well as internal organic deposition from within the wetlands themselves. Due to the flat topography of the Tampa Bay watershed, and corresponding low concentrations of suspended solids in tributary inflows, internal organic deposition tends to be the dominant accretion process in Tampa Bay. Note that some portion of the watershed sediment load is also exported through the Bay to the Gulf by storm flows. Figure 6 shows the topography and bathymetry of the Tampa Bay watershed.

SOURCE: NOAA Tides and Currents:

Tampa Bay Blue Carbon Assessment . D140671

Figure 4
Locations of NOAA Tide Gages in Tampa Bay

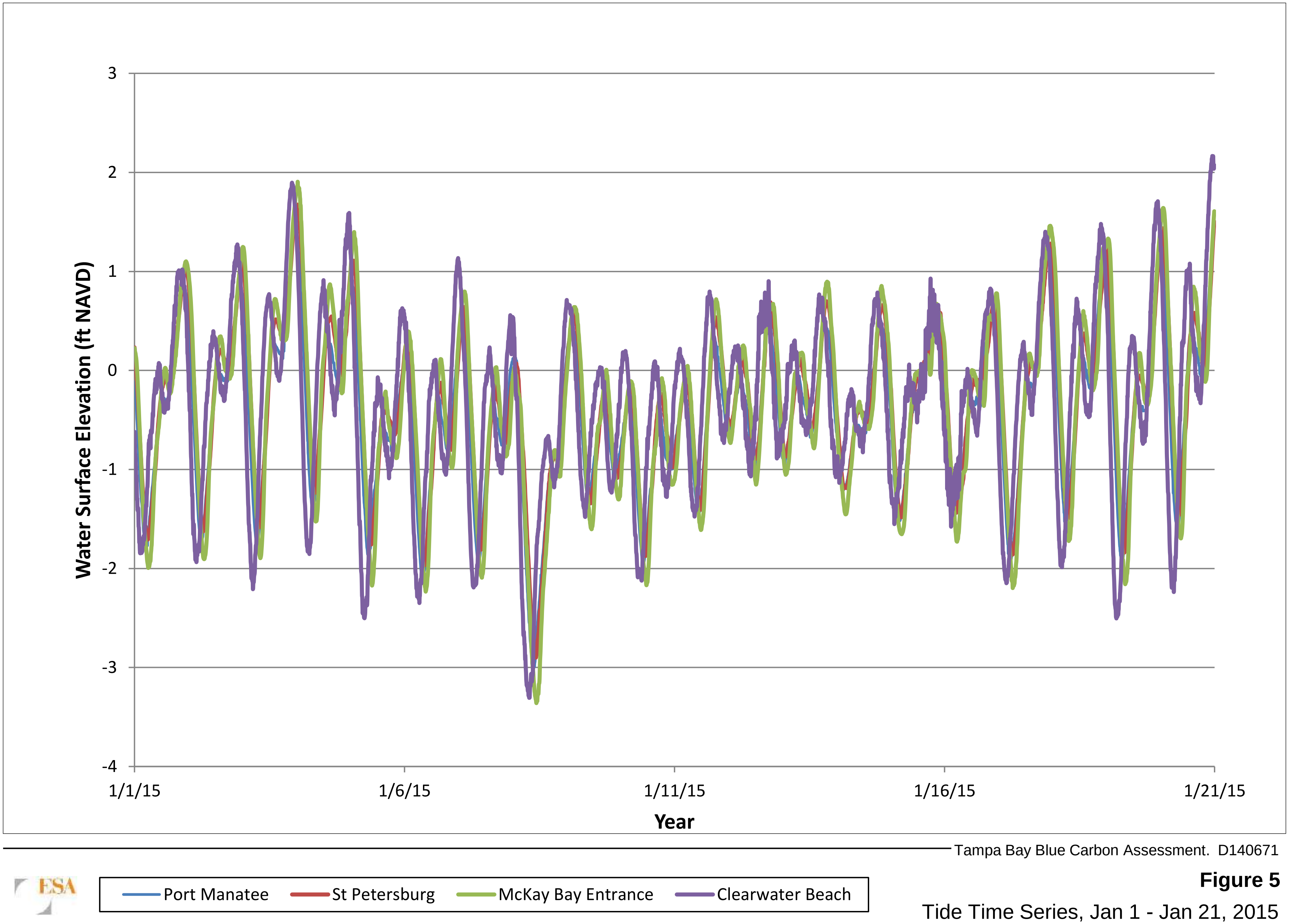

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Figure 5

Tide Time Series, Jan 1 - Jan 21, 2015

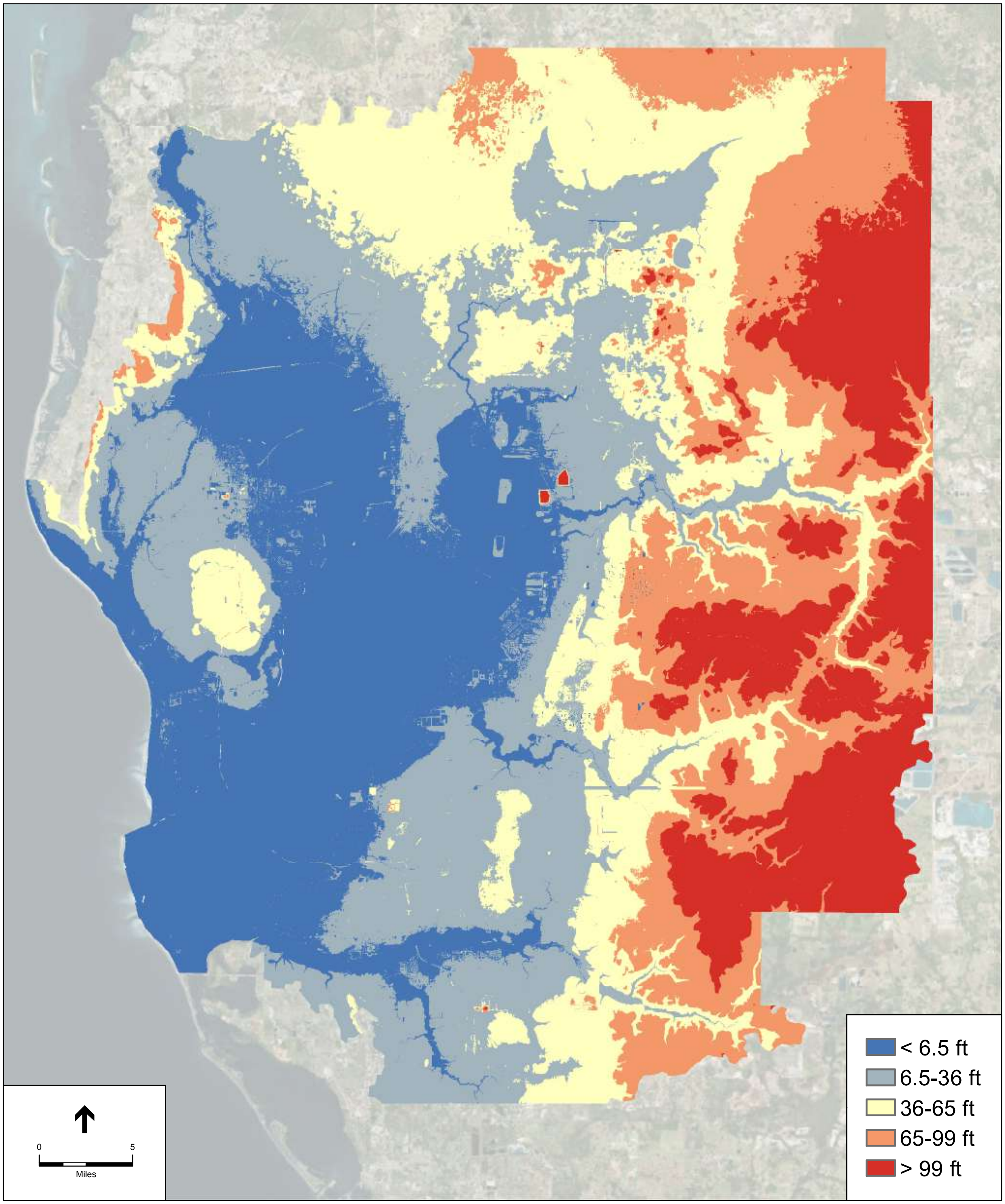

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Figure 6
Tampa Bay Topography and Bathymetry

Accretion rates in Tampa Bay vary depending on location and habitat type. In salt marsh, accretion rates vary from 1.6 to 3.0 mm/yr. (Sherwood and Greening 2013, Geselbracht et al. 2013, Morris et al. 2016). Brackish marsh habitat in Tampa Bay likely experiences accretion rates of 2.25 – 3.75 mm/yr., while freshwater marsh is as high as 3.75 – 4 mm/yr. (Sherwood and Greening 2013, Geselbracht et al. 2013). Accretion in mangroves varies depending on the type of mangrove habitat. For Tampa Bay, mangroves accrete between 1.6 and 5 mm/yr. (Krauss et al. 2013, Krauss Pers. Comm. January 21, 2016).

3.1.1.3 Freshwater Inflow

Freshwater and brackish marsh habitats are either inundated solely by freshwater or are characterized by tidal mixing of ocean water and freshwater inflows, creating brackish salinities. The influence of freshwater determines what type of vegetation can establish in that area. If the extent of freshwater influence increases, the extent of freshwater and brackish marsh habitats will increase. Conversely, if the area of freshwater influence is reduced, the extent of freshwater habitats will be reduced. The area or extent of freshwater influence can be inferred from the extent of existing freshwater habitats, correlated to freshwater inflows, and/or quantified through monitoring and modeling of freshwater inflows and salinity gradients.

Tampa Bay has four major rivers, Hillsborough, Alafia, Manatee, and Little Manatee, which contribute 85% of the flow into the Bay (PBS&J 2010). The Hillsborough River contributes the largest average discharge (650 cfs), followed by the Alafia River (480 cfs), the Manatee River (290 cfs), and Little Manatee River (250 cfs) (FWS 1988). Flows are typically highest in August and September.

3.1.1.4 Sea-Level Rise

Sea-level rise (and associated tidal change) is expected be a major driver of habitat evolution in Tampa Bay. Since most vegetation establishes in areas based on tidal inundation and salinity levels, habitats will evolve as sea-levels rise.

The U.S. Army Corps of Engineers (USACE) provides guidance for projects in planning for sea-level rise (2011). The document provides two different sea-level rise curves, the intermediate NRC-I and high NRC-III curves. These predictions are:

- 4 to 9 inches of sea-level rise by 2030
- 7 to 19 inches of sea-level rise by 2050
- 12 to 32 inches of sea-level rise by 2070
- 20 to 59 inches of sea-level rise by 2100

The Tampa Bay Climate Science Advisory Panel prepared a report in 2015 to address sea-level rise in the Tampa Bay area. The report offered four scenarios, based on the NOAA sea-level rise projections through 2100 and adjusted by the St. Petersburg tide gage. Table 3 provides the four scenarios.

TABLE 3
RELATIVE SEA-LEVEL CHANGE SCENARIOS FOR ST. PETERSBURG, FLORIDA
(INCHES OF SEA-LEVEL RISE SINCE 1992)

Year	NOAA Low	NOAA Intermediate Low	NOAA Intermediate High	NOAA High
1992	0	0	0	0
2025	3.4	4.6	7.2	10.1
2035	4.4	6.4	10.8	15.7
2050	6.0	9.6	17.5	26.6
2065	7.6	13.2	25.8	40.2
2075	8.5	16.0	32.2	50.8
2100	11.2	23.6	51.1	82.7

The NOAA Intermediate Low scenario is similar to the USACE NRC-I curve, while the Intermediate High scenario is close to the NRC-III curve. For this reason, the Intermediate Low and Intermediate High scenarios were used in the HEM for this report.

With climate change, extreme high water levels may change more than mean sea levels due to alterations in the occurrence of strong winds and low pressures. However, this has not been extensively studied for the project area, so it is not included in this conceptual model.

3.1.1.5 Habitats

The northern extent of the Tampa Bay watershed borders between subtropical and temperate climates (Yates et al. 2011), though recent temperatures are trending towards more subtropical climates (Martinez et al. 2012). As a result, a mosaic of subtidal and emergent estuarine wetlands, tolerant to mild subtropical climates, is present. Work by Raabe et al. (2012) indicated that Tampa Bay emergent tidal wetland habitats have changed to more subtropical-dominant mangrove forests since the late 1800s. Raabe et al. (2012) hypothesized that the marsh to mangrove conversions over the 19th to 20th centuries was due to three primary drivers: climate change, hydrologic alterations, and landscape development. A description of the subtidal and emergent estuarine habitats now present in Tampa Bay follows. The final subsection describes where the different habitats are found topographically.

Seagrass Meadows

Five seagrass species occur in Tampa Bay; however, three species are the most predominant. Stable seagrass beds in the higher salinity regions of Tampa Bay – typically towards the mouth of the Bay and adjacent to the Gulf of Mexico – are primarily composed of *Thalassia testudinum* (turtle grass). Turtle grass is the largest seagrass species, with long strap-shaped leaves and robust rhizomes which can provide significant carbon storage and GHG sequestration potential previously recorded for the related species *T. hemprichii* (Chiua et al. 2013). The species *Halodule wrightii* (shoal grass) is the most common species in the Bay, as it is found in every bay segment. Shoal grass has flat, narrow leaves and a shallow root system. Shoal grass can tolerate more frequent exposure from low tides than other Tampa Bay seagrass species, which gave rise to its common name, and allows this species to grow in shallow, fringing areas adjacent to more dense turtle grass beds. The third predominant species, *Syringodium filiforme* (manatee grass), is usually found in the higher salinity regions of Tampa Bay, in association with turtle grass, but typically towards the deeper extent of these meadows. Manatee grass can be distinguished by its long, cylindrical leaves. Shoal grass may also dominate the deep-water edge of Tampa Bay seagrass meadows, depending upon the region. In parts of the Bay that have the lowest and most variable salinity, such as northern portions of Old Tampa Bay, the species *Ruppia maritima* (widgeon grass) is dominant, but is occasionally interspersed with *Halophila englemanii* (star grass).

Globally, seagrass beds are highly valued coastal habitats that are experiencing rapid decline (Waycott et al. 2009; Unsworth et al. 2015). In Tampa Bay, however, historic declines in seagrasses coverage have been reversed via coordinated efforts to reduce bay-wide nitrogen loads, which has resulted in significant recovery of these habitats (Greening et al. 2014, Sherwood et al. 2015). Contemporary restoration efforts continue to focus on maintaining or improving water quality conditions in Tampa Bay so that adequate light reaches shallow (<2m), subtidal flats located throughout the Bay (Greening et al. 2014).

Mangrove Forests

Mangrove forests are the dominant emergent tidal wetland in Tampa Bay, consisting of three primary species. At the lowest elevation usually along the fringing intertidal/shoreline zone, red mangroves (*Rhizophora mangle*) are typical. Black mangroves (*Avicennia germinans*) and white mangroves (*Laguncularia raecmosa*) generally follow in the intertidal zone, with buttonwood (*Conocarpus erecta*), a mangrove associate, located upslope of the intertidal zone (PBS&J 2010; Yates et al. 2011). Mangrove forests produce, sequester, and export large pools of organic carbon (Odum and McIvor 1990), and as such are an important global blue carbon habitat (Donato et al. 2011; Murdiyarso et al. 2015).

Some of the more successful emergent tidal wetland restoration projects in Tampa Bay have involved the creation of mangrove forests. The functional equivalence of these restored habitats in terms of soil carbon storage and accumulation, however, has not yet approached natural systems (Osland et al. 2012).

Polyhaline[12] Salt Marshes

Typically occurring in the Bay proper, polyhaline salt marshes may occur seaward of the fringing mangrove coastline. Smooth cordgrass (*Spartina alterniflora*) is the common species in these circumstances; however, at higher elevations around seasonal high tide levels other species may occur, particularly around beach and dune formations in the lower part of Tampa Bay. In these regions, saltmeadow cordgrass (*Spartina patens*), saltgrass (*Distichlis spicata*), saltwort (*Batis maritima*), and salt jointgrass (*Paspalum vaginatum*) may also be present. For Tampa Bay habitat management purposes, polyhaline salt marshes are typically included as a component of mangrove forests due to the difficulty in partitioning these habitats from mapping and land use cover analyses. Further, tidal wetland restoration practices in Tampa Bay have evolved to include careful grading and planting of pioneering salt marsh species (*S. alterniflora*) to encourage

[12] Salinity between 18 and 30 ppt

recruitment and retention of mangrove seedlings in order to revegetate and restore intertidal sites to a climax mangrove forest condition (Henningsen et al. 2003; Ries 2009; Osland et al. 2012).

Meso-Oligohaline[13] Salt Marshes or Brackish Marsh

Though often not recognized as a distinct plant community, oligohaline or brackish marshes are unique in both their species composition and their ecological role. Oligohaline marshes are typically maintained in reaches where salinity normally ranges between 0.5 to 5.0 ppt. In Florida, oligohaline marshes are herbaceous wetlands located in tidally influenced rivers or streams, or coastal embayments, where the plant community exhibits a mixture of true marine plants and typical freshwater taxa such as cattails (*Typha domingensis*) and sawgrass (*Cladium jamaicense*) that tolerate low salt concentrations. The predominant plant species of oligohaline marshes include black needlerush (*Juncus roemerianus*), leather fern (*Acrostichum danaeifolium*), cattails, sawgrass, bulrush (*Scirpus robustus*), and spider lily (*Hymenocallis palmeri*). Throughout this report, oligohaline marshes are referred to as *Juncus* or brackish marshes.

Ecologically, oligohaline marshes and low salinity mangrove forests are recognized as critical nursery habitats for such species as blue crab (Callinectes sapidus), snook (Centropomus undecimalis), tarpon (Megalops atlanticus), and ladyfish (Elops saurus). Because recognition of this key role in estuarine life cycles has come only recently, much of this habitat has been lost or highly modified. The reduced amount of this habitat type may represent a limiting factor in total population sizes of some estuarine-dependent species.

Salt Barrens

Tampa Bay salt barren habitats are found at the extreme, upper intertidal flat which is inundated typically only by spring tides once or twice a month. This results in hypersaline conditions with seasonal expansion of typically low-growing succulent salt-tolerant vegetation with lower interstitial salinities during the rainy season and retreat with less frequent inundation and rainfall. This produces the characteristic open unvegetated patches of the salt barren substrate. These areas are also referred to as salt flats or salterns.

Salt barrens are typically located slightly upslope of mangrove forests or tidal marshes at a somewhat higher elevation. Distinct common plant species consist of annual glasswort (*Salicornia bigelovii*), perennial glasswort (*Salicornia virginica*), key grass (*Monanthochloe littoralis*), sea lavender (*Limonium carolinianum*), samphire (*Blutaparon vermiculare*), and sea purslane (*Sesuvium portulacastrum*).

Due to their low structural complexity and apparent lack of numerous fauna, salt barrens are often assumed to have low ecological value; however, anecdotal evidence contradicts these assumptions. These areas have unique ecological values as seasonal feeding areas for wading birds when other habitats are unavailable, such as lower elevation mudflats that are more routinely inundated, and as night feeding habitats on spring tides for snook, tarpon, and ladyfish. Nonetheless, the ecological contributions of salt barrens to estuarine dependent species are poorly understood relative to other emergent tidal wetlands.

[13] Salinity between 0.5 and 18 ppt

Habitat Zones

Bay habitat zones can be defined for different areas based on the elevation of the area relative to tidal datums (i.e., as a surrogate for the frequency of tidal inundation) and whether the area is within the zone of freshwater influence. Figure 7 shows the different elevation-based habitat zones for areas outside and within the area of freshwater influence used in the habitat projection model. When there is no freshwater in the area, the upland species establish at the highest elevations, followed by salt barren, high salt marsh, and/or mangroves, seagrass, and last, non-vegetated subtidal habitat. When a freshwater influence is present, freshwater marsh establishes at the highest elevations, followed by salt barren, high salt marsh, low (*Juncus*) saltmarsh, mudflat, seagrass, and subtidal habitat.

3.1.2 Changing GHG Fluxes

The IPCC 2006 GHG accounting framework is based on the following equation:

$$Emissions = -Sequestration = Activity\ Data * Emissions\ Factor$$

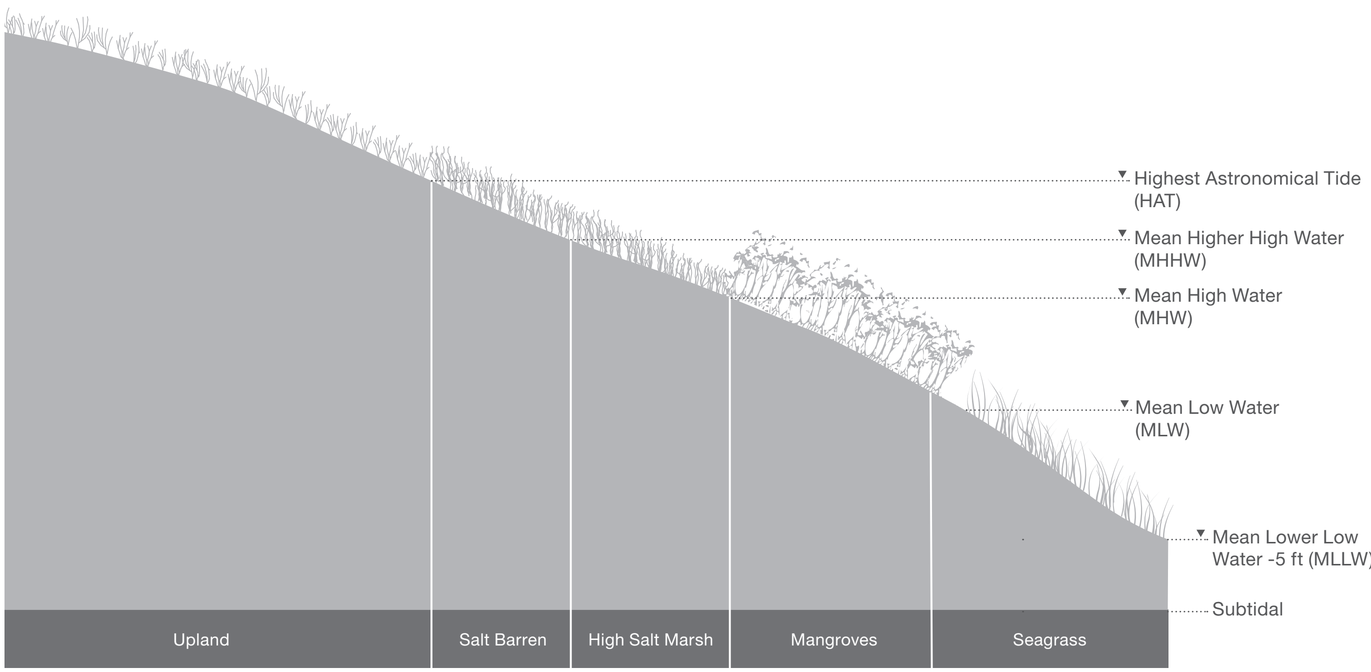
According to IPCC 2006, *activity data* are data on the magnitude of human activity resulting in GHG emissions and removals. For restoration projects, the relevant *activity data* are changes in land cover over time. *Emissions factors* are the rates of GHG emissions and removals[14] associated with a unit of activity data. In this study the *emissions factors* are assumed to bin carbon dioxide (CO_2) and methane (CH_4) fluxes on a per-hectare basis. A removal is a negative emission.

3.1.2.1 Carbon Stocks

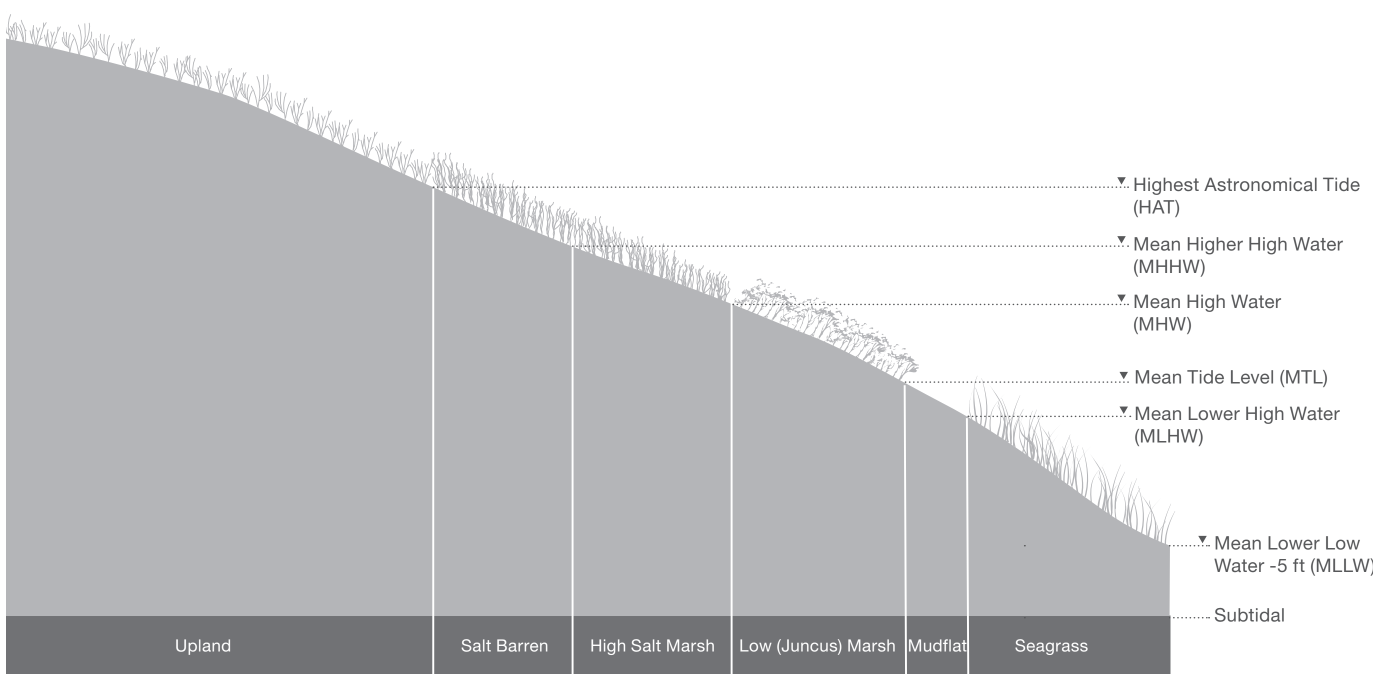
The IPCC Wetlands Supplement to the 2006 accounting guidelines (IPCC 2014) identifies three carbon stocks important to calculating CO_2 removals in coastal wetlands (this also applies to other vegetated land cover types): biomass (aboveground and belowground), dead organic matter (DOM), and soil carbon. To calculate CO_2 removals, each land cover type is assigned an aboveground biomass density (biomass stock density combined with carbon percentage of dry matter), a soil carbon sequestration factor, and a dead organic matter sequestration rate (mangrove habitat only). The soil carbon sequestration rate is assumed to include belowground biomass.

Using habitat acreages, changing carbon stocks can be tracked through time as sea level rises and marshes migrate inland. For example, when land is covered with vegetation, there is a stock of carbon in the biomass and the soil, and the soil carbon increases according to the soil sequestration rate of the habitat, due to the incorporation of dead organic matter back into the soil (Figure 8). When a habitat converts to another habitat (e.g., from coastal hammock to salt marsh), aboveground biomass changes (may increase or decrease) due to the different type of vegetation, and soil sequestration continues, but at the rate of the new habitat type (Figure 8).

[14] The terms “sequestration” and “removal” are synonymous. “Sequestration” is used more often with wetland scientists while “removals” is more common with GHG accounting experts (and refers to a wider range of reductions in GHGs).



No Freshwater Influence

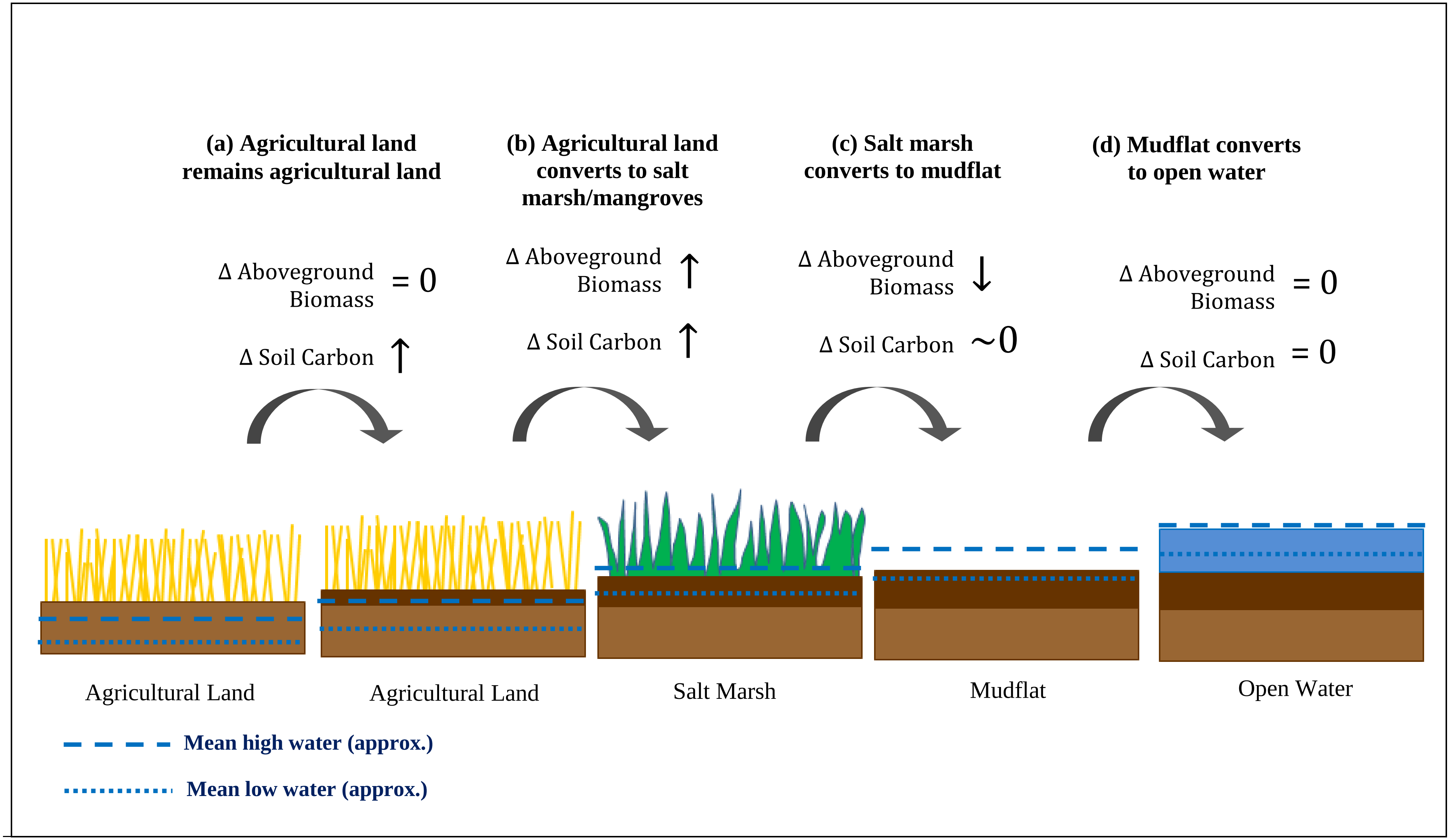


Under Freshwater Influence

SOURCE: ESA

Tampa Bay Blue Carbon Assessment . D140671

Figure 7
Conceptual Habitat Elevation Zone Model



NOTES: This is an example and does not show all possible habitat conversions.
Mean sea level shown for reference only. Time between transitions is not specified and depends on land elevations, rate of sea level rise and accretion rate.

ESA

Tampa Bay Blue Carbon .D140671

Figure 8

Conceptual Model of GHG Accounting Framework

With sea-level rise, when salt marsh converts to mudflat, aboveground biomass is lost and soil sequestration halts, but some soil carbon stored prior to the conversion remains sequestered within the mudflat (Figure 8). This analysis assumes that 60% of the soil carbon is released back to the atmosphere through erosion when habitats convert to subtidal.

Aboveground Biomass

When vegetation is established, carbon in the form of CO_2 is taken up from the atmosphere to build biomass. The size of the carbon stock depends on the vegetation type and density. If the vegetation type changes, the amount of biomass will change as well.

Soil Stock and Belowground Biomass

As vegetation dies, some of the carbon accumulates in the soil, especially in wetlands. Additionally, vegetation has roots, which contribute to belowground biomass in varying degrees (grasses have low belowground biomass, while mangroves have high belowground biomass). This carbon stock changes over time based on the habitat type.

Dead Organic Matter

DOM is an additional carbon stock in mangrove forests. When aboveground biomass dies, the decomposition of wood is slow, and much of the material is buried and accumulates as soil organic matter.

Bicarbonate Pathway in Seagrass

Most of the literature related to quantification of carbon sequestration benefits of seagrass meadows is based on the process of burial of fixed carbon in the sediments below these meadows (e.g., Duarte et al. 2010, Fourqurean et al. 2012, Greiner et al. 2013, McLeod et al. 2013). Using this technique, carbon sequestration is quantified as a function of the rate of accumulation of sediments over time, and the organic carbon content of those same sediments.

When annual estimates of primary production of seagrass meadows in Tampa Bay are compared to literature-based estimates of sequestration via burial, rates of primary production are much higher than even the highest estimated rate of carbon sequestration via burial. This discrepancy is likely due to some combination of factors, such as the likelihood that literature-based estimates of annual primary production are biased on the high end, and that other mechanisms of carbon sequestration other than burial could be involved. The vast majority of carbon assimilation during primary production in seagrass meadows may also not be sequestered in any way, but is recycled back into the water column or exported elsewhere, as noted for *S. filiforme* by Zieman and Wetzel (1980).

In seagrass meadows, carbon sequestration has been documented to occur via an alternative process to burial alone, the so-called bicarbonate pathway, described more than 30 years ago by Smith (1981). In tropical and carbonate-rich sediments, researchers have noted that the very high production rates of *T. testudinum* in the Bahamas did not correlate with similarly high rates of carbon accumulation in sediments. Despite very high densities of seagrass meadows, and high rates of primary production, the organic content of sediments in seagrass meadows in the

Bahamas averaged less than 1 percent (Burdige and Zimmerman 2002). For seagrass meadows, the global average values of organic content of sediments listed in Duarte et al. (2010) and Fourqurean et al. (2012) are 0.7 and 1.4 percent of dry weight, respectively. In contrast, the organic content of sediments associated with mangroves and saltmarshes are typically much higher, ranging from ca. 20 to 80 percent of dry weight (Chmura et al. 2003).

For seagrass meadows, the question of "where does the fixed carbon go?" can be answered in part by Burdige and Zimmerman (2002) based on the following equation:

$$CH_2O + O_2 + CaCO_3 \longleftrightarrow Ca^{2+} + 2HCO_3^-$$

This equation summarizes the process through which fixed carbon (CH_2O) is decomposed in carbonate sediments ($CaCO_3$) under conditions where sediments are oxygenated via the seagrass root/rhizome complex (O_2). The end result of this process is both free calcium ions (Ca^{2+}) and previously fixed carbon now present in the form of bicarbonate ions ($2HCO_3^-$). The bicarbonate portion of the world's oceans has been referred to as a global and benign (in terms of GHG dynamics) carbon sink by various researchers (Rau and Caldeira 1999, Rau et al. 2001, Isobe et al. 2002, Harvey 2008).

In addition, Unsworth et al. (2012) have noted that the bicarbonate sequestration pathway is a mechanism through which seagrass meadows could provide a positive benefit to any nearby coral reefs, via their ability to offset impacts of ocean acidification associated with CO_2 enrichment of coastal waters. The bicarbonate sink pathway was the primary mechanism through which it is believed carbon sequestration occurs for the seagrass meadows in the Bahamas Banks (Burdige and Zieman 2002, Burdige et al. 2010) and Tokyo Harbor (Isobe et al. 2012).

In Tampa Bay, recent work by Yates et al. (2015), which was conducted concurrent with the field investigation described in Section 3.3.2, determined that seagrass meadows were capable of increasing daytime pH values by 0.5 units, consistent with expectations as inorganic carbon is taken up by photosynthesis. Those seagrass meadows were also found to increase carbonate saturation rates in the water column, suggesting that the mechanisms involved in the bicarbonate pathway outlined by Burdige and Zimmerman (2002) could be occurring in Tampa Bay seagrass meadows.

3.1.2.2 Methane Emissions

Methane emissions are produced when microorganisms in wet, poorly aerated soils, such as in freshwater marshes, decompose organic matter. However, high salinities reduce this methane production, so salt marsh is assumed to have negligible emissions (Poffenbarger et al. 2011).

Methane has a 100-year Global Warming Potential (GWP) of 28-34 relative to CO_2, which means the effect of each tonne of CH_4 on the atmosphere in 100 years is 28—34 times greater than that of a tonne of CO_2 (IPCC 2014). The most recent Fifth Assessment Report (AR5) published by the Intergovernmental Panel on Climate Change presents, for the first time, two sets of values for GWP representing scenarios with and without climate-carbon feedbacks. AR5 provides a value of 28 calculated without climate-carbon feedbacks, and 34 with climate carbon feedbacks. Climate-carbon feedbacks measure the indirect effects of changes in carbon storage due to changes in climate (Myhre et al. 2013). GWP values that take into account climate-carbon feedbacks have a higher level of uncertainty because the more feedbacks considered, the more complex and interconnected they become (Myhre et al. 2013). For this reason, a GWP of 28 (without climate carbon feedbacks), rather than 34, as presented in AR5 has been used to calculate CO_2 equivalents of methane emitted for this analysis.

3.1.2.3 Nitrous Oxide Emissions

N_2O is emitted as a by-product of the conversion of ammonia (contained in fish urea) to nitrate. In areas with aquaculture, N_2O emissions should be included in the GHG accounting using fish/shrimp production rates. Tampa Bay has approximately 1,110 ac of aquaculture under existing conditions, but fish/shrimp production rates have not been collected as part of this project. However, according to the HEM results, only 40 acres of aquaculture is at risk due to sea-level rise, and only under the int. high sea-level rise scenario. For this reason, N_2O emissions were not included as part of this study.

3.2 Habitat Acreage Analysis and Modeling

3.2.1 Historic Habitats

The habitats acreages discussed in Section 2.1 were input into the GHG framework to determine changes in GHG flux from 1900 to 2015. Data for all habitat types was not available, so this analysis focuses on salt barrens, salt marshes, mangroves, and seagrass.

3.2.2 Recent Habitat Changes (Restoration Projects under the Government Performance and Results Act)

Modifications to carbon dioxide and methane emissions for Tampa Bay were estimated based on changes in habitat types due to wetland restoration as reported by TBEP per the requirements of the Government Performance and Results Act (GPRA). Emissions and reductions due to operations (e.g. construction) were not included in this study.

The GPRA requires National Estuary Programs (NEPs) such as TBEP to submit reports on the restoration projects that have been implemented as part of the NEP that year. The GPRA reporting requires project managers to include the project name, a description of the existing habitat, a description of the project, the restoration technique, the project benefits, the type of restoration activity, the lead partner or implementer, the acres of the site, the project cost, the source of funding, and the project start date. However, the level of detail included in the GPRA report for each project varies, and often the necessary information for determining GHG reductions and emissions is not included or is unclear. The assumptions used to analyze the GPRA projects are summarized in Section 4.3.

3.2.2.1 Restoration Actions

The GPRA restoration projects for Tampa Bay were analyzed to determine how these projects may be affecting GHG emission and sequestration. Based on the projects reported between 2006 and 2015, the following more general restoration actions were chosen:

- Debris removal
- Erosion control and grading (no plantings)
- Hydrologic restoration
- Invasives control
- Land acquisition
- Mechanical thinning
- Prescribed burn
- Reef construction
- Vegetation establishment
- Other

Some of these project types result in increases or decreases in GHG emissions and sequestrations because they change the habitat area or the habitat type. Each restoration action is discussed in the following pages.

Debris Removal

Debris removal or trash pick-up projects improve the quality of habitat, but do not directly impact GHG emissions and sequestrations, because the habitat area and type stays the same. There may be secondary impacts due to the improved quality of the habitat, but those impacts are not considered in this analysis.

Erosion Control and Grading (No Plantings)

Erosion control and grading that does not include revegetation does not impact GHG emission or sequestration, because the habitat area and type stays the same. There may be secondary impacts due to retention of habitat that may have been eroded without the project, but those impacts are not considered in this analysis.

Hydrologic Restoration

Restoration that involves changing the hydrologic nature of the site may or may not impact GHG emissions or sequestrations. If the restoration changes the existing type of habitat or expands it, then a change in GHG fluxes can be calculated. For example, if tidal flows were restored to an agricultural site, this would convert the habitat from agriculture to tidal wetland and would result in a changing GHG flux. However, if the restoration involves replacing culverts, filling ditches, or any flow re-routing that improves existing habitat, but does not change the type of habitat or the area, the GHG emissions would not change. As for debris removal, there may be secondary impacts due to the improved quality of the habitat, but those impacts are not considered in this analysis.

Vegetation Control

Removal of vegetation (to control exotics or otherwise guide habitat development) decreases the biomass for a given habitat, and therefore reduces the amount of carbon sequestered in the vegetation. Depending on the type of disposal used for the removed vegetation, or in the case of a prescribed burn, this can result in a GHG emission. However, for the purpose of this analysis, the emissions due to vegetation disposal or burning are not considered, and only the change in biomass is analyzed.

For projects involving vegetation removal, replanting is often a next step. In cases where the same type of habitat is replanted, the removal and replanting of vegetation is assumed to cancel out any GHG emissions and sequestrations. For example, if an invasive salt marsh species is removed and native salt marsh vegetation is replanted, the habitat area stays the same and the type (salt marsh) does not change. However, if invasive trees are removed from a site and the site is planted with native grasses, the habitat type could change from upland forest to grassland, and this would result in a decrease in sequestration.

Land Acquisition

Land acquisition in itself does not directly impact GHG emissions and sequestrations, since the habitat type and area do not change. It is assumed for the purpose of this analysis, however, that land acquisition is protecting a specific habitat type from development, which results in continued sequestration.

Reef Construction

Construction of oyster reefs does not directly impact GHG emissions and sequestrations, since the habitat type (subtidal or intertidal) and area do not change. There may be secondary impacts due to protection of onshore land from erosion (and therefore a reduction in habitat area), increases in oyster population (increase in biomass), and improvements to the surrounding habitat (improved seagrass habitat), but these are not considered in this analysis.

Vegetation Establishment

The restoration and establishment of vegetation, either through natural recruitment or through plantings, increases the GHG sequestrations of the habitat. Depending on the initial and final habitat types, sequestration in the soil may increase or decrease. Additionally, vegetation establishment increases sequestration through biomass.

Other

Some projects will not fit into this framework and may be considered “other.” For example, a restoration of least tern habitat that involved building a gravel surface with barriers does not fit into any of the categories above. This category is assumed to not affect GHG emissions and sequestrations.

3.2.2.2 Restoration GHG Decision Tree

Based on the analysis of restoration actions, a decision tree was created to calculate the appropriate GHG emissions or sequestrations. Figure 9 shows this decision tree. For certain actions, including debris removal, erosion control, reef construction, and other, no emissions and sequestrations are calculated. For other actions, including hydrologic restoration, invasive control, mechanical thinning, and prescribed burns, follow-up questions must be answered to determine how to calculate emissions and sequestrations. For vegetation establishment and land acquisition, the GHG fluxes can be calculated directly.

When a restoration action results in a change in emissions and sequestrations, the initial and final habitat types must be determined. Based on the habitat types, the change in soil sequestration, biomass, and methane emissions can be calculated. The sum of these three factors is the total sequestration (or emissions, if negative) from the project.

3.2.3 Future Habitats (Habitat Evolution Model Development)

A GIS-based marsh habitat evolution model was developed for Tampa Bay to estimate the change in acreages of salt marsh, *Juncus* marsh, freshwater marsh, mangrove, seagrass, and salt barren habitats over time for future conditions. Inputs to the model include topography, vegetation and habitat data, tides, projected future sea-level rise, areas of freshwater influence, and habitat-specific accretion rates. The model produces maps of habitat types and habitat acreages on decade intervals (i.e., through 2100 for this analysis).

This report includes model runs for a sensitivity analysis of model parameters to assess the range of likely future habitat acreages under baseline conditions. In the future, proposed restoration actions could be modeled and compared to baseline conditions to inform development of sustainable restoration alternatives and to quantify restoration benefits.

To develop the habitat acreage estimates, ESA first considered applying SLAMM, as discussed in Section 2.2. However, some of the assumptions built into SLAMM do not accurately represent the habitat conversion processes that are important to Tampa Bay. To address these issues, ESA built a habitat evolution model (HEM) specific to Tampa Bay.

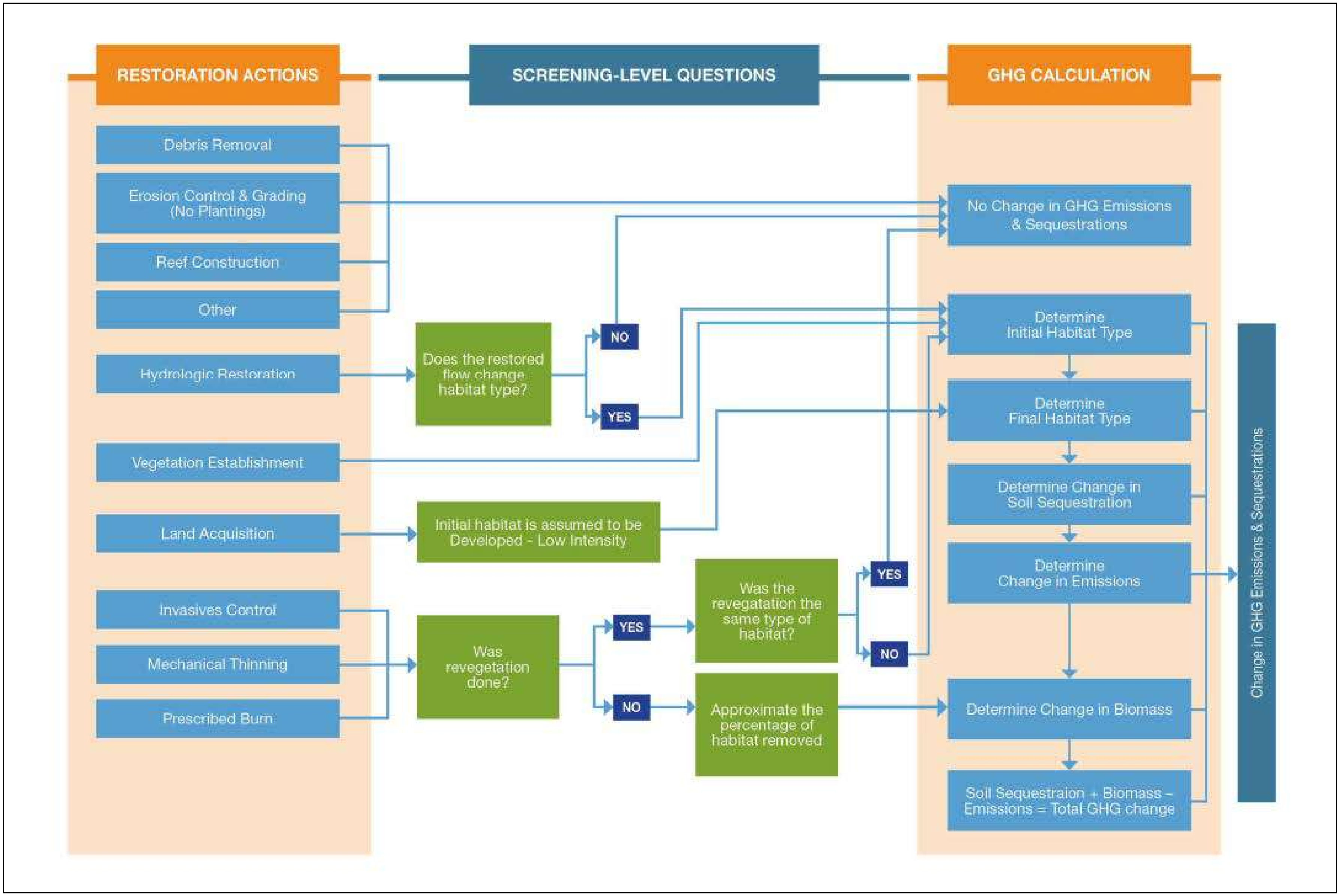


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Figure 9
GHG Calculation Decision Tree
for GPRA-Reported Restoration Projects

The HEM improves upon SLAMM by:

- Creating flexibility to edit the habitat categories to facilitate cross-walks from site-specific vegetation mapping.
- Updating the decision tree to change from one habitat category to another based on biological processes.
- Creating a structure that allows for different "modules" to be added to or updated in the model. For example, the module that determines areas of freshwater influence can be refined so that changes in freshwater flows can be simulated in conjunction with hydrodynamic modeling as a next step.

The HEM has been run at other sites to recreate and match the outputs of SLAMM (ESA 2015). Once the replication of SLAMM was successfully completed, the model was expanded and improved as described above.

To add flexibility to the habitat categories, the HEM allows the user to input habitat types that are specific to the marsh system. For example, this study is interested in considering the evolution of seagrass, which is not a habitat category in SLAMM. As another example, Tampa Bay habitats typically have high salt marsh between salt barrens and mangrove habitats. In SLAMM, salt barren habitats evolve straight to mangroves, without any representation of a high salt marsh zone. The HEM converts salt barren habitats down to high salt marsh and then down to mangroves, and has the flexibility to add additional habitats as needed.

Additionally, the habitat decision tree was revised to allow habitats to evolve in the "reverse direction." For example, mangroves can now convert to low salt marsh (due to freshwater flow) or to high salt marsh (due to sedimentation). In SLAMM, habitats can only convert to lower elevation habitats and eventually drown out due to sea-level rise.

The HEM has been set up to easily allow the addition of modules as they become available. For example, a new module can be developed to represent changes to the area of freshwater influence in response to changes in flow. Currently, the HEM replicates the SLAMM method for determining freshwater and brackish marsh habitats based on a polygon input defining the area of freshwater influence. In the current HEM for Tampa Bay, the area of freshwater influence is defined by the boundary between the existing salt and brackish/freshwater habitats. This method is sufficient if the freshwater input does not change over time. As a next step to further develop the model, the freshwater influence module could be refined to simulate changes in the area of freshwater influence in response to changes in freshwater flows (e.g., to evaluate Bay habitat response to reduced or increased freshwater baseflows). This module could be developed in conjunction with hydrodynamic modeling of the Bay's salinity. The development of a hydrodynamic model at a later stage could therefore facilitate revising the existing freshwater module.

Note that the HEM is focused on long-term habitat changes and processes occurring over a multi-decade time frame. Certain shorter-term processes affect habitat evolution, but are accounted for by modeling long-term cumulative processes and habitat change rather than directly representing these shorter term processes. For example, episodic sediment delivery from large storms events, such as hurricanes, which occur and vary on seasonal and interannual timescales, are not considered directly in the model. Rather, the model uses average decadal sediment loads to account for the overall cumulative amount of sediment that enters the Bay marshes in the long-term.

The HEM was run with the following inputs to look at habitat evolution in Tampa Bay under baseline conditions and to test the sensitivity of the model to different model parameters. Subsequent model runs could be conducted to evaluate potential restoration projects, which can be compared to habitats projected under baseline conditions to quantify enhancement benefits over time.

3.2.3.1 Topography and Bathymetry

Topography is used in the model as input to the habitat evolution decision tree (Figure 10). Figure 6 presents the existing topography of the Tampa Bay watershed, which is from the 2007 LiDAR flown by the Florida Division of Emergency Management. An examination of the topography data compared to the vegetation data compiled for this project (as described below in Section 3.2.3.2) showed that areas with mangroves were showing up at higher elevations than would be expected for this habitat. LiDAR data often picks up the top of vegetation, overestimating the elevation in certain areas. To account for this, areas with mangroves were shifted down to 0.82 ft North American Vertical Datum (NAVD) (0.25 m NAVD), which is a typical elevation at which mangroves occur. The resulting topography was converted to 10 m cells to provide a spatial resolution that is consistent with the vegetation mapping and maintains reasonable model run times.

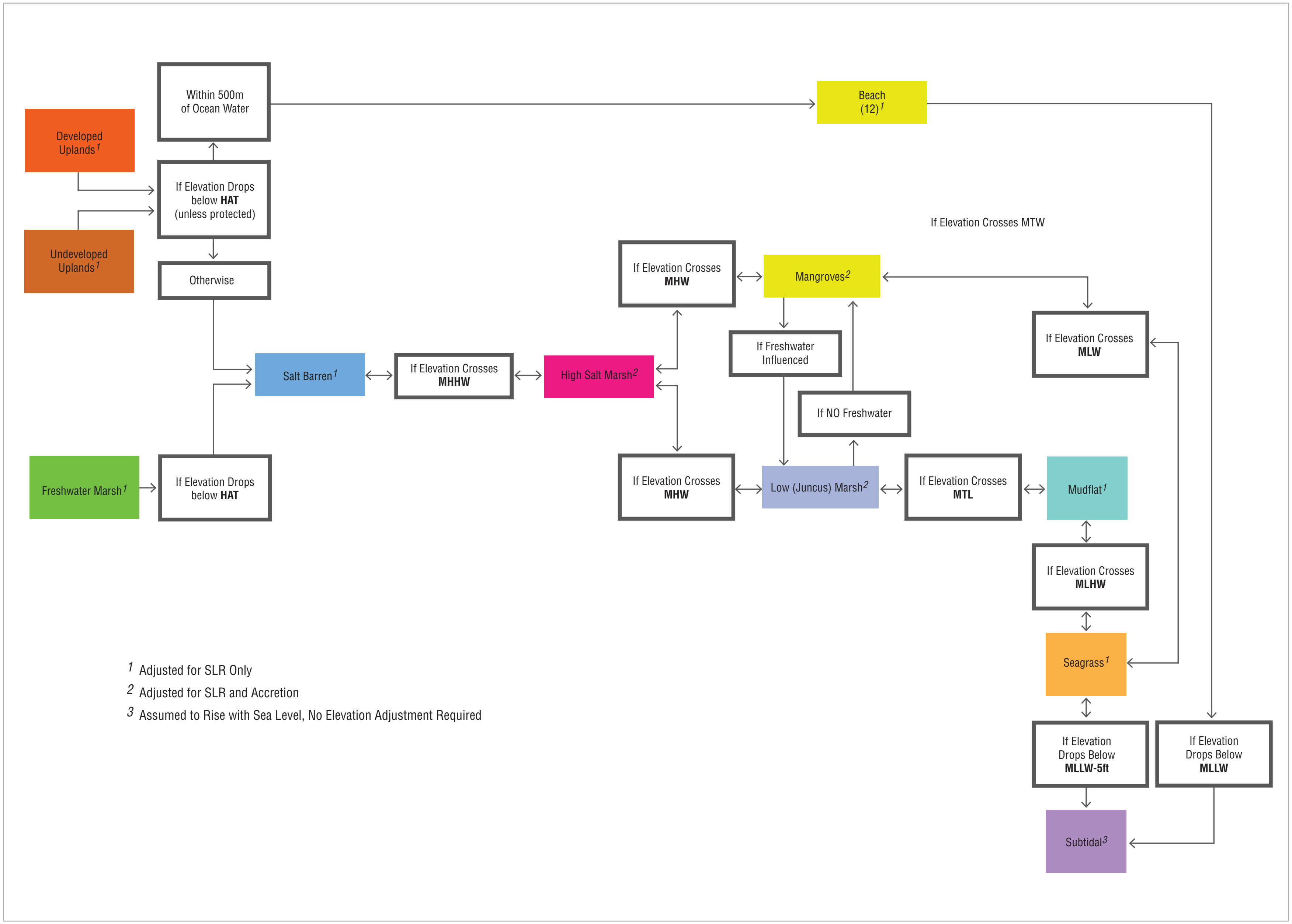
3.2.3.2 Vegetation Mapping

To evaluate how habitats will evolve over time, existing conditions vegetation mapping is needed. Florida Land Use mapping from 2011 was used in combination with seagrass mapping in 2012, both done by Southwest Florida Water Management District (SFWMD) as shown in Figure 1. The land use map was cross-walked into HEM habitat categories, which is presented in Appendix A. The cross-walk was developed based on inundation frequency, salinity preferences, and expected evolution under sea-level rise for each vegetation type. The habitat evolution decision tree is presented in Figure 10.

3.2.3.3 Tides

Tidal Datums

Tidal datums are used within the model as an input to the habitat evolution decision tree (Figure 10). For example, MLLW is the boundary between open water and mudflat or beach, because it indicates the elevation at which land is always inundated (during an average day). If land is below MLLW, it is assumed to be open water; if land is just above, it is either mudflat or beach.



1 Adjusted for SLR Only
2 Adjusted for SLR and Accretion
3 Assumed to Rise with Sea Level, No Elevation Adjustment Required

ESA SOURCE: ESA

Figure 10
Habitat Evolution Decision Tree

The model is divided up into the seven bays or rivers (Lower Tampa Bay, Boca Ciega Bay, Terra Ceia Bay, Manatee River, Middle Tampa Bay, Old Tampa Bay, and Hillsborough Bay) to capture the variation in the tidal datums. Table 4 presents the datums used in the model. Since there is no tide gage in Boca Ciega Bay, Terra Ceia Bay, or Manatee River, the tides there are assumed to match those in Lower Tampa Bay. Mean higher low water (MHLW) was calculated as the difference between MLW and MLLW above MLW (e.g., MHLW = MLW + (MLW-MLLW)).

TABLE 4
TIDAL DATUMS USED IN THE MODEL
(VALUES IN FEET NAVD)

Tidal Datum	Lower Tampa Bay Port Manatee Gage[1]	Middle Tampa Bay St. Petersburg Gage	Old Tampa Bay Old Port Tampa Gage[2]	Hillsborough Bay McKay Bay Entrance Gage
HAT	1.51	1.66	1.90	2.01
MHHW	0.65	0.80	0.90	1.00
MHW	0.37	0.52	0.58	0.66
MTL	-0.40	-0.27	-0.27	-0.25
MHLW	-0.81	-0.69	-0.67	-0.65
MLW	-1.18	-1.07	-1.11	-1.16
MLLW	-1.55	-1.45	-1.56	-1.67

1. NOAA did not have a published NAVD conversion for St. Petersburg. However, the gage did have 1 benchmark with an NAVD value, so that is used to create the conversion here. Additionally, these tides represent Boca Ciega Bay, Terra Ceia Bay, and Manatee River.
2. NAVD approximated as 1.56 ft MLLW based on average of St. Petersburg and McKay Bay gages.

Sea-Level Rise

In the model, sea-level rise is added to each datum by decade. To test the sensitivity of the model to sea-level rise predictions, the model was run with the Tampa Bay—specific NOAA Intermediate Low and Intermediate High rates of sea-level rise from the Tampa Bay Climate Science Advisory Panel (2015) as discussed in Section 3.1.1.4. Table 5 provides the different scenarios by approximately quarter-century.

TABLE 5
SEA-LEVEL RISE SCENARIOS
(VALUES IN INCHES FROM 1992)

Year	Intermediate Low Scenario	Intermediate High Scenario
1992	0	0
2025	4.6	7.2
2050	9.6	17.5
2075	16.0	32.2
2100	23.6	51.1

3.2.3.4 Sedimentation

To evaluate the sensitivity of the model to different accretion rates, two accretion scenarios were run in the model. Table 6 presents the accretion rates by habitat for the high and low accretion scenarios. These values were based on the high and low accretion rates for each habitat type found in the literature (see Section 3.1.1.2 for a summary of sources).

TABLE 6
MODELED ACCRETION RATES

Habitat	Low Accretion Scenario (mm/yr.)	High Accretion Scenario (mm/yr.)
Salt Marsh	1.6	3.0
Juncus Marsh (Freshwater Marsh)	3.75	4.0
Mangrove	1.6	5.0

These values are in line with the recently published study of Tampa Bay accretion rates by Gonneea (2016). Gonneea found average accretion rates of 2.7 mm/yr. for salt marshes (including *Juncus* marsh) and 3.2 mm/yr. for mangroves (2016), which falls within the range used for this analysis. Of note, Gonneea also found that accretion rates at all habitats have been increasing, which is potentially an ecosystem-level response to sea-level rise. For this analysis, the HEM uses constant accretion rates, so these rates may be underestimating the amount of accretion that will occur with higher rates of sea-level rise. Future model runs could look at increasing accretion rates to better capture this phenomenon.

3.2.3.5 Freshwater Inflow

The model defines the area of year-round freshwater influences based on a freshwater influence polygon. For existing conditions, this polygon was defined as the mouth of the major rivers feeding into the Bay (Figure 11). A future version of this model could incorporate hydrodynamic modeling of Bay salinities for existing conditions and future conditions with reduced or increased freshwater flow to quantify changes to the habitat.

3.2.3.6 Potential Management Response Scenarios

To evaluate the impact of different coastal management scenarios, the HEM was run with two different options: protection of existing development and allowing marsh to migrate into “soft” developed areas, such as lands currently used for agriculture and recreation.

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Figure 11
Freshwater Influence Areas in Tampa Bay

3.3 Calculating GHG Fluxes

Carbon aboveground biomass and DOM densities, soil sequestration rates, as well as emission rates of methane were collated for coastal Florida ecosystems, or their proxies in Tampa Bay and on the Gulf of Mexico coast. Habitats included seagrass, mangroves, salt marsh, brackish (*Juncus*) marsh, and freshwater marsh, as well as upland habitats such as cropland and pastureland, tree crops, vineyards, grasslands, shrub and brushland, and upland forests. The following sections include additional information on the values presented in Table 7 (shown on the following page). The equations used in the calculations are presented in Appendix B.

3.3.1 Salt Barren, Salt Marsh, *Juncus* Marsh, and Mangroves

Two field studies were conducted to develop site-specific biomass and soil sequestration values in support of this assessment and report. The first study (Moyer et al. 2016) focused on bulk vegetative and soil carbon stocks in Tampa Bay coastal wetland habitats, while the second, complementary study (Gonneea 2016) examined rates of carbon sequestration and sediment accumulation.

In Moyer et al. (2016) a total of 17 sites were sampled in coastal wetlands across Tampa Bay. Sites included 6 mangrove swamps (3 natural and 3 restored), 6 salt marshes (3 natural and 3 restored) and 5 natural salt barrens. Biomass was measured at each site and sediment cores were taken to determine soil carbon (see Moyer et al. 2016 in Appendix C for further details). The average biomass (or vegetative carbon) from all sites was calculated and used for mangrove, salt marsh, and salt barren habitat (Table 7). Soil carbon was converted to soil carbon sequestration rates for the restoration sites by dividing the total carbon by the number of years since restoration for mangrove and salt marsh habitat. These values are included in Table 7.

Gonneea (2016) collected sediment cores to determine accretion and carbon burial rates at the same sites as Moyer et al. (2016). They completed analyses to determine accretion rates, dry bulk density, loss on ignition, and carbon and nitrogen quantities (see Gonneea 2016 in Appendix D for further details). Results for mangrove and *Juncus* marsh are included in Table 7.

3.3.2 Seagrass

Tomasko et al. (2015; Appendix E) summarized the uncertainties that exist related to carbon sequestration rates for seagrass meadows, and compared bay-wide estimates of carbon sequestration, using different assumptions available in peer-reviewed literature. The separately derived carbon sequestration estimates were compared against a bay-wide estimate of the potential amount of carbon assimilation via seagrass throughout Tampa Bay. Discrepancies between an estimate of bay-wide carbon assimilation and various literature-derived carbon sequestration rates, and potential techniques to address these differences were also discussed.

3.3.2.1 Carbon Sequestration Rates

Literature-derived estimates of carbon sequestration rates for seagrass vary widely. Russell and Greening (2013) used a carbon sequestration rate for seagrass meadows of 138 g C m^{-2} yr^{-1}, as listed in McLeod et al. (2011). In turn, McLeod et al. (2011) developed their estimate from six published and one unpublished study on carbon burial rates in seagrass meadows.

Duarte et al. (2005) derived a global carbon sequestration rate estimate for seagrass meadows of 83 g C m^{-2} yr^{-1}. In a part of the coastal bays system of Virginia, newly reestablishing seagrass meadows were estimated to sequester carbon at a rate of 38 g C m^{-2} yr^{-1} (Greiner et al. 2013) while researchers in Korea developed carbon sequestration rates for seagrass meadows of 20 g C m^{-2} yr^{-1} (Chiu et al. 2013). Table 8 presents the range of values.

TABLE 8
ESTIMATES OF CARBON SEQUESTRATION RATE IN SEAGRASS

Rate (g C/m^2/yr.)	Source
138	MacLeod et al. 2013
83	Duarte et al. 2005
40	Cited in Fourqurean et al. 2012
38	Greiner et al. 2013
20	Chiua et al. 2013
64	Average (Table 11)

Estimates of carbon sequestration rates (amounts of carbon sequestered per year) for seagrasses should be based on the spatial extent of meadows multiplied by area-normalized sequestration rates (g m^{-2} yr^{-1}). However, bay-wide estimates could vary by a factor of nearly sevenfold, depending upon which sequestration rate estimate was used.

3.3.2.2 Seagrass Carbon Assimilation (Biomass) Rates

Rates of primary production have been measured either through changes in biomass over time or rates of carbon uptake for all the major species of seagrass found in Tampa Bay. A summary of area-normalized rates of carbon assimilation, by species, is shown in Table 9, along with the literature from which these rates were derived.

Comparing the carbon sequestration rates with the production rates, it appears that the estimated bay-wide total carbon assimilation by seagrass meadows (described in Tomasko 2015) is substantially higher than even the highest rate of carbon sequestration by burial.

TABLE 7
ABOVEGROUND BIOMASS, REDUCTIONS FACTORS, AND EMISSIONS FACTORS

		Biomass Stock		Carbon Conversion		Existing Soil Carbon Sequestered		Soil Carbon Sequestration		Methane Emissions	
Habitat		**Biomass Stock (tonnes DM/ha)**	**Reference/Assumptions**	**% Carbon in Dry Matter**	**Reference/Assumptions**	**Soil Carbon (tonnes C/ha)**	**Reference/Assumptions**	**C Removal Rate (tonnes C/ha/yr.)**	**Reference/Assumptions**	**CH4 Emission Rate kg CH4 /ha/yr.**	**Reference/Assumptions**
Agriculture	Cropland and Pastureland	2.6	IPCC 2006 V4 Chapter 5 -Table 5.9 (for tropical, moist)	0.45	IPCC 2014 Chapter 4 - Table 4.2	54.5	Mulkey et al. 2008 (Table 12)	0.09	Kroodsma and Field 2006 value for non-rice annual cropland	0	Assumed
	Tree Crops	2.6	IPCC 2006 V4 Chapter 5 -Table 5.9 (for tropical, moist)	0.45	IPCC 2014 Chapter 4 - Table 4.3	54.5	Mulkey et al. 2008 (Table 12)	0.26	Kroodsma and Field 2006 value for orchard	0	Assumed
	Vineyards	2.6	IPCC 2006 V4 Chapter 5 -Table 5.9 (for tropical, moist)	0.45	IPCC 2014 Chapter 4 - Table 4.4	54.5	Mulkey et al. 2008 (Table 12)	0.24	Kroodsma and Field 2006 value for vineyards	0	Assumed
Developed	Low Intensity	0.8	Assume half the stock of grassland	0.45	IPCC 2014 Chapter 4 - Table 4.5	27.25	Assume half the stock of grassland	0.045	Assume half the sequestration of grassland	0	Assumed
	Mid/High Intensity	0	Assumed	0.45	IPCC 2014 Chapter 4 - Table 4.6	0	Assumed	0	Assumed	0	Assumed
Rangeland	Grassland/Herbaceous / Open Land	6.2	IPCC 2006 V4 Chapter 6 – p. 6.29 & Table 6.4 (for tropical, moist)	0.45	IPCC 2014 Chapter 4 - Table 4.7	54.5	Mulkey et al. 2008 (Table 12)	0.09	Kroodsma and Field 2006 value for non-rice annual cropland	0	Assumed
	Shrub and Brushland	41	Hobbs and Mooney 1986, biomass for 3 to 6 year-old shrubs, assume 80% cover	0.45	IPCC 2014 Chapter 4 - Table 4.8	54.5	Mulkey et al. 2008 (Table 12)	0.24	Kroodsma and Field 2006 value for vineyards, which are similarly woody	0	Assumed
Upland Forest	Upland Forest	220	IPCC 2006 V4 Chapter 4 - Table 4.7 (for subtropical humid)	0.45	IPCC 2014 Chapter 4 - Table 4.9	54.5	Mulkey et al. 2008 (Table 12)	0	Assumed	0	Assumed
	Tree Plantations	140	IPCC 2006 V4 Chapter 4 - Table 4.12 (for subtropical humid)	0.45	IPCC 2014 Chapter 4 - Table 4.10	54.5	Mulkey et al. 2008 (Table 12)	0	Assumed	0	Assumed
Wetlands	Freshwater Swamp	136.6	Assumed same as mangroves	0.45	IPCC 2014 Chapter 4 - Table 4.11	54.5	Mulkey et al. 2008 (Table 12)	1.50	Assumed same as mangroves	193.7	
	Mangrove	136.6 ± 14.8	Moyer et al. 2016 (includes DOM)	0.44	Ew et al. 2006, Bouillon et al. 2008 as cited in Moyer et al. 2016	144.9 ± 49.5	Moyer et al. 2016	1.50 ± 0.59	Gonneea 2016 (1950-present)	14.95	Average of Bartlett et al. 1989, and Harriss et al. 1988
	Salt Marsh	26.2 ± 19.6	Moyer et al. 2016	0.45	Howard et al. 2014 as cited in Moyer et al. 2016	60.8 ± 70	Moyer et al. 2016	1.6 ± 69.9	Moyer et al. 2016 (restoration sites only)	0	Assumed
	Salt Barren	5.1 ± 2.7	Moyer et al. 2016	0.45	Howard et al. 2014 as cited in Moyer et al. 2016	18.6 ± 3.7	Moyer et al. 2016	0.32	Assume 20% of salt marsh	0	Assumed
	Freshwater Marsh	26.2	Assumed same as salt marsh	0.45	IPCC 2014 Chapter 4 - Table 4.11	54.5	Mulkey et al. 2008 (Table 12)	1.6	Assumed same as salt marsh	193.7	IPCC 2013 Table 4.14
	Brackish (*Juncus*) Marsh	26.2	Assumed same as salt marsh	0.45	Howard et al. 2014 as cited in Moyer et al. 2016	54.5	Mulkey et al. 2008 (Table 12)	0.71 ± 0.28	Gonneea 2016 (1950-present)	775	Average of Whitting and Chanton 2001
	Open Freshwater	0	Assumed	0.45	IPCC 2014 Chapter 4 - Table 4.10	0	Assumed	0	Assumed	193.7	IPCC 2013 Table 4.14
Beach	Dune	6.2	Assumed same as grassland	0.45	IPCC 2014 Chapter 4 - Table 4.10	0	Assumed	0	Assumed	0	Assumed
Subtidal	Subtidal	0	Assumed	0.45	IPCC 2014 Chapter 4 - Table 4.11	0	Assumed	0	Assumed	0	Assumed
	Seagrass	6.18	Average of Zieman and Wetzel 1980	0.35	Fourqurean et al. 2012	108	IPCC 2014 Chap 4 - Table 4.11	0.64 or 2.19	See Section 3.3.2	0	Assumed

DM = Dry Matter. This is converted to Carbon Stock (in tonnes C/ha) by multiplying by the assumed % Carbon in the next column.

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TABLE 9
LITERATURE-DERIVED AREA-NORMALIZED RATES OF CARBON ASSIMILATION BY SPECIES

Species	Annual net primary production estimate (g C m^{-2} yr^{-1})	Studies used to develop estimate
Halodule wrightii	584	Dillon (1971 [as cited in Zieman and Wetzel 1980]), Tomasko and Dunton (1995), Neely (2000)
Syringodium filiforme	292	Zieman and Wetzel (1980)
Thalassia testudinum	979	Zieman and Wetzel (1980), Tomasko et al. (1996), Tomasko and Hall (199), Lee and Dunton (1996), Chiu et al. (2013)*

*Chiu et al. (2013) is based on *T. hemprichii*, not *T. testudinum*

3.3.2.3 Seagrass Rate Discrepancy

At present, it is not yet known if the discrepancy between bay-wide carbon assimilation rate estimates and carbon sequestration rate estimates is due to unrealistically high rates for assimilation, unrealistically low rates for sequestration, or if there is a natural and large difference between the assimilation of carbon by seagrass meadows and the subsequent sequestration of that carbon via burial.

Although the quantification of carbon sequestration capacities via burial is a logical technique for determining the amount of carbon that can be kept from re-entering the atmosphere after assimilation, burial is not the only method of sequestration that has been invoked as a pathway for sequestration by seagrass meadows. Prior work in the carbonate sediments of the Bahamas Banks has shown that the highly productive *T. testudinum* meadows in that location occur in sediments with organic contents of less than 0.5 percent, on average (Burdige and Zimmerman 2002). In carbonate-rich sediments, potentially significant portions of the inorganic carbon that enters into the water column as CO_2 after diffusion from the atmosphere is then assimilated by seagrass leaves and could then be "chemically sequestered" via the bicarbonate pathway, outlined in Tomasko et al. 2015 (Appendix E).

Not only is sequestration into bicarbonate ions a pathway that could explain at least a portion of the sizable discrepancy between carbon assimilation rate estimates for seagrass and carbon sequestration estimates via burial, bicarbonate ions are the major constituent of the total alkalinity pool of marine waters. Total alkalinity is quantified based on the capacity of an aqueous solution to neutralize acids. Therefore, carbon sequestration via the bicarbonate pathway could also have the additional benefit of offsetting ocean acidification (see Section 5.4 for further discussion).

3.3.2.4 Potential for Sequestration through Combined Processes of Burial and Bicarbonate Sequestration

Unsworth et al. (2012) produced an estimate of 155 g C m^{-2} yr^{-1} for carbon sequestration via the bicarbonate pathway for seagrass meadows in Tampa Bay. This can be combined with the carbon burial rate of 138 g C m^{-2} yr^{-1} (MacLeod et al. 2013) cited in Russell and Greening (2013) for an estimated carbon sequestration rate of 293 g C m^{-2} yr^{-1}. This combined sequestration estimate is nearly identical to the literature-based annualized primary production rate estimate for *S. filiforme*, but lower than the primary production rate estimate of *H. wrightii*, and substantially lower than that of *T. testudinum*.

If this estimate is extrapolated out to the 16,307 ha of seagrass in Tampa Bay (as of 2014) then the annualized bay-wide estimate of carbon sequestration is 41,731 Mg C yr^{-1}. This amounts to approximately 47 percent of the estimated bay-wide annualized carbon assimilation rate for seagrass meadows of 89,255 Mg C yr^{-1}.

To calculate GHG fluxes in Tampa Bay, both the average rate of carbon burial in the literature, 64 g C/m^2/yr. (0.64 tonnes C/ha/yr.) plus the bicarbonate sequestration rate estimated by Unsworth et al. (2012) (64 + 155 g C/m^2/yr. or 2.19 tonnes C/ha/yr.) were used to capture the upper and lower estimates of carbon sequestration by seagrass.

3.4 Prioritizing Upland Parcels for Acquisition and Restoration

As part of this study, the HEM was utilized to identify low-lying coastal uplands that are currently undeveloped, and that are predicted to become intertidal by 2100. Polygons of these areas were then intersected with county parcel data to develop a spatial database of property owners – both from the public and private sector. HEM outputs were used to create a series of maps showing coastal uplands with highest priority for future acquisition, protection, and/or restoration. This information was developed as a tool to identify and prioritize parcels for the potential conservation of habitat migratory pathways that could help offset habitat changes/losses related to future sea-level rise.

To conduct this analysis, 2007 and 2100 habitat data layers from the HEM, and parcel data from Hillsborough, Pinellas, and Manatee counties obtained from Florida Geographic Data Library (FGDL) were used. The 2100 habitat layer was compared to the 2007 layer to identify all areas of uplands that are projected to be inundated. These areas were then compared to the parcel layers, and public parcels within the area to be inundated were identified. Appendix F provides further detail on the specific GIS methods used.

4. RESULTS

4.1 Habitat Acreages and Distribution with Sea-Level Rise

4.1.1 Varying Sea-Level Rise Curves

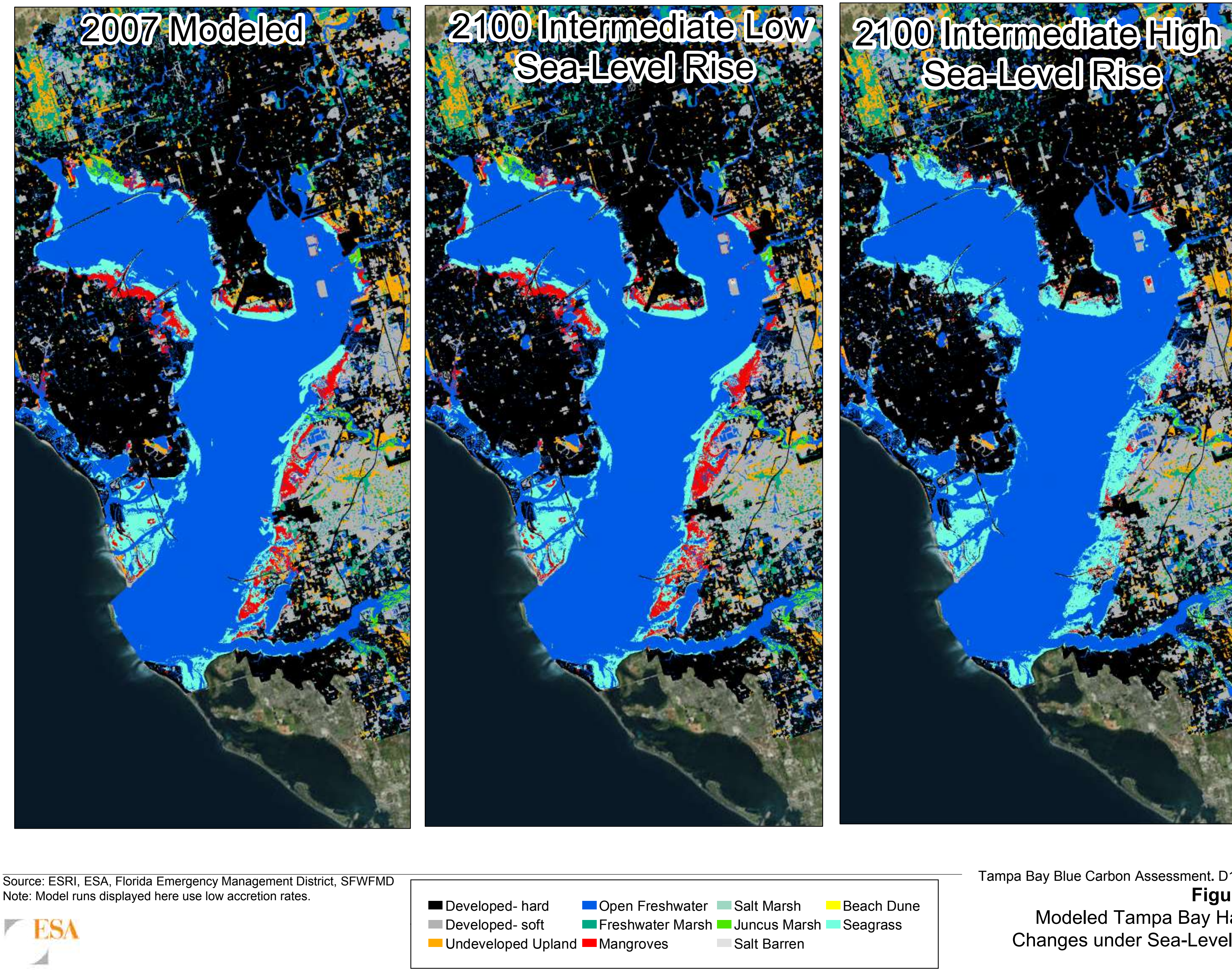
Table 10 presents the modeled habitat acreages for intermediate low (Run 1, int. low) and intermediate high (Run 3, int. high) rates of sea-level rise at 2100, as well as the difference between these habitat acreages and the 2007 modeled habitats[15]. With higher rates of sea-level rise, higher elevation habitats convert to lower elevation habitat types. For example, under the int. high scenario, there is less upland, freshwater marsh, salt barren, high salt marsh, *Juncus* marsh, and mangroves than under the int. low scenario. Mudflat and open water increase, and there are 14,600 more acres of seagrass under the int. high sea-level rise scenario compared to the int. low scenario. Figure 12 shows the 2100 habitat maps for int. low and int. high sea-level rise. (See Appendix G for habitat maps for 2025, 2050, and 2075.)

TABLE 10
HABITAT ACREAGES FOR SEA-LEVEL RISE

Run	Modeled Acreage in 2007	Modeled Acreage in 2100 (Run 1) Int. Low		Modeled Acreage in 2100 (Run 3) Int. High		Difference high-low sea-level rise
Developed Upland - Hard	461,640	461,640	(0)	461,640	(0)	0
Developed Upland - Soft	210,310	210,310	(0)	210,310	(0)	0
Undeveloped Upland	230,600	227,370	(-3,230)	222,870	(-7,730)	-4,500
Freshwater Marsh	81,390	79,260	(-2,130)	77,590	(-3,800)	-1,670
Salt Barrens	1,520	2,870	(+1,350)	2,280	(+760)	-590
High Salt Marsh	2,290	2,500	(+210)	1,090	(-1,200)	-1,410
Juncus Marsh	4,250	4,530	(+280)	2,430	(-1,820)	-2,100
Mangroves	13,990	16,040	(+2,050)	4,870	(-9,120)	-11,170
Mudflat	0	0	(0)	840	(+840)	840
Beach	70	30	(-40)	10	(-60)	-20
Seagrass	33,310	33,550	(+240)	48,280	(+14,970)	8,730
Open Water	338,710	339,960	(+1,250)	345,880	(+7,170)	5,920
Total Intertidal Wetland[1]	20,530	23,070	(+2,540)	8,390	(-12,140)	-14,680

1. Includes High Salt Marsh, Juncus Marsh, and Mangroves

15 Current topography and existing tidal datums were input to the model with no sea level rise or accretion to model the existing conditions (2007) and to validate the model.



Source: ESRI, ESA, Florida Emergency Management District, SFWFMD
Note: Model runs displayed here use low accretion rates.

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Figure 12
Modeled Tampa Bay Habitat Changes under Sea-Level Rise

Figure 13 and Figure 14 show the evolution of habitats over time for int. low (Run 1) and int. high (Run 3) rates of sea-level rise. Under int. low sea-level rise, there is a slight increase in open water at the expense of other habitats. With int. high sea-level rise, open water and seagrass increase dramatically at the expense of the other habitats, with a large loss of mangrove area.

Under int. low sea-level rise, salt marsh, *Juncus* marsh, and mangrove acreage actually increases as these areas convert from upland and freshwater marsh. Under int. high sea-level rise, there is a loss of these habitats, but a large increase in seagrass and open water habitat.

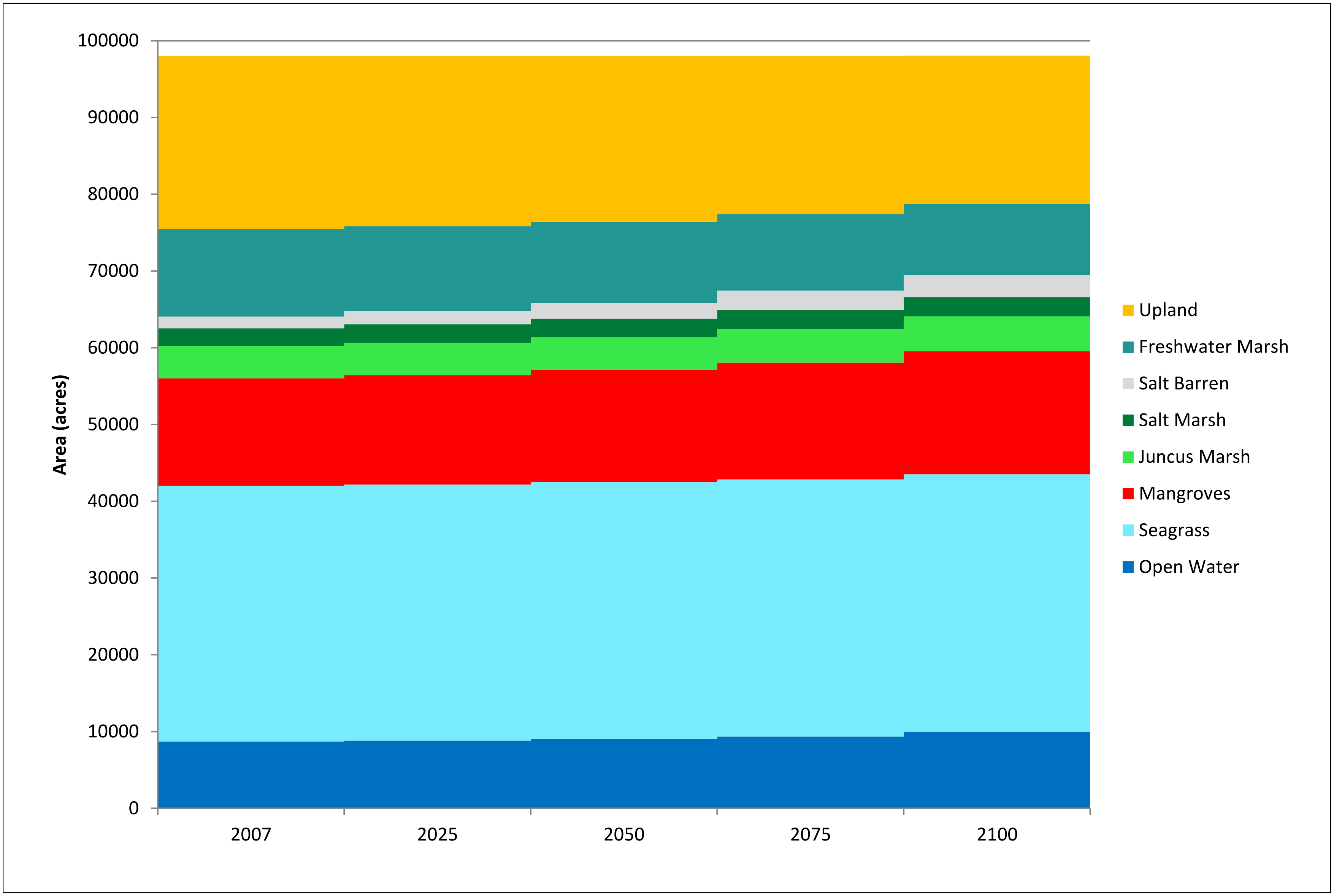
Under both scenarios, salt barren habitat increases substantially. The model likely overestimates salt barren habitat by assuming salt barren completely occupies elevations between HAT and MHHW. In reality, salt barren habitat requires minor changes in topography that will allow salt water to pond and then evaporate, and this specificity is not captured in the model.

4.1.2 Varying Accretion Rates

Table 11 compares the habitat acreage at 2100 for the modeled low accretion rates (Runs 1 and 3) and the high accretion rates (Runs 2 and 4) under the int. low and int. high sea-level rise scenarios. With less sediment accretion, the habitats convert from high salt marsh, *Juncus* marsh, and mangroves to mudflat and seagrass. Under the int. low sea-level rise scenario, the difference in habitat acreages between the high and low accretion rates is very minor (on the order of 100 acres). With int. high sea-level rise, the difference is more substantial (on the order of 10,000 acres). This indicates that under low sea-level rise, the model is not very sensitive to accretion rates, but under high sea-level rise, these inputs become more important.

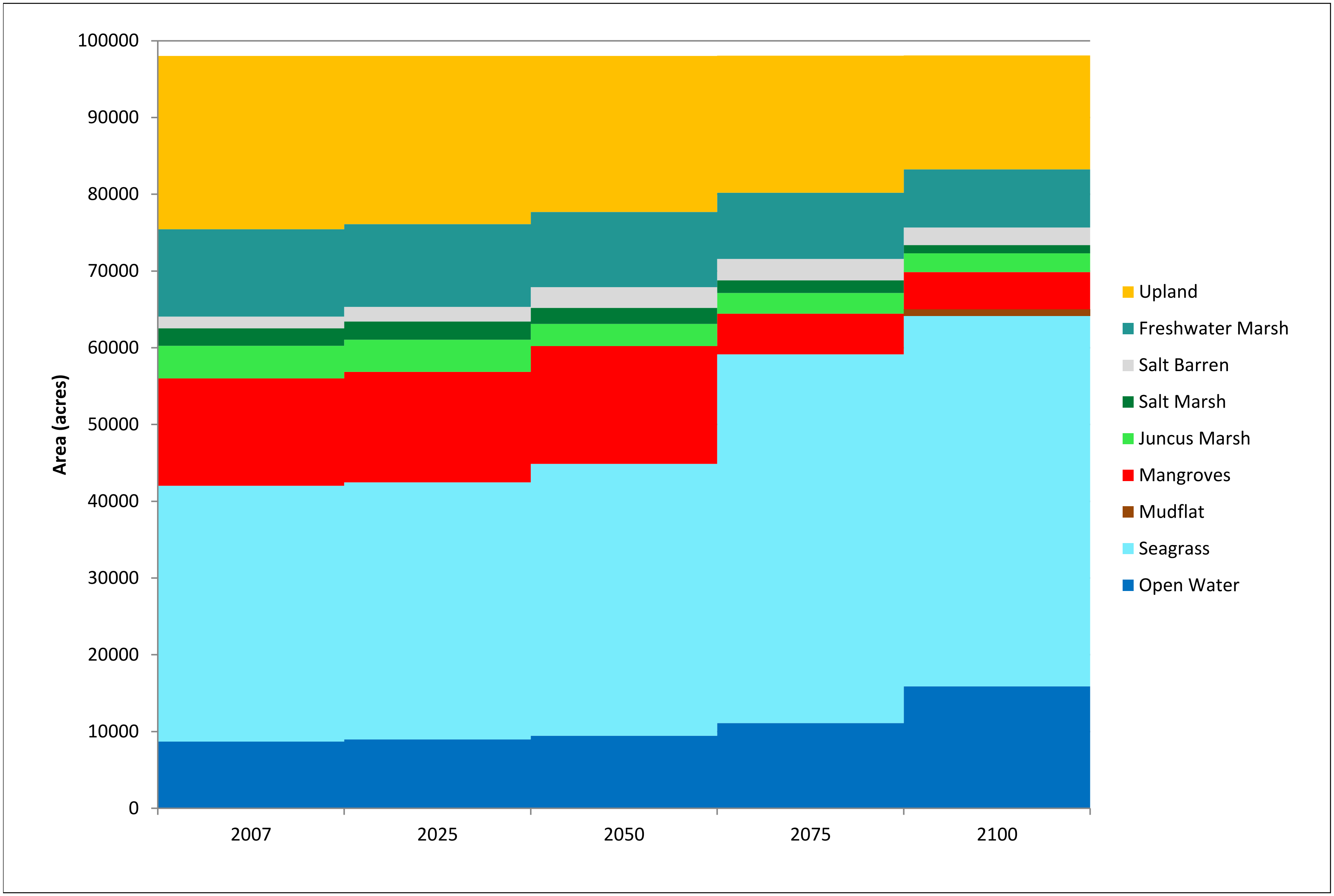
Figure 15 shows the 2100 habitat maps under the two accretion scenarios and int. high sea-level rise compared to the 2007 modeled habitats. Figures 16 through 19 show the habitat evolution over time for Run1 through Run 4.

The model suggests that under lower levels of sea-level rise the accretion rate is less important than under higher levels of sea-level rise. Under the int. high sea-level rise scenario, high accretion could increase the longevity of salt marsh, *Juncus* marsh, and mangrove habitat, and even increase the acreage of *Juncus* marsh and mangroves habitat from 2007 conditions. However, maintaining these habitats would come at the expense of seagrass habitat, since seagrass is limited from migrating inland if the others habitats keep up with sea-level rise.



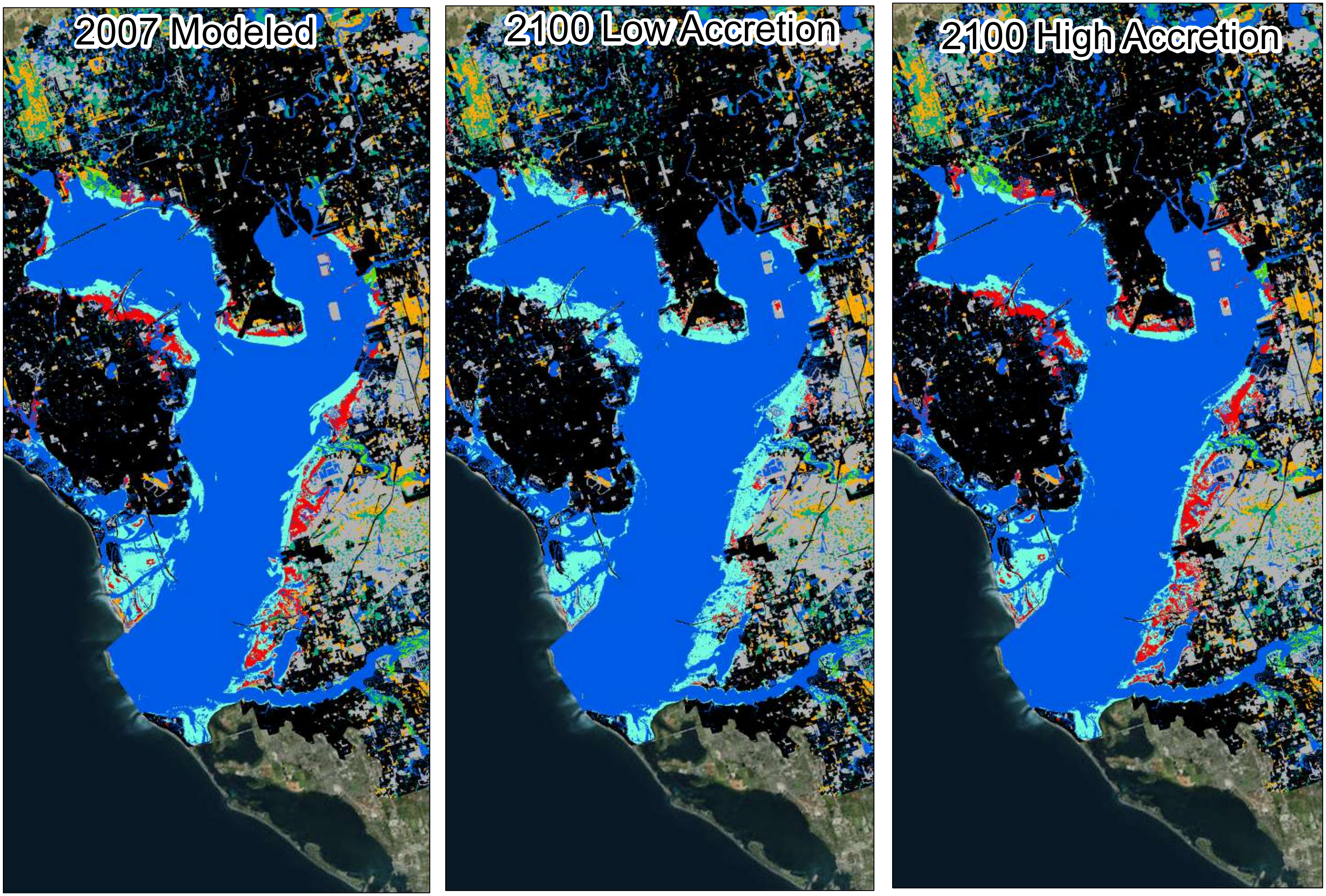
Note: Upland, Freshwater Marsh, and Open Water habitat
adjusted/reduced to better show change.
Model run uses low sediment accretion rates.

Figure 13
Modeled Changes in Tampa Bay Habitats
with Low Sea Level Rise



Note: Upland, Freshwater Marsh, and Open Water habitat adjusted/reduced to better show change.
Model run uses low sediment accretion rates.

Figure 14
Modeled Changes in Tampa Bay Habitats with High Sea-Level Rise



Source: ESRI, ESA, SFWFMD, Florida Emergency Management District
Note: Model runs displayed here use intermediate low rates of sea-level rise

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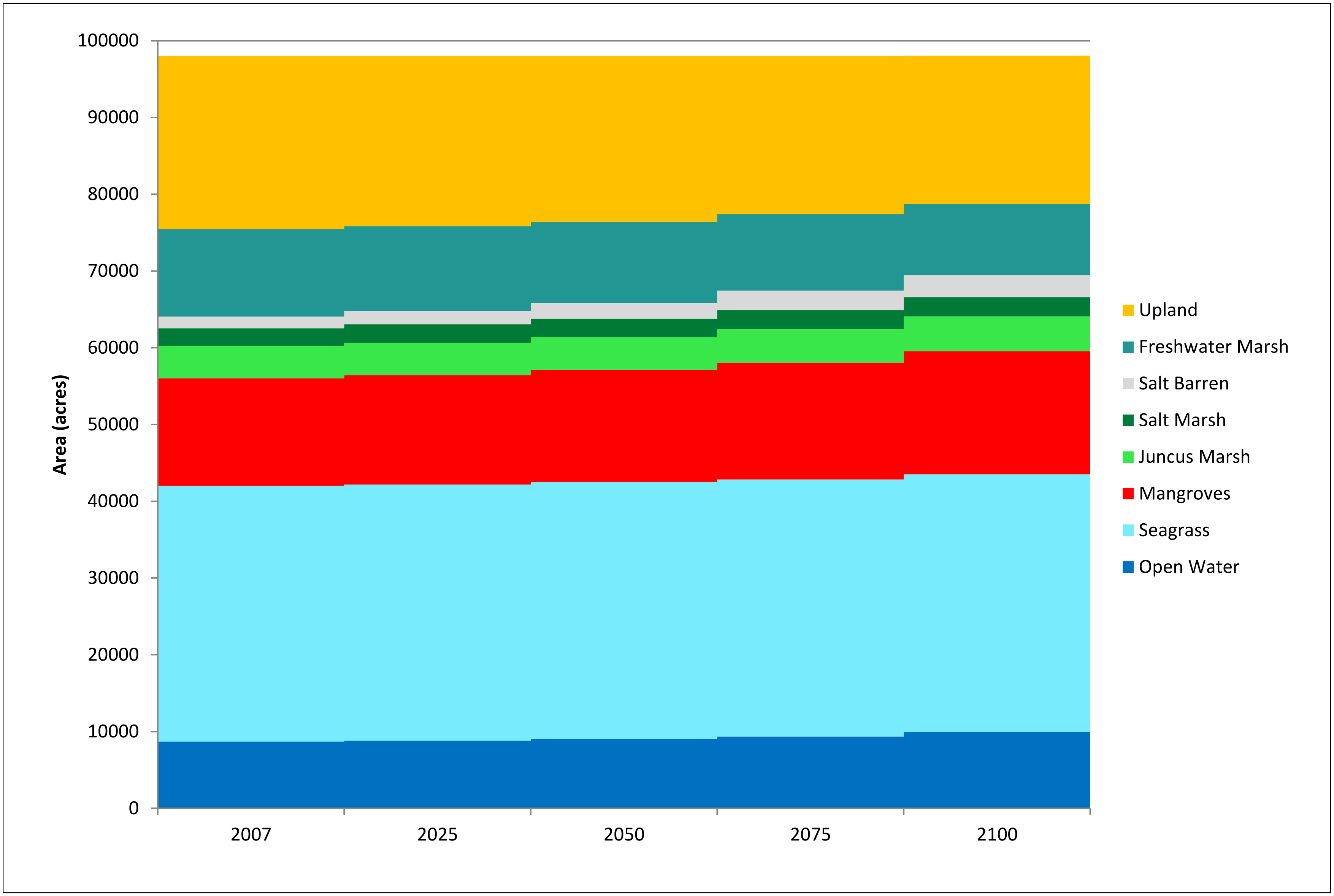
Developed- hard	Open Freshwater	Salt Marsh	Beach Dune
Developed- soft	Freshwater Marsh	Juncus Marsh	Seagrass
Undeveloped Upland	Mangroves	Salt Barren	

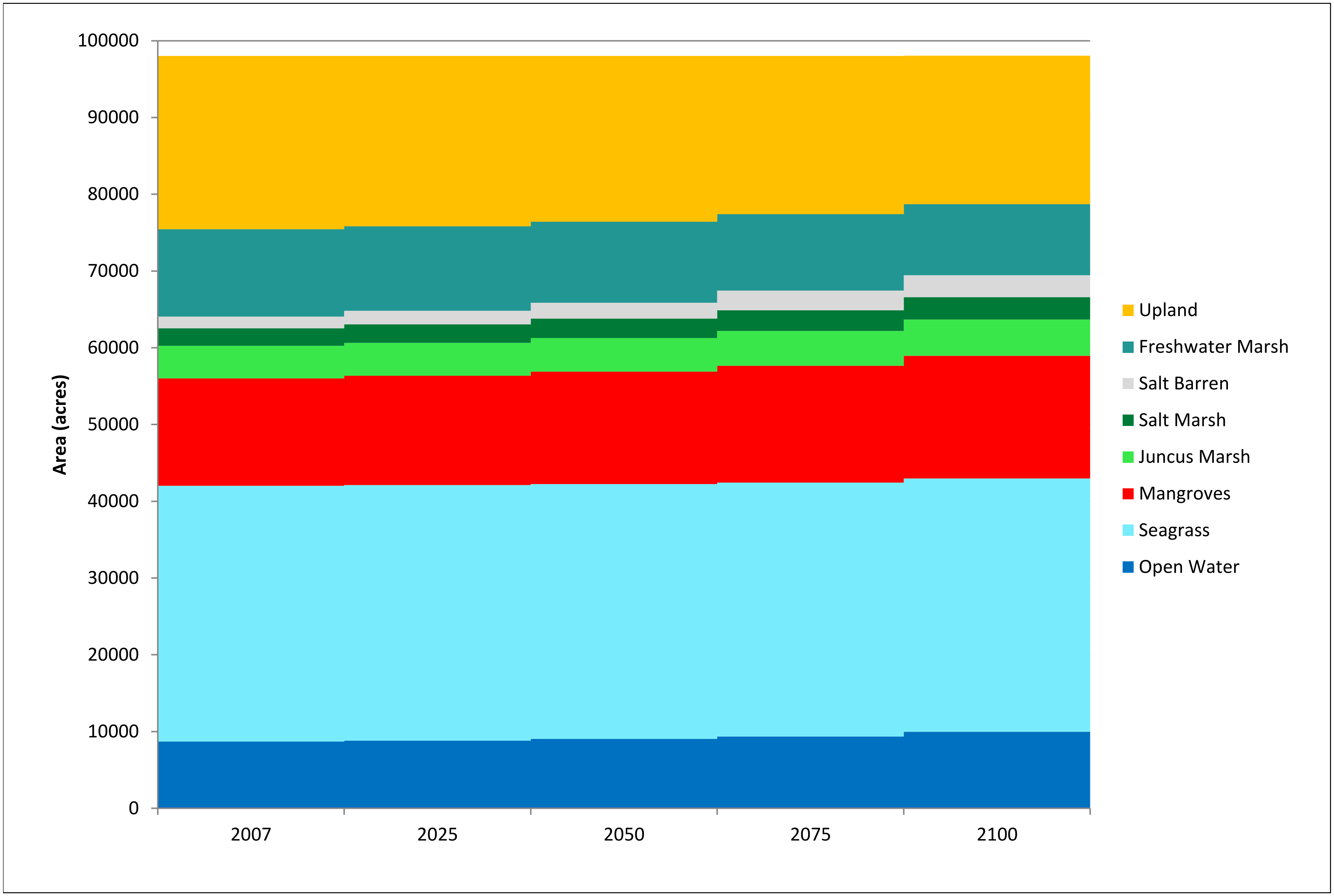
Figure 15
Modeled Tampa Bay Habitat Changes Under Two Different Accretion Rates



Note: Upland, Freshwater Marsh, and Open Water habitat adjusted/reduced to better show change.

Figure 16

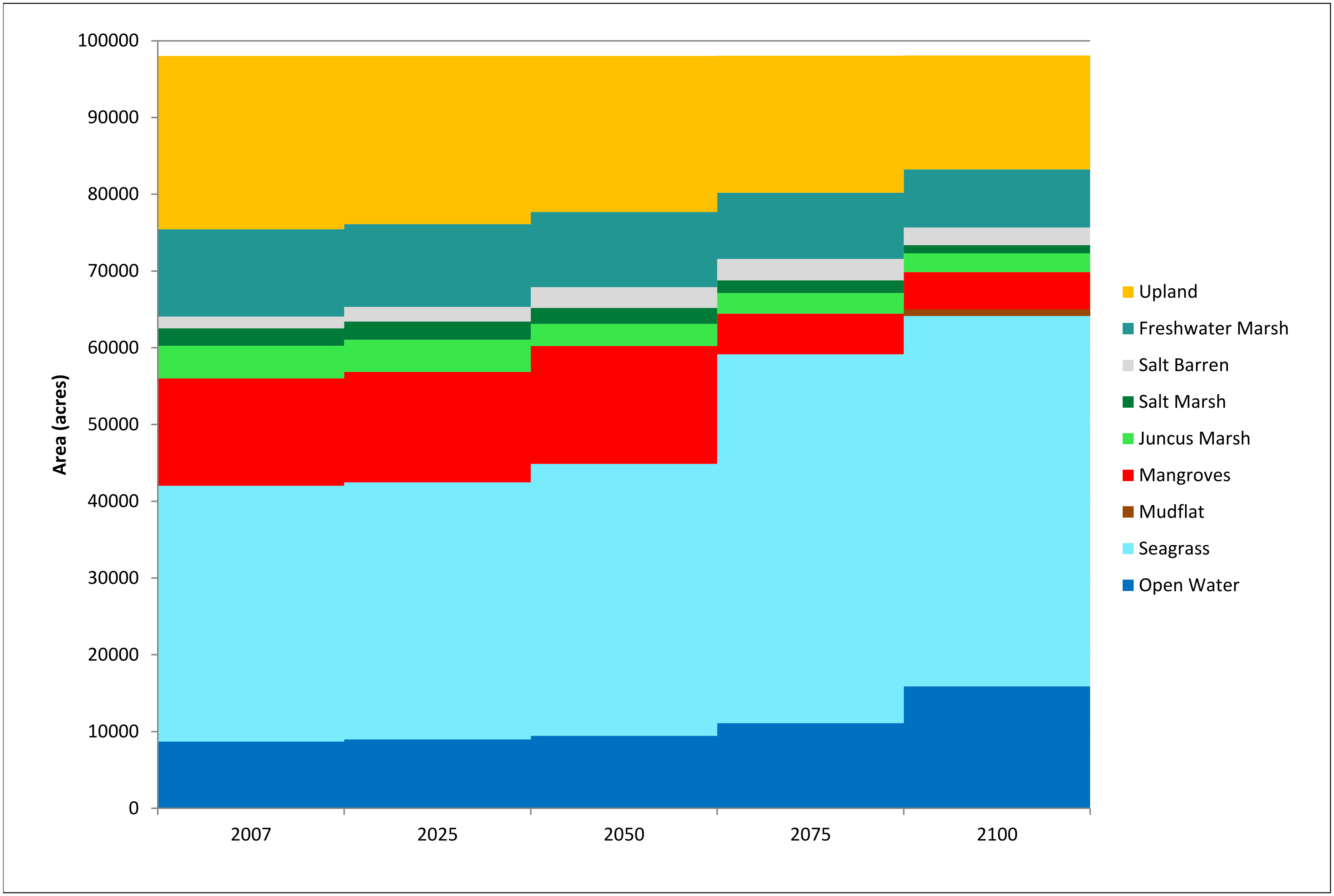
Modeled Changes in Tampa Bay Habitats
with Low Sea-Level Rise and Low Sediment Accretion



Note: Upland, Freshwater Marsh, and Open Water habitat
adjusted/reduced to better show change

Figure 17

Modeled Changes in Tampa Bay Habitats
with Low Sea-Level Rise and High Sediment Accretion



Note: Upland, Freshwater Marsh, and Open Water habitat adjusted/reduced to better show change.

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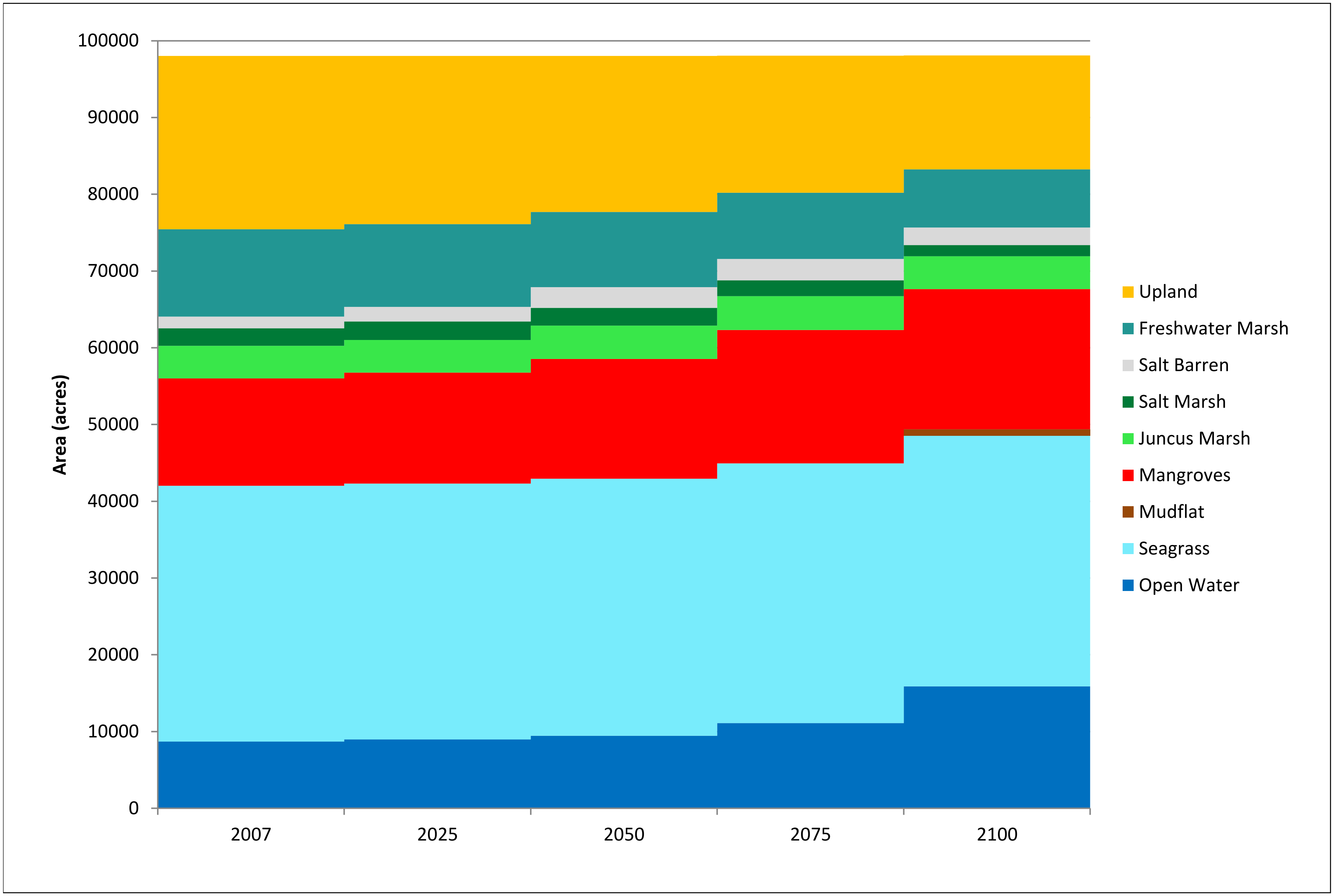
Figure 18

Modeled Changes in Tampa Bay Habitats
with High Sea-Level Rise and Low Sediment Accretion



Note: Upland, Freshwater Marsh, and Open Water habitat
adjusted/reduced to better show change

Tampa Bay Blue Carbon . D140671

Figure 19

Modeled Changes in Tampa Bay Habitats
with High Sea-Level Rise and High Sediment Accretion

TABLE 11
CHANGES IN TAMPA BAY HABITAT ACREAGE FOR DIFFERENT ACCRETION RATES

		Modeled Acreage in 2100									
		Int. Low Sea-Level Rise				Int. High Sea-Level Rise					
Run	**Modeled Acreage in 2007**	**Run 1 (Low Accretion)**		**Run 2 (High Accretion)**		**Run 3 (Low Accretion)**		**Run 4 (High Accretion)**		**Difference (Run 2 –Run 1)**	**Difference (Run 4 –Run 3)**
Developed Upland - Hard	461,640	461,640	(0)	461,640	(0)	461,640	(0)	461,640	(0)	0	0
Developed Upland - Soft	210,310	210,310	(0)	210,310	(0)	210,310	(0)	210,310	(0)	0	0
Undeveloped Upland	230,600	227,370	(-3,230)	227,370	(-3,230)	222,870	(-7,730)	222,870	(-7,730)	0	0
Freshwater Marsh	81,390	79,260	(-2,130)	79,260	(-2,130)	77,590	(-3,800)	77,590	(-3,800)	0	0
Salt Barrens	1,520	2,870	(+1,350)	2,870	(+1,350)	2,280	(+760)	2,280	(+760)	0	0
High Salt Marsh	2,290	2,500	(+210)	2,910	(+620)	1,090	(-1,200)	1,460	(-830)	410	370
Juncus Marsh	4,250	4,530	(+280)	4,730	(+480)	2,430	(-1,820)	4,270	(+20)	200	1,840
Mangroves	13,990	16,040	(+2,050)	15,980	(+1,990)	4,870	(-9,120)	18,260	(+4,270)	-60	13,390
Mudflat	0	0	(0)	0	(0)	840	(+840)	830	(+830)	0	-10
Beach	70	30	(-40)	30	(-40)	10	(-60)	10	(-60)	0	0
Seagrass	33,310	33,550	(+240)	33,010	(-300)	48,280	(+14,970)	32,680	(-630)	-540	-15,600
Open Water	338,710	339,960	(+1,250)	339,960	(+1,250)	345,880	(+7,170)	345,880	(+7,170)	0	0
Total Intertidal Wetland[1]	20,530	23,070	(+2,540)	23,620	(+3,090)	8,390	(-12,140)	23,990	(+3,460)	(550)	(15,600)

1. Includes High Salt Marsh, Juncus Marsh, and Mangroves

4.1.3 Varying Management Options

Table 12 provides the habitat acreage for protecting development (Run 3) and for allowing the marsh to migrate into "soft" development (Run 5). Under the int. high sea-level rise scenario, there is approximately 4,600 acres of developed upland that could be converted to marsh, salt barrens, mangroves, and seagrass. Figure 20 shows the habitat maps under the protected and unprotected scenarios.

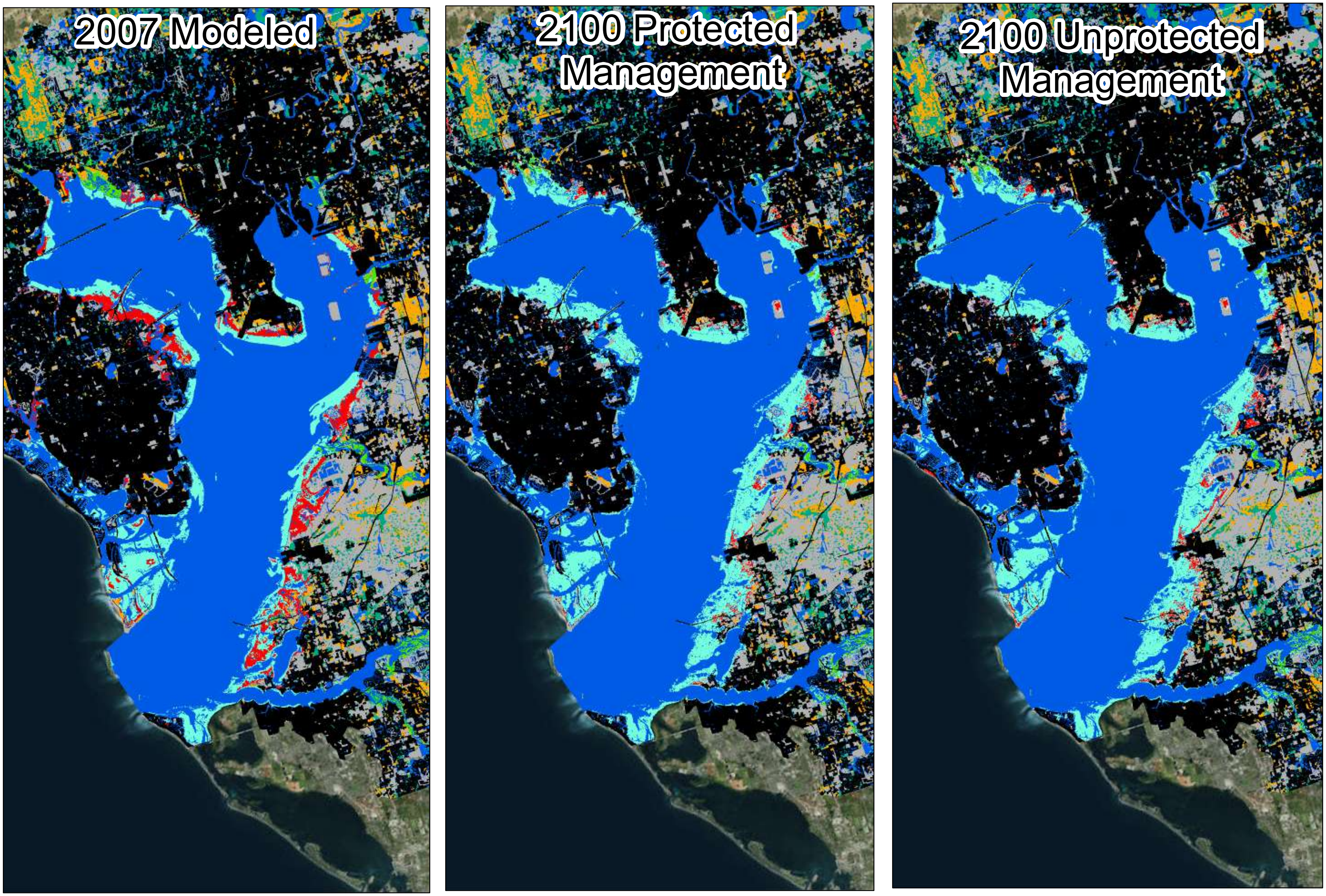
Figure 21 and Figure 22, which show the habitats over time for the protected and unprotected development, illustrate how allowing the marsh to migrate into "soft" developed areas creates more habitat.

TABLE 12
HABITAT ACREAGES FOR MANAGEMENT SCENARIOS

Run	Modeled Acreage in 2007	Acreage in 2100				Difference (Unprotected-Protected)
		(Run 3) Protected		(Run 5) Unprotected		
Developed Upland - Hard	461,640	461,640	(0)	461,640	(0)	0
Developed Upland - Soft	210,310	210,310	(0)	205,690	(-4,620)	-4,620
Undeveloped Upland	230,600	222,870	(-7,730)	222,870	(-7,730)	0
Freshwater Marsh	81,390	77,590	(-3,800)	77,590	(-3,800)	0
Salt Barrens	1,520	2,280	(+760)	3,400	(+1,880)	1,120
High Salt Marsh	2,290	1,090	(-1,200)	1,440	(-850)	350
Juncus Marsh	4,250	2,430	(-1,820)	2,520	(-1,730)	90
Mangroves	13,990	4,870	(-9,120)	6,540	(-7,450)	1,670
Mudflat	0	840	(+840)	890	(+890)	50
Beach	70	10	(-60)	10	(-60)	0
Seagrass	33,310	48,280	(+14,970)	49,590	(+16,280)	1,310
Open Water	338,710	345,880	(+7,170)	345,900	(-7,190)	20
Total Intertidal Wetland[1]	20,530	8,390	(-12,140)	10,500	(-10.030)	2,110

1. Includes High Salt Marsh, Juncus Marsh, and Mangroves

Allowing marsh to migrate into "soft" development is one strategy to maintain marsh habitats into the future. Strategic restoration of agricultural or recreational lands could create up to 1,100 acres of salt barren, 400 acres of salt marsh, 90 acres of *Juncus* marsh, 1,700 acres of mangroves, and 1,300 acres of seagrass by 2100. However, increasing accretion rates (e.g., through dam removal or other sediment supply options) would have a much larger impact on the acreage of *Juncus* marsh and mangrove habitat (and a similar impact on salt marsh). Additionally, efforts to keep sea-level rise to lower levels could have a greater impact on maintaining these habitats, as compared to allowing migration into soft development. Future efforts could look at allowing the marsh to migrate into hard development as well, as sea-level rise threatens existing structures or creates disincentives to develop or redevelop along the shore.



Source: ESRI, ESA, Florida Emergency Management District, SFWFMD

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Developed- hard	Open Freshwater	Salt Marsh	Beach Dune
Developed- soft	Freshwater Marsh	Juncus Marsh	Seagrass
Undeveloped Upland	Mangroves	Salt Barren	

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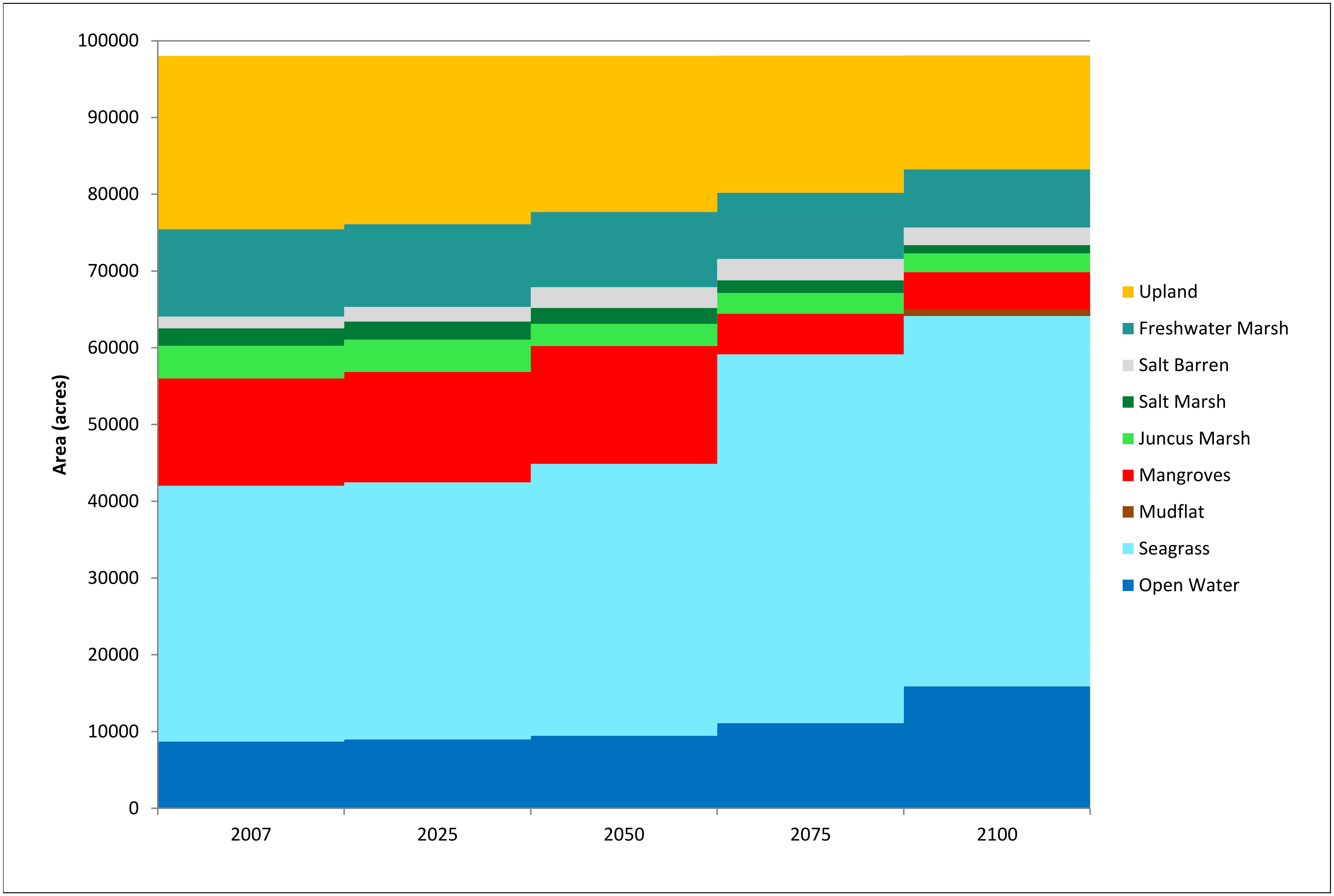
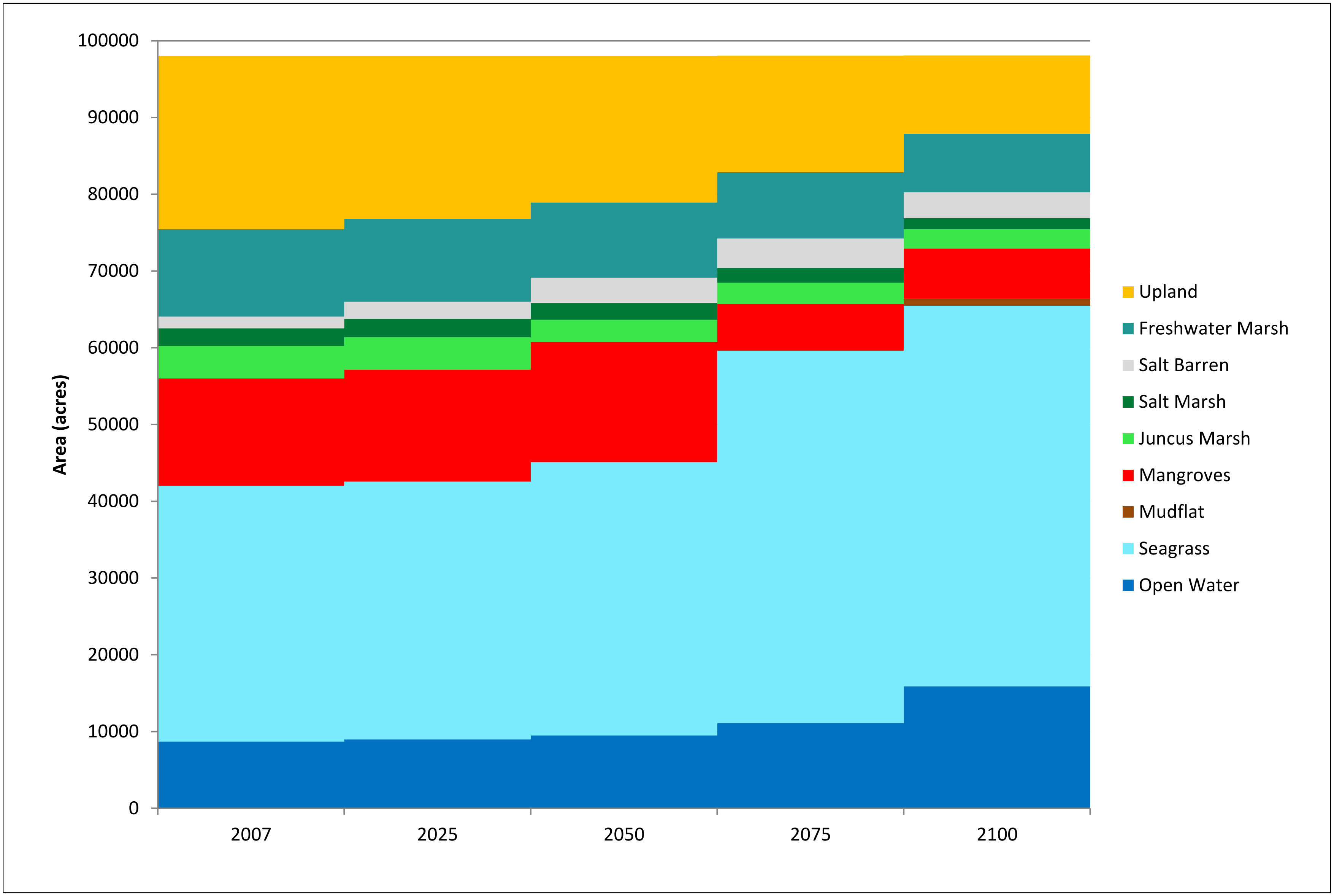
Figure 20

2007 Modeled Vegetation versus Protected and Unprotected Management



Note: Upland, Freshwater Marsh, and Open Water habitat adjusted/reduced to better show change.
Model run uses high sea-level rise and low accretion.

Figure 21
Modeled Changes in Tampa Bay Habitats with Protected Development



Note: Upland, Freshwater Marsh, and Open Water habitat adjusted/reduced to better show change .
Model run uses high sea-level rise and low accretion.

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Figure 22

Modeled Changes in Tampa Bay Habitats with Unprotected "Soft" Development

4.1.4 Habitat Vulnerability Discussion

Coastal habitats were examined further under the int. high sea-level rise and low accretion scenario (Run 3). The higher modeled sea-level rise and lower accretion rate would likely result in the greatest vulnerability for intertidal habitats of the scenarios examined. This analysis was done for four estuarine habitats that occur in Tampa Bay: high salt marsh, low (*Juncus*) marsh, mangroves, and seagrass. Upland and freshwater habitats were not considered and salt barren was not included since the model is likely overestimating this habitat type. Appendix H provides habitat change maps for the four wetland habitats for each bay segment.

4.1.4.1 High Salt Marsh

The model shows an overall loss of salt marsh throughout Tampa Bay between 2007 and 2100 (1,200 acres or 52%), even when the marsh is allowed to migrate into “soft” development (Table 12). Very little existing salt marsh is predicted to remain in 2100, although new marsh will be created. The largest area of existing salt marsh that is predicted to survive through 2100 is in Middle Tampa Bay, just south of MacDill Air Force Base on the interbay peninsula (Figure 23).

According to the model, the largest percentage of salt marsh loss is in Lower Tampa Bay (210 acres, 69% loss), although there is a larger acreage of loss in Middle Tampa Bay (470 acres, 53% loss) and Old Tampa Bay (400 acres, 61% loss). Manatee River is the only bay segment where the model results show an increase in salt marsh (60 acres, 185% gain) by 2100. Appendix I includes acreage results for all of the bay segments.

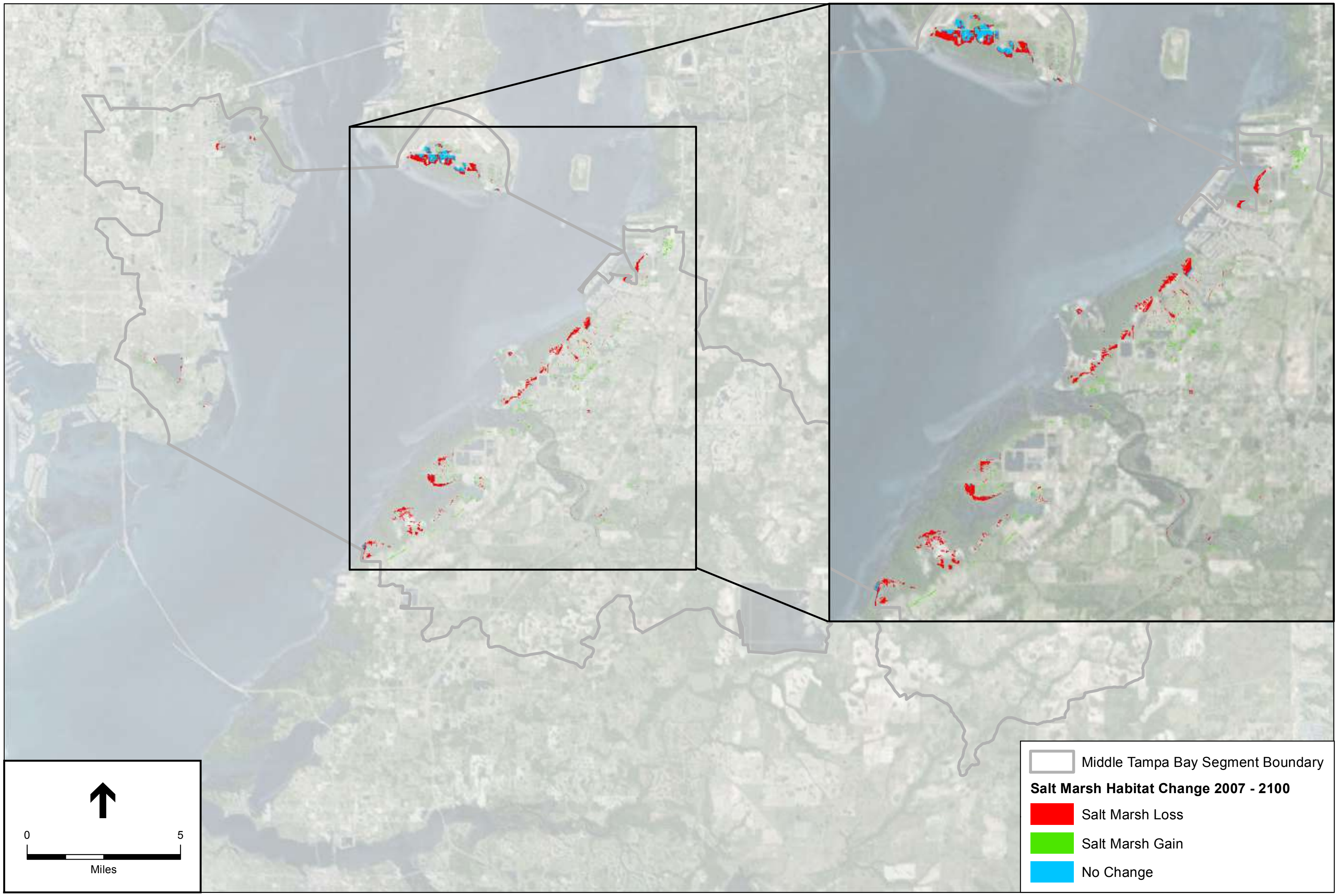
4.1.4.2 Low (*Juncus*) Marsh

Due to the locations of freshwater flow into the Bay, only four of the bay segments include existing *Juncus* marsh habitat: Middle Tampa Bay, Manatee River, Old Tampa Bay, and Hillsborough Bay. Overall loss of *Juncus* marsh was estimated at 1,820 acres (43%). The model shows a loss of *Juncus* habitat in all of these bay segments: 330 acres (37% loss) in Middle Tampa Bay, 560 acres (32% loss) in Manatee River, 600 acres (54% loss) in Old Tampa Bay, and 330 acres (63% loss) in Hillsborough Bay. Each bay shows some *Juncus* marsh will be maintained, but the creation of new *Juncus* marsh is minimal (Figure 24, Appendix H).

4.1.4.3 Mangroves

Under the int. high sea-level rise and with low accretion (Run 3), most of the existing mangrove habitat throughout the Bay drowns out (e.g. very little blue in Figure 25 and Appendix H; loss of 9,120 acres or 65%). However, there is much more new mangrove habitat created than for high salt marsh or *Juncus* marsh.

Terra Ceia Bay experiences the greatest percent loss of mangrove habitat at 86% (loss of 660 ac) according to the model results. However, there is a greater loss in other bays, including Lower Tampa Bay (loss of 1,430 ac, 66%), Middle Tampa Bay (loss of 3,430 ac, 70%), Boca Ciega Bay (loss of 780 ac, 62%) and Old Tampa Bay (loss of 2,720 ac, 69%). Manatee River is the only bay segment predicted to gain mangrove as salt marsh drowns out (gain of 85 acres, 475%).



SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management
NOTE: Map displays results for high sea-level rise and low accretion.

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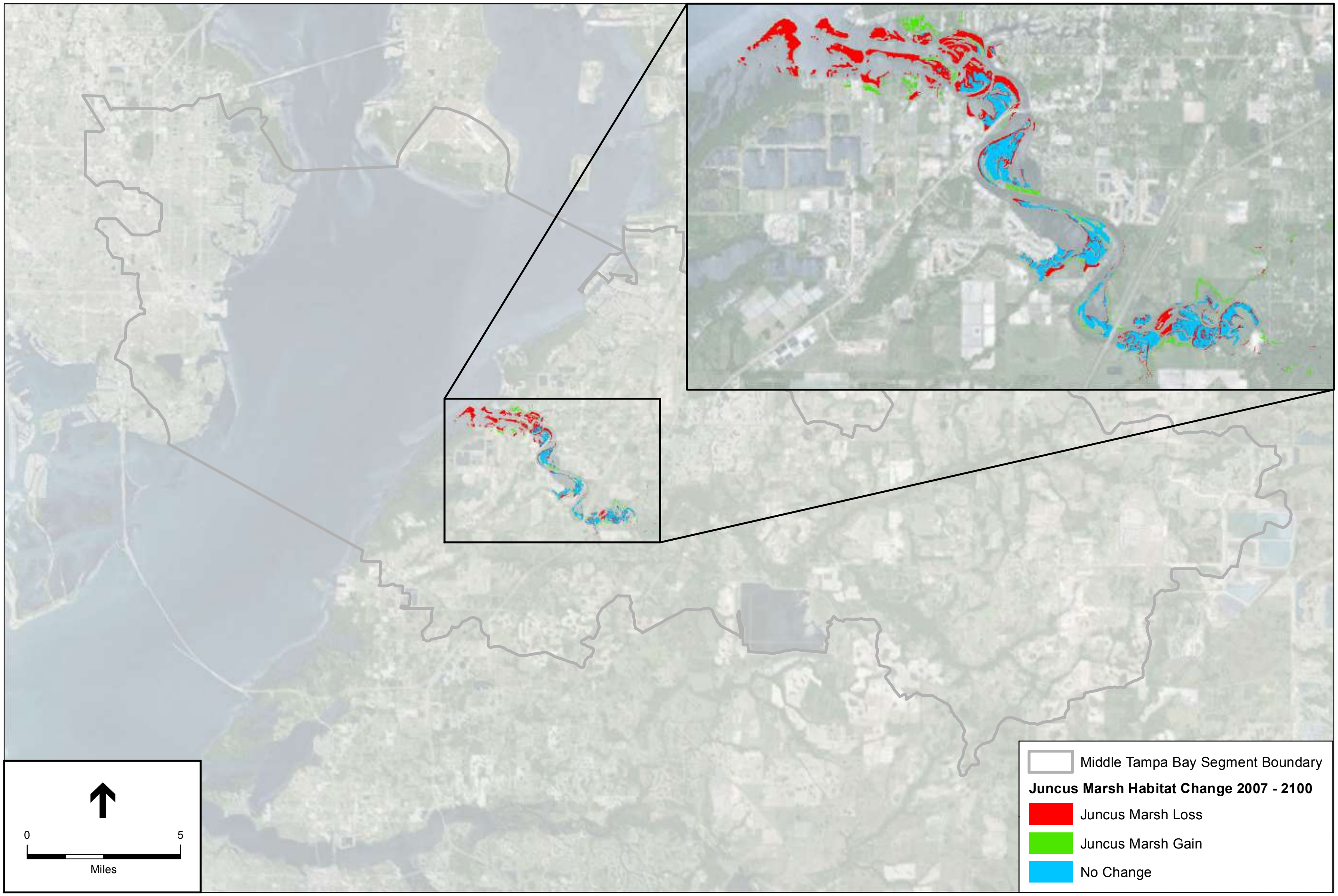
Figure 23
Change in Salt Marsh Habitat
Middle Tampa Bay 2007 - 2100



SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management
NOTE: Map displays results for high sea-level rise and low accretion.

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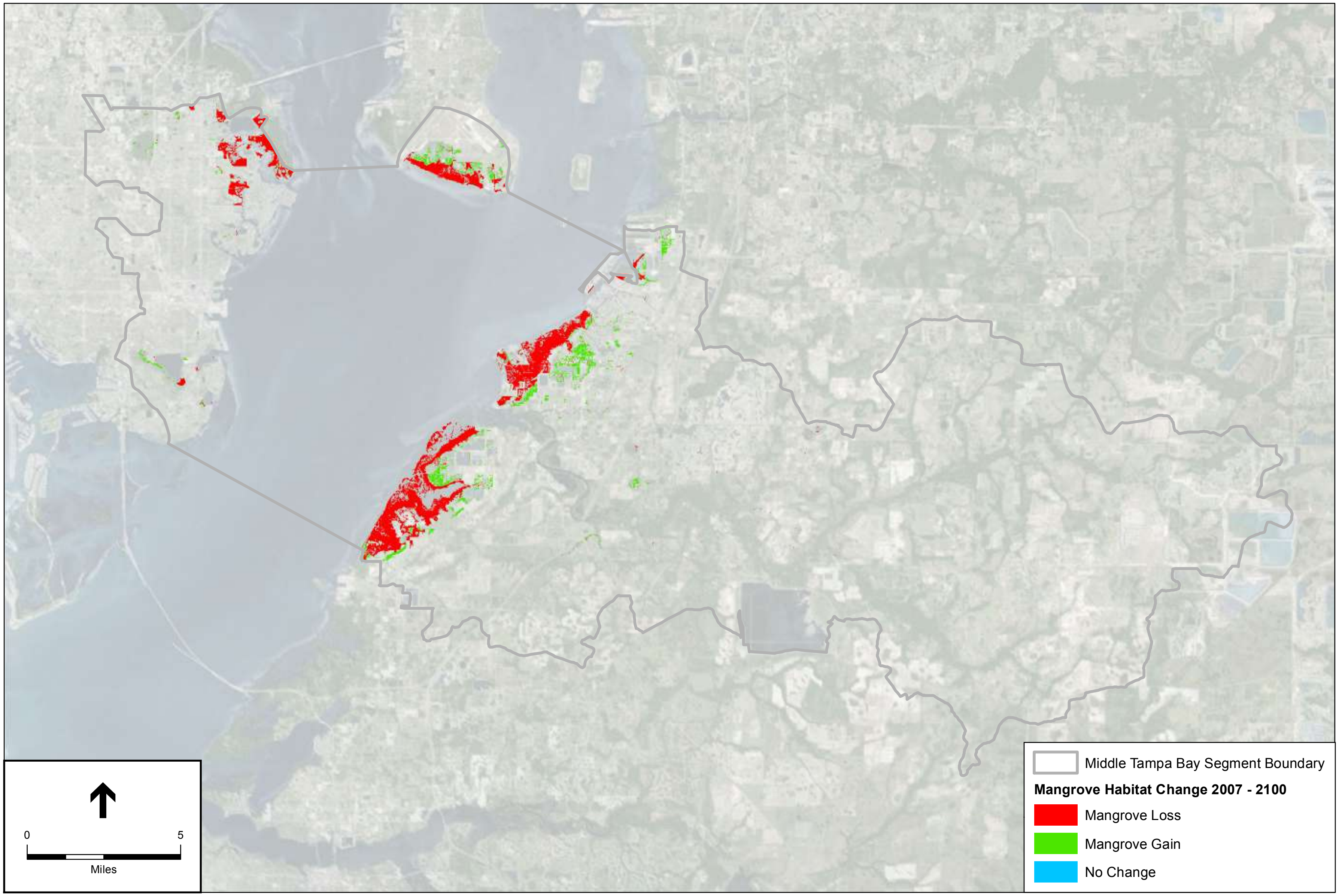
Figure 24
Change in Juncus Marsh Habitat
Middle Tampa Bay 2007 - 2100



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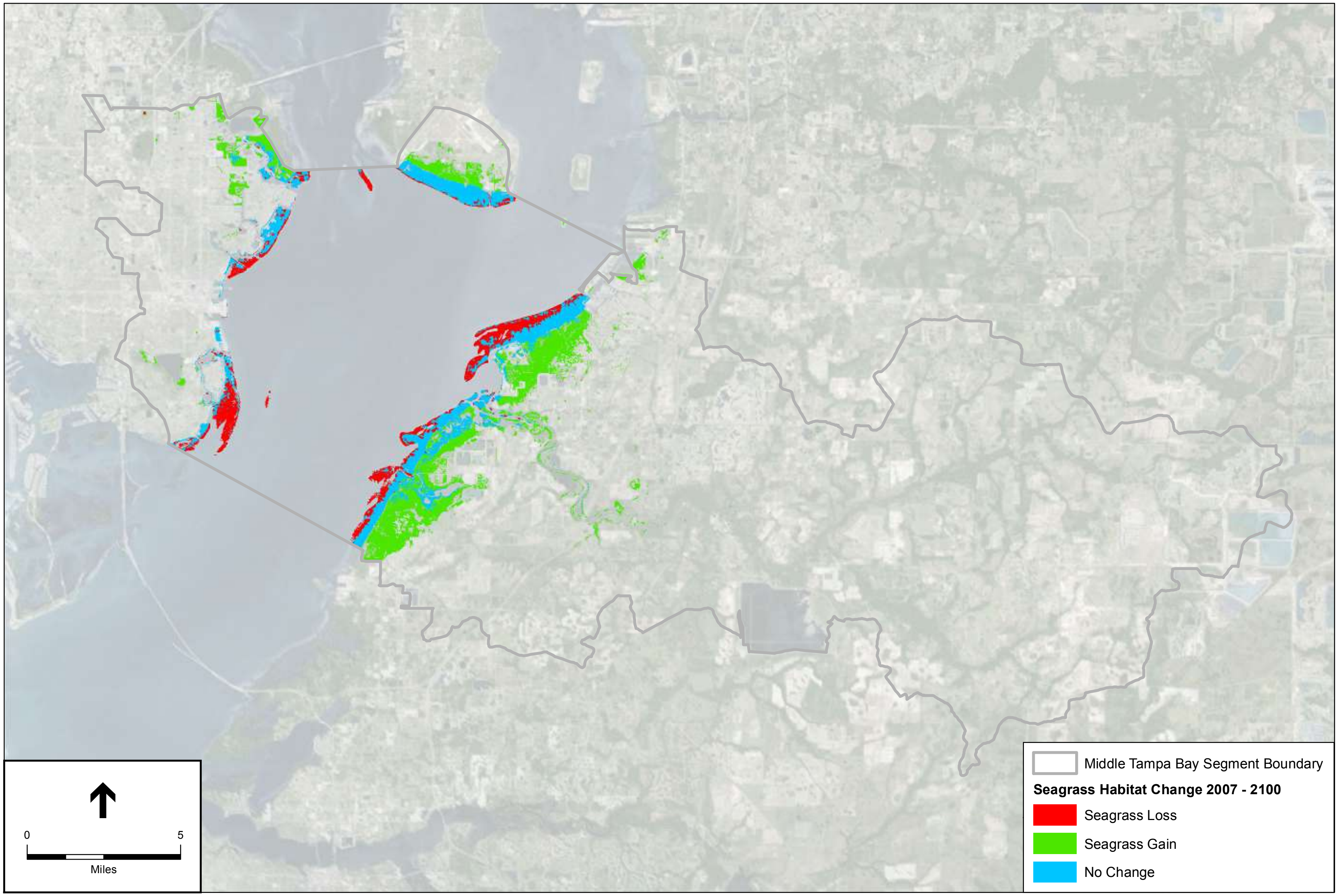
SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management
NOTE: Map displays results for high sea-level rise and low accretion.

Figure 25
Change in Mangrove Habitat
Middle Tampa Bay 2007 - 2100



SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management
NOTE: Map displays results for high sea-level rise and low accretion.

Figure 26
Change in Seagrass Habitat
Middle Tampa Bay 2007 - 2100

4.1.4.4 Seagrass

As all of the other wetland habitats drown out under int. high sea-level rise, the model predicts a large increase in seagrass habitat (14,970 acres, 45%). Each bay segment shows a loss in seagrass habitat along the edge of the Bay, but the gain in every segment outweighs the loss (Figure 26 and Appendix H). Additionally, much of the existing seagrass habitat is predicted to be maintained through 2100, unlike the other wetland habitats. Seagrass acreages are presented in Appendix I and maps of seagrass change are presented in Appendix H.

4.1.4.5 Conclusions

Comparing Figures 23 through 26 illustrates the habitat evolution in Middle Tampa Bay. Areas of loss of salt marsh (red in Figure 23), show up as gains for mangroves (green in Figure 25) and seagrass (green in Figure 26). Similarly, loss of *Juncus* marsh (red in Figure 24), shows up as gains in seagrass (green in Figure 26). Similar patterns are shown throughout the Bay (Appendix H).

The model results indicate that, for the highest vulnerability scenario assessed, and with the exception of seagrasses, wetland habitats are at risk of significant loss. Without a significant rate of accretion, existing habitats may not be self-sustaining in the long-term. However, there are opportunities throughout the Bay for wetland habitats to migrate inland into undeveloped lands. Additionally, coastal managers can use these results to identify areas of “soft” development to target for future acquisition and restoration.

4.2 Historic and Future Bay-wide Changes in GHG Fluxes and Carbon Sequestration

4.2.1 Historic Changes

When the GHG framework is applied to the historic wetland areas provided in Section 2.1, the results reflect the decrease in biomass from 1900 to 1990 (Figure 27). Since then, conservation and restoration efforts have reversed this trend and biomass has been increasing.

Total carbon sequestration, including biomass and soil carbon, has continued to increase over time, although at a slower rate after 1950 (Figure 28). Methane emissions have been fairly constant over time. Since this analysis only considers mangroves and no other methane-emitting habitats, the methane emissions reflect the area of mangrove over time, with a slight drop in methane emissions in 1990/95 corresponding to the lowest mangrove cover on record.

Because not all habitats are considered in the historic analysis, these results should be used for comparison over time, and cannot be compared directly to the results presented in Section 4.2.3.

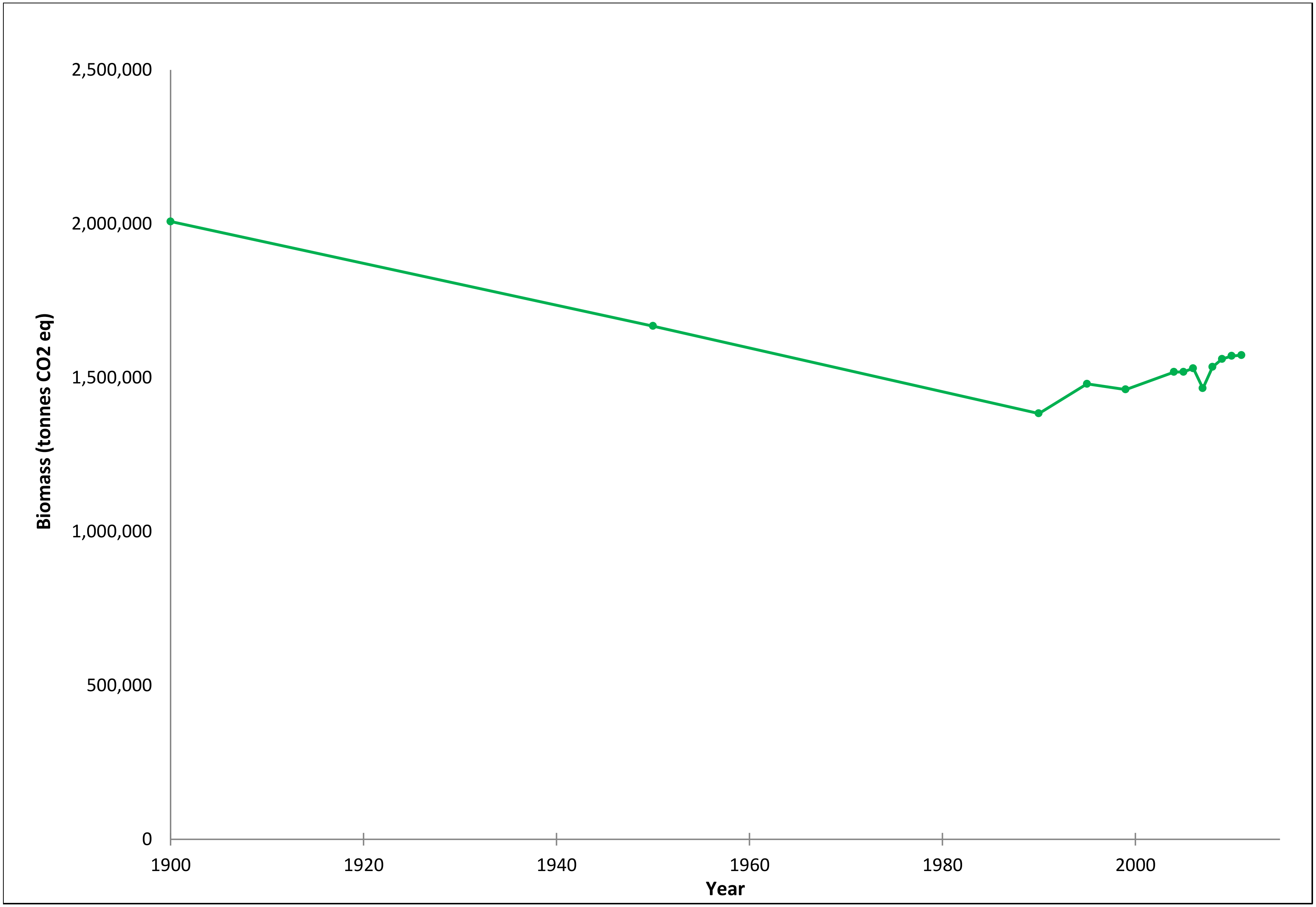


Figure 27
Tampa Bay Change in
Biomass, Historically

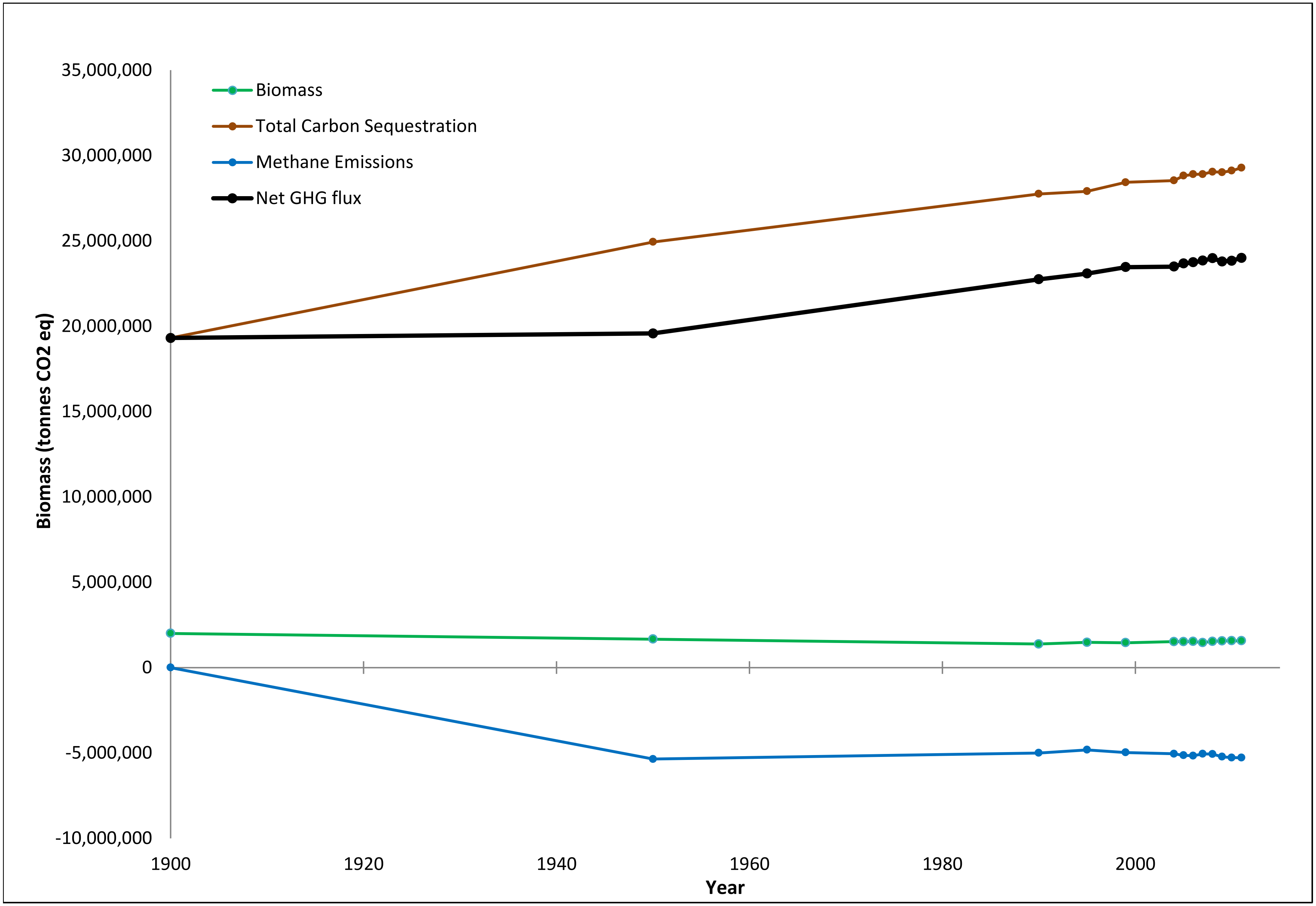


Figure 28
Tampa Bay Net Change in GHG, Historically

4.2.2 Restoration Projects under the Government Performance and Results Act

Applying the framework described above to the Tampa Bay restoration projects from 2006 to 2015, the restoration projects that created new habitat sequestered 236,000 tonnes CO_2 equivalent, which is equal to removing the annual emissions of 49,900 passenger vehicles. This estimate is based on changes in organic carbon stock, but there are likely additional benefits of inorganic carbon sequestration for projects restoring seagrass. The bicarbonate pathway could increase sequestration by up to 42,000 tonnes CO_2 equivalent (almost double the amount of carbon sequestered for all projects). Projects involving invasive control, prescribed burns, or mechanical thinning caused a temporary loss of potential sequestration of 244,000 tonnes CO_2 and habitat conversions to freshwater marsh caused emissions of 700 tonnes CH_4 (20,000 tonnes CO_2 equivalent). In the short-term, the removal of vegetation causes a net loss of biomass and soil sequestration. However, over time, these areas likely revegetate and the other restoration actions result in a net increase in sequestration. Altogether, the projects resulted in a short-term loss of 27,000 tonnes CO_2 equivalent, which would likely be offset by new growth and result in a long-term gain of 216,000 tonnes CO_2 equivalent. Table 13 presents these overall results and is further discussed below.

TABLE 13
TAMPA BAY GPRA GHG EMISSIONS AND SEQUESTRATIONS

	Short-Term			Long-Term		
	Tonnes CO_2 equivalents	Tonnes CH_4 (28 x CO_2)	Vehicles on the road	Tonnes CO_2 equivalents	Tonnes CH_4 (28 x CO_2)	Vehicles on the road
Carbon dioxide sequestration due to creation of new habitat	236,000	-	49,900 removed	236,000	-	49,900 removed
Loss of carbon dioxide sequestration due to vegetation removal	-244,000	-	51,500 added	-	-	-
Methane emissions due to conversion to freshwater habitats	-20,000	-700	4,200 added	-20,000	-700	4,200 added
Net GHG Change (new sequestration – loss of potential – methane emissions)	-27,000	-	5,700 added	217,000	-	45,800 removed

Carbon dioxide sequestration due to creation of new habitat. Restoration that creates new habitat increases both biomass and soil sequestration. From a GHG sequestration perspective, this is a positive action.

Loss of potential carbon dioxide sequestration due to vegetation removal. This row assumes that once vegetation is removed, that land remains unvegetated, so there is a loss of biomass and loss of future sequestration potential. However, the purpose of vegetation removal is usually to allow native vegetation to colonize the cleared area. In this analysis, only planted vegetation was considered, so any areas where vegetation naturally colonized a site were not considered. With these assumptions in mind, this row of Table 13 should be considered a temporary change to sequestration.

Methane emissions due to conversion to freshwater habitats. Restoration that creates freshwater habitat increases biomass and soil sequestration, but it also increases methane emissions. Depending on the land use before restoration, this usually results in an overall emission.

Due to the limited project data available, the GHG flux estimates are approximate, and should be considered accordingly (see Section 4.3.1.2). Better project reporting, which would include one project per restoration site, acreages for each habitat type, clear initial and final habitat types, and an estimate of the percentage of vegetation removed, could vastly improve the GHG flux estimates.

4.2.3 Future GHG Changes Due to Sea-Level Rise

Since greenhouse gas accounting is still highly variable, it should be used as a tool to understand sequestration and emission trends, with less focus on precise values. Sequestration and emission rates can vary largely from site to site, and the results presented above are based on theoretical habitat evolution scenarios, which have errors of their own (see Section 4.3.1).

The difference in net GHG flux amongst the five HEM scenarios is relatively low (Table 14), only varying 1% between runs, due to the fact that habitat conversion throughout Tampa Bay is small compared to the total area analyzed. Figure 29 illustrates the net GHG flux curves for each run. The net GHG sequestered for each run is a combination of the carbon sequestered (positive value) and the methane emitted (negative value). The resulting net GHG emitted for Runs 1, 2, and 4 are within 0.3% of each other and roughly 1% less than the emissions for Runs 3 and 5.

TABLE 14
GHG EMISSIONS BY HEM RUN

Scenario (Run)	Loss in Biomass by 2100 (2100-2007) (tonnes CO_2 equiv.)	Change in Soil Carbon Stock by 2100 (2100-2007) (tonnes CO_2 equiv.)	Cumulative Carbon Sequestered by 2100 (tonnes CO_2 equiv.)	Methane Emissions from 2007 to 2100 (tonnes CO_2 equiv.)	Net GHG Sequestered by 2100 (tonnes CO_2 equiv.)
Run 1-low slr, low accretion	-161,042	30,682,234	102,458,079	-28,302,683	74,155,397
Run 2-low slr, high accretion	-157,558	30,719,337	102,498,667	-28,391,168	74,107,499
Run 3-high slr, low accretion	-1,535,591	29,997,627	100,398,923	-26,983,877	73,415,046
Run 4-high slr, high accretion	-352,169	30,697,049	102,281,768	-27,964,916	74,316,851
Run 5-high slr, low accretion, marshes allowed to migrate	-1,373,153	30,019,445	100,583,179	-27,023,918	73,559,261

SLR = sea-level rise
Positive values indicate sequestration while negative numbers indicate emissions.

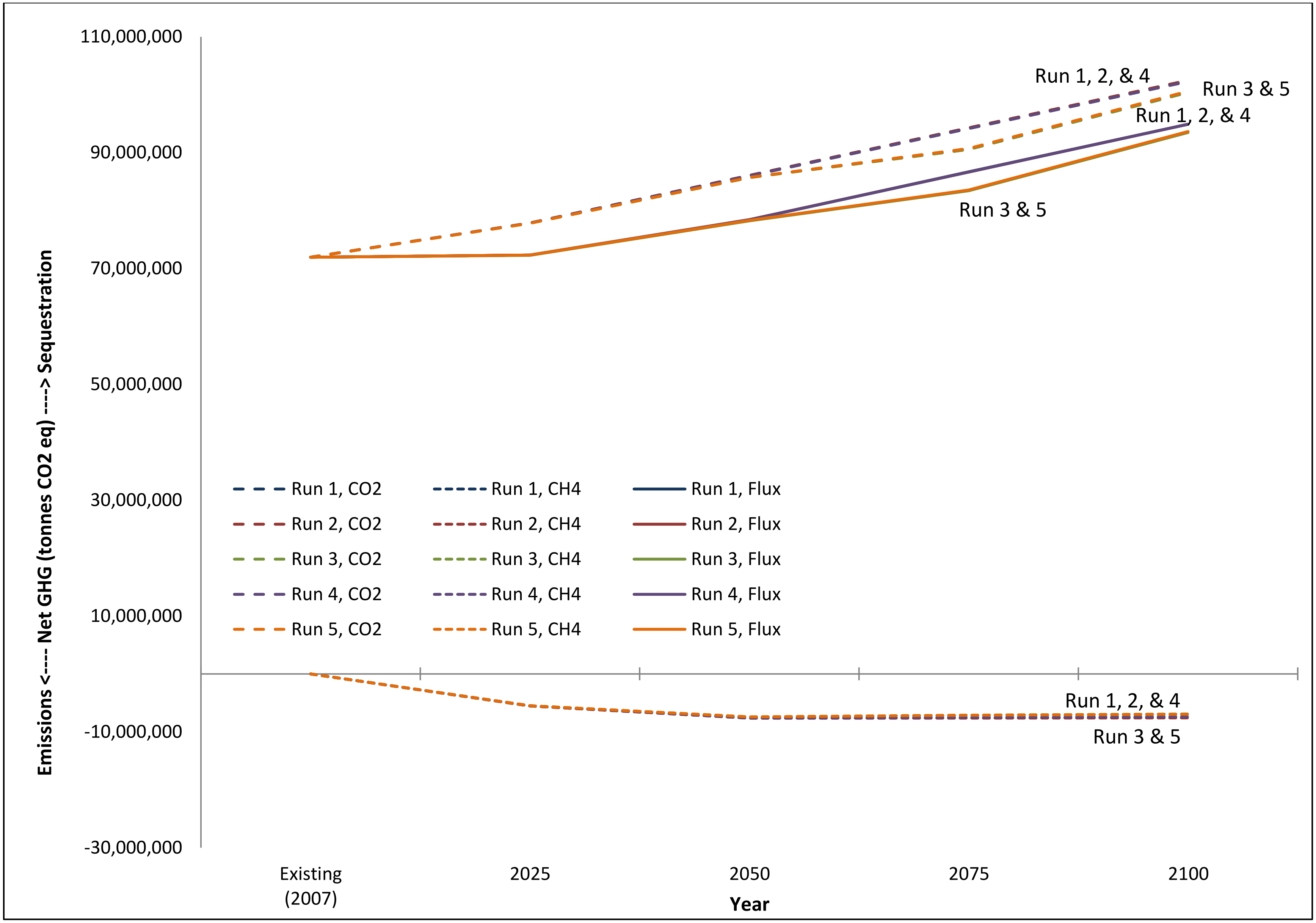


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Figure 29
Tampa Bay Change
in Net GHG Flux, All Runs

4.2.3.1 Sequestration and Emissions by Habitat Type

The habitats with the largest carbon sequestration of biomass are those with large woody plants, such as upland forest and tree plantations (140--220 tonnes dry matter/ha, Table 7). Similarly, mangroves sequester more carbon in biomass than wetland species (137 tonnes dry matter/ha). Other wetland habitats and agricultural lands sequester 2--40 tonnes dry matter/ha.

Mangroves and salt marsh sequester carbon at similar rates (1.5--1.6 tonnes C/ha/yr., Table 7). Brackish (*Juncus*) marsh accumulates at a lower rate of 0.71 tonnes C/ha/yr. Seagrass habitat sequestered slightly less carbon in the sediment than the other vegetated habitats at 0.64 tonnes C/ha/yr. However, if the bicarbonate pathway is considered, the carbon sequestration rate for seagrass is actually higher than all other wetland habitats at 2.19 tonnes C/ha/yr. (see discussions in Section 3.3.2 and 4.3). Areas with minimal vegetation, including developed areas, agricultural lands, salt barrens, and open water habitat, provide little soil sequestration benefit (~0.3 tonnes C/ha/yr. or less).

Given that the IPCC recommends using an emission factor of 0 for salinities greater than 18 ppt and a factor of 193.7 kg CH_4/ha/yr. for lower salinities, only five habitats found within Tampa Bay yield methane emissions. These are all wetland habitats and they include freshwater swamp, mangrove, freshwater marsh, brackish marsh, and open freshwater. Freshwater marsh and freshwater swamp have the greatest methane emission rate (194 kg CH_4/ha/yr.), while mangroves have the smallest nonzero methane emission rate (15 kg CH_4/ha/yr.).

4.2.3.2 Sequestration by Run

In natural settings, as sea level rises upland habitats can convert to salt marsh, increasing carbon sequestration. However, as the marsh begins to convert to mudflat, biomass disappears and soil sequestration stops. Under low sea-level rise (Runs 1 and 2), salt marsh, *Juncus* marsh, and mangrove acreage actually increase as these areas convert from upland and freshwater marsh, although overall biomass decreases slightly (Figure 30). Similarly, under high sea-level rise, but with high accretion rates to offset higher water levels (Run 4), mangrove and *Juncus* marsh habitat increase, so Run 4 biomass is slightly lower, but comparable to Run 1 and Run 2 biomass. However, under high sea-level rise without high accretion rates (Runs 3 and 5), there is a loss of these habitats that sequester the most carbon, resulting in a lower carbon sequestration. When habitats are allowed to migrate into developed uplands (Run 5), there is less loss of biomass.

Under high sea-level rise and low accretion, there appears to be a sharp drop-off point for mangrove habitat within the Bay between 2050 and 2075. This predicted loss of mangrove area (~10,000 ac in Run 3) impacts both biomass (Figure 30) and soil sequestration (Figure 31) dramatically since mangroves are the highest density wetland type and have the highest soil sequestration rates. See Section 4.3 for further discussion of this result.

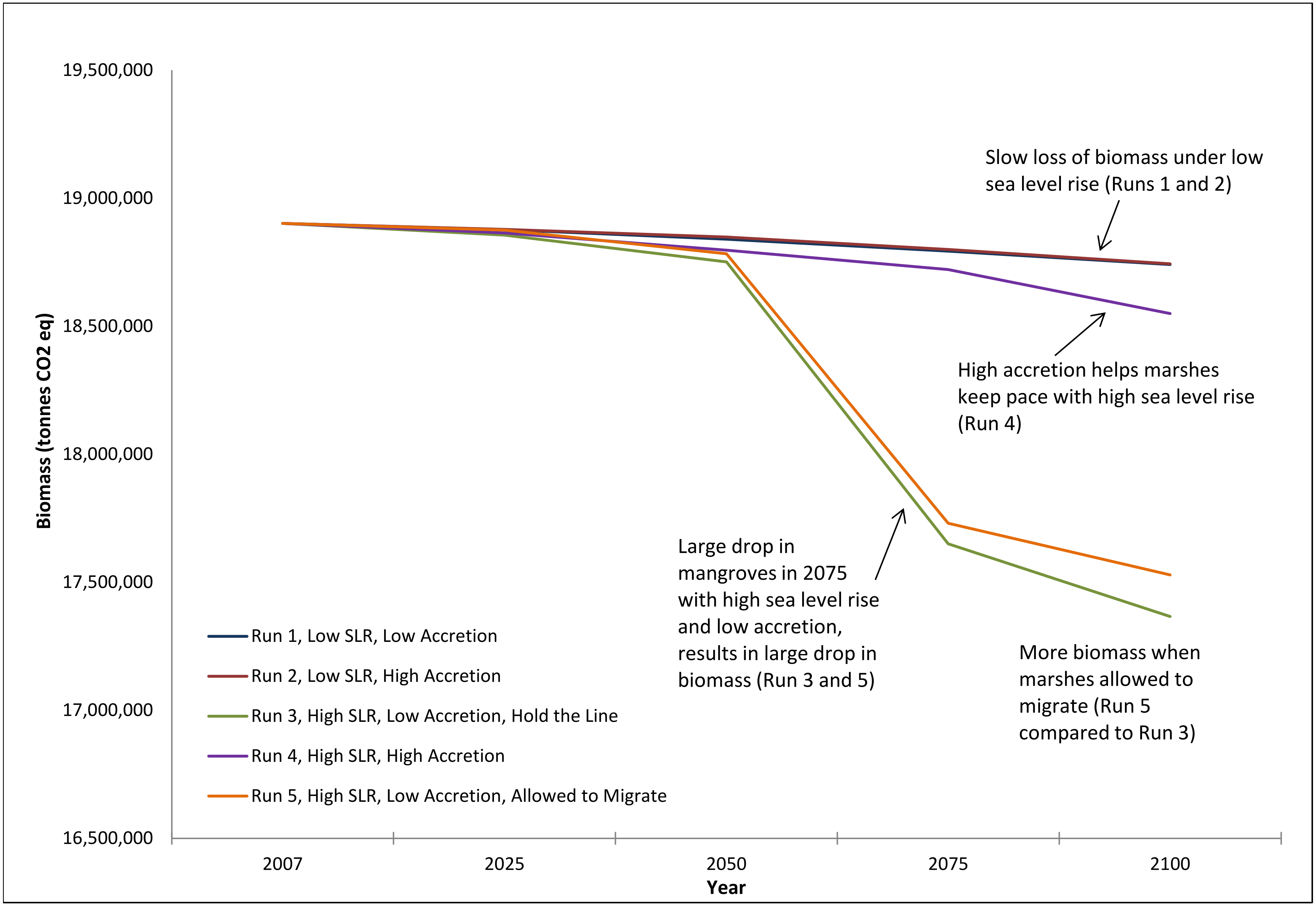

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Figure 30
Modeled Tampa Bay Change in Biomass

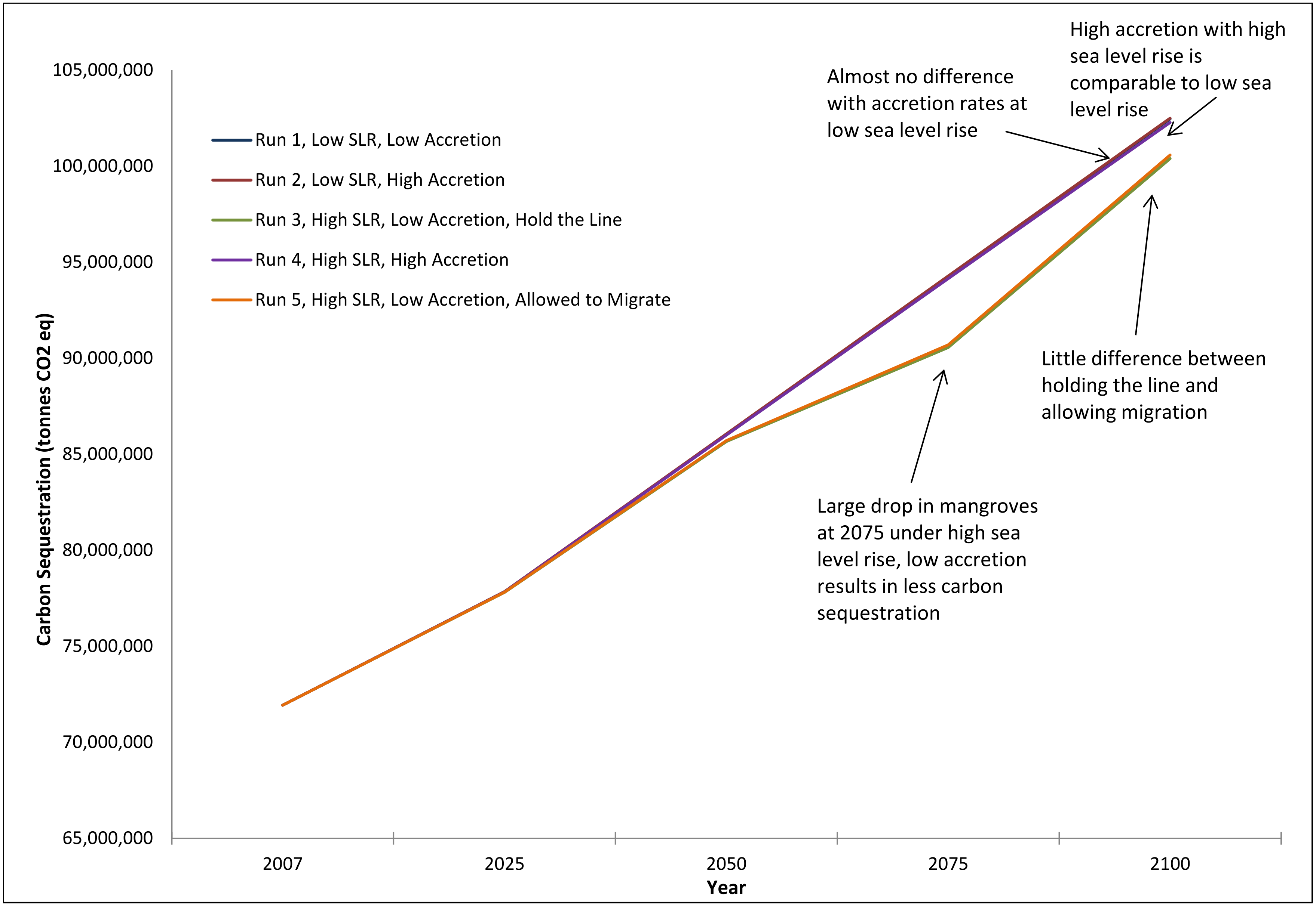


Figure 31
Modeled Tampa Bay Change in
Soil Sequestration

In all habitat evolution scenarios, carbon sequestration increases over time as soils sequester carbon. As shown in Table 14, the low accretion and high sea-level rise scenarios (Run 3 and Run 5) yield the lowest carbon sequestration, while the low sea-level rise scenarios (Run 1 and Run 2) and the high accretion and high sea-level rise scenario (Run 4) yield higher carbon sequestration of similar magnitude.

With low accretion and low sea-level rise (Run 1), approximately 30,680,000 tonnes CO_2 equivalent would be removed from the atmosphere from 2007 to 2100 due to soil sequestration (Figure 31). Carbon sequestration for Run 1 is lower than Run 2 (high accretion, low sea-level rise, 30,719,000 tonnes CO_2 equivalents) because with less sediment, habitats convert from high salt marsh, *Juncus* marsh, and mangroves, to mudflat and seagrass, which sequester carbon more poorly (unless the bicarbonate pathway is considered). The same is the case for Run 3 (low accretion, high sea-level rise) and Run 4 (high accretion and high sea-level rise). At a lower accretion rate, Run 3 sequesters an estimated 29,997,627 tonnes CO_2 equivalents while Run 4, at a higher accretion rate, sequesters 30,697,049 tonnes CO2 equivalents (Table 14).

4.2.3.3 Emissions by Run

Although *Juncus* marshes sequester carbon, they also emit methane. As discussed above, Run 3 and Run 5 result in the lowest acreage of *Juncus* marsh habitat, so they also emit the least amount of methane (Figure 32). The Run 2 scenario maintains *Juncus* marsh more effectively than Run 1, since the higher accretion rates allow the habitat to keep up with sea-level rise, so Run 2 has slightly larger methane emissions than Run 1. Similarly, both Run 1 and Run 2 have larger amounts of *Juncus* marsh than Run 4, so Run 4's emissions are smaller.

It is important to note that areas of methane production are small compared to those that sequester carbon. However, because methane has a global warming potential 28 times that of carbon, even small areas have a large impact on GHG fluxes.

4.3 Prioritizing Upland Parcels for Acquisition and Restoration

Figure 33 shows a map of the prioritized parcels for the Middle Tampa Bay segment. This figure shows undeveloped (e.g., non-impervious) upland parcels in 2007 that are predicted to be intertidal or subtidal in 2100 under the intermediate high sea-level rise scenario, as well as contiguous, undeveloped upland parcels that will be inundated after 2100 (remaining uplands). The parcels associated with these areas are then identified as either publicly- and privately owned.

The map series generated from this analysis is provided in Appendix J, while all parcel information and related metadata are provided in electronic format (CD) as a separate work product (Appendix K).

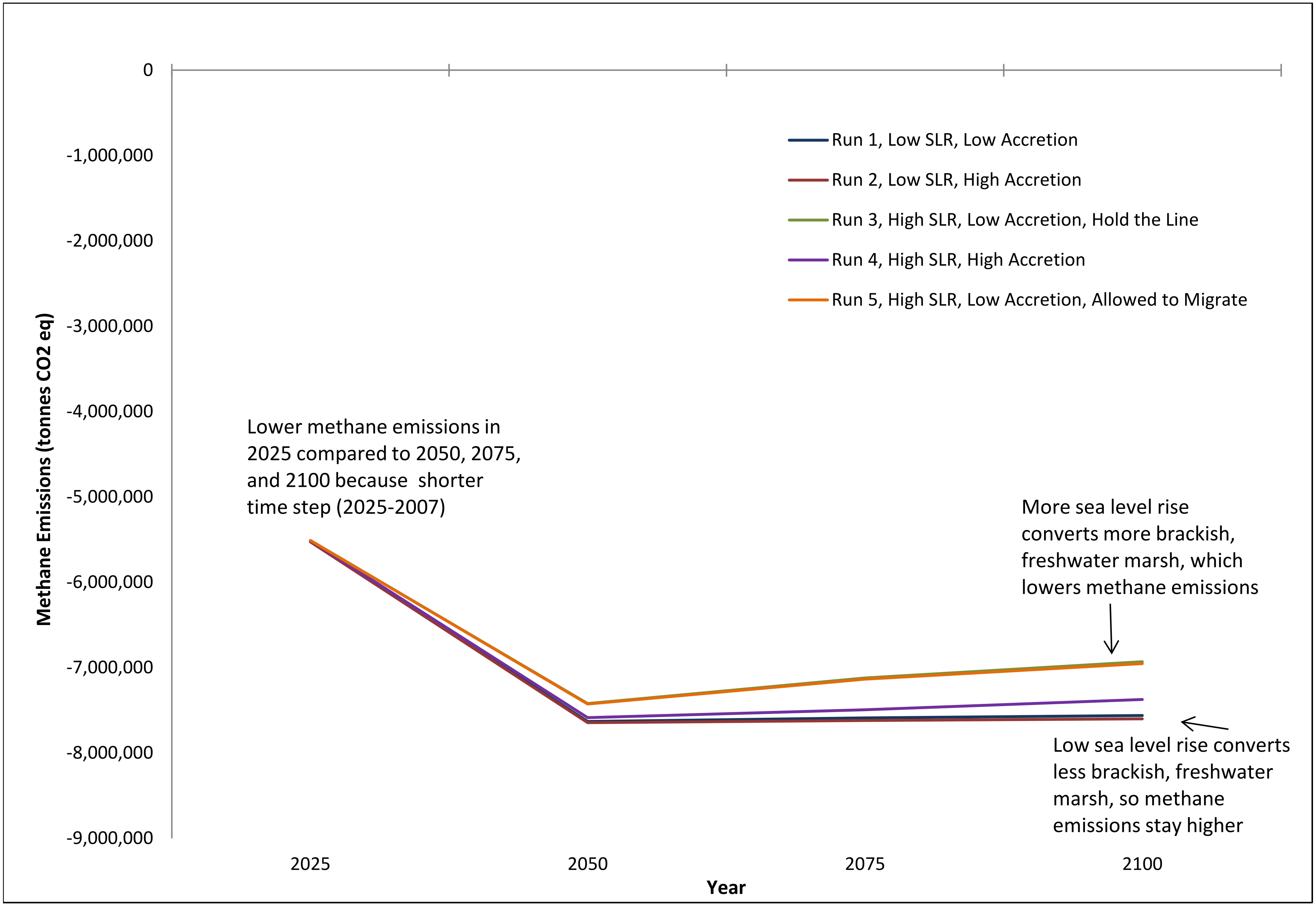
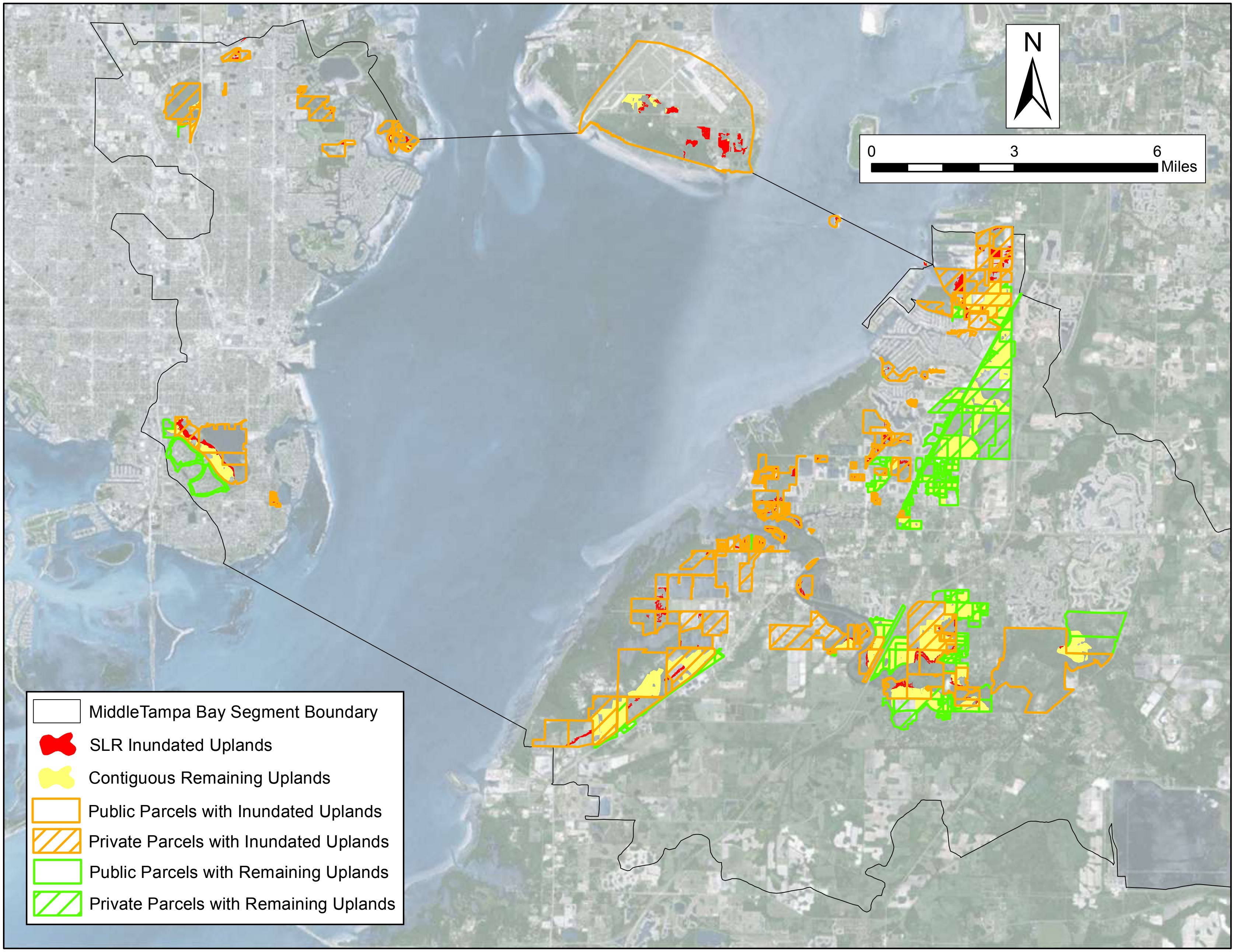


Figure 32
Modeled Tampa Bay Change in Emissions



SOURCE: FDOR 2010, ESA 2016

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Figure 33

Parcel Prioritization in Middle Tampa Bay

4.4 Uncertainty

Each aspect of this analysis is based on a series of assumptions and input data. This section discusses the uncertainty involved in the different pieces of the study.

4.4.1 Habitat Acreages

4.4.1.1 HEM Assumptions

The HEM was compared to existing vegetation to check the model assumptions for the habitat evolution decision tree. Current topography and existing tidal datums were input to the model with no sea-level rise to model the existing conditions (2007) and to validate the model.

When the mapped vegetation is input to the model, some habitats change, since actual vegetation does not always follow the rules of the model. Discussion of some of these habitat shifts is presented below.

- **Undeveloped Upland.** Some mapped upland areas are at elevations that would be suitable for salt barren, salt marsh, mangrove, and *Juncus* marsh habitat, so the model classifies these areas accordingly.
- **Salt Barrens and Salt Marsh.** As mentioned above, the model classifies upland as salt barren and high salt marsh habitat based on the lower elevations where upland occurs.
- **Mangroves and *Juncus* Marsh.** In the model in areas where freshwater is defined, mangrove habitat converts to *Juncus* marsh.
- **Mudflat.** This habitat type was not mapped in the vegetation mapping. Areas that are at the right elevation for mudflat were mapped as open water. The model assumes that anything that is mapped as open water remains open water, so mudflat does not appear in the model until sea-level rise converts higher elevation areas to mudflat.
- **Seagrass, Beaches, and Open Water.** Some areas of mapped seagrass correspond with very low elevations in the bathymetry (< MLLW – 5 ft). Similarly, some area of beach is below MLLW. The model converts these lower areas of seagrass and beach to open water.

The overall difference between mapped and modeled habitats is less than 1%, which means the model is capturing the existing habitats fairly well. The model likely overestimates salt barren (200% in the validation run) and *Juncus* marsh (75%), while underestimating mangroves (9%) and seagrass (2%). Salt barren habitat requires minor changes in topography that will allow salt water to pond and then evaporate, and this specificity is not captured in the model. Conversely, seagrass can grow at a larger range of elevations than what is assumed in the model in some cases. Additionally, mangroves are able to compete with *Juncus* marsh in areas of freshwater influence, but this interplay is not captured in the model.

4.4.1.2 HEM Inputs

Topo

Because LiDAR data often picks up the top of vegetation, the topography used in the model was adjusted in areas where mangroves were mapped, down to an elevation of 0.82 ft NAVD (0.25 m NAVD). Since this adjustment was made uniformly in areas where the elevation was showing up too high, a large portion of the mangroves started at the same elevation in the model. The drop off of mangrove habitat between 2050 and 2075 in the high sea-level rise, low accretion rate run is likely due to this uniform elevation that was set for mangroves. This artifact of the topographic assumptions would likely show up in the low sea-level rise runs at a year sometime after 2100 as well.

Assuming a uniform elevation for mangroves possibly overestimates the loss of mangrove habitat in the high sea-level rise and low accretion run. It is likely that some of the areas that appear higher in the topography are areas of mangrove habitat that naturally occur at higher elevations. These areas would maintain mangroves for longer than the model results show.

Sedimentation

Gonneea 2016 (Appendix D) found that accretion rates for salt marsh, mangrove, and salt barren habitat have been increasing since the 1950s. The study suggests that this is likely a result of sea-level rise during this time. For this analysis, the HEM used constant accretion rates, so these rates may be underestimating the amount of accretion that will occur with higher rates of sea-level rise. This assumption means that intertidal habitats may be more resilient than the model results predict.

4.4.2 GPRA reporting

Since the GPRA project data was limited, the analysis of Tampa Bay's GPRA projects relies on a series of assumptions. Table 15 summarizes the assumptions that were made and the likely effect on the GHG flux results.

4.4.3 GHG Framework

Since GHG accounting is still highly variable, it should be used as a tool to understand sequestration and emission trends, with less focus on precise values. Sequestration and emission rates can vary largely from site to site, and the results presented in Chapter 4 are based on theoretical habitat evolution scenarios, which have errors of their own (see Section 4.3.1).

4.4.3.1 GWP of Methane

Methane emissions accounting is one of the more uncertain aspects of this analysis, since the GWP of methane varies in the literature. The IPCC has updated GWP values over the years as research and understanding of climate science advances (Trottier 2015). As discussed in Section 3.1.2.2, the IPCC presented two GWP values in their AR5 report. Using the higher value of 34, methane emissions would increase roughly 1.2--1.4 times in this analysis.

TABLE 15
TAMPA BAY GPRA PROJECT GHG ANALYSIS ASSUMPTIONS

Assumption	Potential problem with this assumption	Possible impact to the GHG flux results
Each project in the list is a stand-alone project	If land acquisition is followed by restoration in a separate project, sequestration is double-counted.	Decrease in sequestration
Each project in the list is a stand-alone project	If vegetation removal is followed by replanting in a separate project, and the acreages do not agree, this could result in higher or lower sequestration.	Decrease or increase in sequestration
Acreage of project is representative of acreage of habitat change	If a project site or preserve covers a large area, but restoration that resulted in a habitat change was only conducted on a portion of this area, the sequestration or emission change would be overestimated.	Decrease or increase in sequestration Decrease or increase in emissions
10% of vegetation is removed for invasives control, prescribed burns, and mechanical thinning	None of the projects described the amount of vegetation that was removed, so this percentage could be smaller or larger.	Decrease or increase in biomass
Only one habitat type per project	Some projects created multiple habitat types, such as upland and marsh habitat, but only the acreage for the project as a whole was given. Since only one habitat type was chosen for the entire project, this could be an over- or underestimate of sequestration and emissions.	Decrease or increase in sequestration Decrease or increase in emissions
Habitat type	Many of the project descriptions included only a rough description of the starting and ending habitat type. Often the reported habitat category conflicted with the project description, making it difficult to choose a habitat type. Choosing the wrong habitat type could result in an over- or underestimate of sequestration and emissions.	Decrease or increase in sequestration Decrease or increase in emissions

4.4.3.2 Carbon Soil Sequestration

As noted in Section 4.3.1.2, Gonneea 2016 (Appendix D) found that accretion rates for salt marsh, mangrove, and salt barren habitat have been increasing since the 1950s, likely due to sea-level rise. If dry bulk density stays the same, then carbon soil sequestration rates would also increase over time. However, Gonneea found that dry bulk density has decreased with the increase in sedimentation. The GHG framework in this study assumes a constant rate of carbon soil sequestration, but this may be reconsidered as more data becomes available.

4.4.3.3 Seagrass Sequestration through the Bicarbonate Pathway

The results presented in Section 4.2 assume a value of 0.64 tonnes C/ha/yr. for the soil sequestration of seagrass. This value is based on the carbon burial rate, as discussed in Section 3.3.2. However, when the sequestration rate of 2.19 tonnes C/ha/yr. is used to include the bicarbonate pathway, the results of the model runs are reversed. For example, Run 3 and Run 5, with high sea-level rise and low accretion, result in the largest carbon sequestration. This reversal of results is due to the significant increase in seagrass soil sequestration. A value of 2.19 tonnes C/ha/yr. makes seagrass the most efficient soil sequestering habitat, so the runs that result in higher seagrass acreages, result in greater sequestration.

However, it is important to note that all of the runs in this study result in net GHG sequestration within 4%, so a reversal of runs does not necessarily indicate large differences in actual sequestration. For example, sequestration under Runs 1, 2, and 4 only increase by 4% when the bicarbonate pathway is included. Sequestration under Runs 3 and 5 increases by 6%.

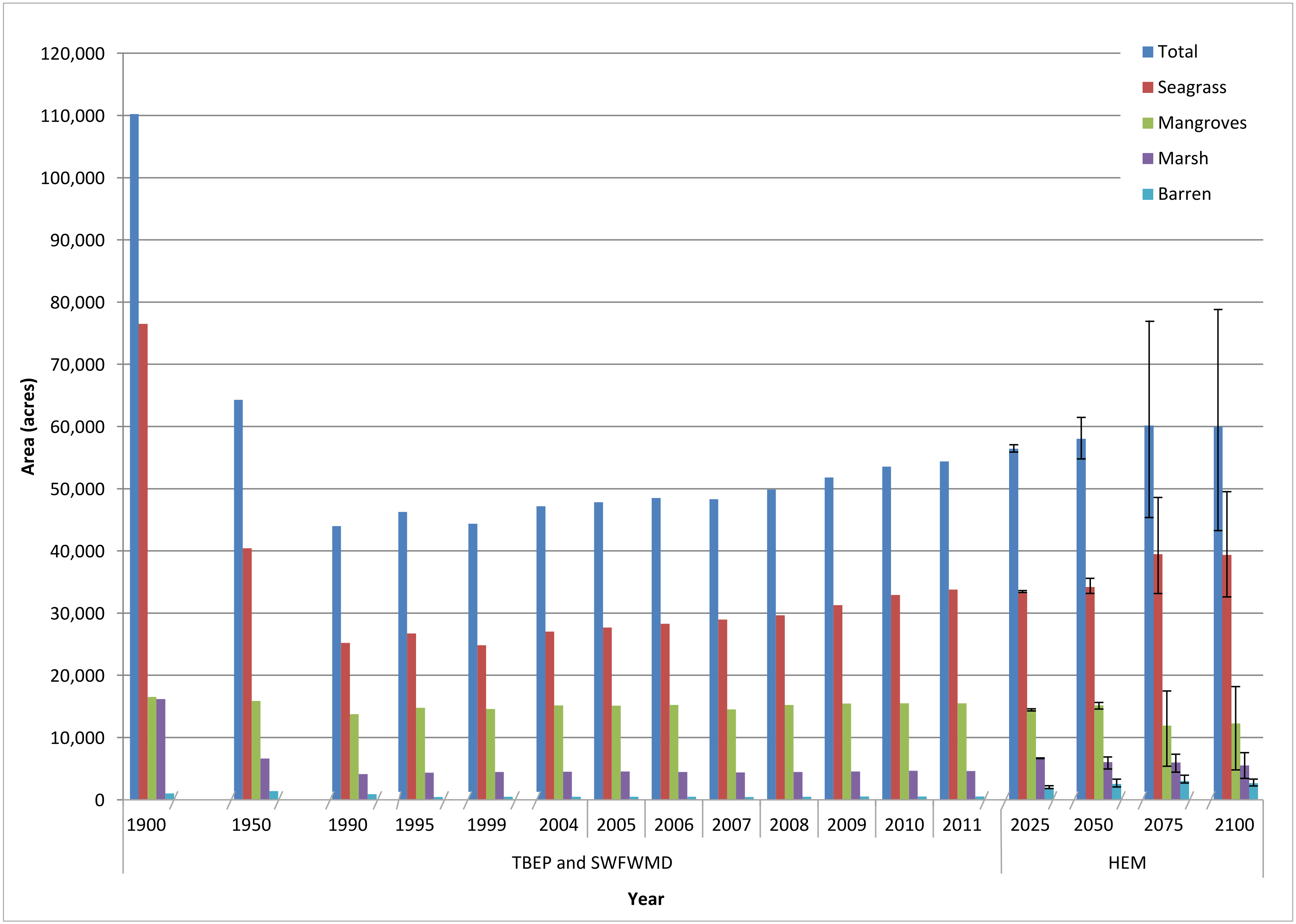
4.5 Conclusions

Figure 34 shows wetland habitats over time for Tampa Bay from 1900 to 2100. The HEM model forecasts that irrespective of assumptions about the rate of sea-level rise or sediment supply, the total extent of intertidal habitat changes little through time, decreasing slightly by 2100 for high rates of sea-level rise and low accretion. However, as the rate of sea-level rise accelerates in the latter half of the century, the capacity of the wetlands to accrete vertically becomes sensitive to the availability of mineral sediments to support soil building. While mangroves will transgress into salt and freshwater wetland areas, there is a projected decline of mangrove area under the low sediment availability and high sea-level rise scenarios (Run 3 and Run 5). Although intertidal habitat is projected to decline through the coming century, this loss is offset by an increase in area of subtidal seagrasses.

Based on the HEM results (Section 3.2.3), the Tampa Bay habitats are expected to remove between 73,415,000 and 74,317,000 tonnes of CO_2 from the atmosphere by 2100, the equivalent of removing approximately 15.5 million vehicles from the roads (EPA, 2016). Future projects should focus on increasing carbon sequestration, as opposed to lowering or eliminating methane emissions, since the habitats that produce methane emissions (e.g., *Juncus* and freshwater marsh) are important to the Tampa Bay ecosystem.

The HEM runs give some insight to potential management strategies. Increased potential for accretion resulted in more wetland habitats and more sequestration, especially with higher rates of sea-level rise. Management strategies that focus on allowing more sediment from the watershed to reach the wetlands or beneficially utilizing available sediment or spoil material could help sustain the habitats and continue carbon sequestration for longer. Additionally, Run 5 results showed that allowing wetlands to migrate into "soft" development would create more habitat and increase carbon sequestration. Coastal managers can use the HEM results to identify areas that should be prioritized for restoration. Even greater benefits could be gained by identifying harder development that may not be sustainable in the long-term for restoration as well. Finally, lower sea-level rise allows habitats to persist and sequester carbon. Strategies to reduce emissions elsewhere and to limit climate change will have a positive effect on habitat extents in the future.

Restoration projects have removed 217,000 tonnes CO_2 equivalents since 2006. While this number is small compared to the total amount of carbon sequestration occurring within existing habitats in Tampa Bay, protecting and restoring habitats, especially those bordering potential habitat migration pathways, will be key to maintaining strong sequestration into the future. There are opportunities identified throughout the Bay for wetland habitats to migrate inland into undeveloped lands. Coastal managers can use these results to identify areas of "soft" development to target for acquisitions and restoration. Section 5 discusses management implications further.



SOURCE: TBEP, SWFWMD and ESA, 2016

ESA

Tampa Bay Blue Carbon Assessment. D140671

Figure 34
Tampa Bay Wetland Habitats Over Time with HEM Results

Note: HEM results display average of all scenarios.
Error bars indicate min and max scenarios.

5. Discussion of Management Implications

5.1 Connecting Coastal Habitat Restoration Opportunities with GHG Management

Based on the HEM model and GHG framework outputs, while there is a change in area of each wetland ecosystems ranging across sea-level rise and sediment availability scenarios, there is not a significant difference in the magnitude of the long-term net GHG removals between scenarios. These results and observations would be different without the previous restoration efforts conducted in Tampa Bay over the past two decades, and are dependent upon maintaining this successful management outcome into the foreseeable future.

If higher sea-level rise projections are realized, creating more space for landward habitat migration, as represented in the soft retreat scenario, will be necessary if a balance of ecosystem types is to be maintained. However, even with a warmer climate in the future, mangroves will likely occupy the niche that marshes currently occupy today.

Further improvements in water quality may help drive further expansion of seagrasses into deeper waters, and also slow the rate of the migration of this boundary with sea-level rise. Additionally, ensuring that seagrasses will expand into newly inundated areas throughout the Bay where other important blue carbon habitats may be lost is crucial in maintaining the Bay's overall carbon sequestration potential. If this is not the case, then it is likely that carbon sequestration would decrease.

Managers might also explore and experiment with the opportunities for including living shoreline reefs to protect intertidal habitats from erosion, supplemented with beneficial reuse of sediment within mangrove areas. Most intertidal ecosystems likely would not keep pace with higher rates of sea-level rise under low sediment availability conditions without sediment supply augmentation, even if living shorelines could be successfully deployed to protect their edges.

Mechanisms and procedures have also been developed to connect coastal wetland management to the carbon market, where appropriate[16]. At the locally relevant landscape level, a growing number of case studies are amassing to inform management agencies and policy developers on coastal wetland management and carbon finance markets[17]. Simpson (2016) provides an

16 http://www.v-c-s.org/methodologies/methodology-tidal-wetland-and-seagrass-restoration-v10

17 These include an assessment of carbon sequestration with ongoing and potential future tidal marsh restoration in the Snohomish Estuary, Washington (Crooks et al. 2014); Implications of regional planning for tidal wetlands restoration in San Francisco Bay (Callaway, Crooks, Schile 2015); forecasting of the effects of coastal protection and restoration of the Mississippi Delta under the Louisiana Coastal Master Plan (Couvillion et al. 2013)); Analysis

alternative project design method called "grouping", which allows project developers to aggregate smaller projects in order to achieve economies of scale (Appendix L). The report describes how to use a grouped project approach and makes recommendations for Tampa Bay stakeholders considering using carbon offset projects to support restoration efforts.

5.2 Identifying Areas of Nearshore Upland Habitat as Sea-Level Rise Buffer Areas

As proposed by Sherwood and Greening (2013), the first management response to the threat of sea-level rise should be the identification, prioritization, and conservation of low-lying, undeveloped coastal uplands as buffer zones to allow for the landward migration of coastal wetlands over time. They recommend the establishment of "refugia" to allow for sensitive coastal wetland habitats to persist under anticipated climate change and sea-level rise impacts. The term "refugia" is typically used in biology to describe areas that are protected for an isolated or relict population of a once-more-widespread species. It is suggested here that a more appropriate term for this strategy is the establishment of "migratory pathways" for dynamic coastal wetlands, with "migration" in this case occurring over multi-decadal time scales.

It should be noted that conserving existing, undeveloped coastal uplands alone will likely not be adequate to ensure the integrity of coastal wetlands in the future. In addition to just conserving parcels, it may be necessary to physically prepare many parcels to properly "accommodate" tidal inundation in a manner that allows for the succession of natural zonation patterns and the establishment of a mosaic of coastal wetland habitats. Such preparation may include grading and contouring, as well as, the creation of drainage pathways and erosion control features, perhaps decades in advance of tidal inundation.

In addition to undeveloped coastal uplands, consideration should be given to identifying low-lying developed areas that will no longer be economically viable to maintain due to persistent tidal flooding and inadequate drainage. Developed lands that are abandoned due to rising sea levels will require considerable preparation above that needed for "softer" areas, as structures, impervious surfaces, and other infrastructure will need to be removed in advance of tidal inundation.

5.3 Role of Water Quality in Enhancing Seagrass Resilience to Climate Change

Globally, coastal ecosystems are being lost at an alarming rate, and the associated CO_2 emissions and lost carbon sequestration capacities have been the focus of many studies. In Tampa Bay, seagrass beds declined by over 50 percent between 1950 and 1982, and emergent tidal wetlands declined by almost 21 percent between 1950 and 1990. However, Tampa Bay may be an example where carbon sequestration is now on the increase due to restoration efforts initiated during the past three decades.

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of impacts of coastal management in Southern California in response to sea-level rise under the Ventura Coast Resilience Project – Sea Level Rise and GHG Assessment (Vandebroek and Crooks, 2014); and the assessment of carbon project development of Cape Cod at the Herring River Estuary Restoration Project (in progress).

Despite a fourfold increase in the population of the Tampa Bay region, water quality in Tampa Bay has been restored to conditions similar to those observed in the 1950s (TBEP 2012). In response, seagrass coverage is now higher than it has been in decades. As of 2014, seagrass coverage in Tampa Bay was estimated at 40,295 acres, 86% higher than the 21,647 acres mapped in 1982. In addition to seagrass recovery, there has been an increase of 433 acres of emergent tidal wetlands between 1995 and 2007, an increase of about 2.2 percent (TBEP 2012).

However welcome this news may be, these hard-fought gains in ecosystem health are at risk under various sea-level rise scenarios. If sea-level rise stresses these ecosystems, then not only could they be lost, partially or in full, but their loss could be part of a positive feedback loop leading to further losses, as seagrass meadows help to stabilize shorelines, filter particulates out of the water column and thus improve water clarity; the loss of seagrass meadows due to impacts of sea-level rise would likely precipitate further losses.

5.4 Connecting Carbon Sequestration to Ocean Acidification Mitigation

A long-term water quality data set from Tampa Bay shows that pH values (collected in the daytime) were elevated in the 1970s, and then decreased to much lower values in the early 1980s. The decrease in pH values is thought to be related to decreased nutrient loads to the Bay, with a subsequent decrease in phytoplankton biomass (Ed Sherwood, personal communication). Since the early 1980s, a long-term increase in pH values in the Bay (Ed Sherwood, personal communication) is likely related to bay-wide increases in seagrass coverage (Greening et al. 2014). Seagrasses are projected to benefit from elevated atmospheric CO_2 (Kleypas and Yates, 2009) and have been found to be able to increase seawater pH values (Unsworth et al. 2012) as well as carbonate mineral saturation states (Manzello et al. 2012). As such, recovering seagrass meadows could well provide protection to organisms living in close association with seagrass beds (Manzello et al. 2012, Unsworth et al. 2012). While there are no coral reefs in Tampa Bay, there are hard corals such as *Siderastrea radians*, as well as numerous organisms (e.g., clams, oysters, mussels, etc.) that could be adversely impacted by altered carbonate precipitation processes that are likely to occur with increased ocean acidification (Tomasko et al. 2016).

As an outgrowth of this project, recent work by Yates et al. (2015) determined that seagrass meadows in parts of Tampa Bay were capable of increasing daytime pH values by 0.5 units, consistent with expectations as inorganic carbon is taken up by photosynthesis. In addition, seagrass meadows were found to increase, at least locally, carbonate saturation rates in the water column, consistent with the findings of Manzello et al. (2012) and suggesting that the mechanisms involved in the bicarbonate pathway outlined by Burdige and Zimmerman (2002) could be occurring in Tampa Bay seagrass meadows.

5.5 Recommendations for Future Analysis

The following recommendations are made for future analysis:

1. Improve understanding of sediment supply to tidal wetlands. In this study the potential ranges in sediment availability were bracketed to forecast implications for mangrove resilience to sea-level rise. Improved understanding of sediment delivery will reduce uncertainty.
2. The maximum capacity of mangroves to build soils through organic sedimentation is not clearly defined within the scientific literature. Understanding of this parameter will reduce uncertainty in mangrove resilience to sea-level rise.
3. As water depths increase in mangroves, increased wave action will drive a landward retreat of the mangrove edge. Monitoring of this process will assist in improving predictions.
4. The application of living shoreline structures to protect mangrove edges, and beneficial use of dredged sediments to aid mangrove soil accumulation should be considered for experimental testing.
5. A potential pathway for carbon sequestration mediated by seagrasses in carbonate sediments has been postulated within this study. Further investigations into inorganic carbon pathways and carbon sequestration within the bicarbonate pool should be undertaken to test this hypothesis.
6. The conversion of habitats from one form to another is response to sea-level rise may be subject to very localized conditions. Further research to track the natural progression and conversion of tidal wetlands in Tampa Bay would help refine HEM assumptions.
7. The outcomes of this study are sensitive to assumptions upon the amount of carbon that is released as mangroves drown and soils are remobilized. Additional studies on both the fate of dead wood and mobilized soil carbon stocks would reduce uncertainty in these assumptions.
8. Refinements in sea-level rise estimates may impact the findings of this study and should be considered.

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APPENDIX A

HEM Habitat Cross-Walk

Appendix A. HEM Habitat Cross-Walk

SWFWMD Code	SWFWMD Name	HEM Name	HEM Code	GHG category
1100	RESIDENTIAL LOW DENSITY < 2 DWELLING UNITS	Upland Developed - Hard	1100	Developed - Low Intensity
1200	RESIDENTIAL MED DENSITY 2->5 DWELLING UNIT	Upland Developed - Hard	1200	Developed - Mid/High Intensity
1300	RESIDENTIAL HIGH DENSITY	Upland Developed - Hard	1200	Developed - Mid/High Intensity
1400	COMMERCIAL AND SERVICES	Upland Developed - Hard	1200	Developed - Mid/High Intensity
1500	INDUSTRIAL	Upland Developed - Hard	1200	Developed - Mid/High Intensity
1600	EXTRACTIVE	Upland Developed - Hard	1200	Developed - Mid/High Intensity
1700	INSTITUTIONAL	Upland Developed - Hard	1200	Developed - Mid/High Intensity
8100	TRANSPORTATION	Upland Developed - Hard	1200	Developed - Mid/High Intensity
8200	COMMUNICATIONS	Upland Developed - Hard	1200	Developed - Mid/High Intensity
8300	UTILITIES	Upland Developed - Hard	1200	Developed - Mid/High Intensity
1800	RECREATIONAL	Upland Developed - Soft	1800	Developed - Low Intensity
1820	GOLF COURSES	Upland Developed - Soft	1820	Rangeland - Grassland/Herbaceous/Open Land
2100	CROPLAND AND PASTURELAND	Upland Developed - Soft	2100	Agriculture - Cropland and Pastureland
2140	ROW CROPS	Upland Developed - Soft	2100	Agriculture - Cropland and Pastureland
2200	TREE CROPS	Upland Developed - Soft	2200	Agriculture - Tree Crops
2300	FEEDING OPERATIONS	Upland Developed - Soft	2100	Agriculture - Cropland and Pastureland
2400	NURSERIES AND VINEYARDS	Upland Developed - Soft	2400	Agriculture - Vineyards
2500	SPECIALTY FARMS	Upland Developed - Soft	2100	Agriculture - Cropland and Pastureland
2550	TROPICAL FISH FARMS	Upland Developed - Soft	2550	Aquiculture
6520	SHORELINES	Upland Developed - Soft	1820	Rangeland - Grassland/Herbaceous/Open Land
1650	RECLAIMED LAND	Upland Undeveloped	1900	Rangeland - Grassland/Herbaceous/Open Land
1900	OPEN LAND	Upland Undeveloped	1900	Rangeland - Grassland/Herbaceous/Open Land
2600	OTHER OPEN LANDS <RURAL>	Upland Undeveloped	1900	Rangeland - Grassland/Herbaceous/Open Land
3100	HERBACEOUS	Upland Undeveloped	1900	Rangeland - Grassland/Herbaceous/Open Land
3200	SHRUB AND BRUSHLAND	Upland Undeveloped	3200	Rangeland - Shrub and Brushland
3300	MIXED RANGELAND	Upland Undeveloped	3200	Rangeland - Shrub and Brushland
4100	UPLAND CONIFEROUS FOREST	Upland Undeveloped	4100	Upland Forest - Upland Forest
4110	PINE FLATWOODS	Upland Undeveloped	4100	Upland Forest - Upland Forest
4120	LONGLEAF PINE - XERIC OAK	Upland Undeveloped	4100	Upland Forest - Upland Forest
4200	UPLAND HARDWOOD FORESTS - PART 1	Upland Undeveloped	4100	Upland Forest - Upland Forest
4340	HARDWOOD CONIFER MIXED	Upland Undeveloped	4100	Upland Forest - Upland Forest
4400	TREE PLANTATIONS	Upland Undeveloped	4400	Upland Forest - Tree Plantations
7400	DISTURBED LAND	Upland Undeveloped	1900	Rangeland - Grassland/Herbaceous/Open Land
6100	WETLAND HARDWOOD FORESTS	Freshwater Marsh	6110	Wetlands - Freshwater Swamp
6110	BAY SWAMPS	Freshwater Marsh	6110	Wetlands - Freshwater Swamp
6200	WETLAND CONIFEROUS FORESTS	Freshwater Marsh	6110	Wetlands - Freshwater Swamp
6210	CYPRESS	Freshwater Marsh	6110	Wetlands - Freshwater Swamp
6300	WETLAND FORESTED MIXED	Freshwater Marsh	6110	Wetlands - Freshwater Swamp
6410	FRESHWATER MARSHES	Freshwater Marsh	6410	Wetlands - Freshwater Marsh
6430	WET PRAIRIES	Freshwater Marsh	6410	Wetlands - Freshwater Marsh
6440	EMERGENT AQUATIC VEGETATION	Freshwater Marsh	6410	Wetlands - Freshwater Marsh
6600	SALT FLATS	Salt Barrens	6600	Salt Barren
6420	SALTWATER MARSHES	High Marsh	6420	Salt Marsh
6425	JUNCUS MARSH	Juncus Marsh	6425	Juncus Marsh
6120	MANGROVE SWAMPS	Mangroves	6120	Mangroves
7100	BEACHES OTHER THAN SWIMMING BEACHES	Beach	7100	Beach - Dune
7200	SAND OTHER THAN BEACHES	Beach	7100	Beach - Dune
5100	STREAMS AND WATERWAYS	Open Water	5200	Wetlands- Open Freshwater
5200	LAKES	Open Water	5200	Wetlands- Open Freshwater
5300	RESERVOIRS	Open Water	5200	Wetlands- Open Freshwater
5400	BAYS AND ESTUARIES	Open Water	5400	Subtidal - Subtidal
5720	GULF OF MEXICO	Open Water	5400	Subtidal - Subtidal
6150	STREAM AND LAKE SWAMPS (BOTTOMLAND)	Open Water	5400	Subtidal - Subtidal
6530	INTERMITTENT PONDS	Open Water	5200	Wetlands- Open Freshwater
9113	Seagrass	Seagrass	9113	Subtidal - Seagrass
9116	Seagrass	Seagrass	9113	Subtidal - Seagrass

APPENDIX B

GHG Framework Equations

Appendix B. GHG Flux Equations

1. Aboveground Biomass

Biomass densities (Table 11) can be used to calculate aboveground carbon stock, using a habitat-specific carbon percentage of dry matter for all land covers. The carbon stock is then converted to CO_2 by multiplying by the ratio of molecular weights:

$$ST_A = CF * AB_A * A * \frac{MW_{CO_2}}{MW_C}$$

Where:

ST_A = Aboveground carbon stock (tonnes CO_2)

CF = Carbon fraction of dry matter

AB_A = Aboveground biomass, per area (tonnes dry matter/ha)

A = Habitat area (ha)

MW_{CO2} = Molecular weight of carbon dioxide (44)

MW_C = Molecular weight of carbon (12)

2. Soil Stock and Belowground Biomass

The change in soil carbon stock can be calculated by multiplying the restored habitat area by the soil sequestration rate (Table 11) and then subtracting the initial habitat area multiplied by the corresponding sequestration rate. This is then multiplied by the number of years since the habitat change occurred. The soil carbon stock is converted from tonnes C to CO_2 equivalents by multiplying by the ratio of molecular weights:

$$\Delta ST_B = (A_{restored} * SS_{restored} - A_{initial} * SS_{initial}) * T * \frac{MW_{CO_2}}{MW_C}$$

Where:

ΔST_B = Change in belowground carbon stock, per area (tonnes CO_2/yr)

$A_{restored}$ = Restored habitat area (ha)

$SS_{restored}$ = Soil sequestration rate for restored habitat type (tonnes C/ha/yr)

$A_{initial}$ = Initial habitat area (ha)

$SS_{initial}$ = Soil sequestration rate for initial habitat type (tonnes C/ha/yr)

T = Time since habitat was restored (yr)

For calculating the soil stock over time with sea level rise, the initial soil stock is added to any change in soil stock between time steps for each habitat type. The change in soil stock between two time steps is calculated as the average of the habitat acreage at the two time steps, multiplied by the soil sequestration rate for the habitat, then multiplied by the time between the time steps and the ratio of molecular weights to convert from C to CO_2 equivalents:

$$ST_{B,t} = ST_{B,t-1} + \frac{A_{t-1} + A_t}{2} * SS * (t - (t-1)) * \frac{MW_{CO_2}}{MW_C}$$

Where:

$ST_{B,t}$ = Belowground carbon stock at time t, per area (tonnes CO_2/yr)

$ST_{B,t-1}$ = Belowground carbon stock at the time step before t, per area (tonnes CO_2/yr)

A_t = Habitat area at time t (ha)

A_{t-1} = Habitat area at time step before t (ha)

SS = Soil sequestration rate for habitat type (tonnes C/ha/yr)

t = time (year)

t-1 = time step before time t (year)

3. Dead Organic Matter

DOM density can be used to calculate the DOM carbon stock for mangrove habitat by multiplying by the area of the habitat, using a conversion from dry matter to carbon, and converting from C to CO_2 equivalents:

$$ST_{DOM} = CF * D * A * \frac{MW_{CO_2}}{MW_C}$$

Where:

ST_{DOM} = Dead organic matter carbon stock (tonnes CO_2)

D = DOM density (tonnes dry matter/ha)

However, in this analysis, DOM was combined with biomass in the aboveground biomass density rates for mangroves (Table 11).

4. Total Carbon Sequestration

The aboveground biomass, soil carbon stock, and DOM carbon stock can then combined to calculate the cumulative CO_2 equivalents sequestered:

$$\Delta ST_{ALL} = \Delta ST_A + \Delta ST_B + \Delta ST_{DOM}$$

Where:

ΔST_{ALL} = Change in total carbon stock (tonnes CO_2)

5. Methane

To calculate CH_4 emissions, each land cover type is assigned a methane emission rate. The IPCC recommends using an emission factor of 0 for salinities greater than 18 ppt and a factor of 193.7 kg CH_4/ha/yr for lower salinities (Table 11, IPCC 2014).

Methane has a 100-year Global Warming Potential (GWP) of 28-34 relative to CO_2, which means the effect of each tonne of CH_4 on the atmosphere in 100 years is 28-34 times greater than that of a tonne of CO_2 (IPCC 2014). The most recent Fifth Assessment Report (AR5) published by the Intergovernmental Panel on Climate Change presents, for the first time, two sets of values for GWP representing scenarios with and without climate-carbon feedbacks. AR5 provides a value of 28 calculated without climate-carbon feedbacks, and 34 with climate carbon feedbacks. Climate-carbon feedbacks measure the indirect effects of changes in carbon storage due to changes in climate (Myhre et al 2013). GWP values that take into account climate-carbon feedbacks have a higher level of uncertainty because the more feedbacks considered, the more complex and interconnected they become (Myhre et al 2013). For this reason, a GWP of 28 (without climate carbon feedbacks), rather than 34, as presented in AR5 has been used to calculate CO_2 equivalents of methane emitted for this analysis.

The change in methane emissions can be calculated by multiplying the emission rate by the habitat area for the restored habitat and subtracting by the emission rate times the habitat area for the initial habitat, multiplied by the years since the restoration. To convert to tonnes CO_2, this is multiplied by the GWP.

$$\Delta E_{CH4} = \frac{tonnes\ CH4}{kg\ CH4} * (A_{restored} * ER_{restored} - A_{initial} * ER_{initial}) * T * \ GWP$$

Where:

ΔE_{CH4} = Change in methane emissions (tonnes CO_2)

$\frac{tonnes\ CH4}{kg\ CH4}$ = Unit conversion (0.001)

$ER_{restored}$ = Methane emission rate for the restored habitat (kg CH_4/ha/yr)

$ER_{initial}$ = Methane emission rate for the initial habitat (kg CH_4/ha/yr)

GWP = Global Warming Potential (28)

To calculate methane emissions over time with sea level rise, a different equation is used. The methane emissions between two time steps is calculated as the average of the habitat acreage at the two time steps, multiplied by the methane emission rate for the habitat, and then multiplied by the time between the time steps, the unit conversion to tonnes methane, and the global warming potential:

$$E_{CH4,t} = \frac{A_{t-1} + A_t}{2} * ER * \big(t - (t-1)\big) * \frac{tonnes\ CH4}{kg\ CH4} * GWP$$

Where:

$E_{CH4,\,t}$ = Methane emissions at time t, per area (tonnes CO_2/yr)

ER = Methane emission rate for habitat type (tonnes C/ha/yr)

6. Total Flux

Total flux is calculated by combining the

$$\Delta GHG = \Delta ST_{ALL} - \Delta E_{CH4}$$

Where:
ΔGHG = Change in GHG sequestrations (positive) and emissions (negative), (tonnes CO_2)

APPENDIX C

Moyer et al. 2016

Quantifying carbon stocks for natural and restored mangroves, salt marshes and salt barrens in Tampa Bay

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Contents

Introduction

Coastal wetlands, which include both salt marshes and mangrove forests in Florida, are important transitional ecosystems that incorporate characteristics of both marine and terrestrial ecosystems. Along with providing critical habitat for many economically important and protected species, they also provide critical ecosystem services including carbon sequestration and wave protection, giving them high economic value. These highly productive ecosystems account for a disproportionately large amount of total organic carbon burial in marine environments relative to their surface area and therefore play an important role in the global carbon cycle (Breithaupt et al. 2012). For this reason, they have been termed 'blue carbon' ecosystems (Howard et al. 2014) as plants remove atmospheric CO_2 and sequester it in living biomass or soil organic carbon (OC).

Among the myriad of global threats to coastal environments, accelerated sea-level rise is perhaps the greatest threat to coastal wetlands. One of the fundamental climate change questions is whether coastal wetland soils will continue to function as a globally significant sink of organic carbon. While changes to precipitation, temperature, hurricane activity, and other factors may influence the natural carbon sequestration provided by these ecosystems, the capability to keep pace with sea-level rise (SLR) is perhaps of greatest immediate concern (Ellison and Stoddart 1991). In addition to the threat of SLR simply outpacing current accretion rates, there is the potential for SLR to accelerate soil OC mineralization. The increase in porewater salinity supplies sulfate, which functions as a terminal electron acceptor that soil microbes can utilize to enhance mineralization in the brackish ecotone regions of coastal wetlands. Coastal wetlands that receive minimal terrigenous sediments are largely dependent on the rate of OC accumulation as a key contributor to accretion (Cahoon and Lynch 1997).

Preliminary results from studies of organic carbon burial in wetland soils along the west coast of Florida indicate that accretion rates have not kept pace with the accelerated rate of SLR observed over the last decade. These locations also have substantially lower OC burial rates than systems that are keeping pace with SLR and are located in the ecotone region most susceptible to enhanced OC mineralization. Thus, single values of OC stock and burial with a given system (e.g. the Tampa Bay Estuary) may not be representative of the variability of carbon dynamics known to occur in coastal wetland soils. It is therefore necessary to measure soil carbon as well as standing biomass in a variety of coastal wetland habitats (mangroves, marshes, salt barrens) to refine estimates of carbon stock and sequestration in these dynamic transitional ecosystems.

This report documents one of two current studies supporting the Tampa Bay Blue Carbon Assessment project. The present study focuses on bulk vegetative and soil carbon stocks in Tampa Bay coastal wetlands habitats, while the other complementary study examines rates of carbon sequestration and sediment accumulation. Information on the carbon sequestration in the coastal wetlands of Tampa Bay will be used in management and conservation decision-making in the Bay area, enabling assessment of climate mitigation benefits of coastal wetland protection and restoration. Restore America's Estuaries and Environmental Science Associates were contracted by the Tampa Bay Estuary Program for completion of this study. Field work, laboratory analyses, and data analysis were completed by the Florida Fish and Wildlife Conservation Commission Coastal Wetlands Group.

Methods

Site Selection

A total of 17 sites were sampled in coastal wetlands across the Tampa Bay area from July to November 2015 (Figure 1, Table 1). Sampling locations were generally on protected land within county or state parks and preserves. Sites included 6 mangrove swamps (3 natural and 3 restored), 6 salt marshes (3 natural and 3 restored) and 5 natural salt barrens. It is rare to find large tracts of wetlands in the Tampa Bay region that are entirely unaffected by ditching, road construction, dredging, spoil piles, or coastal construction. Thus the more “natural” wetlands that were unrestored were often still impacted by ditching or proximity to urban development. “Restored” sites had undergone varying degrees of restoration, ranging from hydrologic improvements to the creation of a new wetland habitat from a location that was previously upland habitat (see Table 1). Detailed site information and coordinates of all plots are available in Appendix A, including before and after aerial images of the wetland restoration sites. Examples of the habitat types are shown in Figures 2-4.

Sites were selected from all regions of Tampa Bay that had remaining coastal wetlands, and habitat replicates were spread out across the estuary. Spacing of site selection was limited by the lack of extensive salt marshes in Pinellas County and an absence of coastal wetlands on the Tampa peninsula due to extensive urban development. Of the 17 transect sites, 6 were selected to collect cores for radiometric dating in order to determine sediment accretion and organic carbon burial rates in a complementary study.

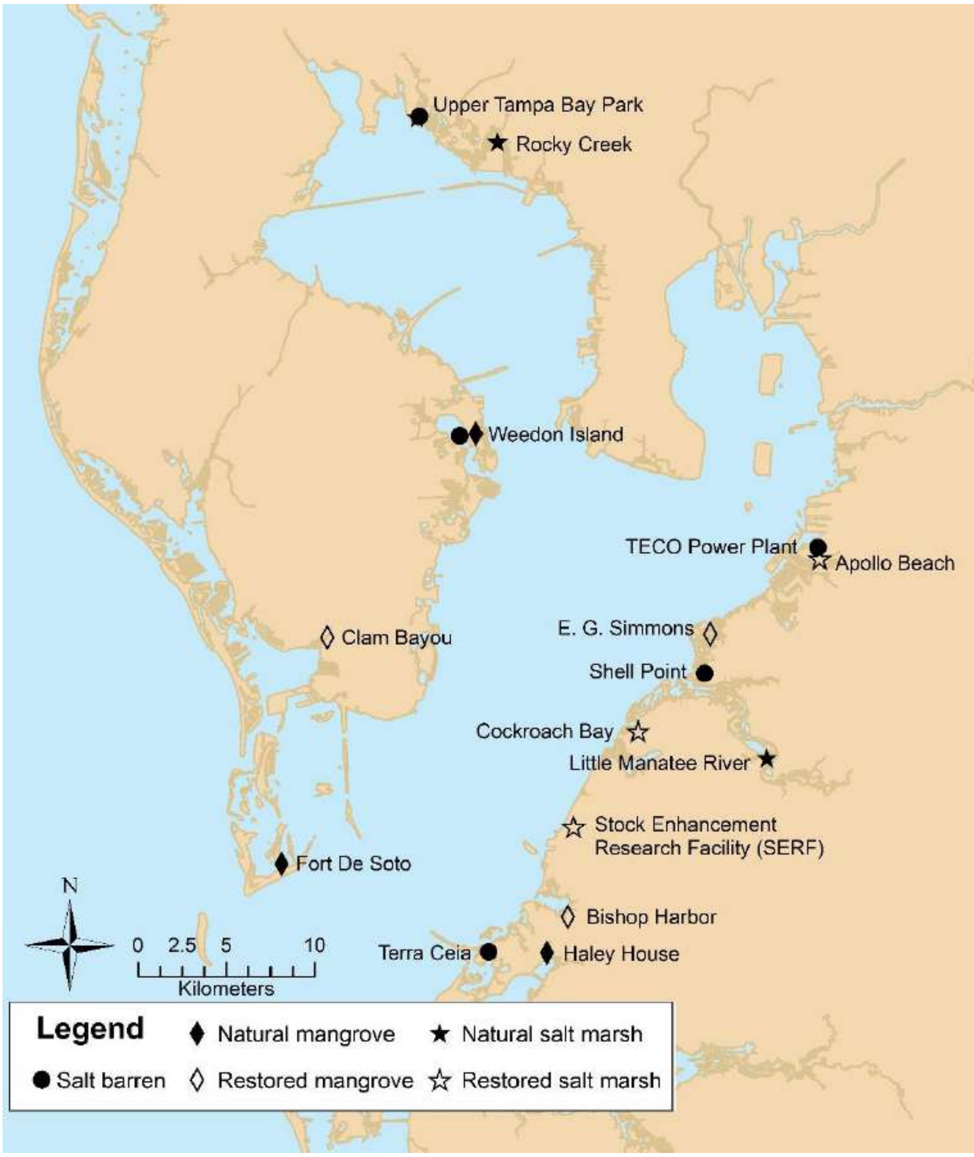


Figure 1. Sampling sites across Tampa Bay included 6 mangrove swamps (3 natural and 3 restored), 6 salt marshes (3 natural and 3 restored) and 5 natural salt barrens.

Table 1. Sampling sites in Tampa Bay, as shown in Figure 1.

Site Name	Habitat Type	Habitat State	Restoration Type	Year Completed	County	Bay Segment	Starting latitude	Starting longitude	Date Sampled
Haley House	Mangrove	Natural			Manatee	Lower Tampa Bay	27° 34.853' N	82° 33.820' W	8/7/2015
Weedon Island	Mangrove	Natural			Pinellas	Old Tampa Bay	27° 50.780' N	82° 36.092' W	7/10/2015
Fort De Soto	Mangrove	Natural			Pinellas	Lower Tampa Bay	27° 37.625' N	82° 42.909' W	10/2/2015
Bishop Harbor	Mangrove	Restored	Hydrologic restoration	2008	Manatee	Lower Tampa Bay	27° 35.955' N	82° 33.108' W	10/23/2015
E.G. Simmons Park	Mangrove	Restored	New wetland	1990	Hillsborough	Middle Tampa Bay	27° 44.533' N	82° 28.063' W	8/28/2015
Clam Bayou	Mangrove	Restored	Hydrologic restoration	2012	Pinellas	Boca Ciega Bay	27° 44.583' N	82°41.233' W	10/9/2015
Upper Tampa Bay Park	Salt Marsh	Natural			Hillsborough	Old Tampa Bay	28° 00.417' N	82° 37.995' W	7/24/2015
Little Manatee River	Salt Marsh	Natural			Hillsborough	Middle Tampa Bay	27° 40.738' N	82° 26.183' W	9/18/2015
Rocky Creek	Salt Marsh	Natural			Hillsborough	Old Tampa Bay	27° 59.658' N	82° 35.156' W	9/11/2015
Stock Enhancement Research Facility (SERF)	Salt Marsh	Restored	New wetland	1997	Manatee	Middle Tampa Bay	27° 38.720' N	82° 32.862' W	8/20/2015
Cockroach Bay	Salt Marsh	Restored	New wetland	1998	Hillsborough	Middle Tampa Bay	27° 41.581' N	82° 30.586' W	8/6/2015
Apollo Beach	Salt Marsh	Restored	New wetland	2013	Hillsborough	Hillsborough Bay	27° 46.804' N	82° 24.277' W	8/14/2015
Terra Ceia	Salt Barren	Natural			Manatee	Lower Tampa Bay	27° 34.893' N	82° 35.788' W	8/11/2015
TECO Power Plant	Salt Barren	Natural			Hillsborough	Hillsborough Bay	27° 47.145' N	82° 24.287' W	8/17/2015
Upper Tampa Bay Park	Salt Barren	Natural			Hillsborough	Old Tampa Bay	28° 00.475' N	82° 37.904' W	9/2/2015
Shell Point	Salt Barren	Natural			Hillsborough	Middle Tampa Bay	27° 43.311' N	82° 28.268' W	10/30/2015
Weedon Island	Salt Barren	Natural			Pinellas	Old Tampa Bay	27° 50.680' N	82° 36.627' W	11/6/2015

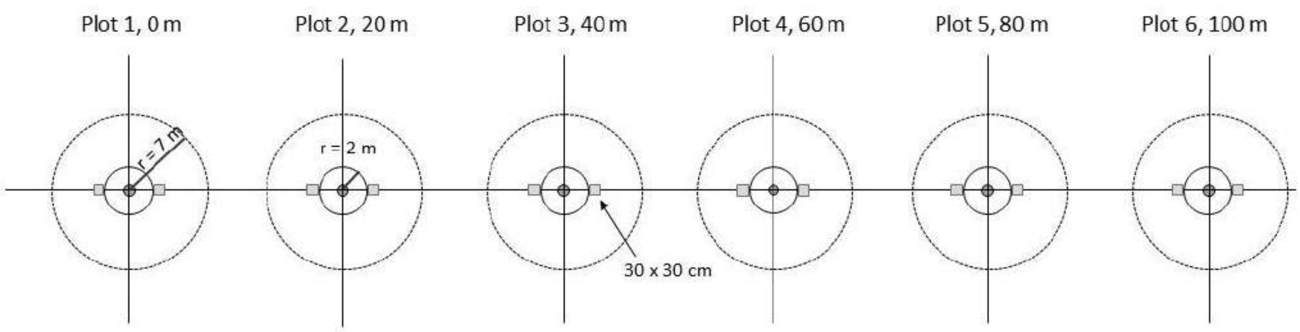
Figure 2. Example of mangrove habitats in E. G. Simmons Park (above) and a spoil pile along the transect in Weedon Island Preserve (below). Many of the wetlands in Tampa Bay have mosquito ditches and spoil piles.

Figure 3. Example of a restored salt marsh dominated by *Spartina alterniflora* in Apollo Beach (above) and a natural *Juncus roemerianus* marsh on the Little Manatee River (below).

Figure 4. Example of a salt barren habitat being overtaken by vegetation in Weedon Island Preserve (above) and a salt barren at high tide in Terra Ceia (below).

Field data collection

A 100 m long transect was sampled at each of the 17 sampling locations. The transect was initiated in a location and direction to maximize contact with the habitat in question, however the direction of the transect was altered if the habitat shifted to a different ecosystem, most commonly to upland or open water. A 7 m radius plot was sampled every 20 m for a total of 6 plots (Figure 5), following the general methods of The Coastal Blue Carbon Manual (Howard et al. 2014). The diameter at breast height (130 cm above the ground, d_{130}) was measured for all live mangrove trees greater than 1.3 m in height within the 7 m radius plot. The total height, diameter at 30 cm, and canopy dimensions (length, width and depth) were measured for all scrub mangroves (height 0.3-1.3 m) within a 2 m radius plot at the center of the 7 m radius plot. Additionally, the total number of mangrove seedlings (height <30 cm) present and the height of the first 25 plants encountered in the 2 m radius plot were recorded. When salt marsh vegetation was present, the species, numbers of stems, and total height of the first 25 plants encountered of each species were counted within two 30 x 30 cm plots placed 2 m from the center of the plot along the primary transect (immediately outside the 2 m radius plot). Approximately 50 stems from each plant species were harvested across the Tampa Bay region for lab analysis to create allometric equations. Field sampling photos are shown in Figures 6-8.



Aboveground biomass sampled in 7 m radius plot:
- All live trees taller than 1.3 m
- Standing dead trees

Aboveground biomass sampled in 2 m radius plot:
- All seedlings (mangroves < 30 cm height)
- All scrubs (mangroves 30-130 cm height)

Aboveground biomass measured in 30 x 30 cm plot:
- Salt marsh vegetation

Fallen dead wood sampled along perpendicular transects:
- Large limbs (>7.5 cm diameter) from 2-12 m
- Medium branches (2.5-7.5 cm diameter) from 2-7 m
- Small branches (0.6-2.5 cm diameter) from 7-10 m

Belowground carbon:
- Sediment core collected in center of each plot

Figure 5. Diagram of 100 m transect and parameters sampled. Procedure based upon Howard et al. (2014).

Standing dead wood was also recorded within each of the 7 m radius plots. A decay class was assigned following Howard et al. (2014), where class 1 referred to a dead tree that still retained most of its branches, class 2 was a dead tree missing its secondary branches, and class 3 was missing all branches. The d_{130} was recorded for all class 1 and 2 trees. For all class 3 trees, the d_{130}, the diameter at the base of the tree, and the height were recorded and a wood sample was collected. All wood and vegetation samples were kept refrigerated at 4.5°C until processed.

Downed dead wood was recorded only when it crossed the crossed the main transect or perpendicular transects (see Figure 5). Large limbs (diameter >7.5 cm) were recorded between 2 and 12 m along the transects as measured from the center of the plot, medium branches (diameter 2.5-7.5 cm) were recorded from 2-7 m, and small branches (diameter 0.6-2.5 cm) were recorded from 7-10 m. The tiny size class (diameter <0.6 cm) was omitted because the small twigs were considered an insignificant source of carbon.

A Russian Peat Corer was used to obtain a peat sample in the center of each of the six plots (Figures 6 and 7). After being photographed, the core was slid into a half PVC tube (internal diameter ~5 cm) and wrapped in plastic wrap. Depths of cores varied widely between sites. If peat was present throughout the first 0-50 cm core, a second 40-90 cm core was collected as well. A second core was not collected if the core transitioned to sand within the first 0-50 cm (Figure 6). If the sediment could not be penetrated far (12 cm or less) by the peat corer due to sediment being primarily composed of sand and shell, sediment was collected in bags in 2 cm depth intervals. All cores and sediment samples were refrigerated at 4.5°C until processed.

Figure 6. Example of cores from a salt marsh (above) and mangrove (below) showing transition from dark peat to lighter-colored sand.

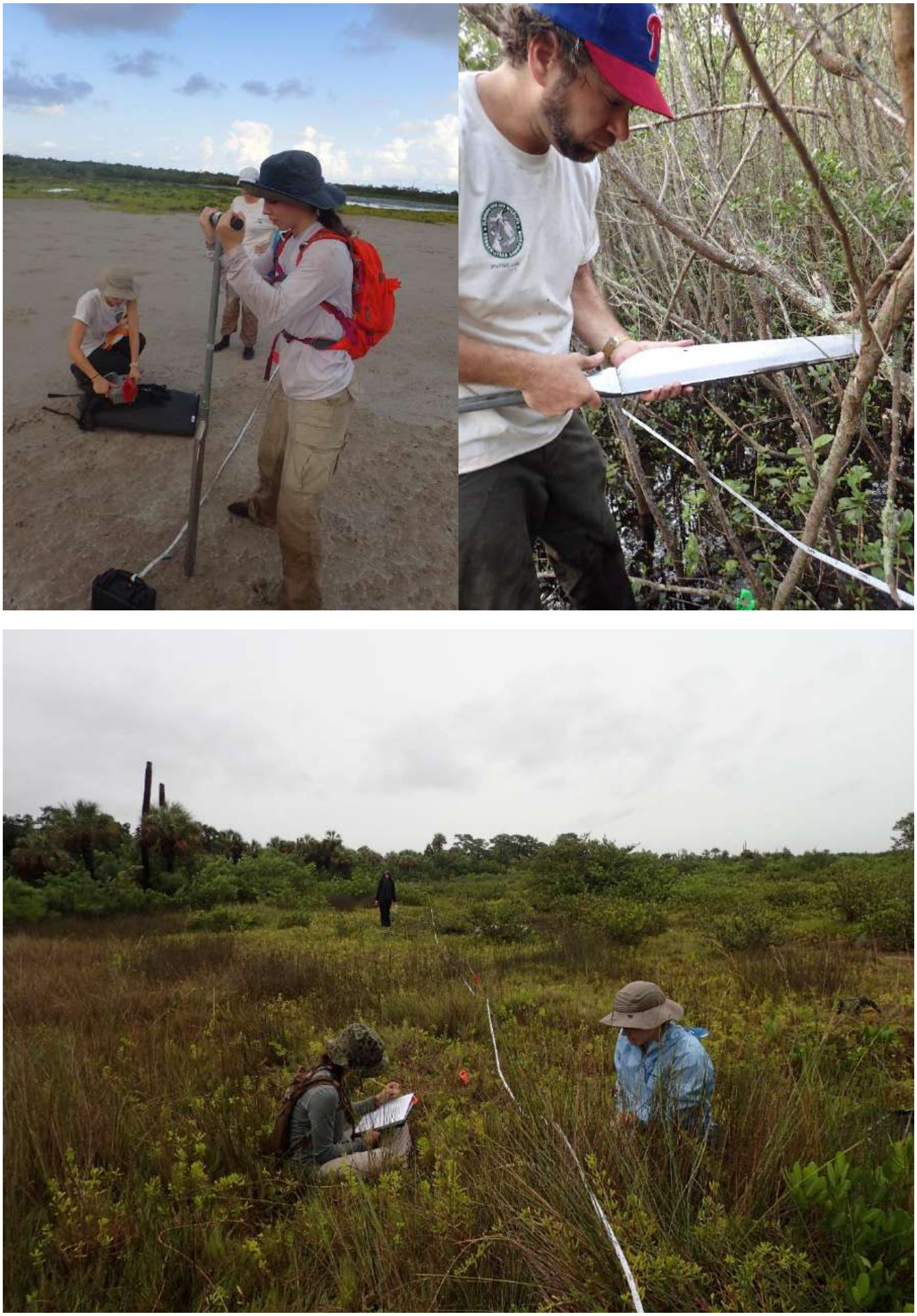


Figure 7. Sediment coring using the Russian peat corer (above) and counting stem density (below).

Figure 8. Recording mangrove tree diameters (above) and measuring *Juncus roemerianus* stem height (below).

Laboratory Analysis

Salt marsh vegetation

Approximately 50 stems or plants of each salt marsh plant species were collected at various sites around Tampa Bay. Roots were trimmed from the vegetation and the plant height was recorded. Vegetation was dried in an oven at 60°C until it reached a constant dry weight (generally 3 days) and weight was recorded to 0.001 g.

Wood density

Density was determined for all samples of class 3 standing dead trees and select samples of downed dead wood. Volume was determined by submerged mass (Howard et al. 2014). Briefly, a piece of wood was lowered using a needle clamped to a ring stand until it was submerged in a beaker of water on an electric scale. The mass was then determined after the wood was dried in an oven at 100°C until it reached a constant dry weight (generally 3 days). Density was calculated from volume and dry weight.

Sediment Cores

The amount of organic carbon within the sediment cores was determined using a loss on ignition (LOI) procedure (Ball 1964, Craft et al. 1991). Sediment was removed from the core in 1 cm thick slices and a cylinder was used to remove an aliquot of known volume (1.131 cm^3). Due to time constraints imposed by this high resolution sampling, some of the cores were processed at a coarser resolution and samples were analyzed at 5 cm rather than 1 cm intervals. Sites primarily processed in 5 cm intervals included Little Manatee River, TECO power plant, Terra Ceia, Shell Point, Clam Bayou, Rocky Creek, Bishop Harbor, E. G. Simmons, and Cockroach Bay. Sediment aliquots were dried in crucibles at 105°C for 24 hours, then combusted at 550°C for 3 hours, with weight recorded after each treatment. The percent of mass loss on ignition ($\%LOI$) was calculated using the dry mass that was weighed after the 105°C drying process (m_{dry}, g), and the mass after combustion at 550°C (m_{550}, g).

$$\%LOI = ((m_{dry} - m_{550})/m_{dry}) * 100$$

The percent organic matter ($\%C_{org}$) in the salt marshes and salt barrens was calculated from $\%LOI$ based upon the equation from Craft et al. (1991).

$$\%C_{org} = 0.4 * \%LOI + 0.0025 * (\%LOI)^2$$

$\%C_{org}$ in the mangrove soils was calculated from % LOI by a constant transformation (Allen 1974, Chmura et al. 2003).

$$\%C_{org} = \frac{\%LOI}{1.724}$$

Total soil carbon within each plot was calculated following methodology in Howard et al. (2014).

Carbon Calculations

Live Mangrove equations

Mangrove Trees

The aboveground dry biomass of the live mangrove trees (b_{AT}, kg) was calculated from d_{130} (cm) using equations developed by Smith and Whelan (2006), as repeated in the Blue Carbon manuals (Kauffman and Donato 2012, Howard et al. 2014).

Avicennia germinans: $b_{AT} = 0.403 * {d_{130}}^{1.934}$

Laguncularia racemosa: $b_{AT} = 0.362 * {d_{130}}^{1.93}$

Rhizophora mangle: $b_{AT} = 0.722 * {d_{130}}^{1.731}$

Scrub Mangroves

The aboveground biomass of scrub mangroves (height <130 cm) was determined using the allometric equations from Ross et al. 2001. Crown volume (*CRWNV*, cm^3) was calculated from measured dimensions (cm):

CRWNV = crown width* crown length * crown depth

Aboveground dry biomass of the scrub mangroves (b_{AS}, g) was calculated from *CRWNV* and diameter of the scrub main stem 30 cm above the ground (d_{30}, cm).

Scrub *Avicennia germinans*:
$\ln(b_{AS}) = 2.134 + \left(0.895 * \ln\left({d_{30}}^2\right)\right) + (0.184 * \ln(CRWNV))$

Scrub *Laguncularia racemosa*:
$\ln(b_{AS}) = 1.095 + \left(0.659 * \ln\left({d_{30}}^2\right)\right) + (0.304 * \ln(CRWNV))$

Scrub *Rhizophora mangle*:
$\ln(b_{AS}) = 2.528 + \left(1.129 * \ln\left({d_{30}}^2\right)\right) + (0.156 * \ln(CRWNV))$

While Howard et al. (2014) mentioned that the carbon conversion factor (proportion of carbon in biomass) generally varies between 0.46 and 0.50 globally in mangroves, this value has been found to be closer to 0.44 in Florida mangroves (Ewe et al. 2006, Bouillon et al. 2008). Therefore, a carbon conversion factor of 0.44 was used in this study for mangroves (trees, scrubs, and seedlings).

Mangrove seedlings

The aboveground dry biomass of the mangrove seedlings (b_{SE}, g) was determined from seedling height (*ht*, cm) based on the allometric equation determined by Ellison and Farnsworth (1997) for *Rhizophora mangle* seedlings (note this equation may overestimate biomass when applied to *L. racemosa* and *A. germinans* seedlings):

$$ln(b_{SE}) = -1.22 + 1.04 * ln(ht)$$

Belowground Biomass

Mangrove trees

The belowground biomass (b_{BG}, kg) of mangrove trees was calculated from average wood density (ρ, g/cm^3) and d_{130} (cm) in the general equation from Komiyama et al. (2005).

$$b_{BG} = 0.199 * \rho^{0.899} * (d_{130})^{2.22}$$

The average wood densities shown in Table 2 were used to calculate belowground biomass (Table modified from Howard et al. 2014). The carbon conversion factor for belowground carbon content was assumed to be 0.39 (Howard et al. 2014).

Table 2. Average wood density of Florida mangroves.

Species	Average density (g/m^3)± std error
Avicennia germinans	0.72±0.04
Laguncularia racemosa	0.60±0.01
Rhizophora mangle	0.87±0.02

Scrub Mangroves

The belowground biomass of the scrub mangroves (b_{BGS}) was calculated from the average species-specific root weight ratios (*RWR*, shown in Table 3) determined by McKee (1995) and the calculated aboveground biomass of the scrub mangroves (b_{AGS}). The carbon conversion factor for belowground carbon content was assumed to be 0.39 (Howard et al. 2014).

$$b_{BGS} = \frac{RWR * b_{AGS}}{(1 - RWR)}$$

Table 3. Average root weight ratio of Florida mangroves.

Species	Average *RWR*
Avicennia germinans	0.31
Laguncularia racemosa	0.33
Rhizophora mangle	0.37

Non-mangrove trees

Non-mangrove trees were a relatively small contribution to overall biomass. Species or genus-specific allometric equations were used if they could be found in available scientific literature, otherwise more general equations were used (see Table 4). Occasionally, literature equations for non-mangrove species called for the use of basal diameter, which was not measured (per field protocol). In these instances, diameter at breast height was estimated to be 2/3 of basal diameter. All non-mangrove biomass from the species listed in Table 4 is included within tree or scrub data, depending on height of the species.

Belowground biomass was calculated using aboveground biomass and the global average root:shoot ratio of 0.23 for temperate deciduous forests (Jackson et al. 1996). The same carbon conversion factors for aboveground and belowground biomass (0.44 and 0.39 respectively) were used for these non-mangrove trees.

Table 4. Allometric equations used for non-mangrove trees, shrubs, and lianas. Equations calculate aboveground biomass (b, kg) based upon diameter at breast height (d_{130}, cm), basal diameter (d_b, cm), or total height (ht_m in meters, ht_{cm} in centimeters).

Species	Common name	Allometric equation	Source
Dalbergia ecastaphyllum	coin vine	$b = (d_{130})^{2.657} * e^{-0.968} * ln(d_{130})$	Schnitzer 2006, Howard et al. 2014 (general liana equation)
Lyonia lucida	fetterbush	$ln(b * 1000) = -1.186 + 1.863 * ln(d_b/10)$	Schafer 2010
Baccharis halimifolia, B. angustifolia	groundsel tree, saltwater false willow	$b = 0.2806 * d_b - 0.3843$	Appolone 2000 (*B. halmifolia* equation)
Iva frutescens	Jesuit's bark	$b = 0.686 * ht_m$	Appolone 2000
Schinus terebinthifolius	Brazilian pepper	$b = 0.16155 * (d_{130})^{2.310647}$	Aguaron and McPherson 2012 (general broadleaf equation)
Conocarpus erectus	buttonwood	$b = 10097.06 * (d_{130}/100)^{2.33}$	Abohassan et al. 2010
Acrostichum danaeifolium	leather fern	$b = (-0.4993 + 0.1086 * ht_{cm}) * 6.75/1000$ $b = (-85.950 + 0.7593 * ht_{cm}) * 6.75/1000$	Sharpe 2010*

*Modification of original equation, assuming an average of 6.75 leaves per plant based on Sharpe 2010 averages. Equations are for leaves less than 130 cm and greater than 130 cm, respectively.

Dead wood

Standing Dead Trees

For standing dead trees that were classified as decay status 1, 2.5% was subtracted from calculated biomass in order to compensate for loss of leaves (Howard et al. 2014). For decay status 2 standing dead trees, 20% was subtracted from calculated biomass. Howard et al. (2014) recommends selecting a value between 10 and 20% to account for lost biomass of decay class 2 trees; the upper end of the range was selected due to the high prevalence of dead mangroves with limited remaining branches in the Tampa Bay area.

Species data was not collected on standing dead wood, so a generalized equation was used to calculate biomass of the decay class 1 and 2 trees (Howard et al. 2014). The biomass of the standing dead trees (b_{SD}, kg) was calculated from the diameter at breast height (d_{130}, cm) and average wood density (ρ, g/cm^3). The average value of all class 3 standing dead trees wood samples (0.431±0.177 g/cm^3, n = 128) was used for wood density.

$$b_{SD} = 0.168 * \rho * (d_{130})^{2.471}$$

Decay status 3 trees (few or no branches, standing stem only) were calculated assuming the tree is like a truncated cone (Howard et al. 2014). The volume of the tree (V, cm^3) was calculated from the diameter of the tree at the top and base (d_{top} and d_{base} respectively, both in cm) and the height (ht, m) of the tree.

$$V = \pi * \left(\frac{100*ht}{12}\right) * (d_{base}^2 + d_{top}^2 + (d_{base} * d_{top}))$$

If the dead tree was too tall to measure the diameter at the top, d_{130} and d_{base} were used to calculate d_{top} (all in cm):

$$d_{top} = d_{base} - [100 * ht * \left(\frac{d_{base} - d_{130}}{130}\right)]$$

The biomass was then determined by multiplying the calculated volume by the density, which was determined for each decay class 3 tree (see above). The carbon content of all standing dead trees was assumed to be 50% (Kauffman and Donato 2012, Howard et al. 2014).

Dead and downed wood

The quadratic mean diameter (*QMD*, cm) was calculated for both the small and medium size classes using the diameter of each piece of wood sampled (D_i, cm) and the total number of samples (n).

$$QMD = \sqrt{\frac{\sum D_i^2}{n}}$$

The volume of downed wood per unit area (V_d, m^3/ha) was calculated individually for each size class using length of the transect (L, m) and the class-specific quadratic mean diameter (QMD_i, cm) and sample size of each size class (n_i).

$$V_d = \pi^2 * \left(\frac{n_i * QMD_i^2}{8 * L}\right)$$

The downed wood biomass was calculated as a function of volume and density. The carbon content of all dead and downed wood was assumed to be 50% (Kauffman and Donato 2012, Howard et al. 2014).

Salt marsh vegetation

Individual allometric equations were created for each species of salt marsh vegetation found across Tampa Bay. Species-specific linear regressions were created for weight vs. height with and without natural logarithmic transformations. The equations with the highest R^2 value were selected as the final allometric equations. SAS Enterprise Guide v. 6.1 was used for linear regressions and statistical analyses. Species-specific graphs of allometric relationships are available in Appendix B. The total biomass for each species was calculated for each plot based on average height and stem density within each 30 x 30 cm plot. Carbon content was assumed to be 45% (Howard et al. 2014).

Salt marsh belowground vegetative biomass

Belowground biomass of the roots and rhizomes was calculated using the equation from Gross et al. (1991). Belowground biomass in the salt marsh (b_{BG}, g) was calculated based upon the total aboveground biomass (b_{AG}, g). Carbon content was assumed to be 34% within the belowground biomass (Howard et al. 2014).

$$\ln(b_{BG}) = 0.713 * \ln(b_{AG}) + 2.235$$

Results

The average density (±SE) of the small and medium size classes of downed dead wood were 0.39±0.02 g/cm^3 (n = 41) and 0.40±0.03 g/cm^3 (n = 28), respectively. No large size class dead wood was found along the sampled transects. The average wood density of the decay class 3 standing dead trees was 0.43±0.02 g/cm^3 (n = 128). The allometric equations for salt marsh vegetation are summarized in Table 5; graphs of allometric equations of each species are presented in Appendix B. The slopes for all models were statistically significant (p<0.0001).

Table 5. Allometric equations for aboveground biomass (*b*, g) in salt marsh vegetation based upon plant height (*ht*, cm).

Species	Common name	Allometric equation	R^2	*n*
Bacopa monnieri[1]	water hyssop	$b = 0.0036ht - 0.0093$	0.7779	50
Batis maritima[2]	saltwort	$\ln(b) = 1.7247\ln(ht) - 5.3885$	0.7295	65
Blutaparon vermiculare[1]	silverhead	$b = 0.0121ht + 0.0464$	0.7228	50
Borrichia frutescens[1]	sea oxeye daisy	$\ln(b) = 1.9697\ln(ht) - 6.8766$	0.7622	52
Fimbristylis castanea[1]	marsh fimbry	$\ln(b) = 2.0161\ln(ht) - 9.5912$	0.6585	48
Fimbristylis cymosa[3]	tropical fimbry	$\ln(b) = 1.5244\ln(ht) - 4.8064$	0.4634	56
Juncus roemerianus[1]	black needlerush	$b = 0.0230ht - 0.6384$	0.9062	63
Limonium carolinianum[4]	sea lavender	$\ln(b) = 1.0071\ln(ht) - 3.9246$	0.7552	59
Monanthochloe littoralis[1]	Key grass	$\ln(b) = 1.4028\ln(ht) - 5.4823$	0.7053	75
Paspalum distichum[1]	knotgrass	$\ln(b) = 1.9210\ln(ht) - 6.6365$	0.8342	51
Rayjacksonia phyllocephala[1]	camphor daisy	$b = 0.1107ht - 0.9224$	0.6832	50
Salicornia virginica[2]	American glasswort	$b = 0.0094ht - 0.0329$	0.9217	51
Schizachyrium scoparium[1]	dusky bluestem	$\ln(b) = 1.8228\ln(ht) - 8.5819$	0.8283	51
Sesuvium portulacastrum[5]	sea purselane	$\ln(b) = 1.1760\ln(ht) - 4.1677$	0.7785	53
Solidago sempervirens[1]	seaside goldenrod	$\ln(b) = 1.2920\ln(ht) - 4.9600$	0.7502	50
Spartina alterniflora[1]	smooth cordgrass	$\ln(b) = 1.9492\ln(ht) - 7.6267$	0.7673	53
Spartina patens[1]	saltmeadow cordgrass	$\ln(b) = 2.1380\ln(ht) - 8.8881$	0.6789	53
Sporobolus virginicus[1]	seashore dropseed	$\ln(b) = 1.2473\ln(ht) - 6.4324$	0.5525	50

[1] Total height of individual stems measured, including flower if present
[2] Total height, each vertical stem measured individually from ground stem
[3] Total height of whole plant, excluding flower if present
[4] Total height of whole plant, including flower if present
[5] Length of each significant branch measured individually

Soil and vegetative carbon stocks ranged widely among sites (Figure 9, Table 6). General trends indicate that mangroves have a larger carbon stock than salt marshes and salt barrens. Exceptions to this trend include the Little Manatee River salt marsh. This *Juncus roemerianus* salt marsh not only had the largest vegetative carbon component of all the salt marshes, but it also had extensive peat deposits with carbon stocks similar to the mangrove habitats (Figure 9, Table 6). Another exception was the Terra Ceia salt barren. According to LOI analysis this site had high soil carbon values, similar to the value found at mangrove sites. However, soils that contain >11% clay minerals may lose water at higher temperatures after the initial low temperature drying stage (Mook and Hoskin 1982, Barillé-Boyer et al. 2003, Howard et al. 2014). Thus the combustion at 550°C results in the loss of both organic matter and water, resulting in the incorrect calculation of high amounts of organic matter. Tables and graphs below therefore include mean values calculated with and without the Terra Ceia salt flat, given the need for further investigation into the sediment qualities of this site.

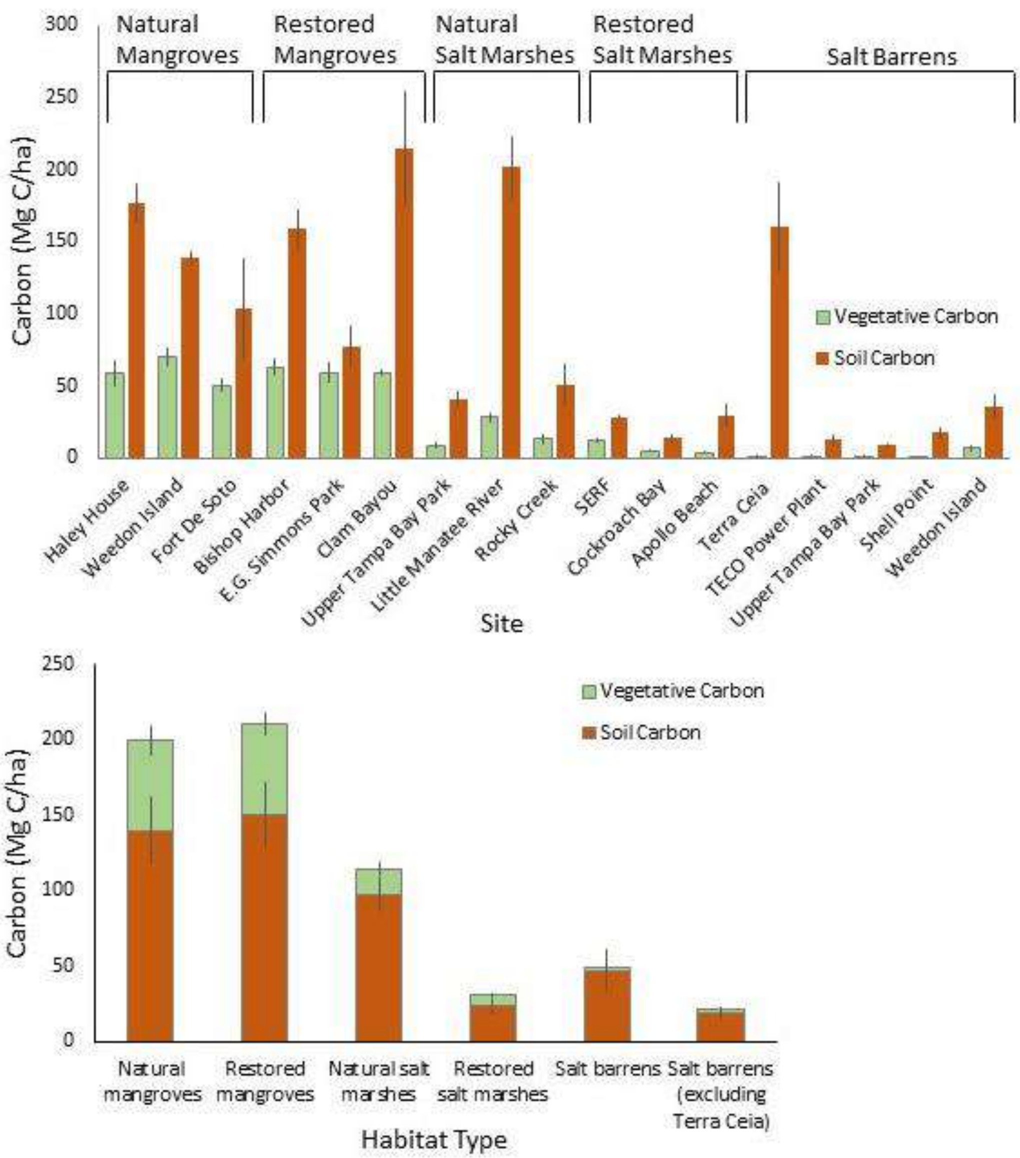


Figure 9. Soil and vegetative carbon (includes both above and belowground biomass) found at the 17 sites across Tampa Bay (top) and binned by habitat type (bottom). Error bars show standard error of the mean for the 6 plots from each site (top) or from 3-5 sites (bottom).

Table 6. Soil and vegetative carbon (includes both above and belowground biomass) found at the 17 sites across Tampa Bay (average ± standard error across 6 plots).

Site Name	Habitat Type	Habitat State	Soil Carbon (MgC/ha)	Core depth (cm)	Vegetative Carbon (MgC/ha)	Total Carbon (MgC/ha)
Haley House	Mangrove	Natural	176.2±13.2	50-90	58.7±9.0	234.9±10.3
Weedon Island	Mangrove	Natural	138.6±4.3	47-50	70.4±6.3	209.0±2.8
Fort De Soto	Mangrove	Natural	103.8±34.9	14-90	50.3±4.4	154.1±37.1
Bishop Harbor	Mangrove	Restored	159.0±13.9	38-50	63.0±6.0	222.0±18.3
E.G. Simmons Park	Mangrove	Restored	77.7±13.6	13-39	59.2±7.1	137.0±16.2
Clam Bayou	Mangrove	Restored	214.3±39.7	21-90	59.2±2.0	273.5±40.4
Upper Tampa Bay Park	Salt Marsh	Natural	40.5±5.8	44-77	8.8±2.0	49.3±5.0
Little Manatee River	Salt Marsh	Natural	201.5±21.7	42-90	28.2±3.5	229.7±21.8
Rocky Creek	Salt Marsh	Natural	50.7±15.1	17-43	13.0±3.6	63.6±13.8
SERF	Salt Marsh	Restored	28.3±1.4	9-13	11.9±1.2	40.2±2.4
Cockroach Bay	Salt Marsh	Restored	13.9±2.5	4-46	5.1±0.7	19.0±2.3
Apollo Beach	Salt Marsh	Restored	29.7±7.6	6-32	3.9±1.0	33.6±8.5
Terra Ceia	Salt Barren	Natural	160.3±31.2	15-85	1.2±1.1	161.4±31.3
TECO Power Plant	Salt Barren	Natural	12.3±3.7	4-50	1.2±0.7	13.5±4.0
Upper Tampa Bay Park	Salt Barren	Natural	8.9±1.4	10-49	1.1±1.1	10.1±2.3
Shell Point	Salt Barren	Natural	17.4±3.3	16-50	0.1±0.0	17.5±3.3
Weedon Island	Salt Barren	Natural	35.9±8.5	4-48	6.9±2.1	42.8±8.8

Total carbon stock ranged from 10.1-273.5 MgC/ha across all sites (Table 6). Average soil and vegetative carbon values in each ecosystem are shown in Table 7. Natural and restored mangroves had similar total carbon storage (199.4 and 210.8 MgC/ha, respectively), while natural salt marshes stored much more carbon than restored salt marshes (114.2 and 30.9 MgC/ha respectively). This trend is primarily driven by the Little Manatee River site, which had 3-4 times the total carbon stock compared to the other two natural salt marsh sites sampled.

Table 7. Carbon stocks and soil composition by habitat type (average of sites ± standard error across 3-5 sites).

Site Name	Soil Carbon (MgC/ha)	Core depth (cm)	Vegetative Carbon (MgC/ha)	Total Carbon (MgC/ha)
Natural mangroves	139.5±22.3	14-90	59.8±9.3	199.4±25.5
Restored mangroves	150.3±21.2	13-90	60.5±7.1	210.8±18.9
Natural salt marshes	97.6±11.3	17-90	16.6±4.3	114.2±11.9
Restored salt marshes	24.0±4.7	4-46	7.0±1.4	30.9±5.0
Salt barrens	47.0±13.5	4-85	2.1±1.1	49.1±13.4
Salt barrens, excluding Terra Ceia	18.6±3.7	4-50	2.3±1.2	21.0±3.6
All mangroves	144.9±20.2	13-90	60.1±2.7	205.1±20.9
All salt marshes	60.8±28.6	4-90	11.8±3.6	72.6±32.0

Figures 10-15 depict carbon stocks at individual plots across all 17 sampling sites. Vegetative carbon includes a breakdown between trees (>1.3 m in height), scrub mangroves (0.3-1.3 m) and seedlings (<0.3 m). Trees, scrub mangroves, and herbaceous plants include both an aboveground and a belowground biomass component while dead wood and seedlings are only calculated as aboveground biomass.

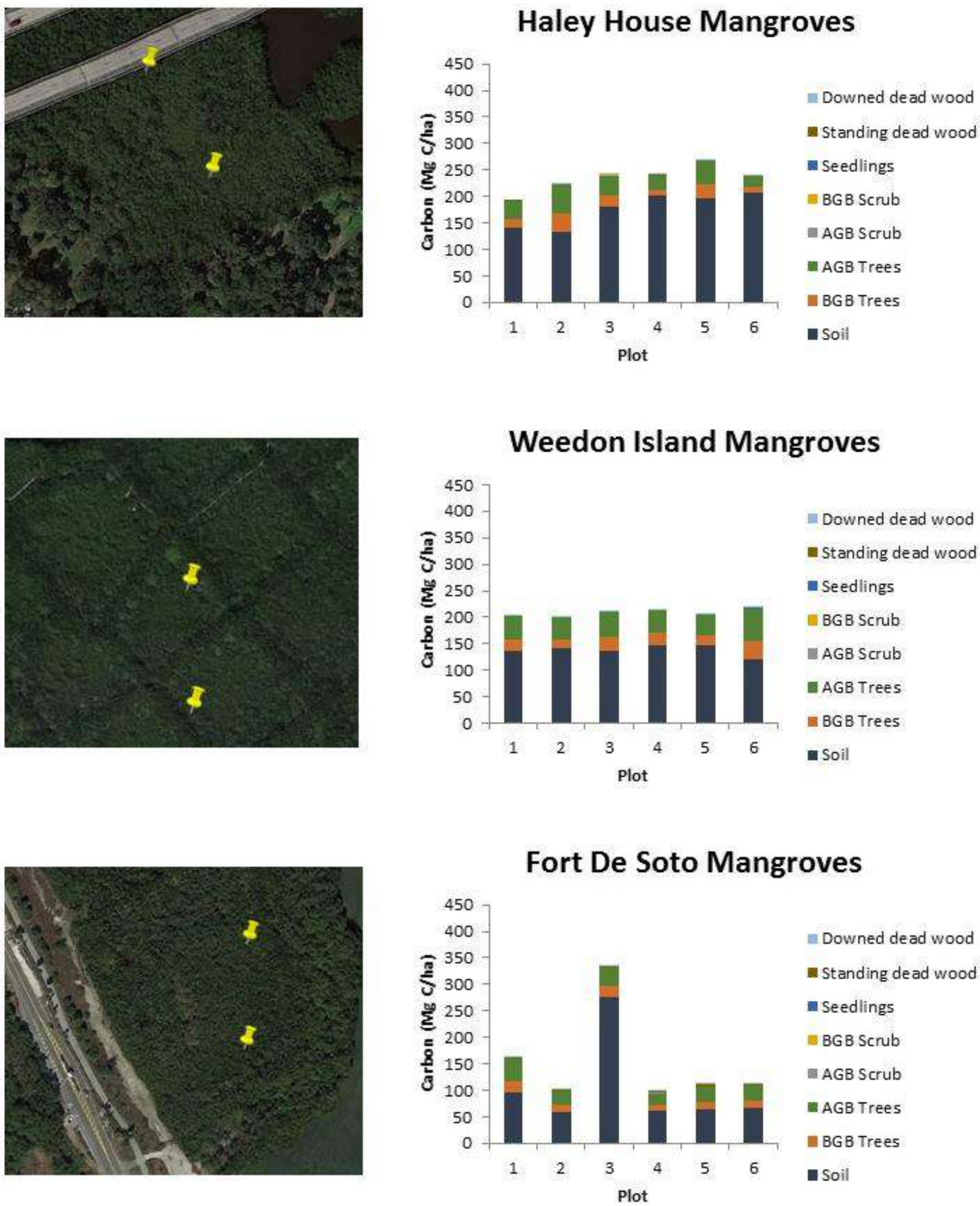


Figure 10. Carbon content in natural (unrestored) mangroves in Tampa Bay, including aboveground biomass (AGB) and belowground biomass (BGB) of vegetation. Pins indicate the centers of Plots 1 and 6.

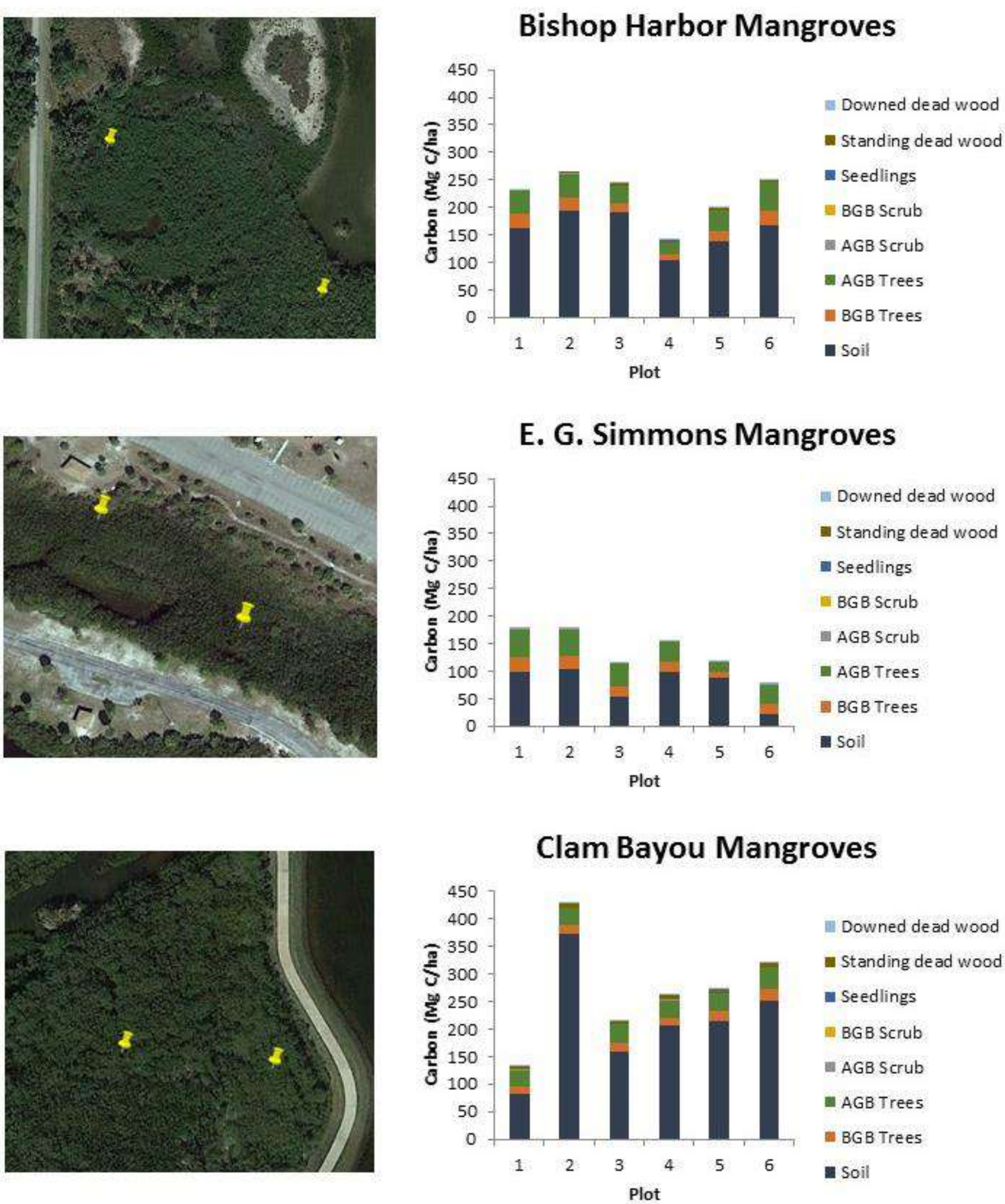


Figure 11. Carbon content in restored mangroves in Tampa Bay, including aboveground biomass (AGB) and belowground biomass (BGB) of vegetation. Pins indicate the centers of Plots 1 and 6.

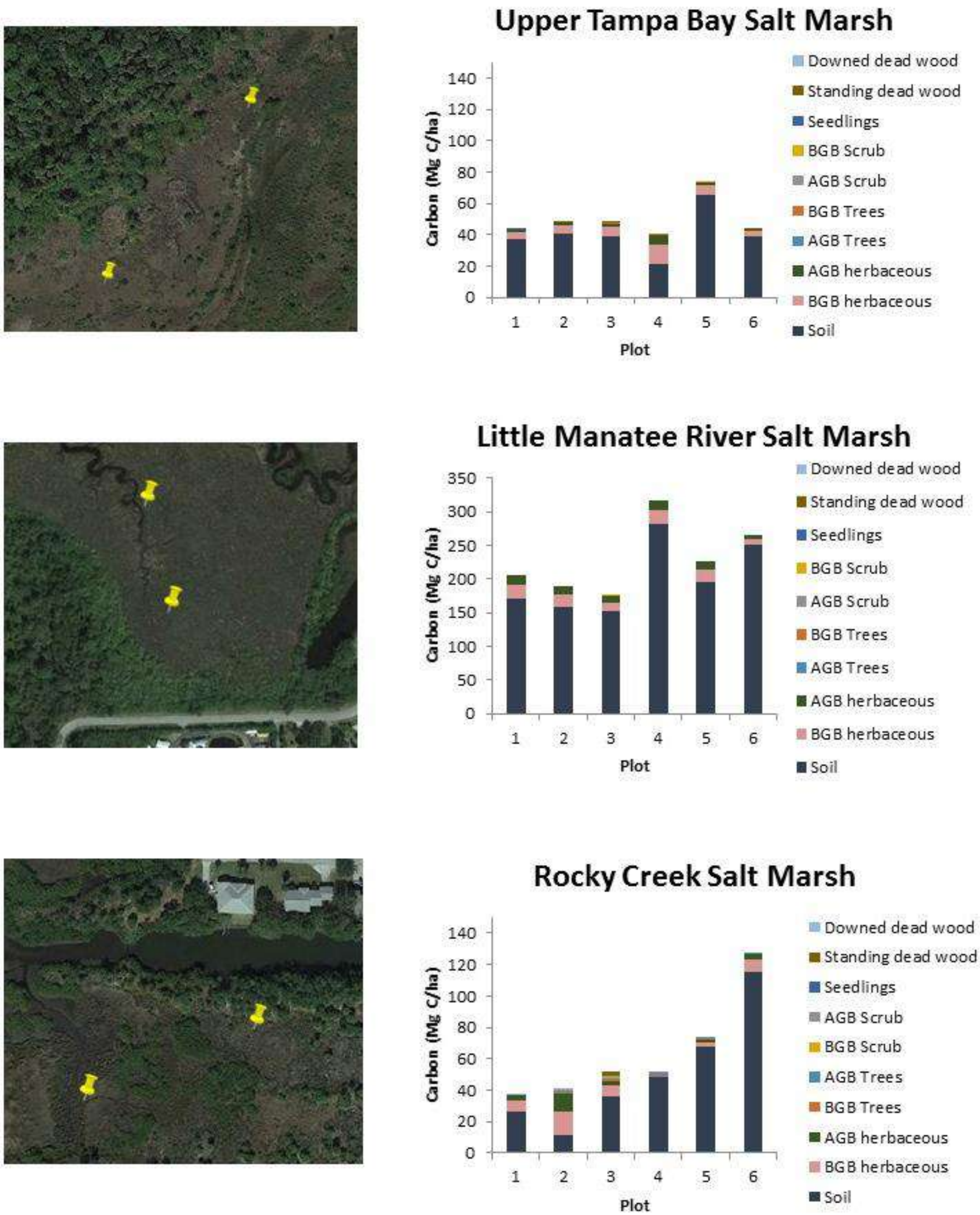


Figure 12. Carbon content in natural (unrestored) salt marshes in Tampa Bay, including aboveground biomass (AGB) and belowground biomass (BGB) of vegetation. Note different scale used for Little Manatee River salt marsh. Pins indicate the centers of Plots 1 and 6.

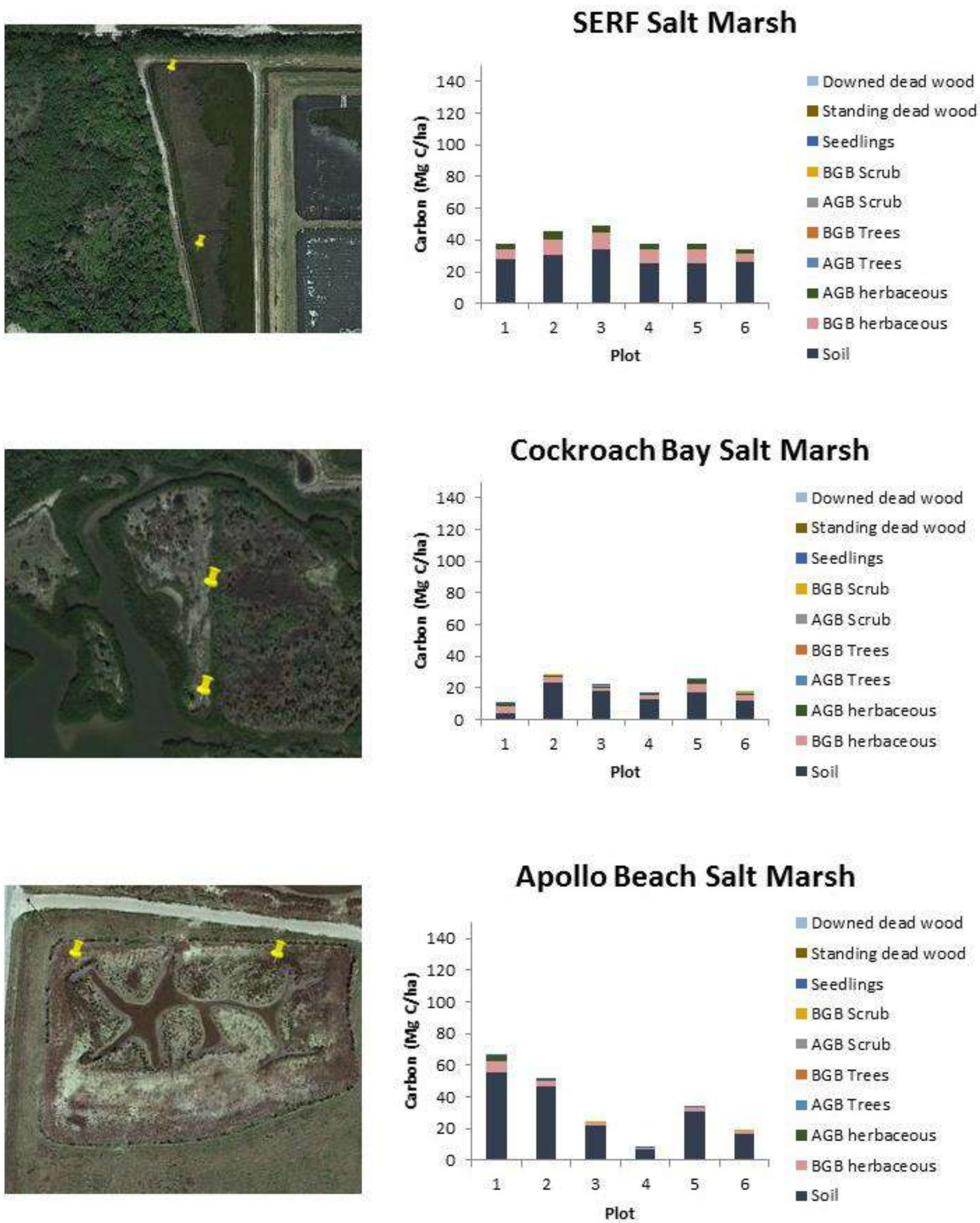


Figure 13. Carbon content in restored salt marshes in Tampa Bay, including aboveground biomass (AGB) and belowground biomass (BGB) of vegetation. Pins indicate the centers of Plots 1 and 6.

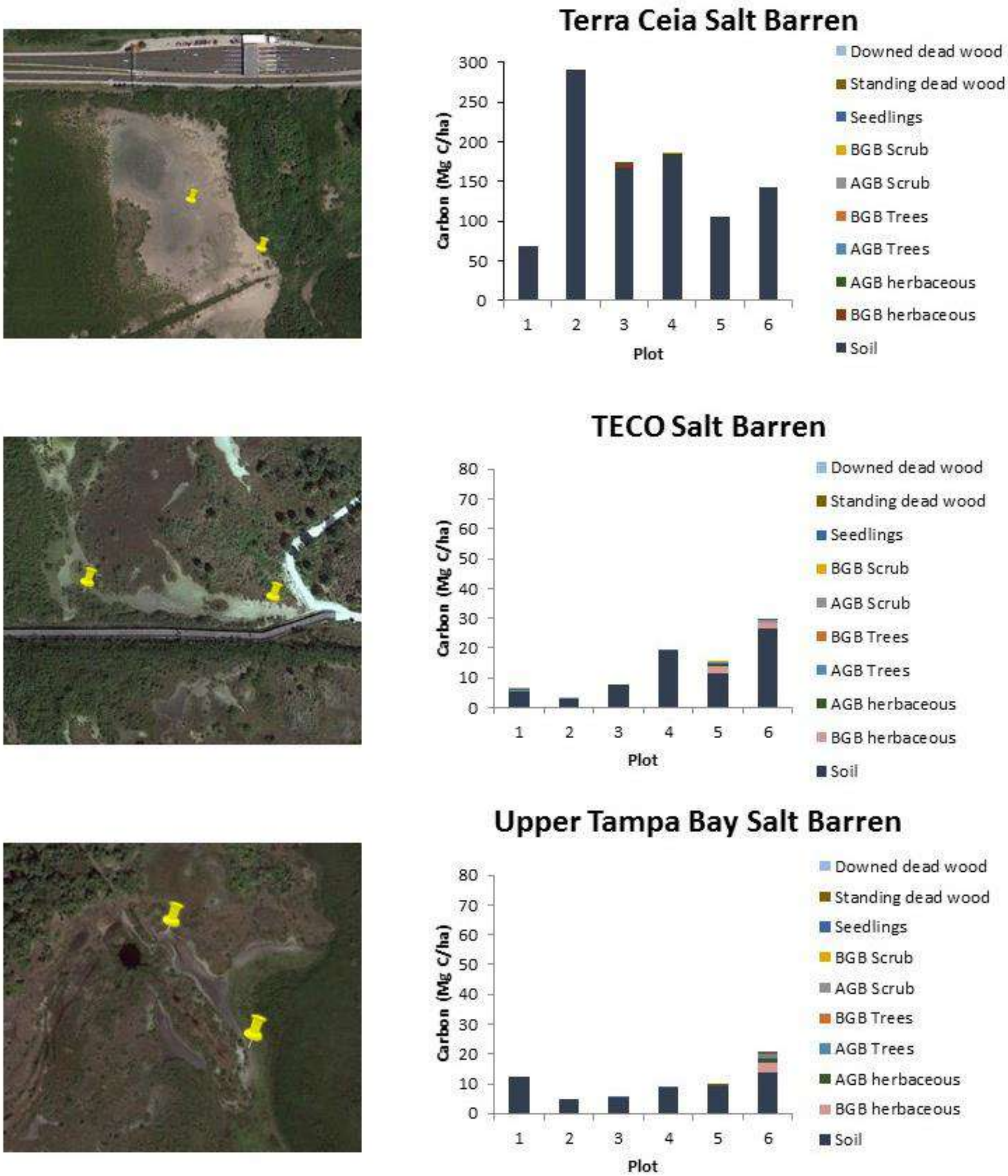
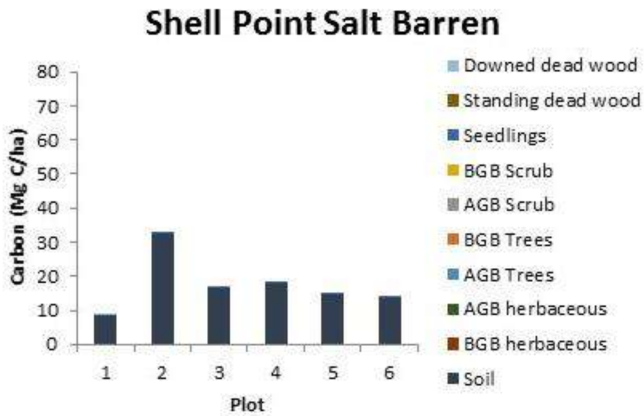


Figure 14. Carbon content in salt barrens in Tampa Bay, including aboveground biomass (AGB) and belowground biomass (BGB) of vegetation. Note different scale used for Terra Ceia Salt Barren. Pins indicate the centers of Plots 1 and 6.



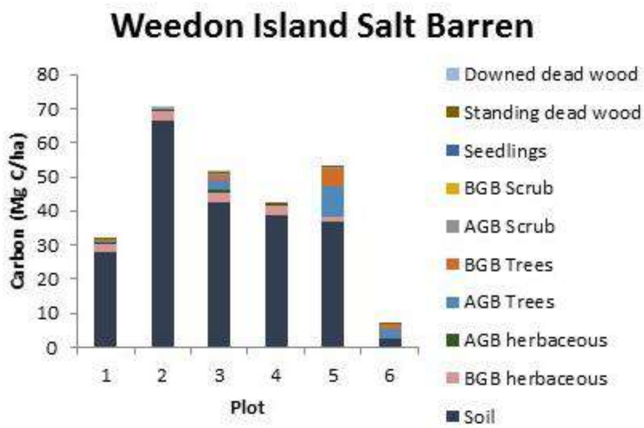


Figure 15. Carbon content in salt barrens of Tampa Bay (continued), including aboveground biomass (AGB) and belowground biomass (BGB) of vegetation. Pins indicate the centers of Plots 1 and 6.

The sediment characteristics of the cores are described in binned intervals of 0-15, 15-30, 30-50, and 50-90 cm in Tables 8-10. As previously mentioned, depths of cores varied among sites and plots. If soil was predominantly sand or shell, retrieved cores were often under 40 cm. A second core was not collected if the core transitioned to sand within the first 0-50 cm. Hence the depth intervals in Tables 8-11 do not always include sediment from all 6 plots at all possible depth intervals, and the sum of these average values for the depth intervals do not equate to the calculated averages per site in Table 6. Depths and coordinates of individual cores are listed in Appendix A.

Table 8. Sediment dry bulk density and carbon composition in natural and restored mangrove sites. Values reported are averages of depth intervals of *n* plots (up to 6 plots per depth interval).

Natural Mangroves	**Depth (cm)**	**Dry bulk density (g/cm^3)**	**% Organic Carbon**	**Carbon density (g/cm^3)**	**Carbon stock (MgC/ha)**	***n***
Haley House	0-15	0.4	15.2	0.038	57.7	6
	15-30	0.8	4.4	0.027	38.5	6
	30-50	1.0	2.8	0.023	45.3	6
	50-90	1.2	1.6	0.017	52.2	4
Weedon Island	0-15	0.6	11.0	0.038	57.3	6
	15-30	0.6	9.5	0.034	50.7	6
	30-50	1.0	2.5	0.019	30.6	6
	50-90					0
Fort De Soto	0-15	0.3	17.4	0.041	60.5	6
	15-30	0.4	19.3	0.037	52.4	2
	30-50	0.1	6.3	0.016	26.6	1
	50-90	0.5	10.8	0.032	128.3	1
Restored Mangroves						
Bishop Harbor	0-15	0.3	18.8	0.046	68.8	6
	15-30	0.8	7.8	0.033	49.8	6
	30-50	1.1	2.5	0.025	40.4	6
	50-90					0
E.G. Simmons Park	0-15	0.5	13.3	0.034	50.2	6
	15-30	0.8	5.2	0.020	27.7	5
	30-50	1.2	0.8	0.010	6.7	4
	50-90					0
Clam Bayou	0-15	0.5	18.1	0.054	81.2	6
	15-30	0.7	9.8	0.037	51.8	6
	30-50	0.6	8.6	0.039	72.4	5
	50-90	1.0	3.8	0.031	126.0	1

Table 9. Sediment dry bulk density and carbon composition in natural and restored salt marsh sites. Values reported are averages of depth intervals of *n* plots (up to 6 plots per depth interval).

Natural Salt Marshes	**Depth (cm)**	**Dry bulk density (g/cm^3)**	**% Organic Carbon**	**Carbon density (g/cm^3)**	**Carbon stock (MgC/ha)**	***n***
Upper Tampa Bay Park	0-15	1.3	1.1	0.012	17.6	6
	15-30	1.4	0.4	0.006	8.9	6
	30-50	1.4	0.4	0.006	10.8	6
	50-90	1.5	0.4	0.006	19.1	1
Little Manatee River	0-15	0.3	20.8	0.042	63.0	6
	15-30	0.4	10.4	0.039	59.1	6
	30-50	0.9	4.2	0.029	50.6	6
	50-90	0.5	1.6	0.007	86.4	2
Rocky Creek	0-15	0.9	4.7	0.016	23.8	6
	15-30	1.1	2.6	0.015	21.9	6
	30-50	1.2	1.0	0.011	7.4	4
	50-90					0
Restored Salt Marshes						
SERF	0-15	0.7	10.2	0.026	28.3	6
	15-30					0
	30-50					0
	50-90					0
Cockroach Bay	0-15	1.2	0.5	0.006	7.2	6
	15-30	1.3	0.4	0.005	6.8	5
	30-50	1.3	0.2	0.003	3.1	2
	50-90					
Apollo Beach	0-15	1.4	1.3	0.018	21.6	6
	15-30	1.3	1.3	0.017	11.0	4
	30-50	1.4	1.6	0.021	4.3	1
	50-90					0

Table 10. Sediment dry bulk density and carbon composition in salt barren sites. Values reported are averages of depth intervals of *n* plots (up to 6 plots per depth interval).

Salt Barrens	Depth (cm)	Dry bulk density (g/cm^3)	% Organic Carbon	Carbon density (g/cm^3)	Carbon stock (MgC/ha)	n
Terra Ceia	0-15	1.0	6.2	0.062	93.0	6
	15-30	1.2	3.2	0.036	39.1	6
	30-50	1.2	1.7	0.018	36.0	5
	50-90	1.3	1.0	0.013	60.7	1
TECO Power Plant	0-15	1.4	0.7	0.009	9.9	6
	15-30	1.4	0.3	0.004	2.9	3
	30-50	1.5	0.2	0.003	5.7	1
	50-90					0
Upper Tampa Bay Park	0-15	1.3	0.4	0.005	6.6	6
	15-30	1.4	0.4	0.006	2.8	3
	30-50	1.5	0.2	0.003	5.9	1
	50-90	1.3				0
Shell Point	0-15	1.4	0.3	0.004	5.8	6
	15-30	1.5	0.3	0.005	5.3	6
	30-50	1.6	0.4	0.006	9.4	4
	50-90					0
Weedon Island	0-15	1.1	1.6	0.014	19.2	6
	15-30	1.2	1.1	0.012	14.4	5
	30-50	1.3	0.7	0.009	9.3	3
	50-90					0

Discussion and Conclusions

These results demonstrate the large variance in carbon stocks not only across different habitats, but also within the same habitat across a single transect. Total carbon stocks varied two-fold across mangrove sites, and by more than an order of magnitude across salt marsh sites. The similar carbon stock values in the restored mangrove sites were likely due to the fact that two of these sites (Bishop Harbor and Clam Bayou) were primarily hydrologic restoration projects, and so already had mature mangrove forests at each location prior to restoration efforts (see aerial images of these restoration projects in Appendix A). The E. G. Simmons location was a newly created mangrove forest at the time of the restoration effort in 1990. Therefore this site was 25 years old at the time of the study. The vegetation carbon stocks at this site are similar to the other 5 mangrove locations, but this location did have the smallest quantity of soil carbon among the mangrove sites (Table 6).

The restored salt marshes did have lower carbon stocks than the natural salt marshes. All three restored sites were wetlands that had been created from upland habitats between 1998 and 2013, so the marshes were between 2 and 17 years old at the time of sampling (aerial images available in Appendix A). The natural salt marshes also had a large degree of variability in carbon stocks. Of the six salt marsh locations, the *Juncus roemerianus* dominated Little Manatee River salt marsh had the greatest stocks of both vegetative and soil carbon (Table 6).

Many of the salt barrens in the study had herbaceous vegetation and mangroves encroaching on the edges of the barren. Encroaching mangroves often contributed the majority of the vegetative carbon stock in these habitats. The Weedon Island salt barren was the most dramatic example of encroaching vegetation to the extent that the site was not a true salt barren, but rather an early transitional salt marsh (see image in Fig. 4).

A similar study on blue carbon stocks in mangroves and salt marshes was recently completed on the East coast of Florida on Merritt Island (Doughty et al. 2015). Vegetative carbon stocks in Merritt Island and Tampa Bay are quite similar in both salt marshes and mangroves (Table 11). Average soil carbon values are higher in Tampa Bay than in Merritt Island, however, much of this variability is likely due to differences in core depths in each study. Doughty et al. (2015) used 30 cm cores, while cores in this study extended up to 90 cm. Both this study and the Merritt Island study indicate that Florida coastal wetlands store less carbon compared to global averages, which include the large carbon stocks of Indo-Pacific mangroves (IPCC 2013, Howard et al. 2014).

Table 11. Comparison of local and global carbon pools in mangroves and saltmarshes.

Habitat	Location	Citation	Soil Carbon (MgC/ha)	Core Depth (cm)	Vegetative Carbon (MgC/ha)	Total Carbon (MgC/ha)
Mangrove	Global	IPCC 2013	386	100		
Mangrove	Tampa Bay, FL	This study	145	13-90	60	205
Mangrove	Merritt Island, FL	Doughty et al. 2015	57	30	66	122
Salt marsh	Global	IPCC 2013	255	100		
Salt marsh	Tampa Bay, FL	This study	61	4-90	12	73
Salt marsh	Merritt Island, FL	Doughty et al. 2015	49	30	11	61

While clear trends did not emerge for the carbon stocks of natural vs. restored coastal wetlands, the large degree of variability across these habitats may instead be due to location, species composition, local hydrology, and habitat age. This large degree of variability reinforces the need for site-specific sampling for blue carbon stock assessments. In addition, even most natural habitats in the Tampa Bay area have been impacted by human development and altered hydrology, leading to shifts that may impact peat accumulation and consequent carbon sequestration.

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Appendix A. Site descriptions

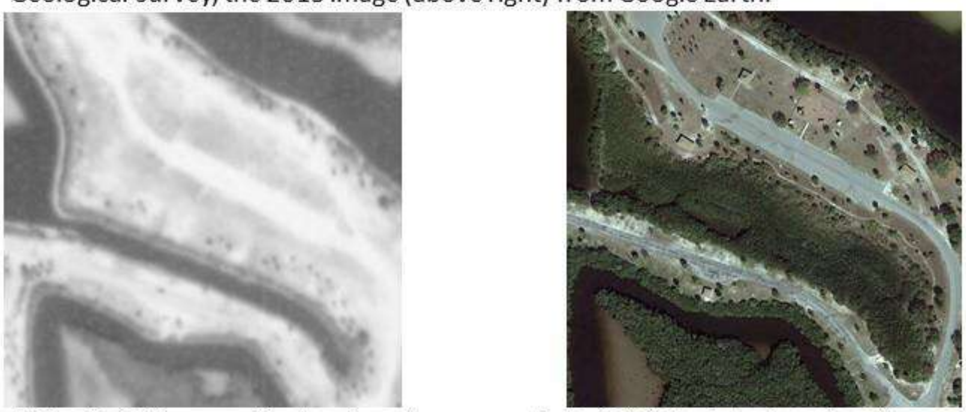
Table A1. Latitude and longitude of all plots and site description.

Site Name	Habitat Type	Habitat State	Plot	Latitude	Longitude	Core depth (cm)	Site Description/Notes
Haley House	Mangrove	Natural	1	27° 34.853' N	82° 33.820' W	50	Transect ran parallel to water way and perpendicular between two roads, ending under I-275. Plot 6 only 1/2 of plot measured as 1/2 was under freeway.
			2	27° 34.841' N	82° 33.818' W	50	
			3	27° 34.849' N	82° 33.808' W	90	
			4	27° 34.860' N	82° 33.825' W	90	
			5	27° 34.870' N	82° 33.833' W	79	
			6	27° 34.878' N	82° 33.837' W	65	
Weedon Island	Mangrove	Natural	1	27° 50.780' N	82° 36.092' W	50	Mangrove ditching in grid pattern and spoil piles with Brazilian pepper present throughout preserve.
			2	27° 50.771' N	82° 36.090' W	48	
			3	27° 50.761' N	82° 36.089' W	49	
			4	27° 50.748' N	82° 36.091' W	50	
			5	27° 50.738' N	82° 36.087' W	47	
			6	27° 50.727' N	82° 36.086' W	49	
Fort De Soto	Mangrove	Natural	1	27° 37.625' N	82° 42.909' W	28	Large spoil piles with cactus present outside of transect from ditching or road construction. Young mangroves (small amount of peat) and old mangrove forest with extensive peat present in same forest.
			2	27° 37.631' N	82° 42.915' W	15	
			3	27° 37.624' N	82° 42.942' W	90	
			4	27° 37.645' N	82° 42.924' W	14	
			5	27° 37.652' N	82° 42.915' W	15	
			6	27° 37.660' N	82° 42.908' W	15	
Bishop Harbor	Mangrove	Restored	1	27° 35.955' N	82° 33.108' W	50	Mangroves adjacent to a salt marsh that was created from upland in 2008, altering mangrove hydrology. Mangroves separated from coast by Bishop Harbor Road.
			2	27° 35.947' N	82° 33.096' W	50	
			3	27° 35.943' N	82° 33.086' W	50	
			4	27° 35.943' N	82° 33.073' W	41	
			5	27° 35.935' N	82° 33.067' W	38	
			6	27° 35.925' N	82° 33.060' W	42	
E.G. Simmons Park	Mangrove	Restored	1	27° 44.533' N	82° 28.063' W	36	Restoration effort in 1990 sculpted tidal channels to ease stagnation and created new wetland habitat. Transect ran along tidal creek, between two roads.
			2	27° 44.543' N	82° 28.066' W	37	
			3	27° 44.551' N	82° 28.071' W	21	
			4	27° 44.557' N	82° 28.077' W	35	
			5	27° 44.562' N	82° 28.092' W	36	
			6	27° 44.560' N	82° 28.101' W	13	
Clam Bayou	Mangrove	Restored	1	27° 44.583' N	82° 41.233' W	21	Mangroves next to a recently (2010-2012) restored canal and recently created stormwater retention ponds. Die-off in past left many dead trees that are still standing, discolored stagnant water in forest.
			2	27° 44.580' N	82° 41.241' W	90	
			3	27° 44.575' N	82° 41.247' W	48	
			4	27° 44.575' N	82° 41.257' W	48	
			5	27° 44.580' N	82° 41.266' W	47	
			6	27° 44.586' N	82° 41.263' W	46	
Upper Tampa Bay Park	Salt Marsh	Natural	1	28° 00.417' N	82° 37.995' W	45	Very diverse salt marsh adjacent to upland habitat. Salt marsh currently being overtaken by mangroves
			2	28° 00.424' N	82° 37.984' W	45	
			3	28° 00.432' N	82° 37.977' W	44	
			4	28° 00.441' N	82° 37.970' W	45	

			5	28° 00.451' N	82° 37.962' W	81	
			6	28° 00.458' N	82° 37.957' W	50	
Little Manatee River	Salt Marsh	Natural	1	27° 40.738' N	82° 26.183' W	48	*Juncus* salt marsh in bend of Little Manatee River. Almost entirely monospecific with occasional mangrove and leather fern.
			2	27° 40.747' N	82° 26.186' W	43	
			3	27° 40.758' N	82° 26.187' W	42	
			4	27° 40.769 ' N	82° 26.188' W	85	
			5	27° 40.780' N	82° 26.189' W	50	
			6	27° 40.790' N	82° 26.196' W	90	
Rocky Creek	Salt Marsh	Natural	1	27° 59.658' N	82° 35.156' W	31	Salt marsh adjacent to neighborhood with occasional ditching. Transect transitioned from diverse upper marsh species and leather fern to *Juncus.* Mangroves also encroaching on marsh
			2	27° 59.653' N	82° 35.164' W	18	
			3	27° 59.646' N	82° 35.175' W	43	
			4	27° 59.639 ' N	82° 35.182' W	44	
			5	27° 59.640' N	82° 35.194' W	36	
			6	27° 59.640' N	82° 35.206' W	32	
Stock Enhancement Research Facility (SERF)	Salt Marsh	Restored	1	27° 38.720' N	82° 32.862' W	10	Salt marsh created from upland in 1997 to remove nutrients from fish ponds and grow donor grasses for marsh restorations. Predominantly *Spartina alterniflora*
			2	27° 38.709' N	82° 32.861' W	12	
			3	27° 38.698' N	82° 32.860' W	13	
			4	27° 38.687' N	82° 32.857' W	11	
			5	27° 38.677' N	82° 32.855' W	12	
			6	27° 38.668' N	82° 32.852' W	9	
Cockroach Bay	Salt Marsh	Restored	1	27° 41.581' N	82° 30.586' W	4	Salt marsh was created from shell mine pit and upland field in 1996-1997. Diverse salt marsh with primarily upper marsh species. Transect adjacent to mangrove ditch and salt barren.
			2	27° 41.590' N	82° 30.588' W	30	
			3	27° 41.601' N	82° 30.587' W	48	
			4	27° 41.612' N	82° 30.589' W	34	
			5	27° 41.622' N	82° 30.589' W	29	
			6	27° 41.632' N	82° 30.582' W	29	
Apollo Beach	Salt Marsh	Restored	1	27° 46.804' N	82° 24.277' W	32	Salt marsh created from upland field in 2013 and planted from SERF donor marsh. Sand and shell substrate, difficult to core. Transect was crooked due to irregular shape of salt marsh
			2	27° 46.793' N	82° 24.279' W	21	
			3	27° 46.793' N	82° 24.266' W	17	
			4	27° 46.791' N	82° 24.253' W	6	
			5	27° 46.800' N	82° 24.246' W	16	
			6	27° 46.803' N	82° 24.232' W	6	
Terra Ceia	Salt Barren	Natural	1	27° 34.893' N	82° 35.788' W	15	Very large salt flat with extensive algae growth and bird population on north end. Adjacent to I-275.
			2	27° 34.898' N	82° 35.799' W	85	
			3	27° 34.904' N	82° 35.808' W	49	
			4	27° 34.910' N	82° 35.817' W	49	
			5	27° 34.917' N	82° 35.828' W	49	
			6	27° 34.923' N	82° 35.837' W	49	
TECO Power Plant	Salt Barren	Natural	1	27° 47.145' N	82° 24.287' W	4	Salt barren being overtaken by succulents and mangroves on the edges adjacent to the TECO power plant. Often used for educational activities.
			2	27° 47.146' N	82° 24.298' W	4	
			3	27° 47.146' N	82° 24.310' W	18	
			4	27° 47.147' N	82° 24.322' W	15	
			5	27° 47.147' N	82° 24.334' W	20	
			6	27° 47.149' N	82° 24.346' W	50	
Upper Tampa Bay Park	Salt Barren	Natural	1	28° 00.475' N	82° 37.904' W	18	Salt barren being overtaken by succulents and mangroves on
			2	28° 00.467' N	82° 37.896' W	12	

			3	28° 00.458' N	82° 37.888' W	14	the edges, transect still mostly barren
			4	28° 00.450' N	82° 37.881' W	10	
			5	28° 00.441' N	82° 37.876' W	21	
			6	28° 00.430' N	82° 37.868' W	49	
Shell Point	Salt Barren	Natural	1	27° 43.311' N	82° 28.268' W	16	Mangroves and succulents encroaching on the edges, transect still mostly barren. Many dead standing trees in and around the transect.
			2	27° 43.321' N	82° 28.270' W	50	
			3	27° 43.332' N	82° 28.271' W	48	
			4	27° 43.340' N	82° 28.268' W	46	
			5	27° 43.346' N	82° 28.257' W	46	
			6	27° 43.354' N	82° 28.247' W	28	
Weedon Island	Salt Barren	Natural	1	27° 50.680' N	82° 36.627' W	29	Habitat in midst of conversion from salt barren to salt marsh. Extensive succulent and mangrove growth on the salt flat, very few barren patches left.
			2	27° 50.690' N	82° 36.627' W	38	
			3	27° 50.687' N	82° 36.614' W	48	
			4	27° 50.683' N	82° 36.605' W	18	
			5	27° 50.674' N	82° 36.595' W	40	
			6	27° 50.674' N	82° 36.588' W	4	

a) The *Bishop Harbor restored mangrove* is adjacent to a 2008 hydrologic restoration and new salt marsh. The 2006 image (above left) is from the U.S. Geological survey, the 2015 image (above right) from Google Earth.

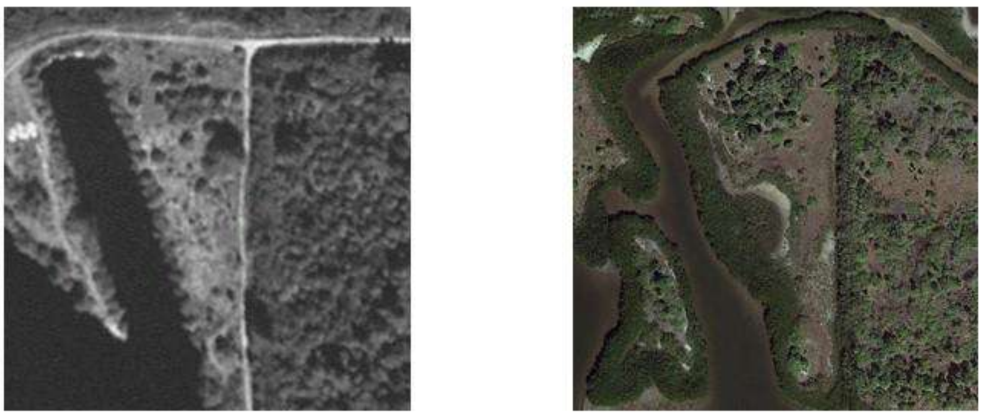


b) The *E. G. Simmons Park restored mangrove* had a 1990 hydrologic restoration and establishment of new mangroves. The 1982 image (above left) is from the University of Florida map and imagery library, the 2015 image (above right) from Google earth.

c) The *Clam Bayou restored mangrove* underwent a hydrologic restoration from 2010 to 2012, including a stormwater retention pond and channel reconfiguration. The 2010 image (above left) and 2015 image (above right) are both from Google earth.

Figure A1. Before and after aerial images of restored mangrove sites.

a) The *Stock Enhancement Research Facility (SERF) restored salt marsh* was created in 1997 adjacent to aquaculture fish ponds. The 1995 image (above left) is from the U.S. Geological survey, the 2015 image (above right) from Google earth.



b) The *Cockroach Bay restored salt marsh* was created from upland in a 1996-1997 restoration project. 1995 image (above left) is from the U.S. Geological survey, the 2015 image (above right) from Google earth.

c) The *Apollo Beach restored salt marsh* was created from upland in 2013. The 2010 image (above left) and 2015 image (above right) are from Google earth.

Figure A2. Before and after aerial images of restored salt marsh sites.

Appendix B. Salt Marsh Allometric Equations

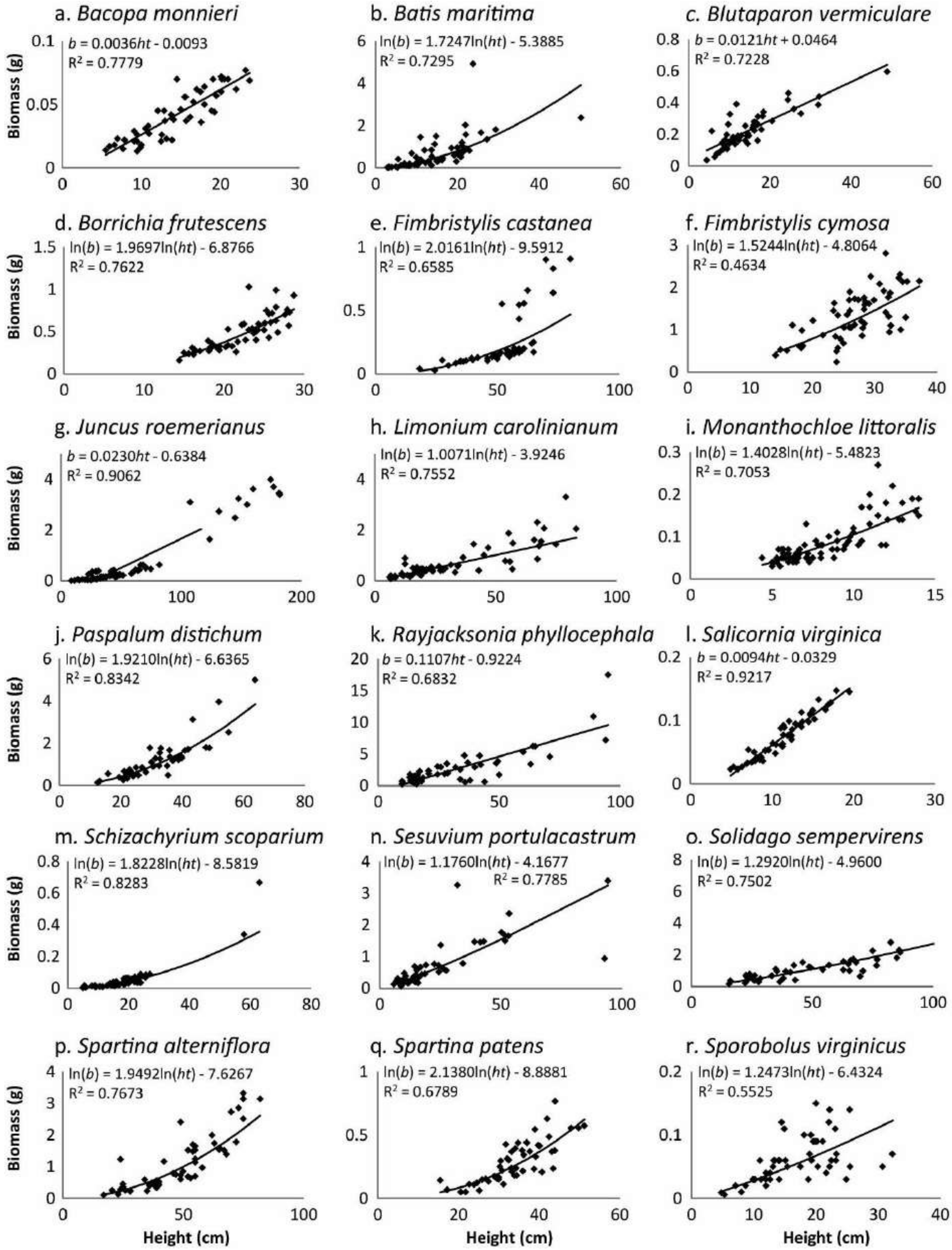


Figure B1. Allometric equations for salt marsh vegetation in Tampa Bay.

APPENDIX D

Gonneea 2016

Tampa Bay carbon burial rates across mangrove and salt marsh ecosystems

Meagan Eagle Gonneea
Woods Hole Coastal & Marine Science Center
U.S. Geological Survey

DRAFT Report to Restore America's Estuaries

March 25, 2016

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1. Field sites

Sites around Tampa Bay were visited on October 19, 20 and 21, 2015 and sediment cores were collected (Figure 1). There were three main vegetation types targeted: salt marsh, dominated by *Juncus* and *Spartina alternaflora*; mangrove, including *Rhizophora mangle, Laguncularia racemosa* and/or *Avicennia germinans*; and young mangrove, where wetlands were created within the last three decades (Table 1). E.G. Simmons park was restored in 1990 (Osland et al., 2012). An additional surface sediment sample was collected from a salt barren, as this site was not conducive to coring.

2. Methods

2.1 Field methods

Sites were co-located with Ryan Moyer's biomass and soil survey. Locations were found using hand-held GPS to locate the transect line used in the survey.

2.1.1 Coring

Sediment cores were taken by pounding 4 inch diameter PVC pipe 20 to 40 cm into the ground. Compaction was monitored by measuring the sediment surface inside and outside the core tube. If compaction was greater than 1 cm (2-3% of total core length), the core was not used. After the core barrel was inserted into the sediment, a rubber gasket and handle was placed over the top and then the core was dug out of the sediment. The gasket allowed the core to be removed without further disturbance. Caps were placed on the top and bottom of each core immediately after collection. The cores were transported upright to the laboratory for further processing. At the salt barren site it was not possible to take a sediment core, so a section of sediment was removed with a shovel, sectioned and bagged in the field. Note at the two restored mangrove sites (E.G. Simmons and Fort de Soto) cores were collected of the organic peat above a compact sand layer, which was not conducive to coring. Thus these cores are only 20-24 cm deep, compared to other cores that were 30-40 cm deep.

2.1.2 Site elevation

Site elevation was evaluated with a differential global positioning system (DGPS). This system uses information from satellites combined with a ground station correction to ideally provide sub-centimeter location accuracy in both the horizontal (latitude, longitude) and vertical (elevation) planes. Briefly, at each site a 3-meter antenna pole was staked at the core location for 20-30 minutes during core collection (Figure 2).

2.2 Laboratory methods

All cores were transported to the U.S. Geological Survey in St. Petersburg, FL, the day of collection and immediately sectioned. Cores were sectioned on a spinning wheel, which was calibrated to push 1 cm of sediment out of the core top (Figure 3). This interval was removed, placed in a labeled whir-pak bag, weighed (wet weight) and frozen. Samples were shipped frozen overnight to the U.S. Geological Survey in Woods Hole, MA, where all further laboratory analysis was done.

2.2.1 Dry bulk density

All sediment samples were kept frozen (-40°C) until freeze dried. Samples were kept in original sample bags and placed in a freeze dryer for 1 week until constant weight was achieved. Samples were immediately weighed (dry weight). Dry bulk density (DBD, g cm^{-3}) was calculated according to:

1) $DBD = \frac{dry\ weight}{sediment\ volume}$

2.2.2 Gamma analysis

Dry sediment samples were homogenized in a blender and placed in labeled plastic counting jars. The samples were then counted on planar germanium gamma detectors (Canberra Industries, model #GS2020S) for 1 to 2 days. The radionuclides ^{210}Pb, ^{214}Pb, ^{7}Be and ^{137}Cs were measured at 46.5, 352, 477.6 and 661.6 KeV gamma-ray peaks, respectively. Lead-214 at 352 KeV is in secular equilibrium with ^{226}Ra, the parent isotope for supported ^{210}Pb. The ^{226}Ra activity was subtracted from the ^{210}Pb activity to determine excess ^{210}Pb according to:

2) $^{210}Pb_{excess} = {}^{210}Pb_{total} - {}^{226}Ra$

The detector efficiency over the 26.5 to 661.6 KeV energy range was calibrated with an Environmental Protection Agency (EPA) pitchblende ore standard in the same geometry as the samples. Correction for self-adsorption on all radionuclides was made based on the geometry of the gamma-counted samples. Results are reported as as dpm per dry weight. Counting errors are calculated as one sigma according to:

3) $\%\ uncertainty = \frac{\sqrt{G+B}}{N} \times 100\%$

where G is gross counts, B is background counts and N is net counts.

2.2.3 Loss on ignition

A fraction of sediment (1 to 10 grams) was weighed, then burned in a muffle furnace for 4 hours at 450°C and reweighed to determine %LOI:

4) $LOI\% = \frac{pre\ weight - post\ weight}{pre\ weight} \times 100\%$

2.2.4 Carbon and nitrogen

Dry sediment was placed in a ball mill and homogenized and ground. A subset of this sample (10-30 µg) was weighed into a silver capsule, moistened and placed in a fuming hydrochloric acid desiccator overnight. The sample was subsequently dried at 60°C and then encapsulated for carbon and nitrogen analysis via a Perkin Elmer 2400 Series II CHNS/O analyzer. Standards, blanks and reference sediment with a known carbon and nitrogen content were run to verify results.

3. Data

3.1 Site elevation

Site elevation data is provided in Table 1. We found that the antenna height was not sufficient to achieve accurate results within the mangrove canopy, therefore elevation data for those sites is not well resolved. One marsh and salt barren sites had much better accuracy for elevation (<1 cm, Table 1). Upper Tampa Bay and Rocky Creek marsh elevations were 91 and 24 cm and the salt barren at 49 cm. Mean sea level at Mckay Bay is -7 cm and mean high water is 20 cm (NOAA tidal datum for station #8726667, tidesandcurrents.noaa.gov). Thus the Rocky Creek marsh likely experiences a greater flooding frequency than the Upper Tampa marsh. The mangrove site elevations were not sufficiently resolved to compare to sea level.

3.2 Dry bulk density

All sites displayed an increase in dry bulk density (DBD) with depth (Figure 4). Generally, the marsh cores surface DBD was 0.5-0.8 g cm^{-3}, increasing to >1 g cm^{-3}. The mangrove sites had much lower DBD, generally 0.1-0.4 g cm^{-3} at the surface, increasing to 0.6-1 g cm^{-3} at depth. Note that the restored sites, E.G. Simmons and Fort de Soto, have sharp increases of density at ~15 cm compared to the older mangrove sites. This may be a result of a change in vegetation and/or sedimentation at this site following restoration work. No duplicates were run in DBD since the entire interval of sediment was used to measure DBD. Also no DBD was determined from the salt barren due to the sampling method.

3.3 Loss on ignition

Samples were run for loss on ignition (%LOI) to determine the operationally-defined organic matter content. %LOI is commonly used as a proxy for organic carbon content, since %LOI is an easy and inexpensive approach. Thus these samples will be used to determine a relationship between %LOI and %C (see section 4.3). Twenty duplicate %LOI sets were run with an average standard deviation of the pairs of 0.8%, which we will use to report uncertainty for %LOI. All LOI data are included in Table 2.

3.4 Carbon and nitrogen

The percent carbon and nitrogen content of sediment samples were determined for approximately 50% of the total sediment samples collected (129 intervals). A reference standard sediment, MESS-2, an estuarine marine sediment, was determined to have a wt%C of 2.16±0.3 and wt%N of 0.20±0.05, compared to published values of 2.15±0.03 and 0.16 respectively. Twenty-five pairs of duplicates were also analyzed with an average standard deviation of 5.5% for carbon and 5.7% for nitrogen, which we will use to report uncertainty for these parameters. All carbon and nitrogen data are included in Table 2.

3.5 Lead-210, radium-226 and cesium-137

The activity of ^{210}Pb, ^{226}Ra and ^{137}Cs was determined at one centimeter intervals for 9 sediment cores, three of each vegetation type: salt marsh, young (restored) mangrove and mature mangrove. For each vegetation type, two of the three cores were from the same location and may be considered "environmental duplicates". In addition, a much coarser (5 cm) ^{210}Pb and ^{226}Ra profile was determined for a salt barren at E.G. Simmons, however there was no excess ^{210}Pb at this site, so no dates were determined. The ^{210}Pb dating method requires use of $^{210}Pb_{excess}$, or the $^{210}Pb_{total}$ activity minus the ^{226}Ra activity. All profiles demonstrated variability in ^{226}Ra activity throughout the profile, thus it is important to determine ^{226}Ra activity for each interval, not just a "background" value to subtract from the entire profile (Figure 5a-c). $^{210}Pb_{excess}$ for each core was used to calculate age and accretion rate (Figure 6a-c). ^{137}Cs was only present in the two Holly House (mature mangrove) cores (Figure 7). Cesium is frequently mobile in organic rich and carbonate sediments, so its efficacy as a dating horizon is minmal in the Tampa Bay setting.

4. Analysis

4.1 Age model

There are two age models that utilize the ^{210}Pb activity of sediment profiles. The first is the constant initial concentration (CIC) model, also referred to as constant flux constant sedimentation rate (CF:CS) model, whereby the initial concentration of ^{210}Pb within the top layer of sediment is assumed to be constant through time, the rate of sedimentation is constant and decay is the only process controlling the down-core activity of ^{210}Pb following:

5) $C_x = C_0 e^{-\lambda t}$

where C_x is the activity at depth x, C_0 is the initial activity, λ is the decay constant of ^{210}Pb (0.03114 y^{-1}) and t is the age. In this model, a plot of the log normalized activity versus depth will result in a linear relationship, with the slope (m) related to the linear sedimentation rate (LSR, mm y^{-1}):

6) $LSR = \lambda m$

This model will yield one LSR per interval where a slope is fitted.

Recognition that the assumption of constant sedimentation rates may not be valid in many environments, particularly those experiencing rapid change, lead to the variant on the advection-decay equation known as the constant rate of supply model (CRS). Again, this model assumes that ^{210}Pb supply to the sediment surface is constant through time, but allows for both changing sedimentation rates and decay to control the down core activity of ^{210}Pb (Goldberg, 1963; Appleby and Oldfield, 1978). The common form of the CRS model as derived by Appleby and Oldfield (1978) solved for age t is:

7) $t = \frac{1}{\lambda} ln \frac{I_0}{I_x}$

where I_0 is the total inventory of ^{210}Pb in the sediment column and I_x is the inventory below depth x. Inventory is the summed ^{210}Pb activity (dpm cm^{-2}) in the entire profile according to:

8) $I_0 = \sum_{x=0}^{n} C_x DBD_x \, i$

where *i* is the interval thickness (length) and n is the depth at which there is no excess ^{210}Pb. MAR is then calculated as:

9) $MAR = \frac{\Delta t}{i} \times DBD$

where the age (t) of the top and bottom of an interval is calculated according to equation 7, i is the interval thickness and DBD is the dry bulk density.

This analysis was performed for each core collected and accretion rates and ages were determined for each 1 cm interval (Figure 8). Surface accretion rates largely ranged between 3 and 6 mm y^{-1}. By 15 cm, this rate had decreased to 1 to 4 mm y^{-1}. There is no statistical difference between accretion rates in the three vegetation types analyzed here. Ovser the past century, accretion rates were very similar for each ecosystem: restored marsh sites (2.5 mm y^{-1}), followed by the salt marshes (2.7 mm y^{-1}) and mature mangroves (3.2 mm y^{-1}) (Figure 9, Table 3).

4.2 Carbon density and accretion rates

To determine the total carbon burial, the mass accretion rates were multiplied by the carbon content of the sediment as follows:

10) $CAR = LSR \times CD$
where LSR is the linear sedimentation rate and CD is the carbon density:
11) $CD = DBD \times wt\%C$
where DBD is the dry bulk density and wt%C is weight percent carbon. Since carbon accretion rates are a product of both the linear sedimentation rate and the carbon density, variability in either or both may result in down core trends. In these cores, there is a strong trend of decreasing accretion rates down core (Figure 8) and a much less pronounced trend in carbon density (Figure 10). Carbon density itself is a product of the dry bulk density and wt%C. Dry bulk density has a strong trend of increasing with depth, while wt%C has a strong decrease with depth, which result in carbon density trends being less pronounced. All together, the strong increase in carbon burial rate at the tops of the cores is largely drive by the accretion rate, not the carbon density (Figure 11). Carbon density is much less in the salt marsh cores (22.5 kg m^{-3}) than in the mangrove (young: 33.2 kg m^{-3} and mature: 32.9 kg m^{-3}, Figure 12, Table 3). The resulting carbon burial rates over the past century thus vary as a function of vegetation type, with mature mangroves burying on average 163 g C m^{-2} y^{-1}, compared to young (restoring) mangroves with an average of 94 g C m^{-2} y^{-1} and the salt marsh with an average of 64 g C m^{-2} y^{-1} (Figure 13, Table 3).

4.3 LOI, DBD and %C relationships

Dry bulk density and LOI are less expensive and require less analytical capacity than measuring carbon, thus correlative relationships between %LOI and %C as well as DBD and %C may be helpful for calculating carbon content based on these other metrics. For this data set the following relationships were found:
12) $wt\%C = 0.501\%LOI + 0.438$
with an average standard error of 2 wt%C and an r^2 of 0.96 (Figure 14).
13) $wt\%C = 31.733e^{-2.694DBD}$
with an average standard error of 5 wt%C and an r^2 of 0.84 (Figure 15). Note however that this relationship becomes less accurate as DBD becomes smaller, i.e. in sediments with high wt%C.

4.4 Conclusions

This study was requested largely to determine 1) carbon burial rates in typical Tampa Bay ecosystems and 2) their resilience to sea level rise. Addressing topic one, in this report we show that accretion rates demonstrate a marked increase at present across all environments. This is likely an ecosystem response to sea level rise, which was 2.59 mm y^{-1} from 1947 to 2014 at the St. Petersburg NOAA tide station (NOAA, tidesandcurrents.noaa.gov, updated with 2014 data). Note that concurrent with this increase in accretion rate is a large decrease in dry bulk density. This change in dry bulk density is greater than that expected due to compaction of organic material and is consistent with greater sand content, although this has not been verified with grain size analysis. This increase in sand content may be indicative of a changing depositional environment through time, thus some of the increase in accretion rate may also be due to changes in the depositional setting, as well as ecosystem response to sea level rise. Since variability in accretion rate drives much of the variability in carbon burial rates, it is important to match both the depositional setting and sea level rise framework for determining carbon burial rates in Tampa Bay. Thus, I recommend considering carbon burial rates over the past fifty years, integrating the same time frame as the sea level rise rate, to determine an accurate rate of carbon burial. Salt marshes bury 71 g C m^{-2} y^{-1}, young (restored) mangroves bury 122 g C m^{-2} y^{-1} and mature mangroves bury 178 g C m^{-2} y^{-1}.

The second goal was to determine resilience to sea level rise. Over the same time frame that sea level rise rates have been determined (1947-2014), all ecosystems demonstrate a rate of accretion that exceeds the 2.59 mm y^{-1} reported for sea level rise: salt marsh 3.1 mm y^{-1}, young (restored) mangrove, 2.9 mm y^{-1} and mature mangrove, 3.5 mm y^{-1}. Thus, these ecosystems are keeping up with sea level rise. In addition, accretion rates at the top of each core all demonstrate increased accretion, with no evidence that accretion rates are slowing. I find no evidence in the accretion rates that these ecosystems are currently stressed by present sea level rise rates.

5. Acknowledgements

Field work was supported by Dr. Ryan Moyer's team at the Florida Fish & Wildlife Institute, St. Petersburg, FL. Dr. Chris Smith at U.S. Geological Survey in St. Pete provided laboratory space and assistance. Dr. Nicole Khan provided laboratory and field assistance.

6. References

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Osland, M.J., A.C. Spivak, J.A. Nestlerode, J.M. Lessmann, A.E. Almario, P.T. Heitmuller, M.J. Russell, K.W. Krauss, F. Alvarez, D.D. Dantin, J.E. Harvey, A.S. From, N. Cormier, C.L. Stagg. 2012. Ecosystem Development after mangrove wetland creation: Plant-soil change across a 20-year chronosequence. Ecosystems 15: 848-866.

7. Figures

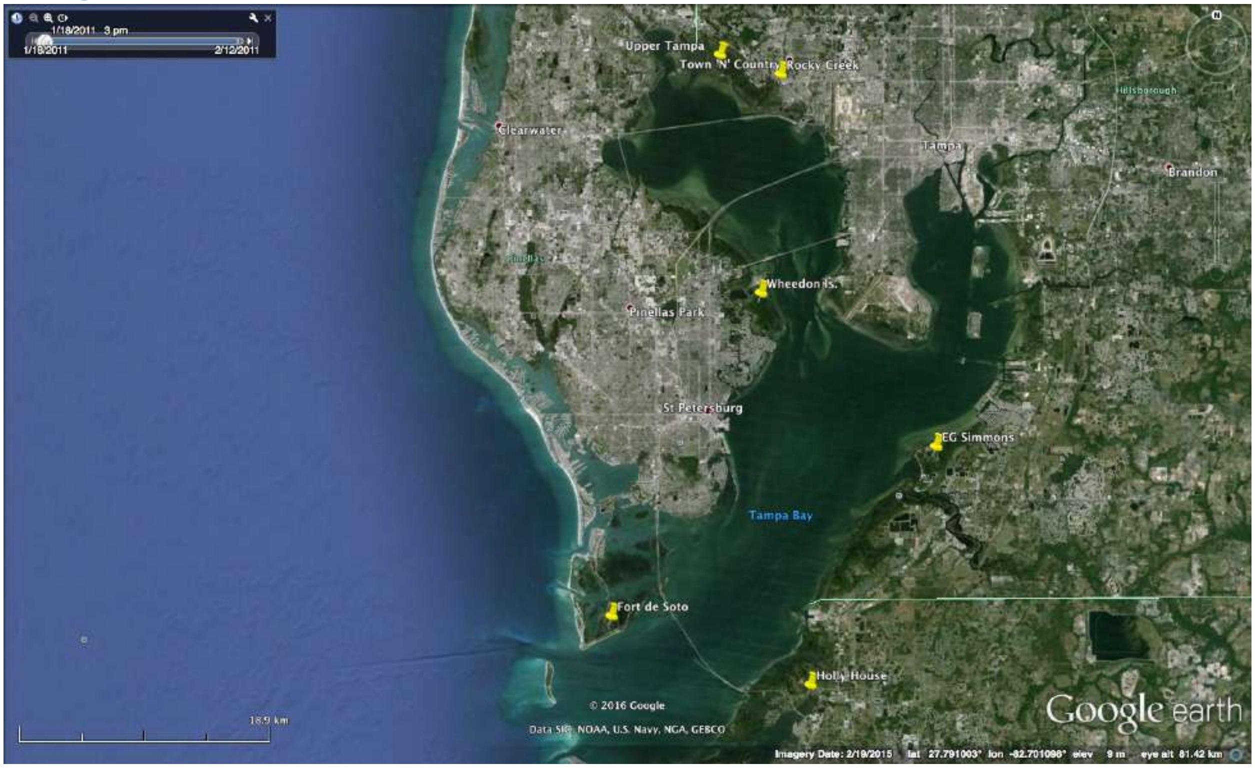

Figure 1: Google Earth map of Tampa Bay field sites.

Figure 2: Differential GPS antenna at Upper Tampa Bay salt barren site and E.G. Simmons mangrove site. Antenna is clearly below the canopy at the mangrove site.

Figure 3: Spinning core extraction wheel and close up of 1 cm interval ready to be sliced off core.

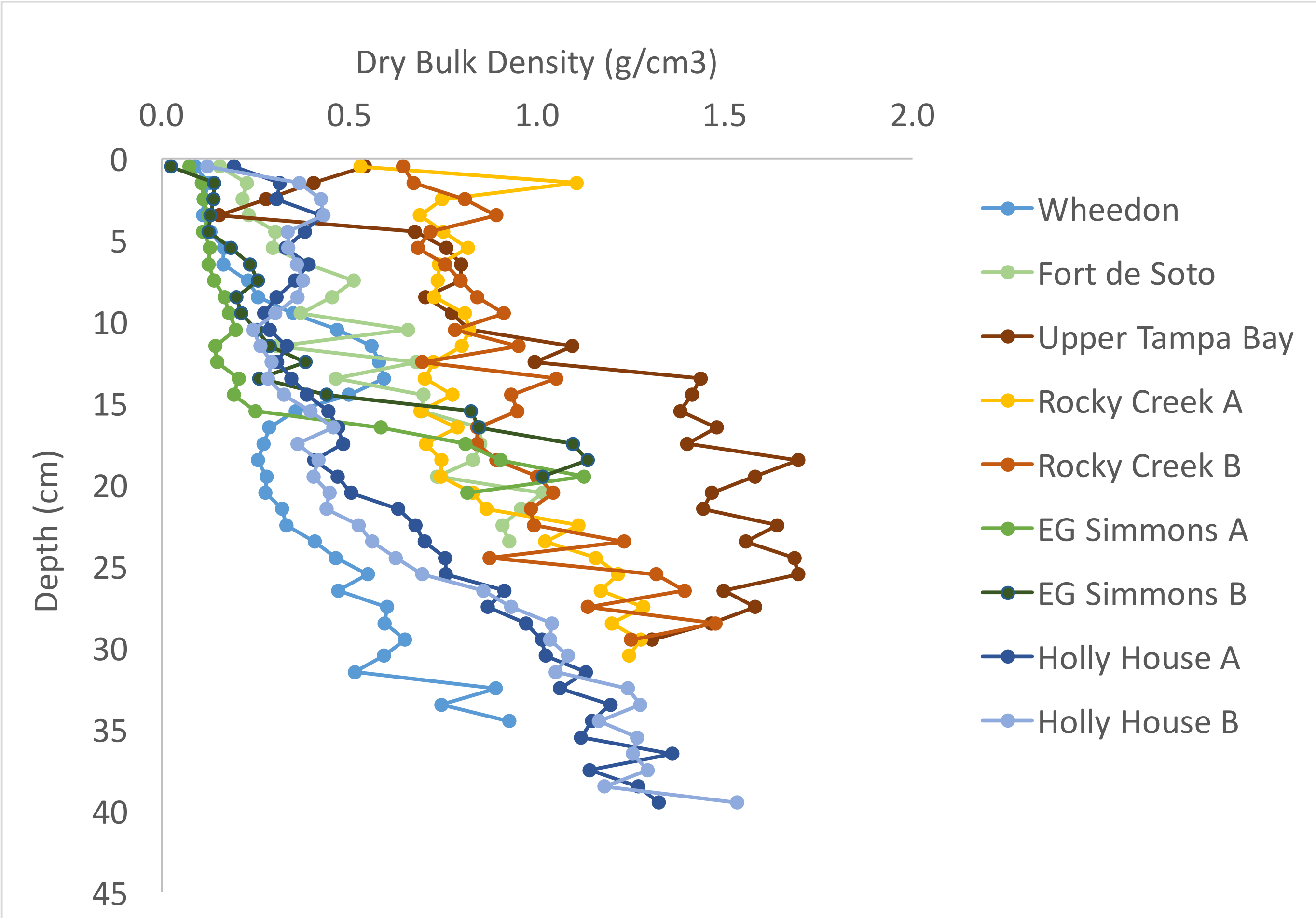

Figure 4: Dry bulk density for all cores. Blues: Mangrove, Greens: Restored mangrove and Oranges: marsh. All cores demonstrate a trend of increasing dry bulk density with depth.

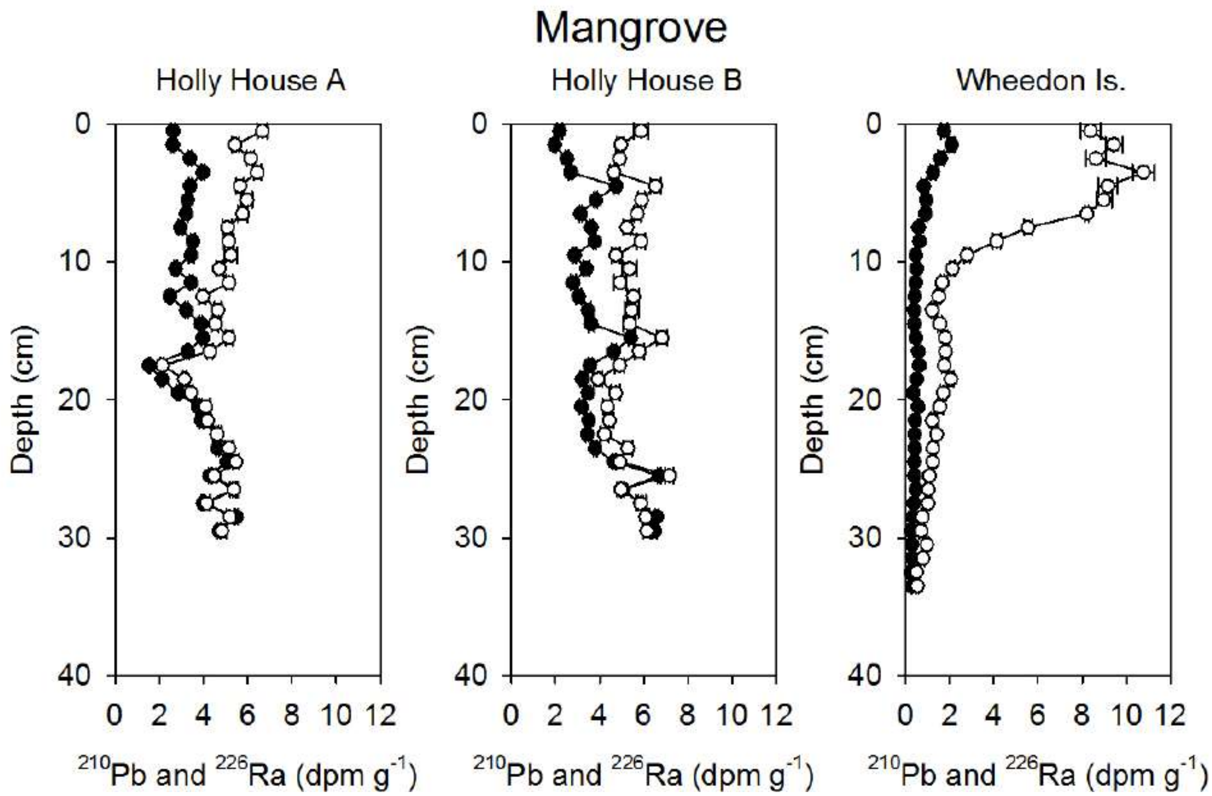

Figure 5a: 210Pb and 226Ra for three mangrove cores. Holly House A and B are "environmental duplicate" cores collected in close proximity. ^{210}Pb (empty) and ^{226}Ra (filled).

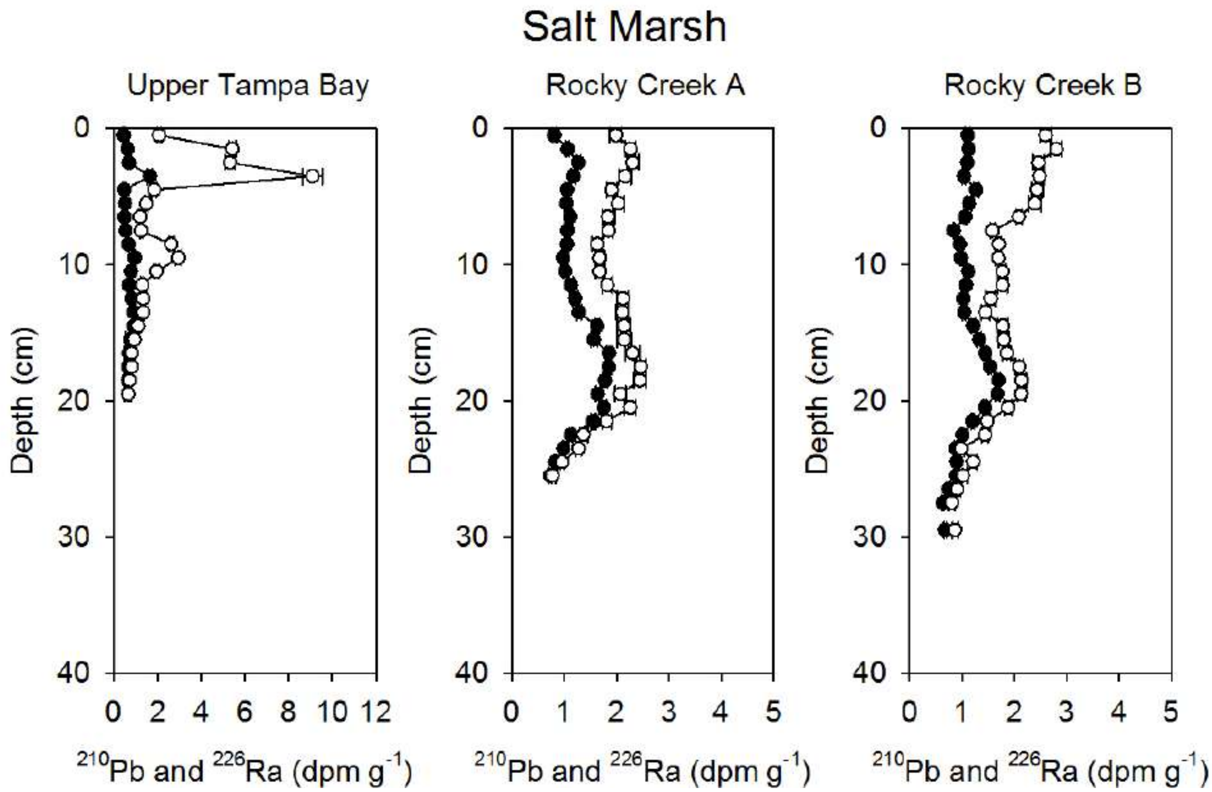

Figure 5b: 210Pb and 226Ra for three salt marsh cores. Rocky Creek A and B are "environmental duplicate" cores collected in close proximity. ^{210}Pb (empty) and ^{226}Ra (filled).

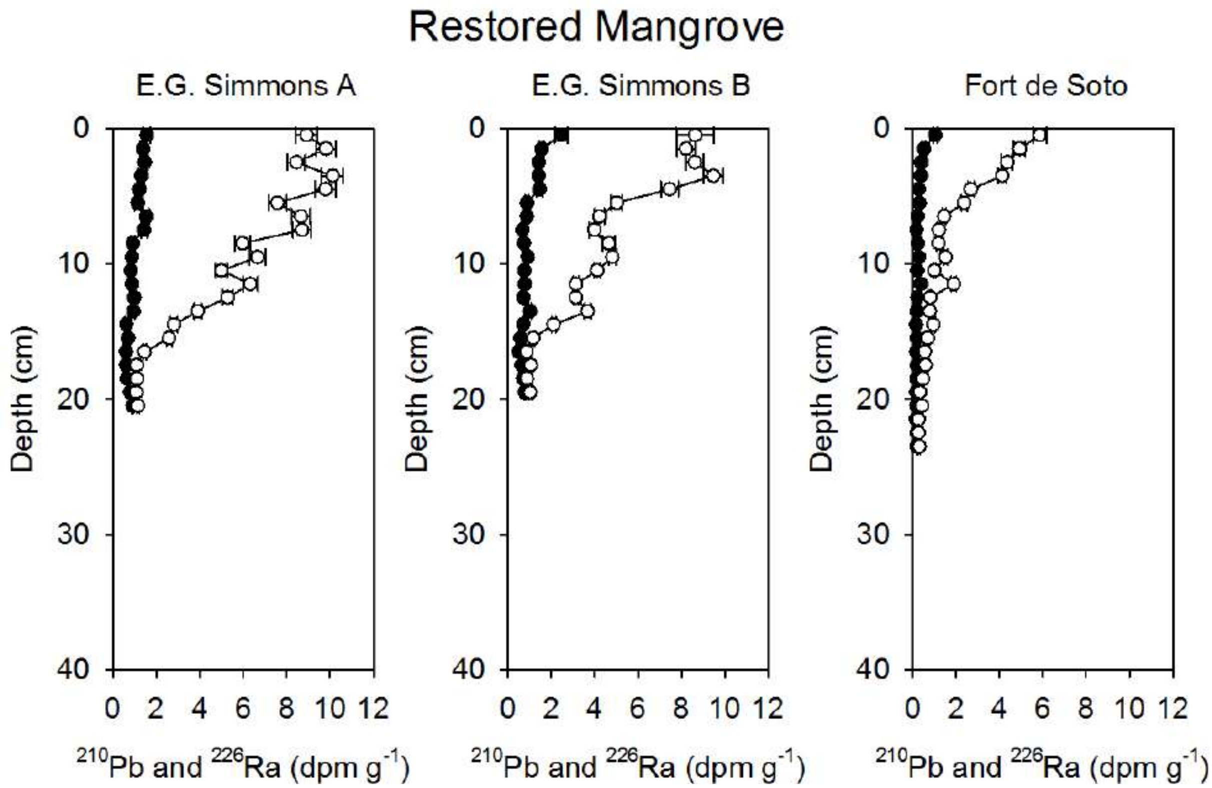

Figure 5c: 210Pb and 226Ra for three young (restored) mangrove cores. E.G. Simmons A and B are "environmental duplicate" cores collected in close proximity. ^{210}Pb (empty) and ^{226}Ra (filled).

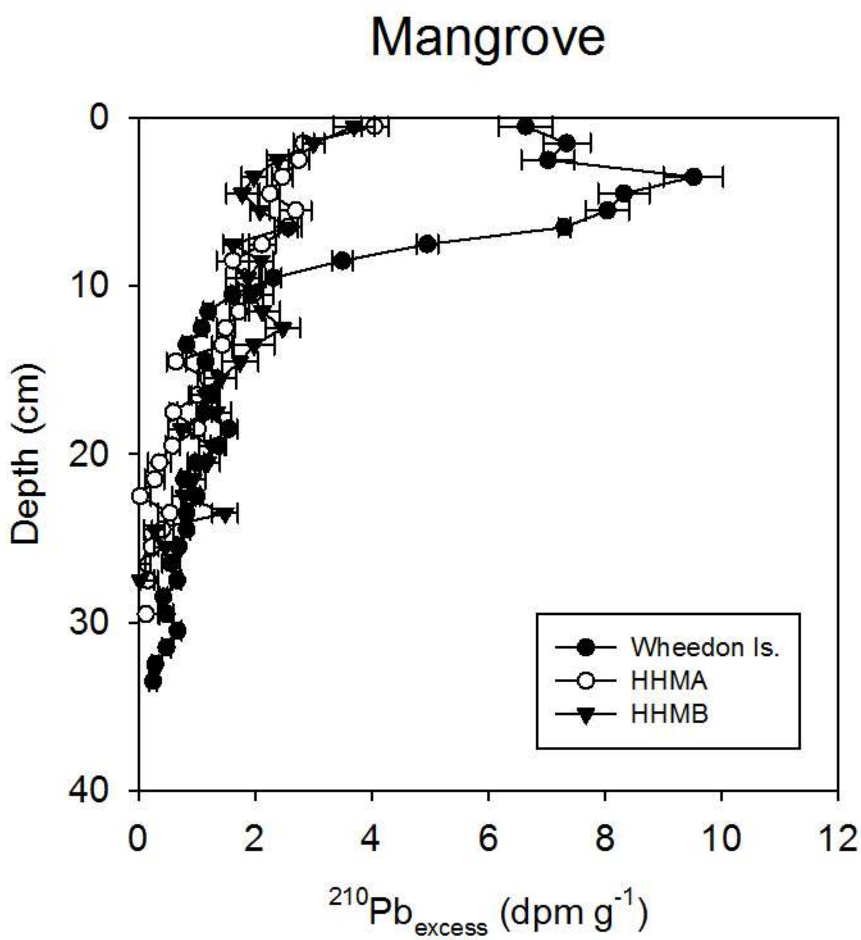

Figure 6a: 210Pbexcess for the three mangrove cores.

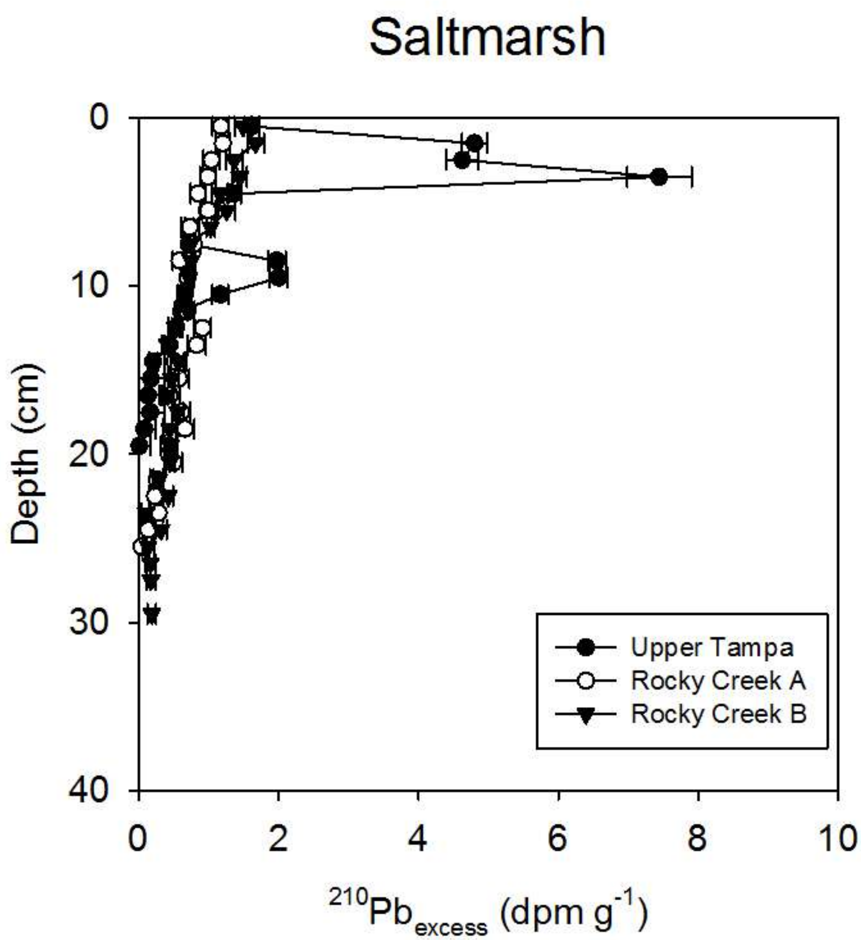

Figure 6b: 210Pbexcess for the three salt marsh cores.

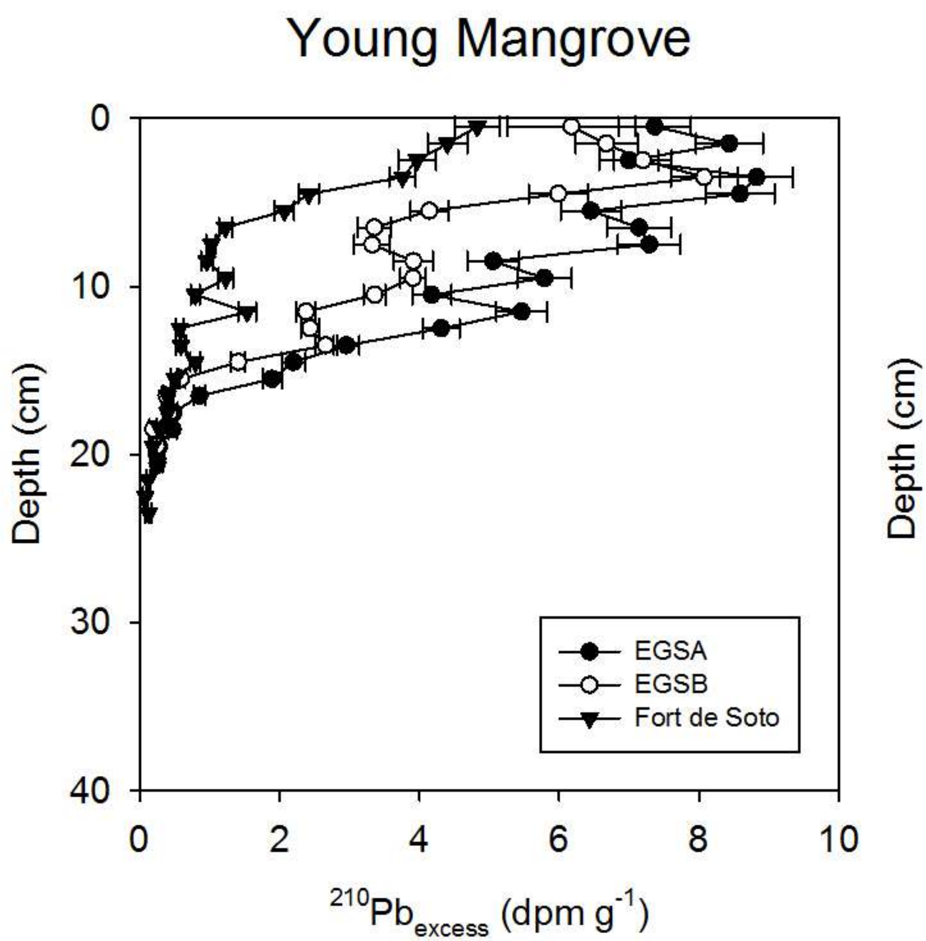

Figure 6c: 210Pbexcess for the three young (restored) mangrove cores.

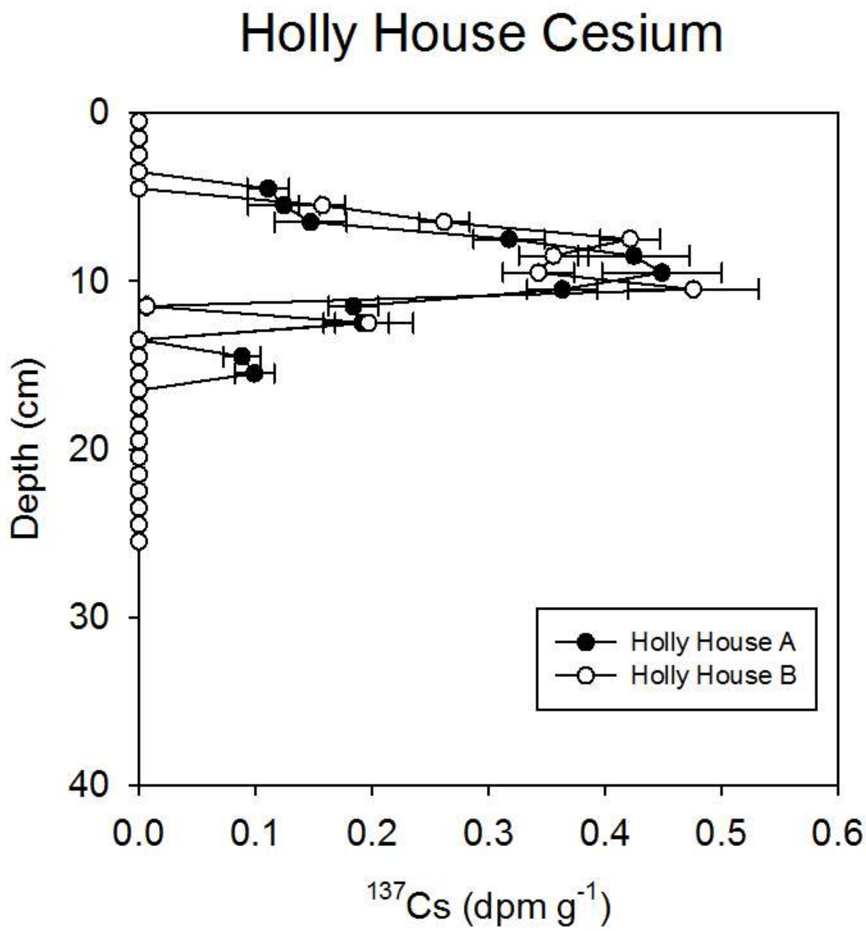

Figure 7: 137Cs peaks were observed in the 2 cores from the Holy House mangrove site, with good reproducibility between the duplicate cores.

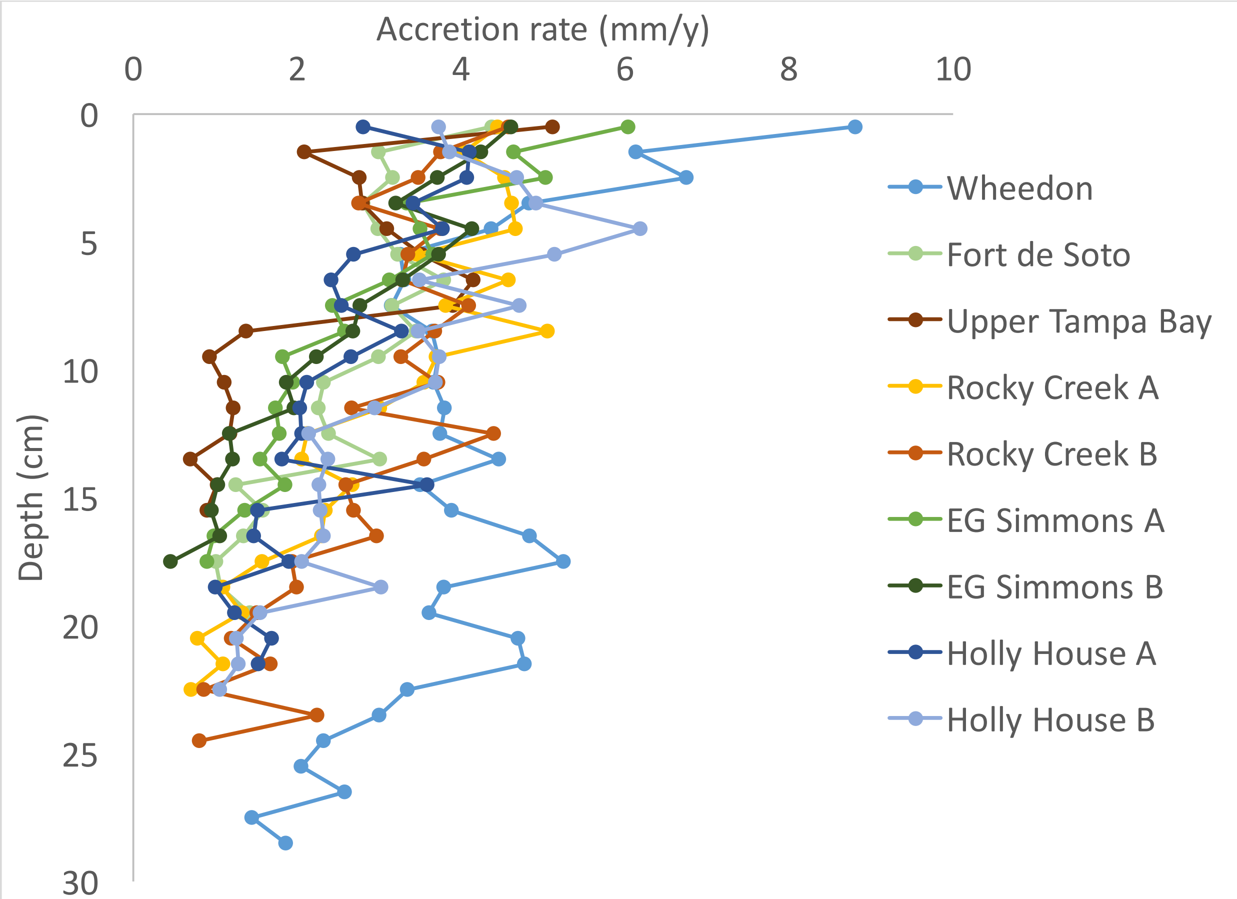

Figure 8: Accretion rate versus depth for all cores. Blues: Mangrove, Greens: Restored mangrove and Oranges: marsh. All cores show a trend of increasing accretion towards the top of the core.

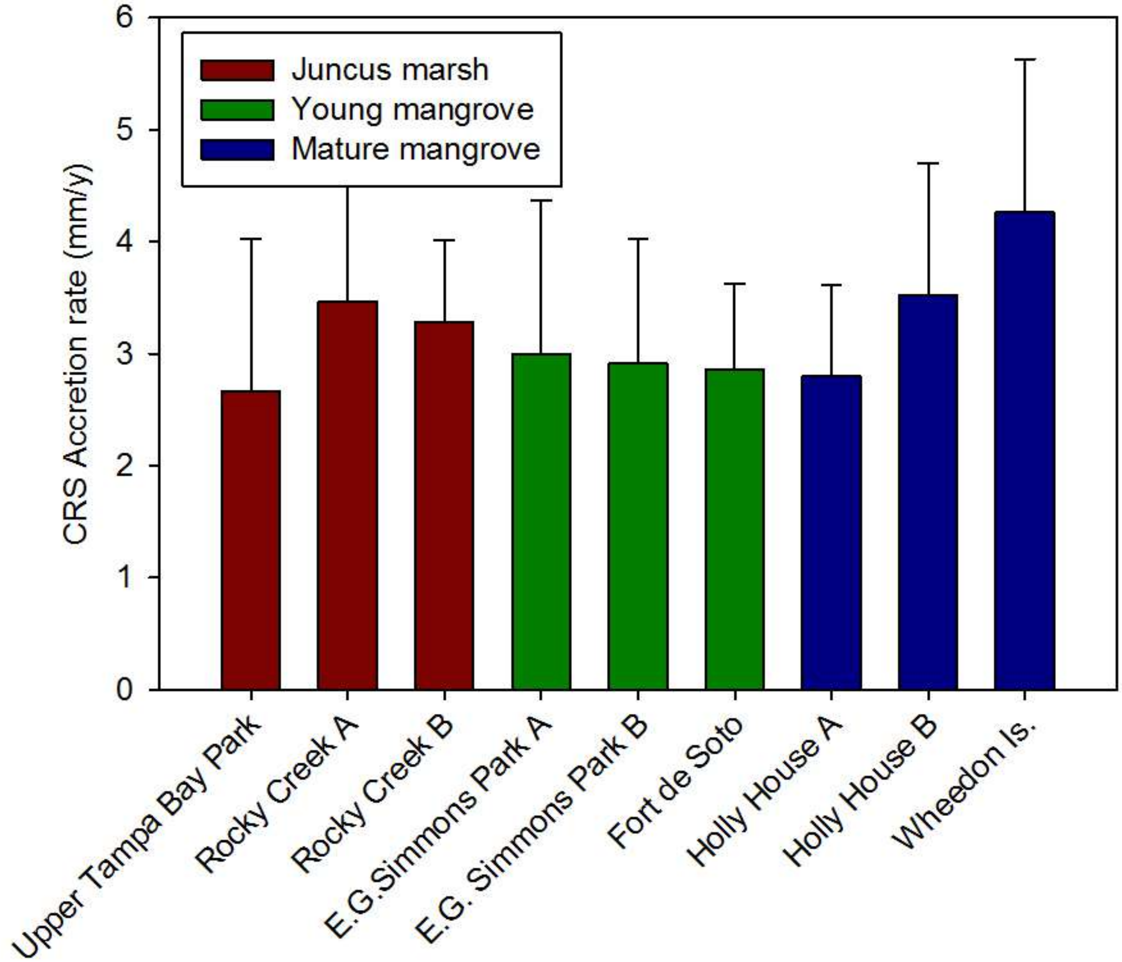

Figure 9: Accretion rate at each site since 1950 calculated according to equation 7. Standard deviation is noted by error bars.

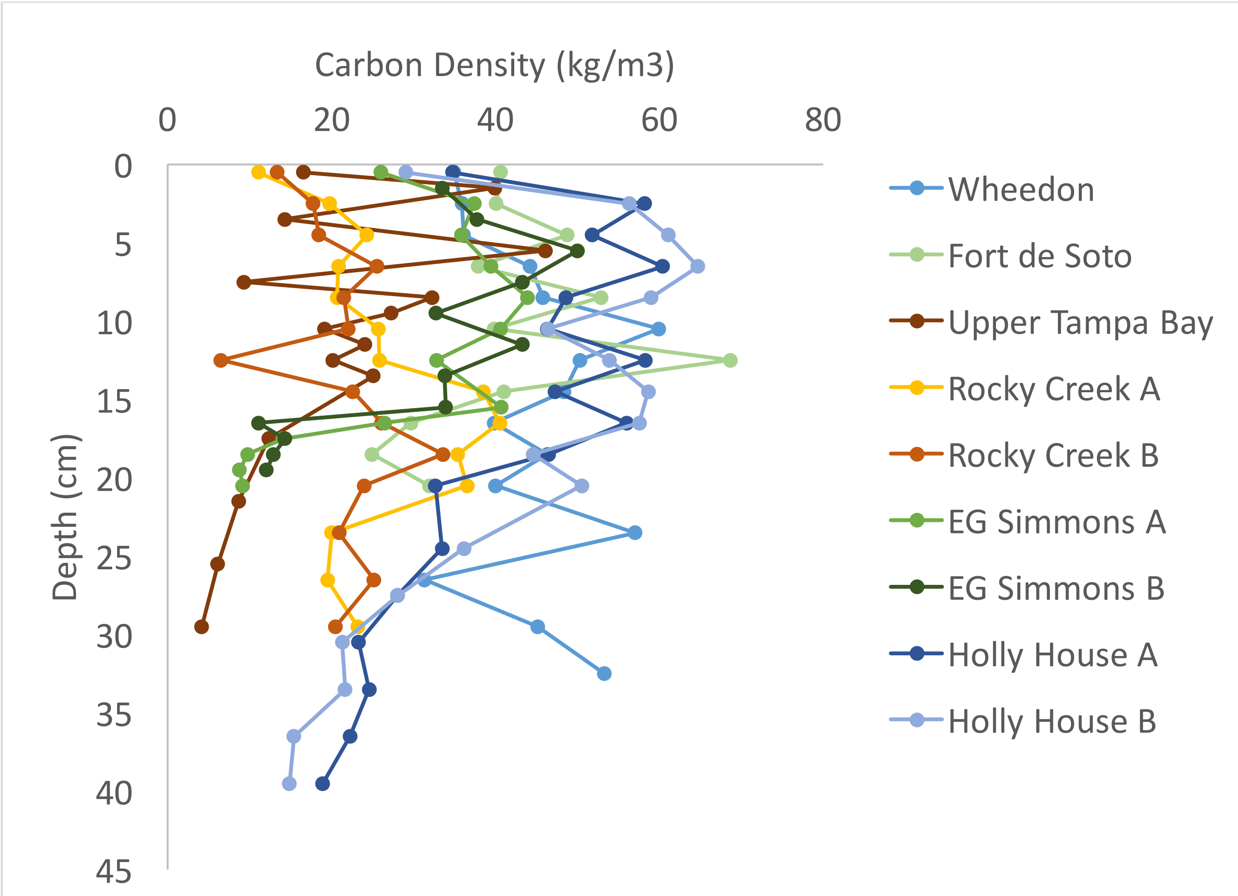

Figure 10: Carbon density versus depth for all 9 cores. Blues: Mangrove, Greens: Restored mangrove and Oranges: marsh. Note the depth trends are much less pronounced that DBD or wt%C.

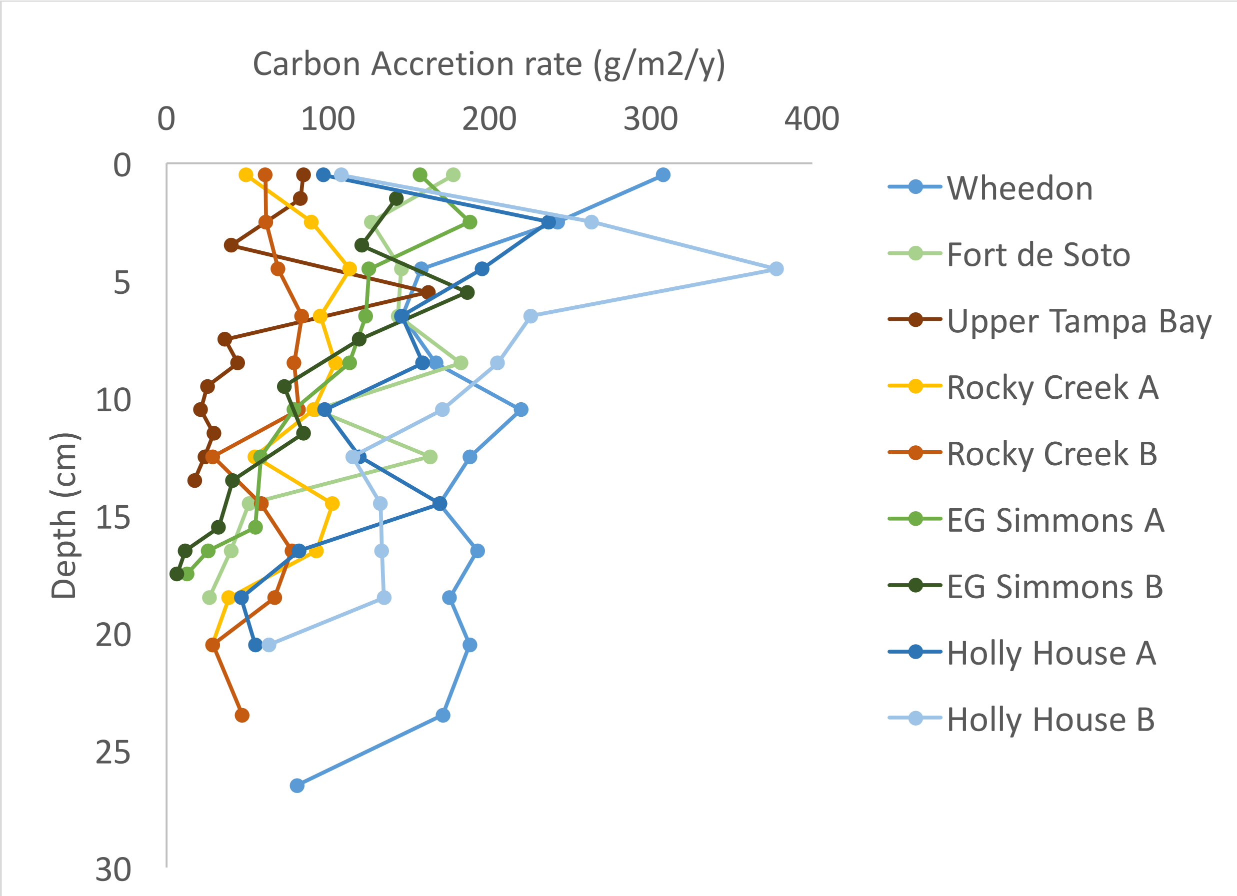

Figure 11: Carbon accretion rate versus depth for all 9 cores. Blues: Mangrove, Greens: Restored mangrove and Oranges: marsh. Carbon accretion is highest at the surface, largely due to high linear accretion rates.

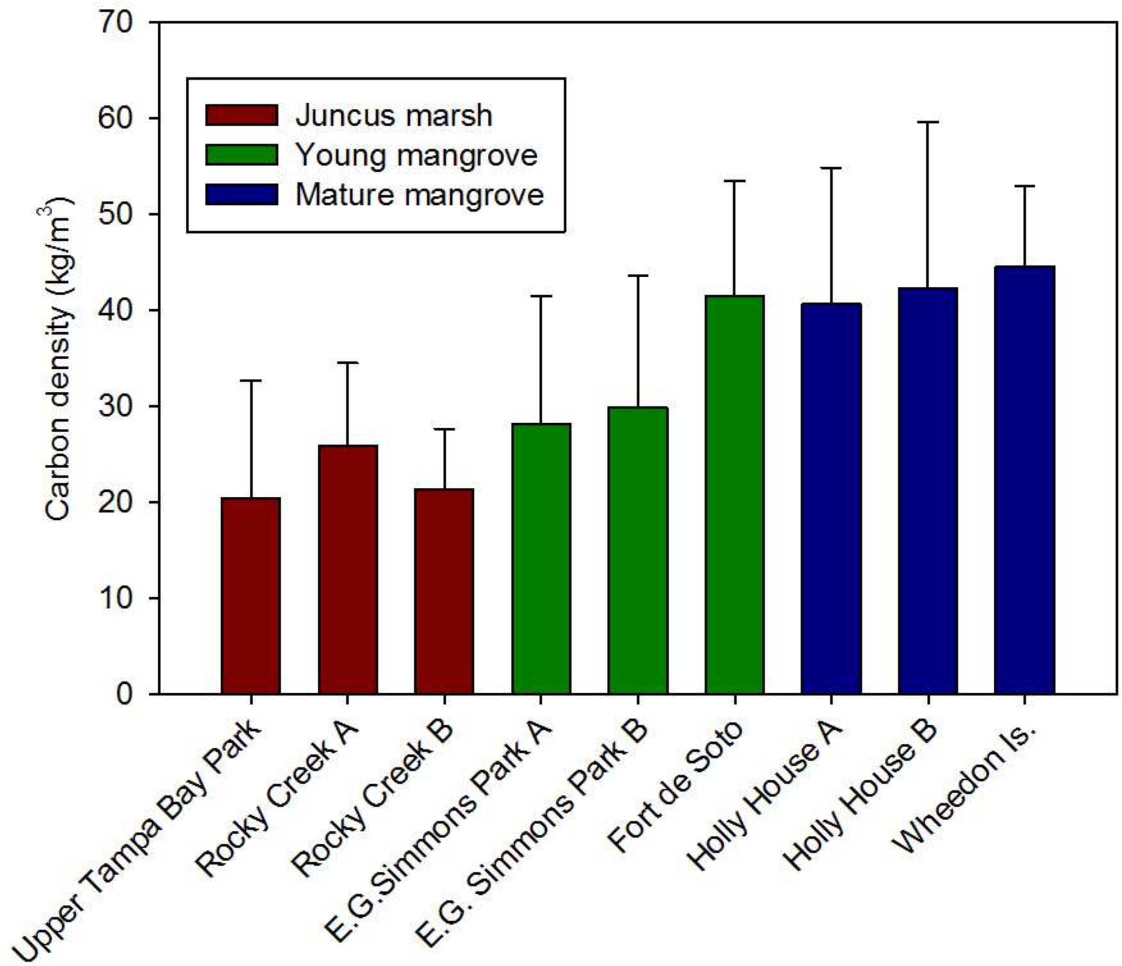

Figure 12: Average carbon density at each site since 1950. Standard deviation is noted by error bars.

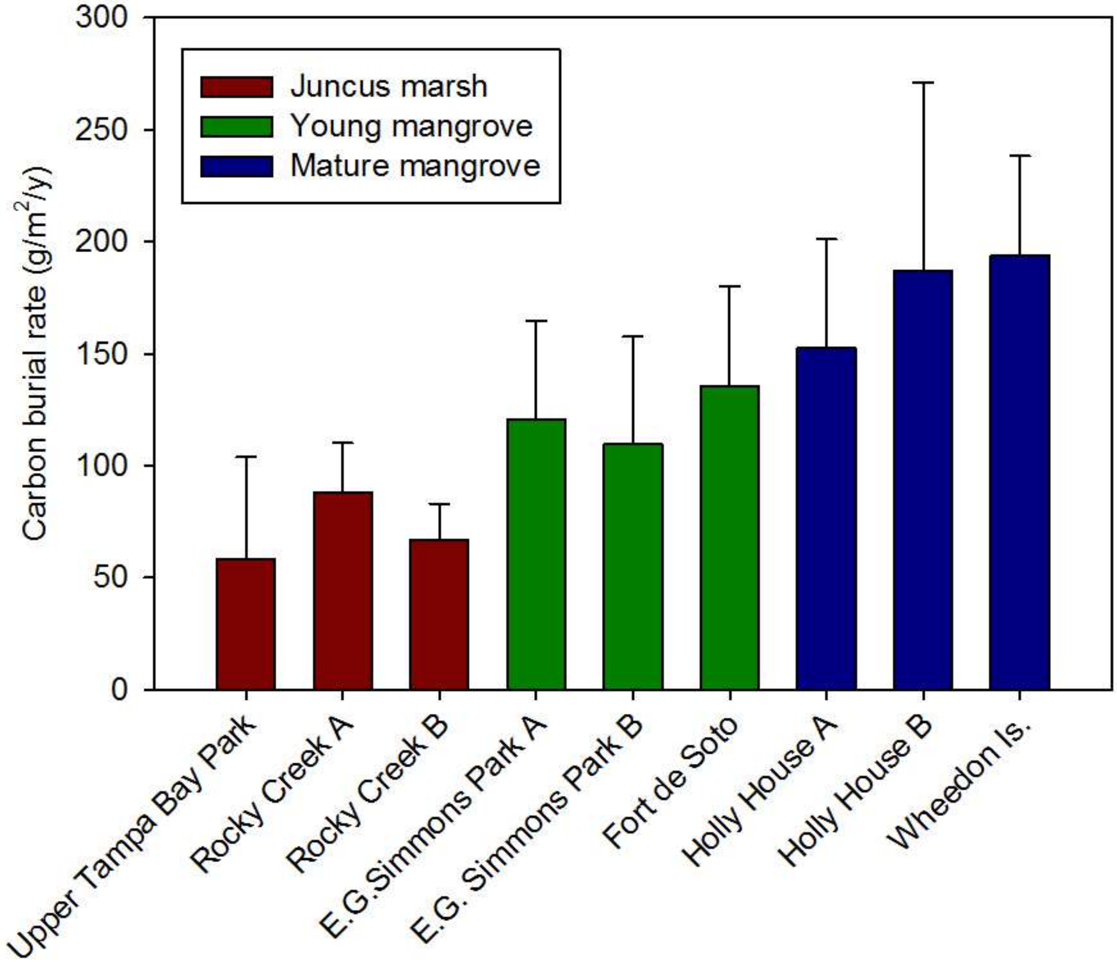

Figure 13: Average carbon burial at each site for the past 50 years. Standard deviation is noted by error bars.

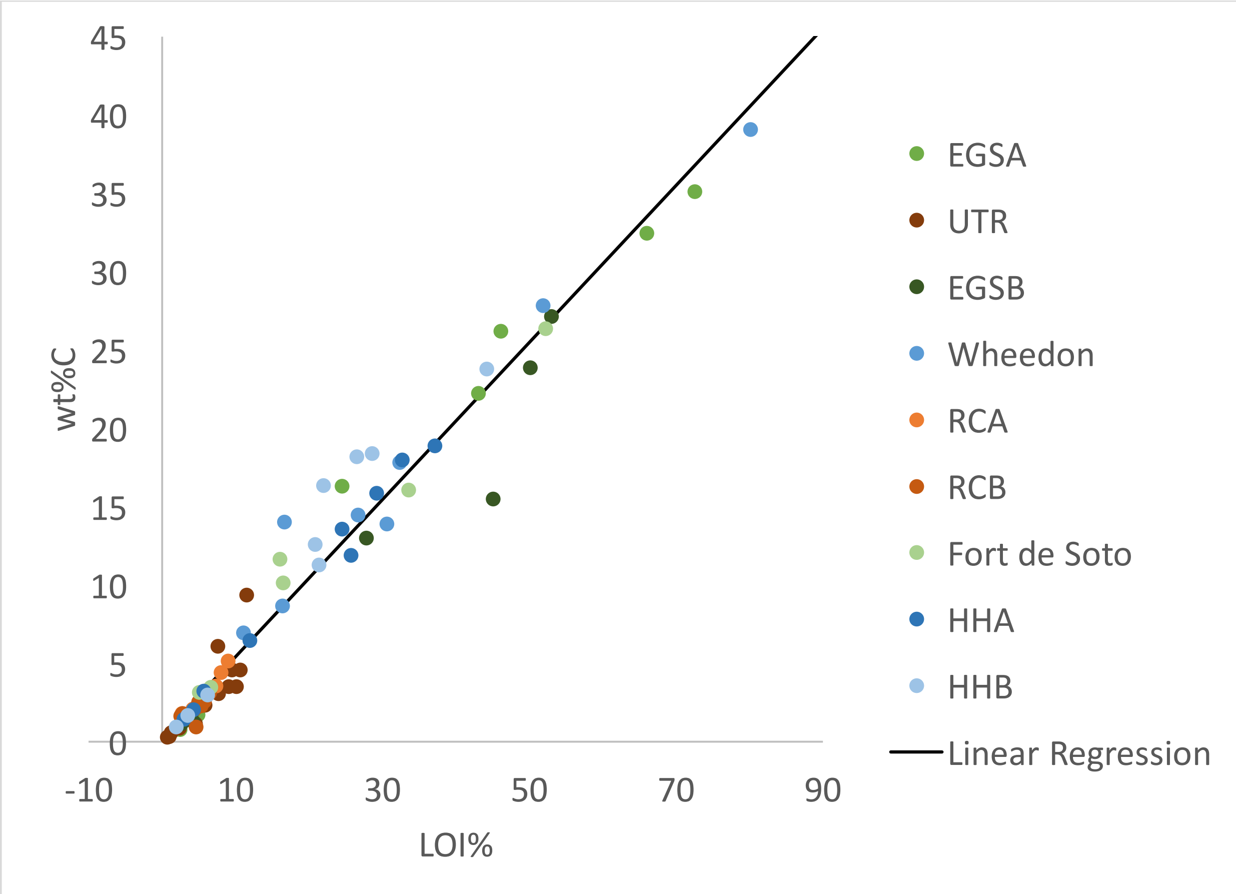

Figure 14: Linear regression between %LOI and wt%C: $wt\%C = 0.501\%LOI + 0.438$ with an average standard error of 2 wt%C and an r^2 of 0.96.

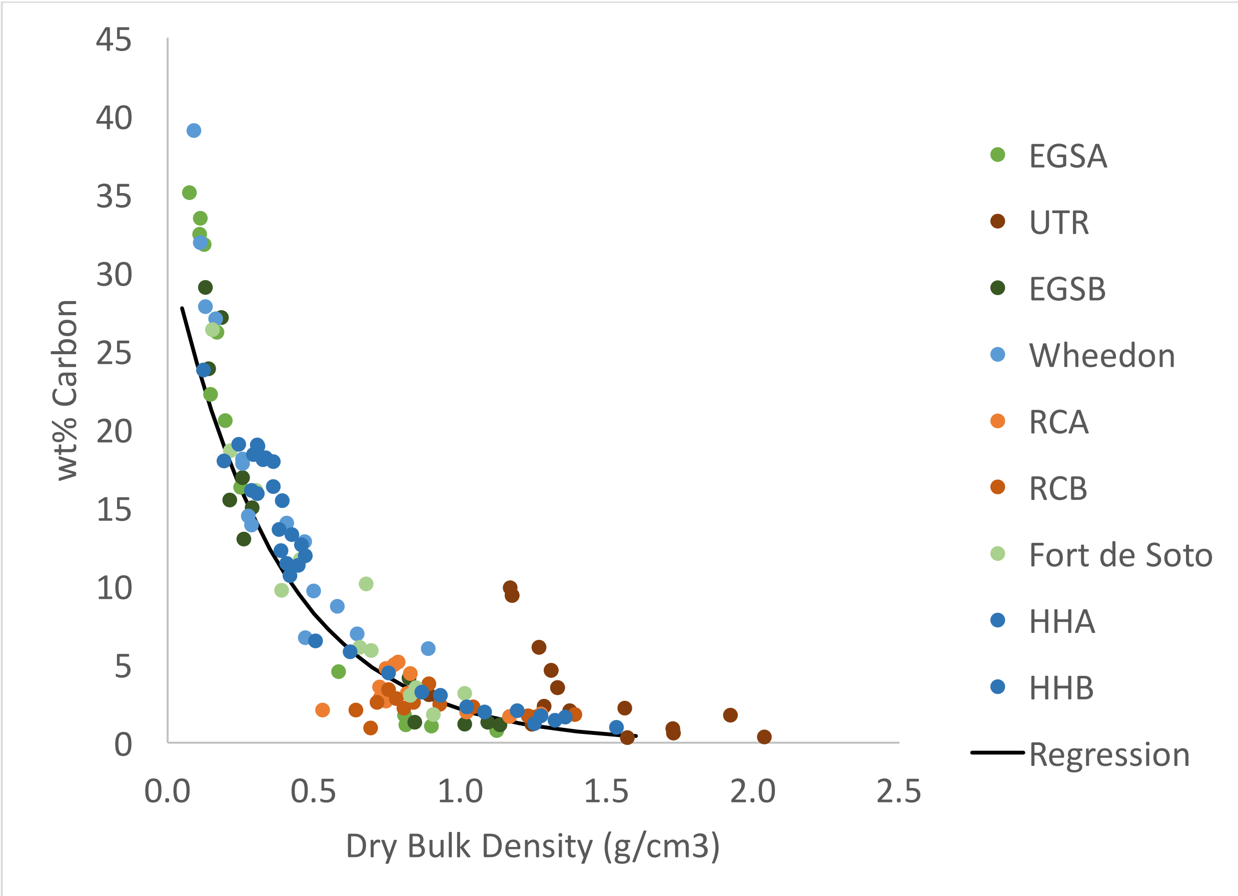

Figure 15: Exponential regression between dry bulk density and wt%Carbon: $wt\%C = 31.733e^{-2.694DBD}$, with an average standard error of 5 wt%C and an r^2 of 0.84

6. Data Tables

Table 1: Site vegetation, location and elevation.

Site	Vegetation	Latitude (N)	Longitude (W)	Elevation NAVD88 (cm)	Horizontal Accuracy (cm)	Vertical accuracy (cm)
Upper Tampa Bay	Salt barren	28.007596	82.631427	49.1	0.3	0.4
Upper Tampa Bay	Juncus marsh	28.007103	82.633002	90.8	6	7.1
Rocky Creek	Juncus marsh	27.993991	82.586612	23.7	0.3	0.6
E.G. Simmons	Young Mangrove	27.742156	82.467600	146.2	182.7	205.3
Fort de Soto	Young Mangrove	27.627500	82.715883	-77.1	136.6	251.2
Holly House	Mangrove	27.580827	82.563715	-23.3	7.9	9.7
Weedon Is	Mangrove	27.846063	82.601500	-12.9	44.6	59.7

Table 2: E.G. Simmons Core A radionuclides and age model

EGSA Depth interval midpoint (cm)	226Ra (dpm/g)	226Ra uncertainty (dpm/g)	210Pb (dpm/g)	210Pb uncertainty (dpm/g)	210Pbexcess (dpm/g)	210Pbexcess uncertainty (dpm/g)	CRS Age (years)	CRS Date uncertainty	CRS Date	CRS AR (mm/y)	CIC model AR (mm/y)	CIC model AR depth interval
0.5	1.5	0.2	8.9	0.5	7.4	0.5	1.7	1	2014	6.0	4.0	0-13
1.5	1.4	0.1	9.8	0.5	8.4	0.5	3.8	2	2012	4.6	0.8	13-20
2.5	1.5	0.1	8.4	0.4	7.0	0.4	5.8	2	2010	5.0		
3.5	1.3	0.1	10.1	0.5	8.8	0.5	8.8	2	2007	3.3		
4.5	1.2	0.1	9.8	0.5	8.6	0.5	11.7	2	2004	3.5		
5.5	1.1	0.1	7.6	0.4	6.5	0.4	14.4	2	2001	3.7		
6.5	1.5	0.1	8.7	0.4	7.1	0.5	17.6	2	1998	3.1		
7.5	1.4	0.1	8.7	0.4	7.3	0.5	21.7	2	1994	2.4		
8.5	0.9	0.1	6.0	0.4	5.1	0.4	25.6	3	1990	2.6		
9.5	0.9	0.1	6.7	0.4	5.8	0.4	31.1	3	1985	1.8		
10.5	0.8	0.1	5.0	0.3	4.2	0.3	36.2	4	1980	1.9		
11.5	0.9	0.1	6.3	0.4	5.5	0.4	42.0	5	1974	1.7		
12.5	1.0	0.1	5.3	0.2	4.3	0.3	47.6	5	1968	1.8		
13.5	0.9	0.1	3.9	0.2	3.0	0.2	54.1	7	1962	1.5		
14.5	0.6	0.1	2.8	0.2	2.2	0.2	59.5	8	1956	1.9		
15.5	0.7	0.0	2.6	0.1	1.9	0.1	66.9	10	1949	1.4		
16.5	0.6	0.0	1.4	0.1	0.9	0.1						
17.5	0.6	0.0	1.1	0.1	0.5	0.1						
18.5	0.6	0.0	1.1	0.1	0.5	0.1						
19.5	0.8	0.0	1.1	0.1	0.3	0.1						
20.5	0.9	0.0	1.1	0.1	0.3	0.1						

Table 2: E.G. Simmons Core A soil carbon and DBD

EGSA Depth interval midpoint (cm)[2]	Water content (%)[3]	Dry bulk density (g/cm3)[4]	%Carbon	%Nitrogen	%LOI	Carbon density (kg/m3)	CRS Carbon burial rate (g/m2/y)
0.5	87%	0.074	35.1	1.5	72.5	26.0	157
1.5	88%	0.107					
2.5	87%	0.112	33.5	1.4		37.4	188
3.5	87%	0.124					
4.5	86%	0.111	32.5	1.4	66.0	35.9	125
5.5	85%	0.129					
6.5	85%	0.124	31.8	1.3		39.5	123
7.5	86%	0.140					
8.5	83%	0.168	26.2	1.2	46.2	43.9	113
9.5	83%	0.180					
10.5	82%	0.198	20.6	0.9		40.7	79
11.5	84%	0.143					
12.5	83%	0.147	22.3	0.9	43.1	32.8	58
13.5	78%	0.205					
14.5	74%	0.192					
15.5	71%	0.250	16.3	0.6	24.5	40.7	55
16.5	51%	0.583	4.5	0.2		26.5	26
17.5	38%	0.809	1.7	0.1	4.8	14.1	13
18.5	31%	0.902	1.1	0.1		9.7	
19.5	28%	1.125	0.8	0.0	2.5	8.8	
20.5	31%	0.814	1.1	0.0		9.2	

Table 2: E.G. Simmons Core B radionuclides and age model

EGSB Depth interval midpoint (cm)	226Ra (dpm/g)	226Ra uncertainty (dpm/g)	210Pb (dpm/g)	210Pb uncertainty (dpm/g)	210Pbexcess (dpm/g)	210Pbexcess uncertainty (dpm/g)	CRS Age (years)	CRS Date uncertainty	CRS Date	CRS AR (mm/y)	CIC model AR (mm/y)	CIC model AR depth interval
0.5	2.5	0.3	8.6	0.9	6.2	0.9	2.2	1.7	2013.7	4.6	2.9	0-13
1.5	1.5	0.1	8.2	0.4	6.7	0.4	4.5	1.8	2011.4	4.2	0.7	13-20
2.5	1.4	0.1	8.6	0.4	7.2	0.4	7.2	1.9	2008.7	3.7		
3.5	1.4	0.1	9.5	0.5	8.1	0.5	10.3	2.0	2005.5	3.2		
4.5	1.5	0.1	7.4	0.4	6.0	0.4	12.8	2.1	2003.1	4.1		
5.5	0.9	0.1	5.0	0.3	4.1	0.3	15.4	2.3	2000.4	3.7		
6.5	0.9	0.1	4.2	0.2	3.4	0.2	18.5	2.5	1997.4	3.3		
7.5	0.7	0.1	4.0	0.2	3.3	0.3	22.1	2.7	1993.8	2.8		
8.5	0.7	0.1	4.6	0.3	3.9	0.3	25.8	3.0	1990.1	2.7		
9.5	0.9	0.1	4.8	0.2	3.9	0.2	30.3	3.4	1985.6	2.2		
10.5	0.7	0.0	4.1	0.1	3.4	0.2	35.7	4.0	1980.2	1.9		
11.5	0.8	0.0	3.1	0.1	2.4	0.1	40.8	4.7	1975.1	2.0		
12.5	0.7	0.0	3.1	0.1	2.4	0.1	49.3	6.1	1966.6	1.2		
13.5	1.0	0.1	3.7	0.2	2.7	0.2	57.6	7.9	1958.3	1.2		
14.5	0.7	0.0	2.1	0.1	1.4	0.1	67.3	10.7	1948.6	1.0		
15.5	0.6	0.0	1.2	0.1	0.6	0.1	77.9	14.9	1938.0	0.9		
16.5	0.5	0.0	0.9	0.1	0.4	0.1	87.4	20.1	1928.5	1.1		
17.5	0.6	0.0	1.1	0.1	0.4	0.1						
18.5	0.7	0.0	0.9	0.1	0.2	0.1						
19.5	0.8	0.0	1.0	0.1	0.2	0.1						

Table 2: E.G. Simmons Core B soil carbon and DBD

EGSB Depth interval midpoint (cm)	Water content (%)	Dry bulk density (g/cm3)	%Carbon	%Nitrogen	%LOI	Carbon density (kg/m3)	CRS Carbon burial rate (g/m2/y)
0.5	91%	0.02					
1.5	86%	0.14	23.9	1.5	50.1	33.5	142
2.5	85%	0.14					
3.5	86%	0.13	29.1	1.6		37.8	121
4.5	85%	0.12					
5.5	81%	0.18	27.1	1.1	53.0	50.0	186
6.5	76%	0.24					
7.5	72%	0.26	16.9	0.7		43.3	119
8.5	78%	0.20					
9.5	78%	0.21	15.5	0.7	45.1	32.7	73
10.5	74%	0.25					
11.5	73%	0.29	15.0	0.6		43.3	85
12.5	67%	0.38					
13.5	76%	0.26	13.0	0.6	27.8	33.8	41
14.5	63%	0.44					
15.5	47%	0.82	4.1	0.2		34.0	32
16.5	38%	0.85	1.3	0.1	4.2	11.1	12
17.5	31%	1.09	1.3	0.1		14.3	6
18.5	30%	1.13	1.1	0.1	2.6	12.9	
19.5	33%	1.01	1.2	0.1		12.1	

Table 2: Weedon Is. radionuclides and age model

Weedon Is. Depth interval midpoint (cm)	226Ra (dpm/g)	226Ra uncertainty (dpm/g)	210Pb (dpm/g)	210Pb uncertainty (dpm/g)	210Pbexcess (dpm/g)	210Pbexcess uncertainty (dpm/g)	CRS Age (years)	CRS Date uncertainty	CRS Date	CRS AR (mm/y)	CIC model AR (mm/y)	CIC model AR depth interval
0.5	1.7	0.1	8.4	0.4	6.6	0.5	1.2	1.2	2014.7	8.3	2.6	0-30
1.5	2.1	0.1	9.4	0.4	7.3	0.4	2.9	1.2	2012.9	5.8		
2.5	1.6	0.1	8.6	0.4	7.0	0.5	4.5	1.3	2011.4	6.3		
3.5	1.3	0.1	10.8	0.5	9.5	0.5	6.7	1.4	2009.1	4.5		
4.5	0.8	0.1	9.2	0.4	8.3	0.4	9.2	1.5	2006.7	4.1		
5.5	0.9	0.1	9.0	0.4	8.0	0.4	12.5	1.6	2003.3	3.0		
6.5	0.9	0.1	8.2	0.1	7.3	0.1	15.8	1.8	2000.0	3.0		
7.5	0.6	0.0	5.5	0.2	5.0	0.2	19.4	1.9	1996.5	2.9		
8.5	0.6	0.0	4.1	0.2	3.5	0.2	22.4	2.1	1993.5	3.3		
9.5	0.5	0.0	2.8	0.1	2.3	0.1	25.4	2.3	1990.4	3.3		
10.5	0.5	0.0	2.1	0.1	1.6	0.1	28.5	2.5	1987.3	3.2		
11.5	0.5	0.0	1.7	0.1	1.2	0.1	31.6	2.8	1984.3	3.3		
12.5	0.4	0.0	1.5	0.1	1.1	0.1	34.7	3.1	1981.2	3.2		
13.5	0.4	0.0	1.2	0.1	0.8	0.1	37.4	3.3	1978.5	3.8		
14.5	0.4	0.0	1.6	0.1	1.1	0.1	40.8	3.7	1975.1	2.9		
15.5	0.5	0.0	1.8	0.1	1.3	0.1	43.9	4.1	1971.9	3.2		
16.5	0.6	0.0	1.8	0.1	1.2	0.1	46.5	4.4	1969.4	3.9		
17.5	0.6	0.0	1.8	0.1	1.1	0.1	48.9	4.7	1967.0	4.2		
18.5	0.5	0.0	2.1	0.1	1.5	0.1	52.3	5.3	1963.6	2.9		
19.5	0.3	0.0	1.7	0.1	1.4	0.1	56.0	5.9	1959.9	2.7		
20.5	0.6	0.0	1.6	0.1	1.0	0.1	58.9	6.5	1957.0	3.5		
21.5	0.4	0.0	1.2	0.1	0.8	0.1	61.8	7.1	1954.1	3.4		
22.5	0.4	0.0	1.4	0.1	1.0	0.1	66.1	8.1	1949.8	2.3		
23.5	0.4	0.0	1.2	0.0	0.8	0.1	71.1	9.5	1944.8	2.0		
24.5	0.4	0.0	1.2	0.1	0.8	0.1	78.0	11.8	1937.9	1.4		
25.5	0.4	0.0	1.1	0.0	0.7	0.0	86.7	15.4	1929.2	1.2		
26.5	0.5	0.1	1.0	0.1	0.6	0.1	94.4	19.8	1921.4	1.3		
27.5	0.4	0.0	1.0	0.1	0.7	0.1						
28.5	0.3	0.0	0.8	0.1	0.4	0.1						
29.5	0.2	0.0	0.7	0.1	0.5	0.1						
30.5												
31.5												
32.5												
33.5												
34.5												

Table 2: Weedon Is. soil carbon and DBD

Weedon Is. Depth interval midpoint (cm)	Water content (%)	Dry bulk density (g/cm3)	%Carbon	%Nitrogen	%LOI	Carbon density (kg/m3)	CRS Carbon burial rate (g/m2/y)
0.5	83%	0.09	39.1	1.6	80	35	308
1.5	84%	0.12					
2.5	84%	0.11	31.9	1.8		36	242
3.5	85%	0.11					
4.5	84%	0.13	27.8	1.5	52	36	158
5.5	82%	0.17					
6.5	82%	0.16	27.0	1.6		44	146
7.5	77%	0.23					
8.5	74%	0.26	17.8	0.9	32	46	167
9.5	67%	0.35					
10.5	62%	0.47	12.8	0.6		60	220
11.5	57%	0.56					
12.5	57%	0.58	8.7	0.4	16	50	188
13.5	55%	0.59					
14.5	59%	0.50	9.7	0.4		48	169
15.5	67%	0.36					
16.5	70%	0.29	13.9	0.6	31	40	193
17.5	72%	0.27					
18.5	74%	0.26	18.1	0.8		46	175
19.5	71%	0.28					
20.5	71%	0.28	14.5	0.6	27	40	188
21.5	68%	0.32					
22.5	65%	0.33					
23.5	60%	0.41	14.0	0.6	17	57	171
24.5	58%	0.46					
25.5	57%	0.55					
26.5	55%	0.47	6.7	0.3		31	81
27.5	52%	0.60					
28.5	49%	0.59					
29.5	51%	0.65	7.0	0.3	11	45	
30.5	56%	0.59					
31.5	48%	0.51					
32.5	43%	0.89	6.0	0.2		53	
33.5	39%	0.74					
34.5	39%	0.93			4		

Table 2: Fort de Soto radionuclides and age model

Fort de Soto Depth interval midpoint (cm)	226Ra (dpm/g)	226Ra uncertainty (dpm/g)	210Pb (dpm/g)	210Pb uncertainty (dpm/g)	210Pbexcess (dpm/g)	210Pbexcess uncertainty (dpm/g)	CRS Age (years)	CRS Date uncertainty	CRS Date	CRS AR (mm/y)	CIC model AR (mm/y)	CIC model AR depth interval
0.5	1.0	0.1	5.9	0.3	4.8	0.3	2.3	1.8	2013.6	4.4	1.80	0-23
1.5	0.5	0.1	4.9	0.3	4.4	0.3	5.6	2.0	2010.3	3.0		
2.5	0.4	0.1	4.4	0.3	4.0	0.3	8.8	2.1	2007.1	3.2		
3.5	0.4	0.0	4.1	0.2	3.8	0.2	12.4	2.3	2003.5	2.8		
4.5	0.3	0.0	2.7	0.1	2.4	0.1	15.7	2.6	2000.2	3.0		
5.5	0.3	0.0	2.4	0.1	2.1	0.1	18.8	2.8	1997.1	3.2		
6.5	0.2	0.0	1.4	0.1	1.2	0.1	21.4	3.0	1994.4	3.8		
7.5	0.2	0.0	1.2	0.1	1.0	0.1	24.6	3.2	1991.3	3.2		
8.5	0.2	0.0	1.2	0.1	1.0	0.1	27.5	3.5	1988.4	3.5		
9.5	0.3	0.0	1.5	0.1	1.2	0.1	30.9	3.9	1985.0	3.0		
10.5	0.2	0.0	1.0	0.1	0.8	0.1	35.2	4.4	1980.7	2.3		
11.5	0.4	0.0	1.9	0.1	1.5	0.1	39.6	5.1	1976.3	2.3		
12.5	0.2	0.0	0.8	0.1	0.6	0.1	43.8	5.8	1972.1	2.4		
13.5	0.2	0.0	0.8	0.1	0.6	0.1	47.1	6.4	1968.8	3.0		
14.5	0.2	0.0	1.0	0.1	0.8	0.1	55.2	8.3	1960.7	1.2		
15.5	0.2	0.0	0.7	0.1	0.5	0.1	61.5	10.1	1954.4	1.6		
16.5	0.2	0.0	0.6	0.0	0.4	0.0	68.9	12.8	1947.0	1.3		
17.5	0.2	0.0	0.6	0.0	0.4	0.0	78.9	17.6	1937.0	1.0		
18.5	0.2	0.0	0.5	0.0	0.3	0.0	88.3	23.7	1927.6	1.1		
19.5	0.2	0.0	0.3	0.1	0.2	0.1	95.3	29.7	1920.5	1.4		
20.5	0.2	0.0	0.4	0.0	0.3	0.0						
21.5	0.2	0.0	0.3	0.0	0.1	0.0						
22.5	0.2	0.0	0.3	0.0	0.1	0.0						
23.5	0.2	0.0	0.3	0.0	0.1	0.0						

Table 2: Fort de Soto soil carbon and DBD

Fort de Soto Depth interval midpoint (cm)	Water content (%)	Dry bulk density (g/cm3)	%Carbon	%Nitrogen	%LOI	Carbon density (kg/m3)	CRS Carbon burial rate (g/m2/y)
0.5	83%	0.15	26.36	1.47	52	41	178
1.5	78%	0.23					
2.5	76%	0.22	18.64	1.02		40	127
3.5	75%	0.23					
4.5	71%	0.30	16.09	0.87	34	49	145
5.5	72%	0.30					
6.5	62%	0.39	9.72	0.5		38	143
7.5	55%	0.51					
8.5	59%	0.45	11.67	0.56	16	53	182
9.5	57%	0.37					
10.5	52%	0.66	6.08	0.32		40	92
11.5	78%	0.31					
12.5	52%	0.68	10.13	0.33	16	69	163
13.5	50%	0.46					
14.5	47%	0.70	5.89	0.23		41	51
15.5	43%	0.69					
16.5	40%	0.85	3.5	0.18	7	30	40
17.5	41%	0.85					
18.5	38%	0.83	3.01	0.16		25	26
19.5	37%	0.73					
20.5	38%	1.01	3.15	0.16	5	32	
21.5	32%	0.96					
22.5	31%	0.91	1.803	0.090			
23.5	33%	0.93					

Table 2: Upper Tampa Bay radionuclides and age model

Depth interval midpoint (cm)	226Ra (dpm/g)	226Ra uncertainty (dpm/g)	210Pb (dpm/g)	210Pb uncertainty (dpm/g)	210Pbexcess (dpm/g)	210Pbexcess uncertainty (dpm/g)	CRS Age (years)	CRS Date uncertainty	CRS Date	CRS AR (mm/y)	CIC model AR (mm/y)	CIC model AR depth interval
0.5	0.5	0.0	2.1	0.1	1.6	0.1	2.0	2.0	2013.9	5.1	1.01	0-20
1.5	0.6	0.0	5.4	0.2	4.8	0.2	6.8	2.2	2009.1	2.1		
2.5	0.7	0.1	5.3	0.2	4.6	0.2	10.4	2.3	2005.5	2.8		
3.5	1.6	0.1	9.1	0.4	7.4	0.5	14.0	2.5	2001.9	2.8		
4.5	0.5	0.0	1.8	0.1	1.4	0.1	17.2	2.7	1998.7	3.1		
5.5	0.5	0.0	1.5	0.1	1.0	0.1	20.0	2.8	1995.9	3.5		
6.5	0.5	0.0	1.2	0.1	0.7	0.1	22.4	2.9	1993.4	4.1		
7.5	0.5	0.0	1.2	0.1	0.7	0.1	25.0	3.1	1990.9	3.9		
8.5	0.7	0.0	2.6	0.1	2.0	0.1	32.3	3.8	1983.6	1.4		
9.5	0.9	0.0	2.9	0.1	2.0	0.1	43.1	5.2	1972.8	0.9		
10.5	0.8	0.0	2.0	0.1	1.2	0.1	52.1	6.8	1963.8	1.1		
11.5	0.7	0.0	1.3	0.1	0.6	0.1	60.3	8.9	1955.5	1.2		
12.5	0.8	0.0	1.3	0.1	0.5	0.1	68.9	11.6	1947.0	1.2		
13.5	0.9	0.0	1.3	0.1	0.4	0.1	83.4	18.3	1932.5	0.7		
14.5	0.9	0.0	1.1	0.1	0.2	0.1	93.2	25.1	1922.7	1.0		
15.5	0.8	0.2	0.9	0.1	0.2	0.2	104.3	40.5	1911.6	0.9		
16.5	0.7	0.2	0.8	0.0	0.1	0.2						
17.5	0.7	0.2	0.8	0.0	0.2	0.2						
18.5	0.7	0.2	0.7	0.1	0.1	0.2						
19.5	0.6	0.2	0.7	0.1	0.0	0.2						
20.5												
21.5												
22.5												
23.5												
24.5												
25.5												
26.5												
27.5												
28.5												
29.5												

Table 2: Upper Tampa Bay soil carbon and DBD

Depth interval midpoint (cm)	Water content (%)	Dry bulk density (g/cm3)	%Carbon	%Nitrogen	%LOI	Carbon density (kg/m3)	CRS Carbon burial rate (g/m2/y)
0.5	39%	0.54	3.1	0.2	7.7	17	85
1.5	65%	0.40	9.9	0.7		40	83
2.5	68%	0.28			21.5		
3.5	87%	0.15	9.4	0.5		14	40
4.5	46%	0.67			9.8		
5.5	40%	0.76	6.1	0.3		46	162
6.5	37%	0.80			6.2		
7.5	36%	0.80	1.2	0.1		9	36
8.5	46%	0.70	4.6	0.3	9.5	32	44
9.5	42%	0.77	3.5	0.2		27	25
10.5	36%	0.82	2.3	0.1	5.8	19	21
11.5	30%	1.09	2.2	0.1		24	29
12.5	28%	0.99	2.0	0.1	4.3	20	24
13.5	25%	1.43	1.8	0.1		25	17
14.5	23%	1.41			3.4		
15.5	21%	1.38					
16.5	20%	1.48					
17.5	19%	1.40	0.9	0.0	2.3	12	
18.5	18%	1.69					
19.5	17%	1.58					
20.5	17%	1.47					
21.5	17%	1.44	0.6	0.0	1.2	9	
22.5	16%	1.64					
23.5	16%	1.56					
24.5	17%	1.69					
25.5	17%	1.70	0.4	0.0	0.9	6	
26.5	17%	1.50					
27.5	17%	1.58					
28.5	17%	1.46					
29.5	17%	1.31	0.3	0.0	0.7	4	

Table 2: Rocky Creek A radionuclides and age model

RCRA Depth interval midpoint (cm)	226Ra (dpm/g)	226Ra uncertainty (dpm/g)	210Pb (dpm/g)	210Pb uncertainty (dpm/g)	210Pbexcess (dpm/g)	210Pbexcess uncertainty (dpm/g)	CRS Age (years)	CRS Date uncertainty	CRS Date	CRS AR (mm/y)	CIC model AR (mm/y)	CIC model AR depth interval
0.5	0.8	0.0	2.0	0.1	1.2	0.1	2.2	1.5	2013.6	4.4	5.4	0-20
1.5	1.1	0.0	2.3	0.1	1.2	0.1	4.7	1.6	2011.2	4.0	0.6	20-26
2.5	1.3	0.0	2.3	0.1	1.0	0.1	6.9	1.6	2009.0	4.5		
3.5	1.2	0.0	2.2	0.1	1.0	0.1	9.1	1.7	2006.8	4.6		
4.5	1.1	0.0	1.9	0.1	0.8	0.1	11.2	1.8	2004.6	4.7		
5.5	1.0	0.0	2.0	0.1	1.0	0.1	14.1	2.0	2001.8	3.5		
6.5	1.1	0.0	1.8	0.1	0.7	0.1	16.3	2.1	1999.6	4.6		
7.5	1.1	0.0	1.8	0.1	0.8	0.1	18.9	2.2	1996.9	3.8		
8.5	1.1	0.0	1.6	0.1	0.6	0.1	20.9	2.3	1995.0	5.1		
9.5	1.0	0.0	1.7	0.1	0.7	0.1	23.6	2.5	1992.3	3.7		
10.5	1.0	0.0	1.7	0.1	0.7	0.1	26.4	2.7	1989.4	3.5		
11.5	1.1	0.0	1.8	0.1	0.7	0.1	29.8	3.0	1986.1	3.0		
12.5	1.2	0.0	2.1	0.1	0.9	0.1	34.5	3.5	1981.4	2.1		
13.5	1.3	0.0	2.1	0.1	0.8	0.1	39.4	4.1	1976.5	2.0		
14.5	1.6	0.0	2.1	0.1	0.5	0.1	43.1	4.6	1972.8	2.7		
15.5	1.6	0.1	2.1	0.1	0.6	0.1	47.4	5.3	1968.5	2.3		
16.5	1.9	0.1	2.3	0.1	0.4	0.1	51.7	6.2	1964.1	2.3		
17.5	1.9	0.1	2.5	0.1	0.6	0.1	58.1	7.6	1957.8	1.6		
18.5	1.8	0.1	2.4	0.1	0.7	0.1	67.3	10.2	1948.6	1.1		
19.5	1.6	0.0	2.1	0.1	0.4	0.1	74.8	13.0	1941.0	1.3		
20.5	1.8	0.0	2.3	0.1	0.5	0.1	87.7	19.6	1928.2	0.8		
21.5	1.6	0.0	1.8	0.1	0.3	0.1	96.8	26.3	1919.1	1.1		
22.5	1.1	0.0	1.4	0.1	0.2	0.1						
23.5	1.0	0.0	1.3	0.1	0.3	0.1						
24.5	0.8	0.0	1.0	0.0	0.1	0.0						
25.5	0.7	0.0	0.8	0.1	0.0	0.1						
26.5												
27.5												
28.5												
29.5												
30.5												

Table 2: Rocky Creek A soil carbon and DBD

RCRA Depth interval midpoint (cm)	Water content (%)	Dry bulk density (g/cm3)	%Carbon	%Nitrogen	%LOI	Carbon density (kg/m3)	CRS Carbon burial rate (g/m2/y)
0.5	44%	0.530	2.09	0.12	4.2	11.1	49
1.5	35%	1.106					
2.5	40%	0.747	2.65	0.17		19.8	90
3.5	43%	0.688					
4.5	42%	0.749	3.25	0.21	5.8	24.3	113
5.5	41%	0.815					
6.5	44%	0.739	2.82	0.17		20.8	95
7.5	46%	0.736					
8.5	43%	0.726	2.85	0.17	5.6	20.7	105
9.5	41%	0.807					
10.5	41%	0.819	3.14	0.18		25.7	91
11.5	43%	0.800					
12.5	46%	0.724	3.57	0.24	7.3	25.8	55
13.5	47%	0.701					
14.5	46%	0.774	4.98	0.33		38.6	103
15.5	46%	0.689					
16.5	46%	0.787	5.15	0.4	9.0	40.5	93
17.5	47%	0.703					
18.5	46%	0.745	4.753	0.330		35.4	39
19.5	45%	0.743					
20.5	43%	0.829	4.41	0.31	8.0	36.5	28
21.5	39%	0.865					
22.5	35%	1.111					
23.5	32%	1.022	1.96	0.13		20.0	
24.5	30%	1.157					
25.5	29%	1.216					
26.5	28%	1.169	1.67	0.1	2.7	19.5	
27.5	28%	1.283					
28.5	28%	1.198					
29.5	27%	1.275	1.82	0.11	2.7	23.2	
30.5	26%	1.245					

Table 2: Rocky Creek B radionuclides and age model

RCRB Depth interval midpoint (cm)	226Ra (dpm/g)	226Ra uncertainty (dpm/g)	210Pb (dpm/g)	210Pb uncertainty (dpm/g)	210Pbexcess (dpm/g)	210Pbexcess uncertainty (dpm/g)	CRS Age (years)	CRS Date uncertainty	CRS Date	CRS AR (mm/y)	CIC model AR (mm/y)	CIC model AR depth interval
0.5	1.1	0.0	2.6	0.1	1.5	0.1	2.2	1.2	2013.7	4.6	3.18	0-16
1.5	1.1	0.0	2.8	0.1	1.7	0.1	4.9	1.3	2011.0	3.7		
2.5	1.1	0.0	2.5	0.1	1.4	0.1	7.7	1.4	2008.2	3.5		
3.5	1.0	0.0	2.5	0.1	1.4	0.1	11.4	1.6	2004.5	2.7		
4.5	1.3	0.0	2.4	0.1	1.2	0.1	14.0	1.7	2001.8	3.7		
5.5	1.1	0.0	2.4	0.1	1.3	0.1	17.0	1.8	1998.9	3.4		
6.5	1.1	0.0	2.1	0.1	1.0	0.1	20.1	2.0	1995.8	3.3		
7.5	0.8	0.0	1.6	0.0	0.7	0.1	22.5	2.1	1993.4	4.1		
8.5	1.0	0.0	1.7	0.1	0.7	0.1	25.2	2.2	1990.7	3.7		
9.5	1.0	0.0	1.7	0.1	0.7	0.1	28.3	2.4	1987.6	3.3		
10.5	1.1	0.0	1.8	0.1	0.7	0.1	31.0	2.6	1984.9	3.7		
11.5	1.1	0.0	1.8	0.1	0.7	0.1	34.7	3.0	1981.1	2.7		
12.5	1.0	0.0	1.6	0.1	0.5	0.1	37.0	3.2	1978.9	4.4		
13.5	1.0	0.0	1.4	0.1	0.4	0.1	39.8	3.5	1976.0	3.5		
14.5	1.2	0.0	1.8	0.1	0.6	0.1	43.7	4.0	1972.2	2.6		
15.5	1.3	0.0	1.8	0.1	0.5	0.1	47.4	4.5	1968.5	2.7		
16.5	1.4	0.0	1.9	0.1	0.4	0.1	50.8	5.0	1965.1	3.0		
17.5	1.5	0.0	2.1	0.1	0.6	0.1	56.0	5.9	1959.9	1.9		
18.5	1.7	0.0	2.1	0.1	0.4	0.1	61.0	6.9	1954.9	2.0		
19.5	1.7	0.0	2.1	0.1	0.4	0.1	67.6	8.6	1948.3	1.5		
20.5	1.4	0.0	1.9	0.1	0.4	0.1	76.0	11.2	1939.9	1.2		
21.5	1.2	0.0	1.5	0.1	0.3	0.1	82.0	13.6	1933.9	1.7		
22.5	1.0	0.0	1.4	0.1	0.4	0.1						
23.5	0.9	0.0	1.0	0.1	0.1	0.1						
24.5	0.9	0.0	1.2	0.1	0.3	0.1						
25.5	0.9	0.0	1.0	0.1	0.1	0.1						
26.5	0.7	0.0	0.9	0.1	0.2	0.1						
27.5	0.6	0.0	0.8	0.1	0.2	0.1						
28.5												
29.5	0.7	0.0	0.9	0.1	0.2	0.1						

Table 2: Rocky Creek B soil carbon and DBD

RCRB Depth interval midpoint (cm)	Water content (%)	Dry bulk density (g/cm3)	%Carbon	%Nitrogen	%LOI	Carbon density (kg/m3)	CRS Carbon burial rate (g/m2/y)
0.5	44%	0.64	2.08	0.14	4.5	13.4	61
1.5	42%	0.67					
2.5	42%	0.81	2.2	0.12		17.8	62
3.5	41%	0.89					
4.5	43%	0.72	2.58	0.17	5.8	18.5	69
5.5	42%	0.68					
6.5	44%	0.76	3.38	0.19		25.5	84
7.5	42%	0.80					
8.5	40%	0.84	2.56	0.15	5.0	21.5	79
9.5	39%	0.91					
10.5	40%	0.78	2.823	0.170		22.0	82
11.5	39%	0.95					
12.5	40%	0.69	0.940	0.060	4.6	6.5	29
13.5	37%	1.05					
14.5	38%	0.93	2.43	0.16		22.6	59
15.5	39%	0.95					
16.5	41%	0.84	3.11	0.21	6.5	26.1	78
17.5	41%	0.84					
18.5	40%	0.89	3.77	0.26		33.6	67
19.5	38%	1.00					
20.5	36%	1.04	2.3	0.16	5.3	24.0	29
21.5	33%	0.98					
22.5	32%	0.99					
23.5	30%	1.23	1.7	0.11		20.9	47
24.5	30%	0.87					
25.5	29%	1.32					
26.5	27%	1.39	1.81	0.11	2.8	25.2	
27.5	26%	1.13					
28.5	27%	1.47					
29.5	27%	1.25	1.64	0.1	2.5	20.5	

Table 2: Holly House A radionuclides and age model

HHMA Depth interval midpoint (cm)	226Ra (dpm/g)	226Ra uncertainty (dpm/g)	210Pb (dpm/g)	210Pb uncertainty (dpm/g)	210Pbexcess (dpm/g)	210Pbexcess uncertainty (dpm/g)	CRS Age (years)	CRS Date uncertainty	CRS Date	CRS AR (mm/y)	CIC model AR (mm/y)	CIC model AR depth interval
0.5	2.6	0.1	6.7	0.2	4.0	0.2	3.6	1.0	2012.3	2.8	3.1	0-19
1.5	2.6	0.1	5.4	0.2	2.8	0.2	6.0	1.1	2009.9	4.1		
2.5	3.4	0.1	6.1	0.2	2.7	0.2	8.5	1.1	2007.4	4.1		
3.5	4.0	0.1	6.4	0.2	2.5	0.2	11.4	1.2	2004.5	3.4		
4.5	3.4	0.1	5.6	0.2	2.3	0.2	14.0	1.3	2001.9	3.8		
5.5	3.3	0.1	6.0	0.2	2.7	0.3	17.8	1.4	1998.1	2.7		
6.5	3.2	0.1	5.8	0.2	2.6	0.2	21.9	1.6	1994.0	2.4		
7.5	3.0	0.1	5.1	0.2	2.1	0.2	25.8	1.8	1990.1	2.5		
8.5	3.5	0.1	5.1	0.3	1.6	0.3	28.9	2.0	1987.0	3.3		
9.5	3.4	0.1	5.2	0.3	1.8	0.3	32.7	2.3	1983.2	2.7		
10.5	2.7	0.1	4.7	0.2	2.0	0.2	37.4	2.6	1978.5	2.1		
11.5	3.4	0.1	5.2	0.1	1.7	0.2	42.3	3.0	1973.6	2.0		
12.5	2.5	0.1	4.0	0.1	1.5	0.2	47.2	3.5	1968.7	2.1		
13.5	3.2	0.1	4.6	0.2	1.4	0.2	52.7	4.2	1963.2	1.8		
14.5	3.9	0.1	4.5	0.2	0.6	0.2	55.5	4.6	1960.4	3.6		
15.5	4.0	0.1	5.1	0.1	1.2	0.2	62.1	5.6	1953.8	1.5		
16.5	3.3	0.1	4.3	0.1	1.0	0.1	68.9	7.0	1947.0	1.5		
17.5	1.5	0.0	2.1	0.1	0.6	0.1	74.2	8.2	1941.7	1.9		
18.5	2.1	0.1	3.1	0.1	1.0	0.1	84.2	11.3	1931.7	1.0		
19.5	2.8	0.1	3.4	0.1	0.6	0.1	92.4	14.6	1923.5	1.2		
20.5	3.7	0.1	4.1	0.2	0.4	0.2	98.3	17.7	1917.6	1.7		
21.5	3.9	0.1	4.2	0.1	0.3	0.2	104.9	21.9	1911.0	1.5		
22.5	4.6	0.1	4.6	0.2	0.0	0.2						
23.5	4.6	0.1	5.2	0.2	0.5	0.2						
24.5	5.1	0.1	5.5	0.2	0.4	0.2						
25.5	4.3	0.0	4.5	0.1	0.2	0.1						
26.5	5.4	0.1	5.4	0.2	0.0	0.2						
27.5	4.0	0.1	4.1	0.1	0.2	0.2						
28.5	5.5	0.1	5.2	0.2	-0.3	0.2						
29.5	4.7	0.1	4.8	0.2	0.1	0.2						

Table 2: Holly House A soil carbon and DBD

HHMA Depth interval midpoint (cm)	Water content (%)	Dry bulk density (g/cm3)	%Carbon	%Nitrogen	%LOI	Carbon density (kg/m3)	CRS Carbon burial rate (g/m2/y)
0.5	74%	0.19	18	0.78	33	35	97
1.5	68%	0.31					
2.5	68%	0.31	19.01	0.78		58	237
3.5	63%	0.43					
4.5	64%	0.38	13.59	0.64	24	52	195
5.5	70%	0.33					
6.5	66%	0.39	15.46	0.81		60	146
7.5	70%	0.36					
8.5	71%	0.31	15.88	0.82	29	49	159
9.5	74%	0.27					
10.5	73%	0.29	16.11	0.823		46	98
11.5	69%	0.33					
12.5	71%	0.31	18.91	0.83	37	58	119
13.5	68%	0.35					
14.5	64%	0.39	12.24	0.57		47	169
15.5	62%	0.44					
16.5	59%	0.47	11.92	0.54	26	56	82
17.5	62%	0.48					
18.5	63%	0.41	11.44	0.61		47	46
19.5	61%	0.47					
20.5	56%	0.50	6.48	0.34	12	33	55
21.5	53%	0.63					
22.5	50%	0.68					
23.5	47%	0.70					
24.5	46%	0.75	4.44	0.25		34	
25.5	45%	0.76					
26.5	42%	0.91					
27.5	40%	0.87	3.23	0.17	6	28	
28.5	37%	0.97					
29.5	36%	1.01					
30.5	36%	1.02	2.28	0.13		23	
31.5	34%	1.13					
32.5	34%	1.06					
33.5	33%	1.19	2.06	0.12	4	25	
34.5	32%	1.15					
35.5	31%	1.12					
36.5	29%	1.36	1.64	0.097		22	
37.5	28%	1.14					
38.5	28%	1.27					
39.5	28%	1.32	1.43	0.09	3	19	

Table 2: Holly House B radionuclides and age model

HHMB Depth interval midpoint (cm)	226Ra (dpm/g)	226Ra uncertainty (dpm/g)	210Pb (dpm/g)	210Pb uncertainty (dpm/g)	210Pbexcess (dpm/g)	210Pbexcess uncertainty (dpm/g)	CRS Age (years)	CRS Date uncertainty	CRS Date	CRS AR (mm/y)	CIC model AR (mm/y)	CIC model AR depth interval
0.5	2.2	0.1	5.9	0.3	3.7	0.4	2.7	0.9	2013.2	3.7	4.5	0-23
1.5	2.0	0.1	5.0	0.2	3.0	0.2	5.3	1.0	2010.6	3.9		
2.5	2.5	0.1	4.9	0.2	2.4	0.2	7.4	1.0	2008.5	4.7		
3.5	2.7	0.1	4.7	0.2	2.0	0.2	9.4	1.1	2006.4	4.9		
4.5	4.8	0.1	6.5	0.2	1.8	0.3	11.1	1.1	2004.8	6.2		
5.5	3.8	0.1	5.9	0.2	2.1	0.2	13.0	1.2	2002.9	5.1		
6.5	3.1	0.1	5.7	0.1	2.6	0.2	15.9	1.3	2000.0	3.5		
7.5	3.6	0.1	5.2	0.2	1.6	0.2	18.0	1.3	1997.9	4.7		
8.5	3.8	0.1	5.9	0.2	2.1	0.2	20.9	1.4	1995.0	3.5		
9.5	2.9	0.1	4.7	0.2	1.9	0.2	23.5	1.5	1992.3	3.7		
10.5	3.4	0.1	5.4	0.3	1.9	0.4	26.3	1.7	1989.6	3.7		
11.5	2.8	0.1	4.9	0.3	2.1	0.3	29.7	1.9	1986.2	2.9		
12.5	3.1	0.1	5.5	0.3	2.5	0.3	34.3	2.2	1981.6	2.1		
13.5	3.5	0.1	5.5	0.3	2.0	0.3	38.5	2.5	1977.3	2.4		
14.5	3.6	0.1	5.4	0.3	1.7	0.3	43.0	2.9	1972.9	2.3		
15.5	5.4	0.1	6.8	0.3	1.4	0.3	47.3	3.3	1968.5	2.3		
16.5	4.6	0.1	5.8	0.2	1.1	0.2	51.7	3.8	1964.2	2.3		
17.5	3.6	0.1	4.9	0.2	1.3	0.2	56.5	4.5	1959.4	2.1		
18.5	3.2	0.1	3.9	0.2	0.7	0.2	59.8	5.0	1956.1	3.0		
19.5	3.5	0.1	4.7	0.2	1.3	0.2	66.3	6.1	1949.6	1.5		
20.5	3.2	0.1	4.4	0.2	1.2	0.2	74.3	7.9	1941.6	1.3		
21.5	3.5	0.1	4.4	0.2	0.9	0.2	82.1	10.1	1933.8	1.3		
22.5	3.4	0.1	4.2	0.2	0.8	0.2	91.5	13.6	1924.3	1.1		
23.5	3.8	0.1	5.3	0.2	1.5	0.2						
24.5	4.7	0.1	4.9	0.2	0.3	0.2						
25.5	6.7	0.1	7.2	0.2	0.5	0.2						
26.5	5.1	0.1	5.0	0.2	-0.1	0.2						
27.5	5.8	0.1	5.9	0.2	0.0	0.2						
28.5	6.6	0.1	6.1	0.2	-0.5	0.2						
29.5	6.5	0.1	6.1	0.2	-0.4	0.2						

Table 2: Holly House B soil carbon and DBD

HHMB Depth interval midpoint (cm)	Water content (%)	Dry bulk density (g/cm3)	%Carbon	%Nitrogen	%LOI	Carbon density (kg/m3)	CRS Carbon burial rate (g/m2/y)
0.5	78%	0.12	23.79	0.86	44	29	108
1.5	70%	0.37					
2.5	63%	0.42	13.28	0.56		56	263
3.5	66%	0.43					
4.5	68%	0.34	18.193	0.793	26	61	378
5.5	67%	0.34					
6.5	68%	0.36	17.95	0.84		65	226
7.5	69%	0.38					
8.5	69%	0.36	16.34	0.86	22	59	205
9.5	73%	0.30					
10.5	76%	0.24	19.03	1.02		46	171
11.5	75%	0.26					
12.5	73%	0.29	18.39	0.91	29	54	115
13.5	74%	0.28					
14.5	71%	0.33	18.05	0.92		59	133
15.5	67%	0.40					
16.5	64%	0.46	12.61	0.6	21	58	133
17.5	66%	0.36					
18.5	64%	0.42	10.68	0.55		45	135
19.5	65%	0.40					
20.5	63%	0.45	11.31	0.53	21	51	63
21.5	62%	0.44					
22.5	59%	0.53					
23.5	57%	0.56					
24.5	52%	0.62	5.8	0.32		36	
25.5	50%	0.69					
26.5	44%	0.86					
27.5	40%	0.93	3.013	0.183	6	28	
28.5	37%	1.04					
29.5	36%	1.03					
30.5	34%	1.08	1.97	0.12		21	
31.5	33%	1.05					
32.5	31%	1.24					
33.5	29%	1.27	1.7	0.1	4	22	
34.5	29%	1.16					
35.5	29%	1.27					
36.5	28%	1.25	1.23	0.08		15	
37.5	27%	1.29					
38.5	26%	1.18					
39.5	25%	1.53	0.97	0.08	2	15	

Table 2: Upper Tampa Bay Salt Barren

UTSB Depth interval midpoint (cm)	%LOI
2.5	1.1
7.5	1.2
12.5	1.2
17.5	1.1
22.5	1.2
27.5	1.4

Table 3: Average and standard deviation of accretion rate, carbon density and carbon burial rate

Site Name	Vegetation Type	Whole core CAR g/m2/y	Stdev	1900-1950 CAR g/m2/y	Stdev	1950-present CAR g/m2/y	Stdev	Carbon density kg/m3	Stdev	CRS AR mm/y	Stdev	1950-present CRS AR mm/y	Stdev	CIC AR mm/y	CIC depth int	CIC AR mm/y	CIC depth int	137Cs AR mm/y
Upper Tampa Bay Park	Juncus marsh	52	43	23	6	58	45	20	12	2.2	1.4	2.7	1.4	1.0	0-20			1.7
Rocky Creek A	Juncus marsh	78	30	33	7	88	22	26	9	2.9	1.4	3.5	1.1	5.4	0-20	0.6	20-26	
Rocky Creek B	Juncus marsh	62	19	47	19	67	16	21	6	2.9	1.0	3.3	0.7	3.2	0-16	1.7	16-28	
E.G.Simmons Park A	Young Mangrove	86	60	25	22	121	44	28	13	2.6	1.5	3.0	1.4	4.0	0-13	0.8	13-20	
E.G. Simmons Park B	Young Mangrove	82	60	17	14	110	48	30	14	2.5	1.3	2.9	1.1	2.9	0-13	0.7	13-20	
Fort de Soto	Young Mangrove	115	58	33	9	135	45	41	12	2.5	1.0	2.9	0.8	1.8	0-23			
Holly House A	mangrove	128	59	61	19	153	48	41	14	2.4	0.9	2.8	0.8	3.1	0-19			1.9
Holly House B	mangrove	175	88	111	41	187	84	16	20	3.1	1.4	3.5	1.2	4.5	0-23			2.1
Wheedon Is.	Mangrove	185	53	147	58	194	45	45	8	3.9	1.5	4.3	1.4	2.6	0-30			

Table 4: Summary of post 1950 accretion rates (AR) and carbon accretion rates (CAR). Accretion rate calculated with CRS ^{210}Pb model

Site Name	Vegetation Type	1950-present CAR g/m2/y	Stdev	1950-present CRS accretion rate mm/y	Stdev
Upper Tampa Bay Park	Juncus marsh	58	45	2.7	1.4
Rocky Creek A	Juncus marsh	88	22	3.5	1.1
Rocky Creek B	Juncus marsh	67	16	3.3	0.7
E.G.Simmons Park A	Young Mangrove	121	44	3.0	1.4
E.G. Simmons Park B	Young Mangrove	110	48	2.9	1.1
Fort de Soto	Young Mangrove	135	45	2.9	0.8
Holly House A	mangrove	153	48	2.8	0.8
Holly House B	mangrove	187	84	3.5	1.2
Wheedon Is.	Mangrove	194	45	4.3	1.4

APPENDIX E

Tomasko et al. 2015

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memorandum

date February 2, 2015

to Steve Emmett-Mattox
Holly Greening

from David Tomasko, Ph.D.

subject Quantification of carbon sequestration rates for seagrass (D140671)

Background

Over the past few years, the term "blue carbon" has gained significant levels of attention by marine researchers and resource managers. Blue carbon refers to that amount of carbon storage and sequestration that is associated with marine ecosystems. Tampa Bay is one of four members of the EPA's National Estuary Program to contain all three major blue carbon habitats: salt marshes, mangroves, and seagrass beds.

Advancing coastal blue carbon is a strategic priority for both Restore America's Estuaries (RAE) and the Tampa Bay Estuary Program (TBEP). Both RAE and the TBEP are looking for ways to increase the variety of partners associated with estuarine restoration programs and projects. The rate of restoration could benefit from increased public and private investment in the restoration and protection of blue carbon habitats through enhanced recognition of their climate mitigation benefits.

While carbon storage values and sequestration rates are fairly well documented for some coastal systems, a translation of these carbon values to an estuary restoration and protection setting needs to be carefully developed,. Carbon sequestration rates for seagrass meadows need to take into account that they represent fully submerged habitats, and the fate of assimilated carbon is likely more strongly influenced by water chemistry and tidal influences than is the case with salt marshes and mangroves.

This Technical Memorandum summarizes the uncertainties that exist related to carbon sequestration rates for seagrass meadows, and will compare bay-wide estimates of carbon sequestration against each other, using different assumptions available in peer-reviewed literature. In addition, these separately derived carbon sequestration estimates will be compared against a bay-wide estimate of the potential amount of carbon assimilation via seagrass throughout Tampa Bay. Discrepancies between an estimate of bay-wide carbon assimilation and various literature-derived carbon sequestration rates will be discussed, and potential techniques to address these differences will be outlined.

Methods

Developing literature-based carbon sequestration rates for seagrass

Bay-wide estimates of carbon sequestration rates were developed based on an approach outlined in Russell and Greening in press). In that paper, the authors used bay-wide estimates of seagrass coverage for various years and combined that information with literature-derived estimates of carbon sequestration rates. Using those two parameters, estimates of carbon sequestration across the entire bay were then developed (Russell and Greening, in press). For purposes of the assessment outlined in this memorandum, the bay-wide seagrass coverage estimate for the year 2012 of 35,194 acres (14,243 ha) was used (data from SWFWMD).

Literature-derived estimates of carbon sequestration rates for seagrass vary widely. In their paper, Russell and Greening (2013) used a carbon sequestration rate for seagrass meadows of 138 g C m^{-2} yr^{-1}, as listed in McLeod et al. (2011), In turn, McLeod et al. (2011) developed their estimate from six published and one unpublished study on carbon burial rates in seagrass meadows.

Other researchers have published carbon sequestration rates via burial in seagrass meadows. Duarte et al. (2005) derived a global carbon sequestration rate estimate for seagrass meadows of 83 g C m^{-2} yr^{-1}. In a part of the coastal bays system of Virginia, newly reestablishing seagrass meadows were estimated to sequester carbon at a rate of 38 g C m^{-2} yr^{-1} (Greiner et al. 2013) while researchers in Korea developed carbon sequestration rates for seagrass meadows of 20 g C m^{-2} yr^{-1} (Chiu et al. 2013).

If bay-wide estimates of carbon sequestration rates (amounts of carbon sequestered per year) are based on the spatial extent of meadows multiplied by area-normalized sequestration rates (g m^{-2} yr^{-1}) then bay-wide estimates could vary by a factor of nearly 7-fold, depending upon which sequestration rate estimate was used.

Developing literature-based carbon assimilation rate estimates for seagrass

While the topic of carbon sequestration by marine macrophytes appears to be relatively new, the discussion of carbon sequestration via macro-algae and seagrass – later to be termed blue carbon – dates at least as far back as an article in the journal "Science" by researchers from the University of Hawaii (Smith 1981). Estimates of primary production rates of seagrass meadows date back more than 100 years, when Peterson (1918, as cited in Zieman and Wetzel 1980) estimated production rates of *Zostera marina* in Danish waters.

Rates of primary production have been measured either through changes in biomass over time or rates of carbon uptake for all the major species of seagrass found in Tampa Bay. A summary of area-normalized rates of carbon assimilation, by species, is shown in Table 1, along with the literature from which these rates were derived. For those studies where production was originally expressed in units of grams dry weight, rather than grams of carbon, we assumed a carbon content of 35 percent of dry weight to convert units of dry weight to units of carbon, as per Fourqurean et al. (2012). When values were not available on a yearly basis, the annual estimate was based on the average of minimum and maximum values (sometimes estimated from graphs if no data was shown in tabular form) for each report. The values in Table 1 are the arithmetic averages of all the annual estimates for each species from each report cited.

Table 1 – Literature-derived area-normalized rates of carbon assimilation by species.

Species	Annual net primary production estimate (g C m^{-2} yr^{-1})	Studies used to develop estimate
Halodule wrightii	584	Dillon (1971 [as cited in Zieman and Wetzel 1980]), Tomasko and Dunton (1995), Neely (2000)
Syringodium filiforme	292	Zieman and Wetzel (1980)
Thalassia testudinum	979	Zieman and Wetzel (1980), Tomasko et al. (1996), Tomasko and Hall (199), Lee and Dunton (1996), Chiu et al. (2013)*

*Chiu et al. (2013) is based on *T. hemprichii*, not *T. testudinum*

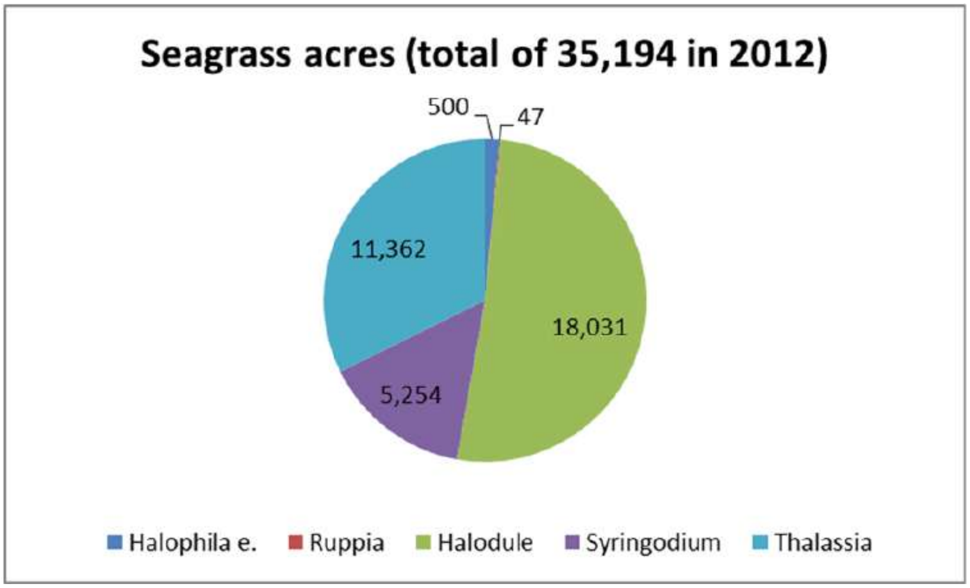
For the species *S. filiforme*, prior work has shown that perhaps 60 percent of above-ground productivity is exported to other locations (Zieman 1980). For the purposes of this study, that amount of exported productivity is not counted, as the purpose here is to estimate the potential for carbon sequestration within Tampa Bay itself. Export rates of 1 percent were applied to areal production rate estimates for both *H. wrightii* and *T. testudinum*, consistent with estimates from Zieman and Wetzel (1980).

Results

The area-normalized net primary production rate estimates shown in Table 1 vary by a factor of more than three between species. To develop bay-wide estimates of net primary production, seagrass acreage estimates for different bay segments were combined with transect data to come up with estimated coverage, by species, for each major segment of Tampa Bay. Species composition in each of the major bay segments was estimated from the data within the report by Avery and Johansson (2001). In their report, Avery and Johansson (2001) report on species distribution along each of 61 transects throughout the bay. Transects were located in Hillsborough Bay (11), Old Tampa Bay (12), Middle Tampa Bay (13), Lower Tampa Bay (14) and Boca Ciega Bay (11). When seagrass was found, the percent frequency by species was calculated and that frequency of occurrence was then multiplied by the acreage of seagrass for those same species for the most recent year (2012). For example, if the combined transects in Old Tampa Bay had *H. wrightii* occurring 75 percent of the time when seagrass was found, and *T. testudinum* occurring 25 percent of the time when seagrass was found, and the total acreage of seagrass mapped was 500 acres, then it would be estimated that *H. wrightii* meadows would account for 375 acres of seagrass (0.75 x 500 acres) and *T. testudinum* would account for 125 acres of seagrass (0.25 x 500 acres).

The species composition estimates by bay segment were then compiled for the bay as a whole, with the pattern of distribution shown in Figure 1.

Figure 1 – Species distribution of seagrass meadows in Tampa Bay. See text for methodology.



These species-specific acreage estimates were derived for each major bay segment, and then those coverage estimates were multiplied by the annual primary production estimates shown in Table 1 to derive primary production rates for each bay segment. The production rate estimates for each bay segment were then summed. Based on this technique, the estimated bay-wide rate of primary production is 89,255 Mg C per year (note: Mg = mega gram = 1,000 kg = 1 British Tonne).

Comparison of literature derived carbon sequestration rates with bay-wide carbon assimilation estimate

Figure 2 compares estimates of bay-wide net primary production (in units of carbon) by seagrass meadows to various estimates of bay-wide carbon sequestration by seagrass meadows, using different carbon burial rate estimates in the literature.

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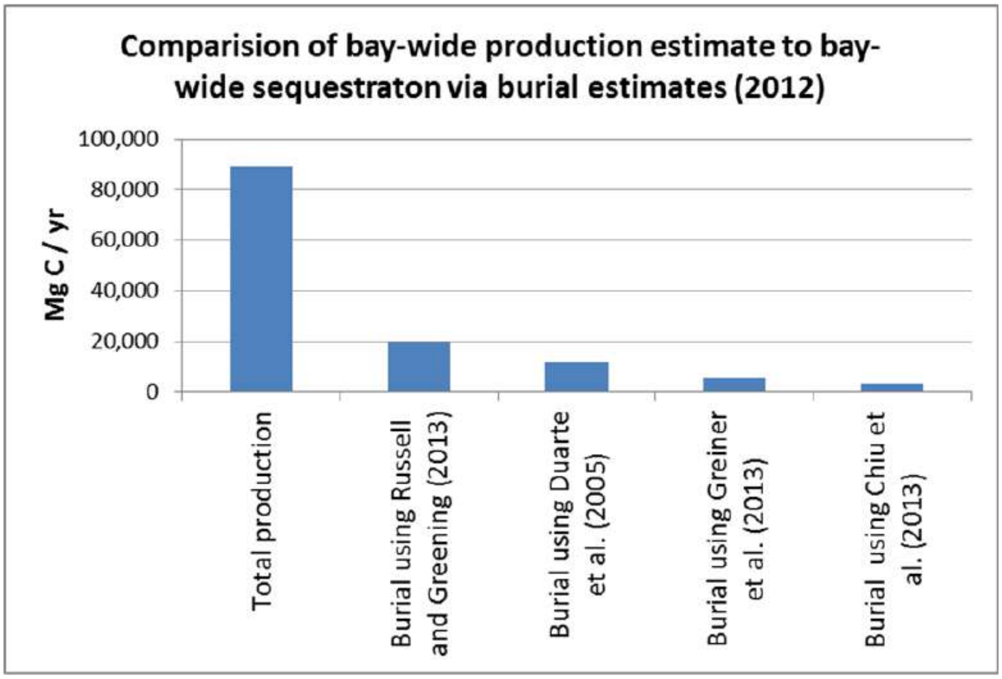
Figure 2 – Species distribution of seagrass meadows in Tampa Bay. See text for methodology.



Based on the techniques described above, it appears that the estimated bay-wide total carbon assimilation by seagrass meadows is substantially higher than even the highest rate of carbon sequestration by burial. Upon multiplying the 2012 bay-wide seagrass coverage estimate of 35,194 acres (14,243 ha) by the same literature-derived rate estimate for seagrass carbon sequestration (138 g C m-2 yr-[1]) used in Russell and Greening (2013) the bay-wide seagrass carbon sequestration quantity comes to 19,655 Mg C per year, a value 78 percent below the bay-wide carbon assimilation rate estimate of 89,255 Mg C per year.

Using the much lower seagrass carbon sequestration rate estimates listed in Duarte et al. (2005), Greiner et al. (2013) and Chiu et al. (2013) results in bay-wide carbon sequestration rates that are 87, 94 and 96 percent lower, respectively, than the bay-wide carbon assimilation rate estimate of 89,255 Mg C per year.

Discussion

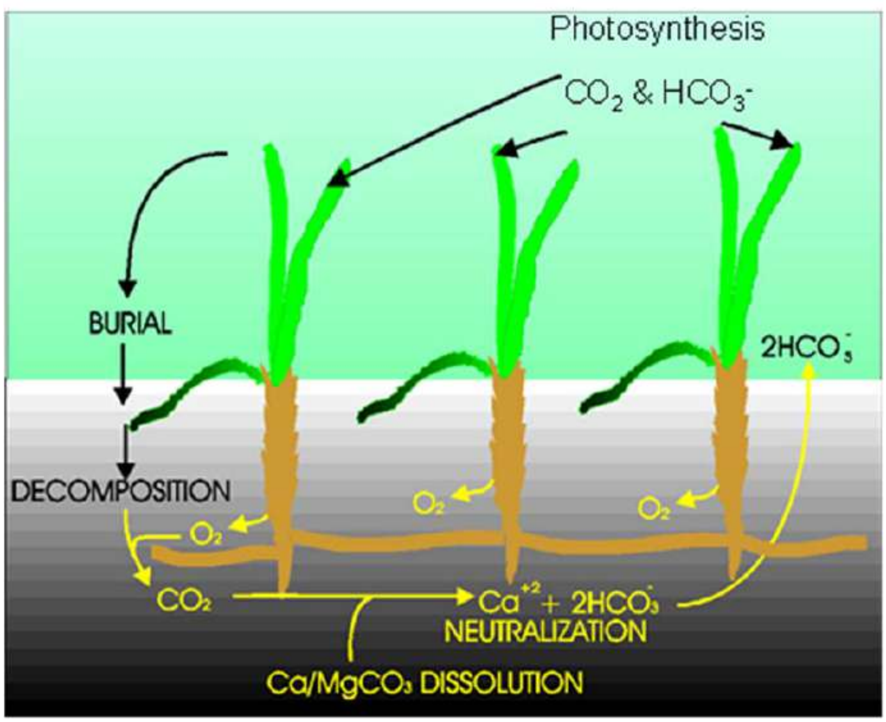
At present, it is not yet known if the discrepancy between bay-wide carbon assimilation rate estimates carbon sequestration rate estimates is due to unrealistically high rates for assimilation, unrealistically low rates for sequestration, or if there is a natural and large difference between the assimilation of carbon by seagrass meadows and the subsequent sequestration of that carbon via burial. Discrepancies between measured rates of net primary production and the quantification of destinations of that fixed carbon have been noted as far back as Lindeman (1942); it is not unusual that a gap is found here as well. In terms of the accuracy of any of the measurements used here, it should be noted that the majority of data used to develop the bay-wide carbon assimilation rate estimate of 89,255 Mg C per year came from studies conducted in various Florida estuaries, including Tampa Bay itself (Neely 2000), adjacent Sarasota Bay (Tomasko et al. 1996) and the contiguous estuary of Charlotte Harbor (Tomasko and Hall

1999). In contrast, none of the carbon sequestration rate estimates, which varied by a factor of nearly seven-fold (i.e., 20 to 138 g C m^{-2} yr^{-1}) were based on data from the contiguous estuaries of Tampa Bay, Sarasota Bay or Charlotte Harbor.

Although the quantification of carbon sequestration capacities via burial is a logical technique for determining the amount of carbon that can be kept from re-entering the atmosphere after assimilation, burial is not the only method of sequestration that has been invoked as a pathway for sequestration by seagrass meadows. Prior work in the carbonate sediments of the Bahamas Banks has shown that the highly productive *T. testudinum* meadows in that location occur in sediments with organic contents of less than 0.5 percent, on average (Burdige and Zimmerman 2002). In carbonate-rich sediments, potentially significant portions of the inorganic carbon that enters into the water column as CO_2 after diffusion from the atmosphere is then assimilated by seagrass leaves and could then be "chemically sequestered" via the bicarbonate pathway, outlined below.

The first step of the process of bicarbonate sequestration is the re-mineralization of previously fixed CO_2 in sediment porewaters, as shown in Figure 3. Seagrass roots and rhizomes leak oxygen into porewater in part to offset the impacts of sulfide toxicity.

Figure 3 – Illustration of carbon uptake into seagrass biomass, and its initial fate (graphic from R.C. Zimmerman).



The chemical reaction of fixed carbon being re-mineralized through aerobic respiration is thus:

$$CH_2O + O_2 \rightarrow CO_2 + H_2O$$

The second step involves the reaction between respired CO_2, water and free carbonate ions (found in carbonate-rich sediments):

$$CO_2 + H_2O + CO_3^{2-} \rightarrow 2HCO_3^-$$

.

The consumption of carbonate ions in this step lowers the saturation level of carbonate ions in the porewater, leading to dissolution of calcium carbonate sediments and the formation of calcium ions and bicarbonate ions:

$$CaCO_3 + H_2O + CO_2 \rightarrow Ca^{2+} + 2HCO_3^-$$

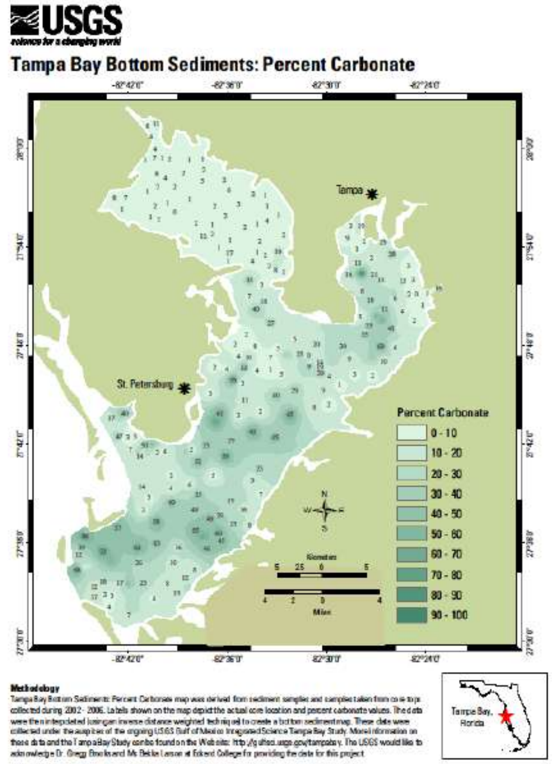
In this process, organic carbon is broken down via aerobic respiration in carbonate-rich sediments, with the end result that previously asimilated CO_2 (including CO_2 that could be derived from an anthropogenically enriched atmosphere) is chemically sequestered in the oceanic bicarbonate pool. Bicarbonate in the global ocean does not "outgas" back into the atmosphere, and it becomes part of a sink for atmospheric CO_2 where it would "…add minimally to the large, benign pool of these ions already present in seawater" (Rau et al. 2001). Whle bicarbonate sequestation may appear to be an unusual or potentially challenging process to consider, it was first discussed more than 30 years ago, when Smith (1981) noted that although direct burial of carbon by marine macrophytes would be a readily quantifiable carbon sink, "…detrital material that is oxidized and liberates CO_2 may also serve as a mechanism of CO_2 storage". Further, Smith (1981) noted that "…decaying macrophytes make the surrounding water more capable of dissolving $CaCO_3$, thus adding CO_2 to the alakalinity pool of the oceans."

In Tokyo Harbor, cabon sequestration via the bicarbonate pathway was the only mechanism of carbon sequetration considered in the "International Workshop for the Seagrass Ecosystem Eco-Engineering and Carbon Sequestration Project" (see Isobe et al. 2002 and references within).

Not only is sequestration into bicarbonate ions a pathyway that could explain at least a portion of the sizable discrepancy between carbon assimilation rate etimates for seagrass and carbon sequestration estimates via burial, bicanboate ions are the major consituent of the total alkalinity pool of marine waters. Total alkalinty is quantified based on the capacity of an aqueous solution to neutralize acids. Therefore, carbon sequstration via the bicarbonate pathway could also have the additional benefit of offsetting ocean acidification as well. Recent research by Unsworth et al. (2012) has pointed out the benefits to carbonate-depositing organisms such as corals of the bicarbonate produciton processes of adajcent seagrass meadows.

While it is unknown what role, if any, is played by bicarbonate sequestration for seagrass meadows in Tampa Bay, it could be important to test for the presence of this process for the following reasons: 1) there is a large difference between bay-wide estimates of carbon assimilation by seagrass and bay-wide estimates of carbon sequestration via burial, 2) while export of seagrass blades can be a mechanism though which fixed carbon is not buried on-site, export of blades was incorporated into the bay-wide carbon assimilation estimate, and 3) bay-wide, the carbonate content of surface sediments is much higher than the organic content of sediments, as shown in Figures 4 and 5, respectively, suggesting that carbonate-rich sediments could be allowing for significant amounts of bicarbonate sequestration of previously assimilated carbon.

Figure 4 – Display of percent carbonate of sediments in Tampa Bay. Figure from USGS.



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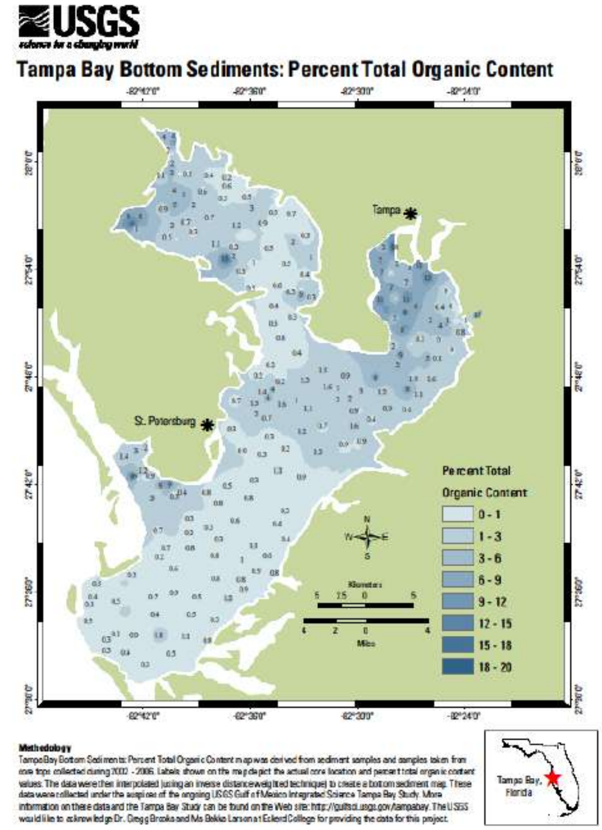
. **Figure 5 – Display of percent organic content of sediments in Tampa Bay. Figure from USGS.**



In the high carbonate content sediments of the Bahamas Banks, Burdige et al. (2010) found that the amount of carbon sequestered through the bicarbonate pathway was positively correlated with leaf area index, which itself correlates with biomass on a per m^2 basis. The very lush seagrass meadows of Lower Tampa Bay are located in the part of Tampa Bay with the highest sediment carbonate contents (Figure 4) although most measurements in Figures 4 and 5 do not appear to have been taken within seagrass meadows, but in deeper areas of the bay. Nonetheless, Lower Tampa Bay is the part of the bay where bicarbonate sequestration (if it occurs) would likely be greatest.

While uncertainty is to be expected with any attempt to model biological processes, the amount of uncertainly that exists in terms of carbon sequestration via burial in seagrass meadows is such that bay-wide estimates would vary by nearly seven-fold, based on which literature-derived value is used. Even when "global" estimates of sequestration are constructed, estimates can vary two-fold depending upon which organic content value is used to develop sequestration estimates (e.g., Duarte et al. 2005 and Fourqurean et al. 2012).

Potential for sequestration through combined processes of burial and bicarbonate sequestration

Burdige and Zimmerman (2002) and Burdige et al. (2012) quantified the additional carbon sequestration capacity that can occur with the bicarbonate pathway. However, those studies were conducted on seagrass meadows in the tropical waters and the carbonate platform of the Bahamas Bank; such rates might not be entirely transferable to the sub-tropical waters of Tampa Bay.

A literature based seagrass productivity model produced by Unsworth et al. (2012) was based on a compilation of measurements from 11 studies from a combined 64 separate locations (albeit from tropical regions). In their study, Unsworth et al. (2012) calculated carbon sequestration through modeling changes in carbon concentrations in the water column. Bicarbonate sequestration was noted to be a significant sink for fixed carbon, and the authors noted that "…in addition to their importance to fisheries, sediment stabilization and primary production, seagrass meadows may enhance coral reef resilience to future ocean acidification." While there are no coral reefs in Tampa Bay, there are hard corals such as *Siderastrea radians*, as well as numerous organisms (e.g., clams, oysters, mussels, etc.) that could be adversely impacted by altered carbonate precipitation processes that are likely to occur with increased ocean acidification.

The net annual carbon sequestration rate estimated by Unsworth et al. (2012) can be used as an estimate (perhaps on the upper end) of the amount of carbon sequestration via the bicarbonate pathway for seagrass meadows in Tampa Bay. The mean annual average carbon sink derived by Unsworth et al. (2012) is 155 g C m^{-2} yr^{-1}, a rate slightly higher than the carbon burial rate of 138 g C m^{-2} yr^{-1} (MacLeod et al. 2013) cited in Russell and Greening (in press).

If one assumes that carbon sequestration processes of seagrass meadows in Tampa Bay could be accomplished via the combined pathways of carbon burial and bicarbonate sequestration, and if rate estimates of these processes are assumed to be 138 and 155 g C m^{-2} yr^{-1}, respectively, then the gap between carbon sequestration estimates on a bay-wide basis and estimates of bay-wide total productivity is reduced substantially. After including estimates of perhaps 10 percent of carbon being transferred to higher trophic levels (e.g., Lindeman 1942) the gap between bay-wide net primary production and bay-wide carbon sequestration (via both burial and bicarbonate sequestration) becomes smaller still, with the "gap" between these two estimates likely falling within the range of accumulated errors associated with the multiple measurements that are involved.

Recommendations for additional data collection

Seagrass researchers have worked in Tampa Bay at least as far back as the 1960s, and productivity estimates for seagrasses themselves date back almost 100 years (i.e., Petersen 1918, as cited in Zieman and Wetzel 1980). However, seagrass meaodws in Tampa Bay have not received much attention as regards their role as potential carbon sinks, and no sequestration rate estimates are available for Tampa Bay, either by burial or the bicarbonate sequestration pathway.

To increase the confidence of carbon sequestration estimates for seagrass meadows in Tampa Bay, it would be useful to have local data collection on sediment characteristics within seagrass meadows, as well as the collection of data that could be used to test for the presence of the carbonate dissolution and bicarbonate sequestration pathways outlined by Burdige and Zimmerman (2002), Burdige et al. (2012) and Unsworth et al. (2012). With this additional information, sequestration rate estimates could be derived other than through the use of literature alone, and resource managers would have enhanced levels of confidence in their model output. Without this additional data collection, the carbon sequestration values derived for seagrass meadows could vary considerably, dependent upon which study was used in bay-wide calculations.

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APPENDIX F

Parcel Prioritization Methods

Appendix F. Parcel Prioritzation Methods

Methods

As part of this study the HEM was utilized to identify low-lying coastal uplands that are currently undeveloped, and that are predicted to become intertidal by 2100. Polygons of these areas were then intersected with county parcel data to develop a spatial database of the property owners – both public and private sector. HEM output was exported to GIS to create a series maps showing high priority coastal uplands. This information was developed as a tool to identify and prioritize parcels for the potential conservation of habitat migratory pathways that could help offset habitat changes/losses related to future sea level rise.

To conduct this analysis, 2007 and 2100 habitat data layers from the HEM, and parcel data from Hillsborough, Pinellas and Manatee counties obtained from Florida Geographic Data Library (FGDL) were used. The analysis was conducted in GIS using the steps summarized below:

1. The 2100 layer was subtracted from the 2007 layer using the "minus" tool. This subtracted the value of each 2100 cell from that of the 2007 cells. The resulting raster had cells of various positive and negative numbers representing all possible forms of change (with zeros in areas of no change).

2. An Excel table was developed that generated all possible values that would have been created by this raster. For each value in the raster, the table was searched to determine "from-to" habitat changes, focusing only on those changes in the 2000, 3000 or 4000 land use classification series ("unprotected" uplands), giving all uplands that are projected to be inundated.

3. This raster was reclassified, giving a value of 1 for inundated uplands and 0 for anything else.

4. This new raster was converted to polygons to create the SLR Inundated Uplands layer used in the map series.

5. The 2100 layer was then reclassified giving a value of 1 to any unprotected uplands in that layer (i.e. those that will remain) and 0 for anything else.

6. This raster was converted to polygons to create the Contiguous Remaining Uplands layer.

7. From the parcel data, any parcels intersecting inundated uplands were extracted.

8. The same was done for any parcels intersecting remaining uplands.

9. Since there were several parcels that would overlap both inundated and remaining uplands, any parcels from the remaining wetlands that were "within" the layer of the

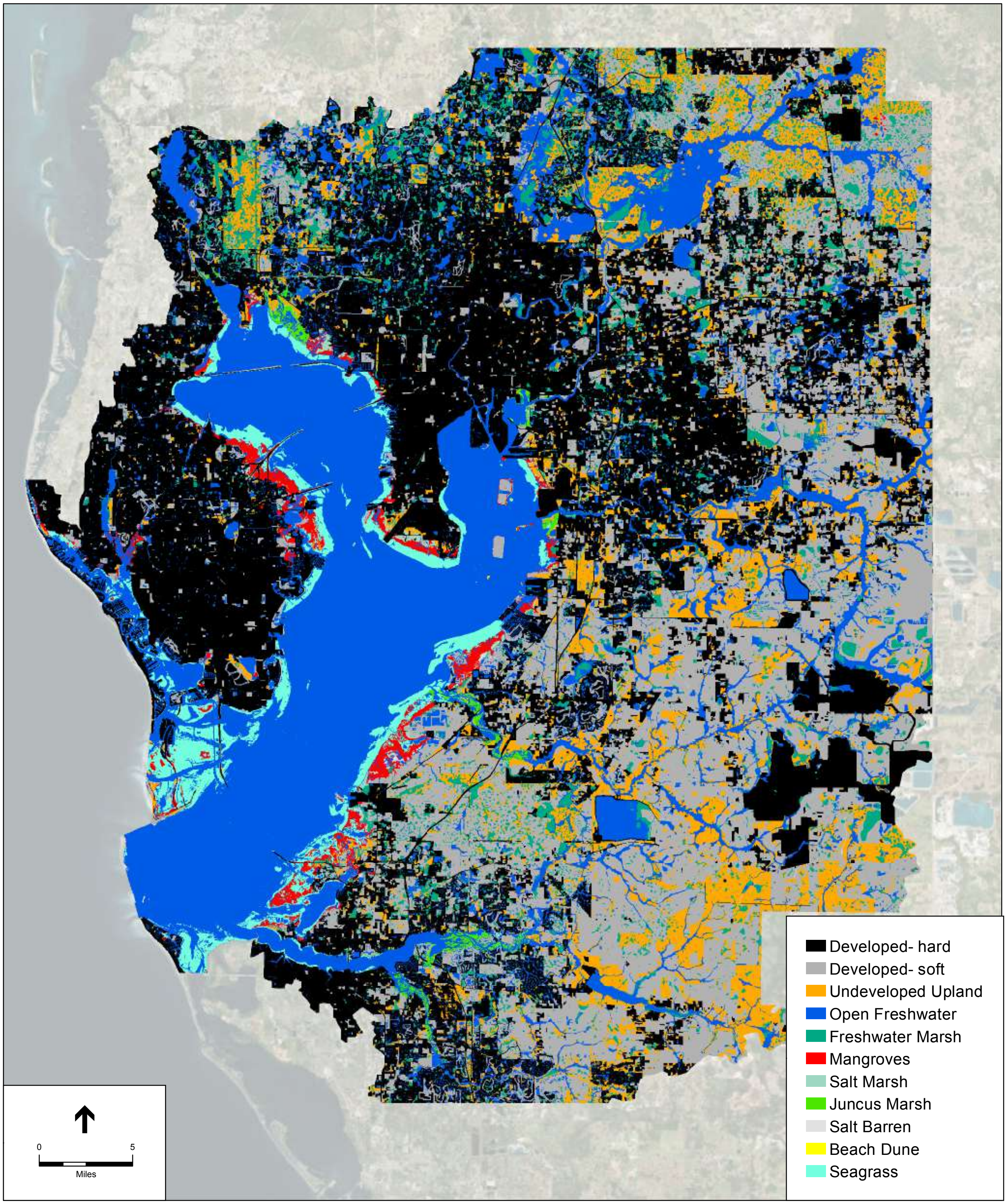
parcels from the inundated uplands were identified and removed, leaving only those parcels that intersected the remaining uplands.

10. All parcel layers have a field for identifying the entity that owns it (if publicly owned). For both layers, any parcels where this field was blank were extracted as Private Parcels.

11. The selection was then switched to select parcels where any value was assigned to that field. These parcels were extracted as Public Parcels.

12. Each upland and parcel category were assigned unique display characteristics to create the map series.

APPENDIX G
Habitat Maps



SOURCE (all maps in Appendix C): ESRI, ESA, SFWFMD, Florida Division of Emergency Management

Figure G-1

Tampa Bay Habitat Evolution Modeling Results
Run 1: Low Sea-Level Rise, Low Accretion, 2007

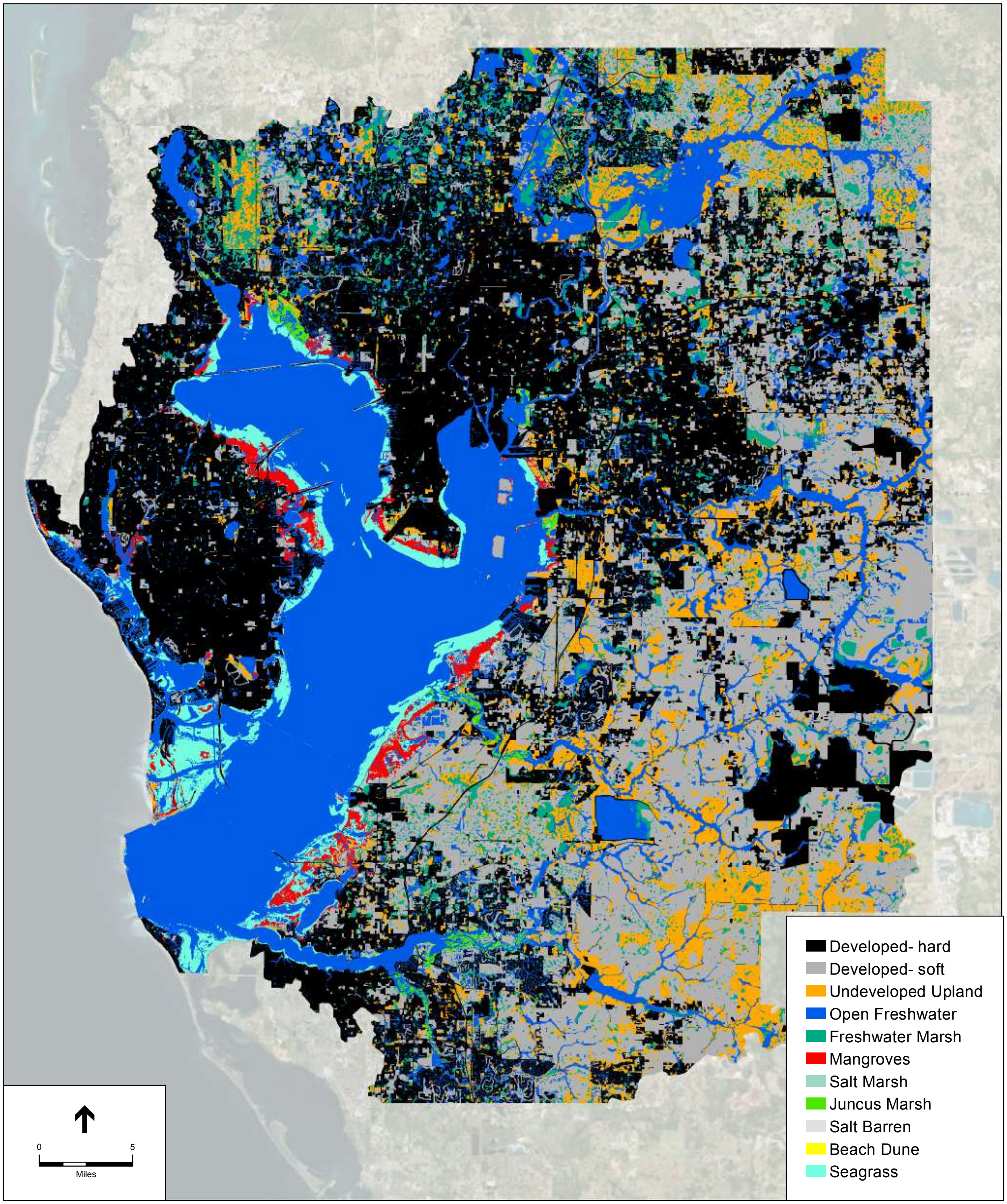


Figure G-2
Tampa Bay Habitat Evolution Modeling Results
Run 1: Low Sea-Level Rise, Low Accretion, 2025

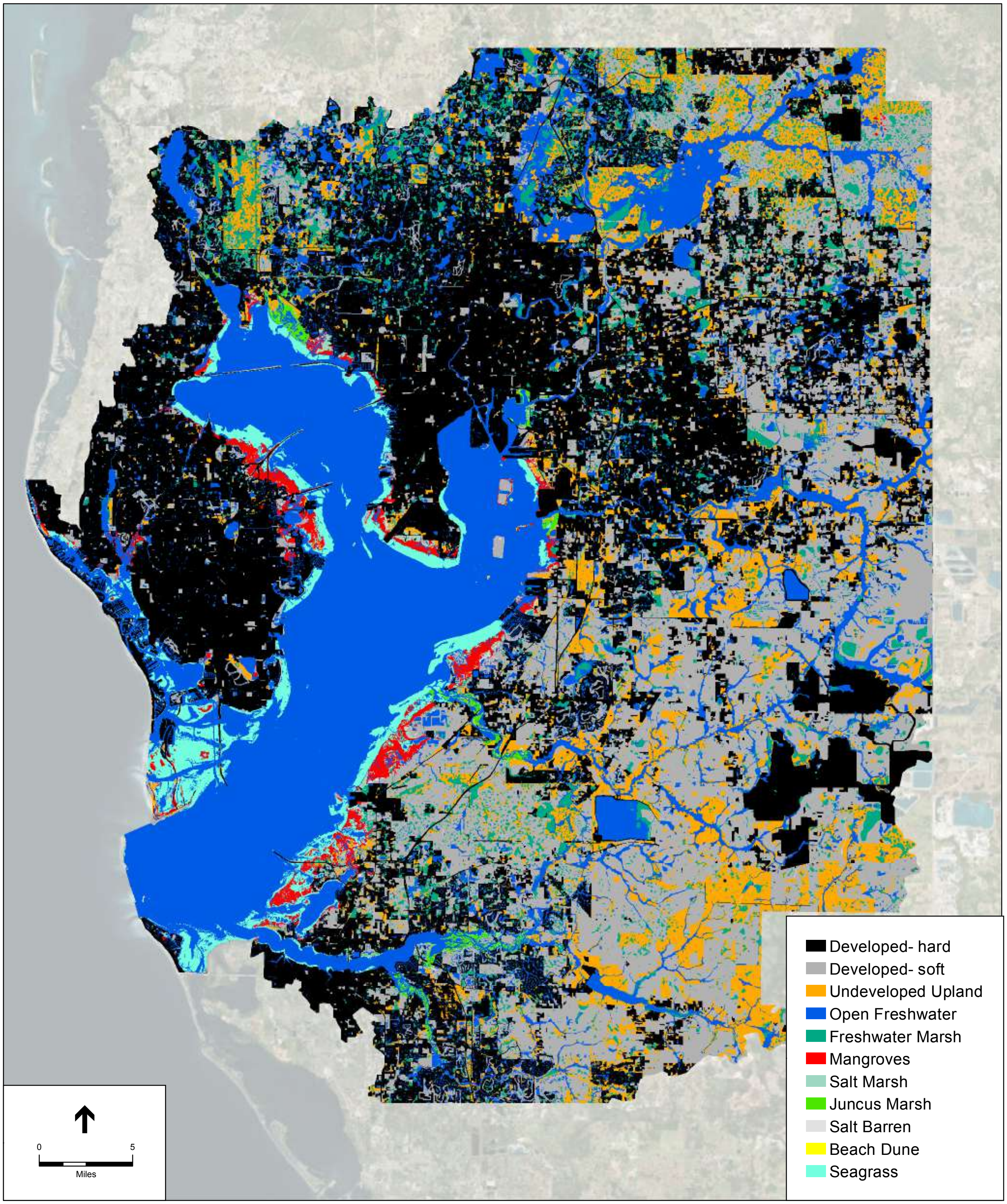


Figure G-3
Tampa Bay Habitat Evolution Modeling Results
Run 1: Low Sea-Level Rise, Low Accretion, 2050

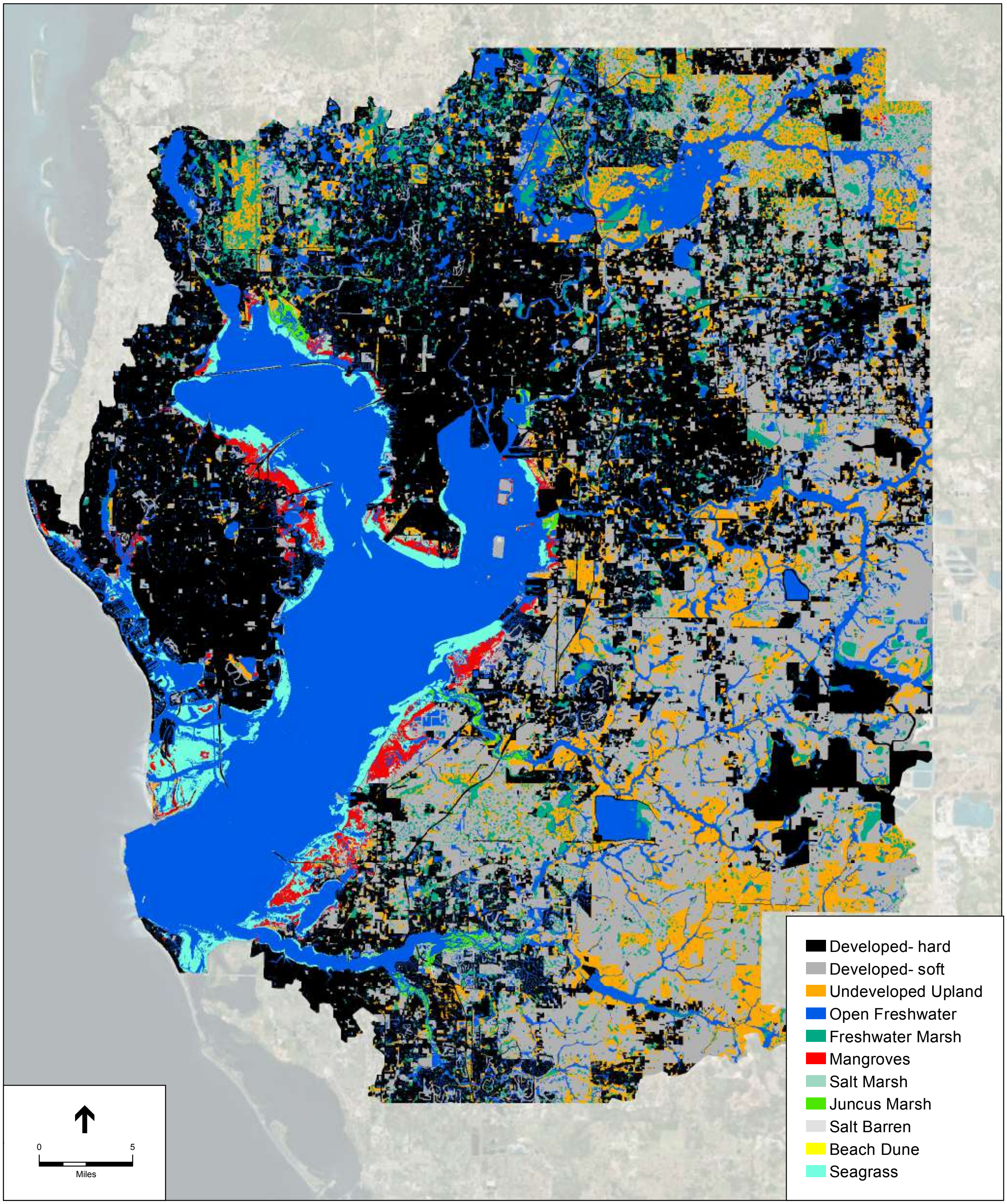


Figure G-4
Tampa Bay Habitat Evolution Modeling Results
Run 1: Low Sea-Level Rise, Low Accretion, 2075

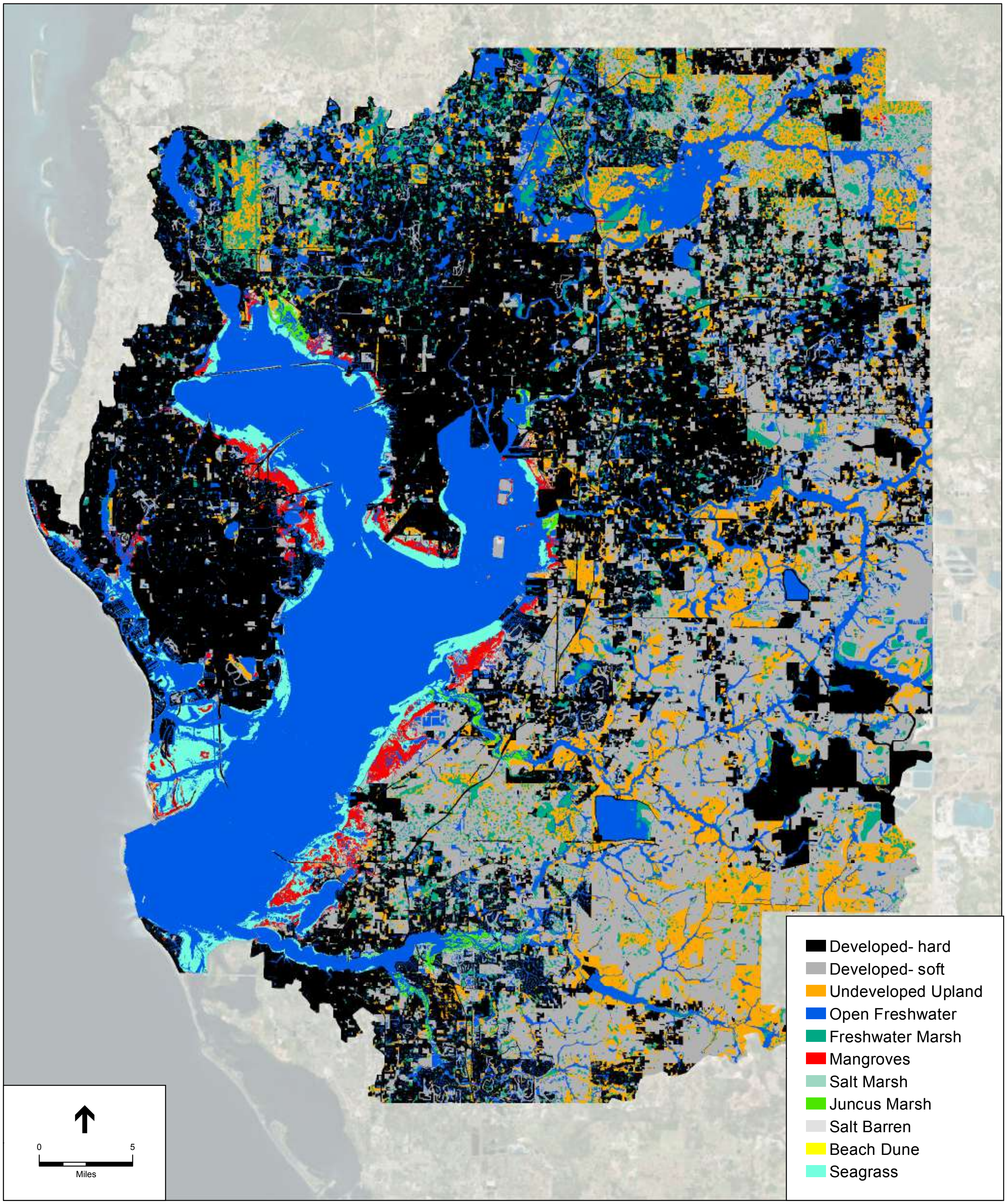
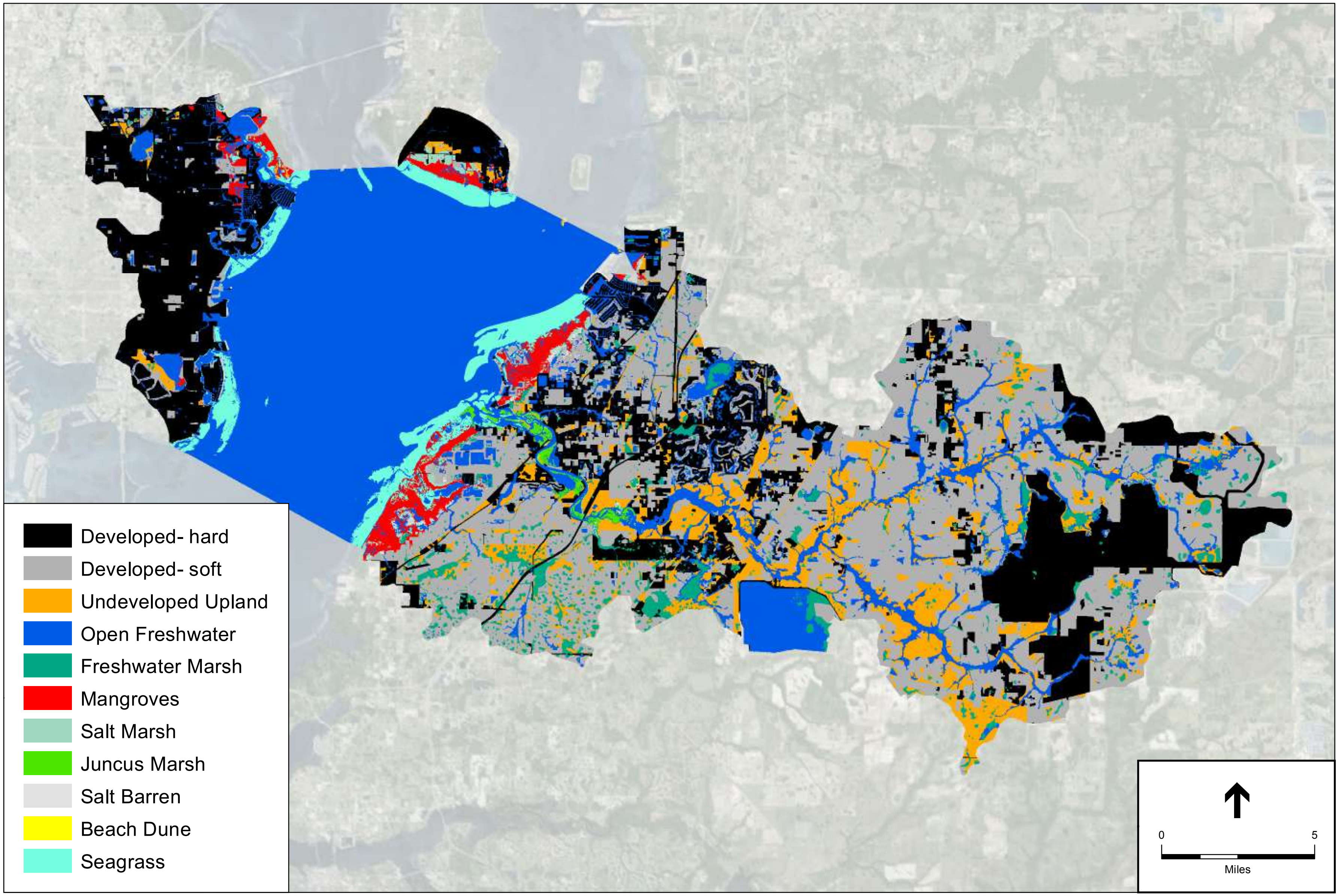


Figure G-5
Tampa Bay Habitat Evolution Modeling Results
Run 1: Low Sea-Level Rise, Low Accretion, 2100



Tampa Bay Blue Carbon Assessment. .D140671

Figure G-6

Tampa Bay Habitat Evolution Modeling Results

Run 1: Low Sea-Level Rise, Low Accretion, MTB 2007

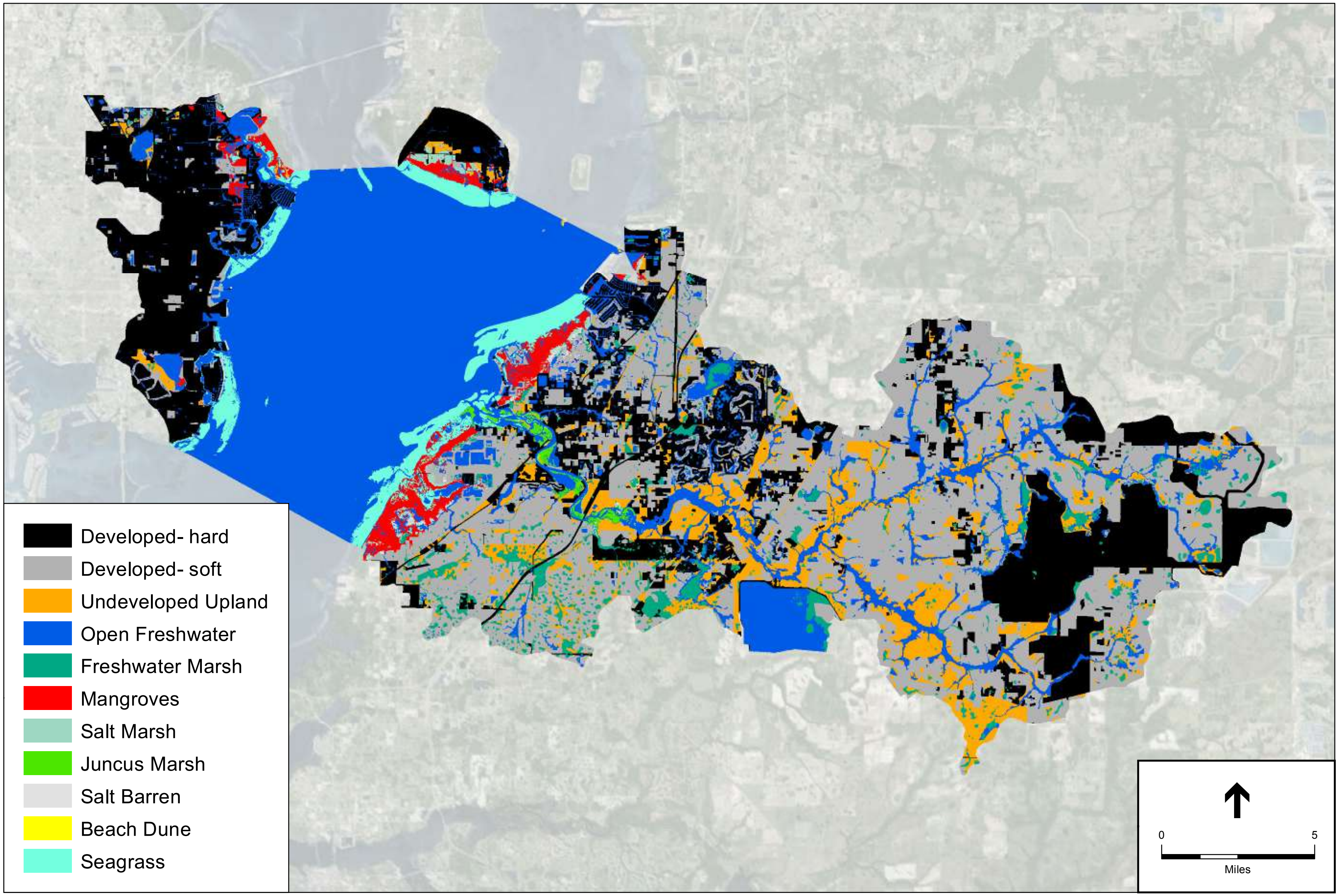
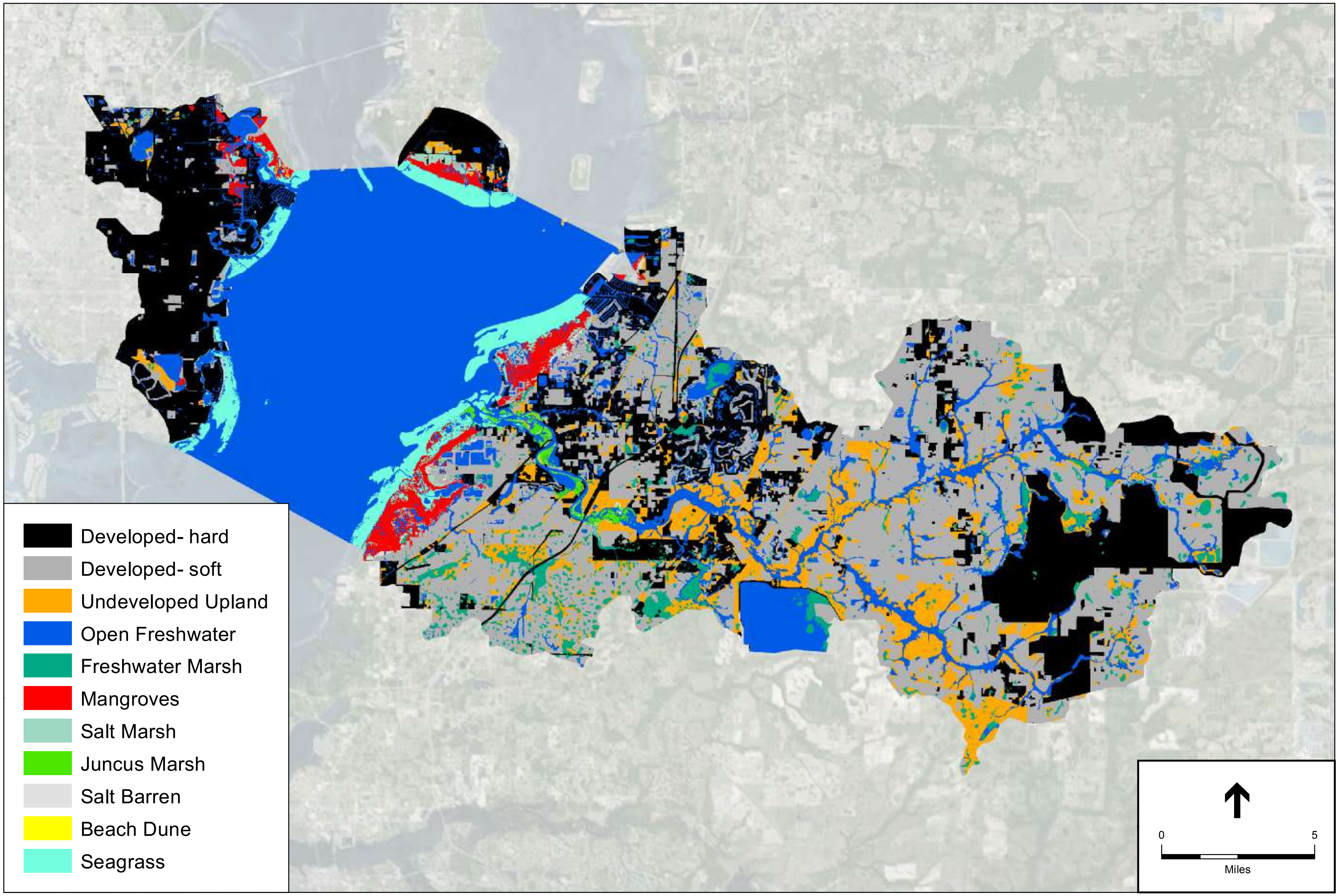


Figure G-7
Tampa Bay Habitat Evolution Modeling Results
Run 1: Low Sea-Level Rise, Low Accretion, MTB 2025



Tampa Bay Blue Carbon Assessment. .D140671

Figure G-8

Tampa Bay Habitat Evolution Modeling Results

Run 1: Low Sea-Level Rise, Low Accretion, MTB 2050

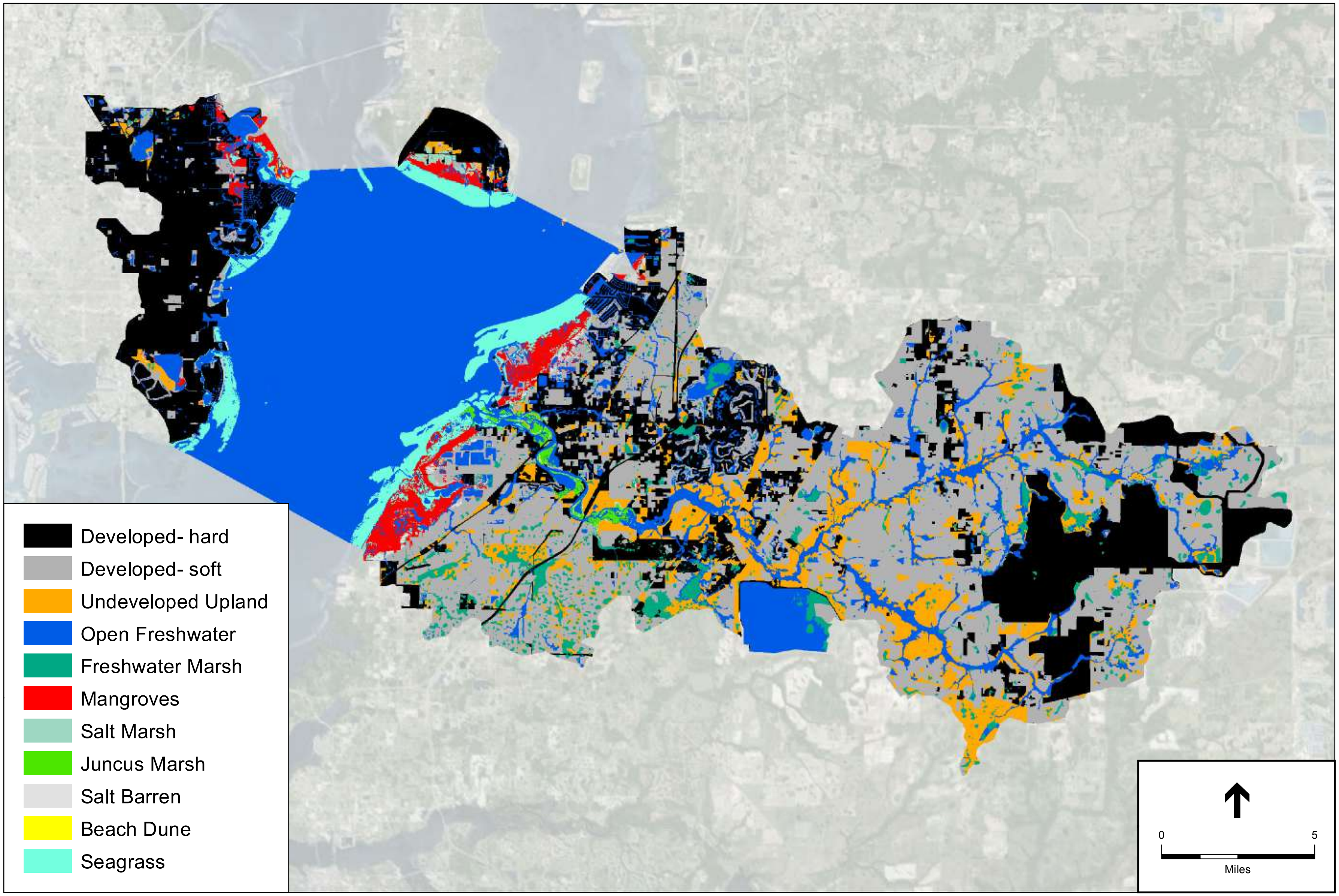


Figure G-9
Tampa Bay Habitat Evolution Modeling Results
Run 1: Low Sea-Level Rise, Low Accretion, MTB 2075

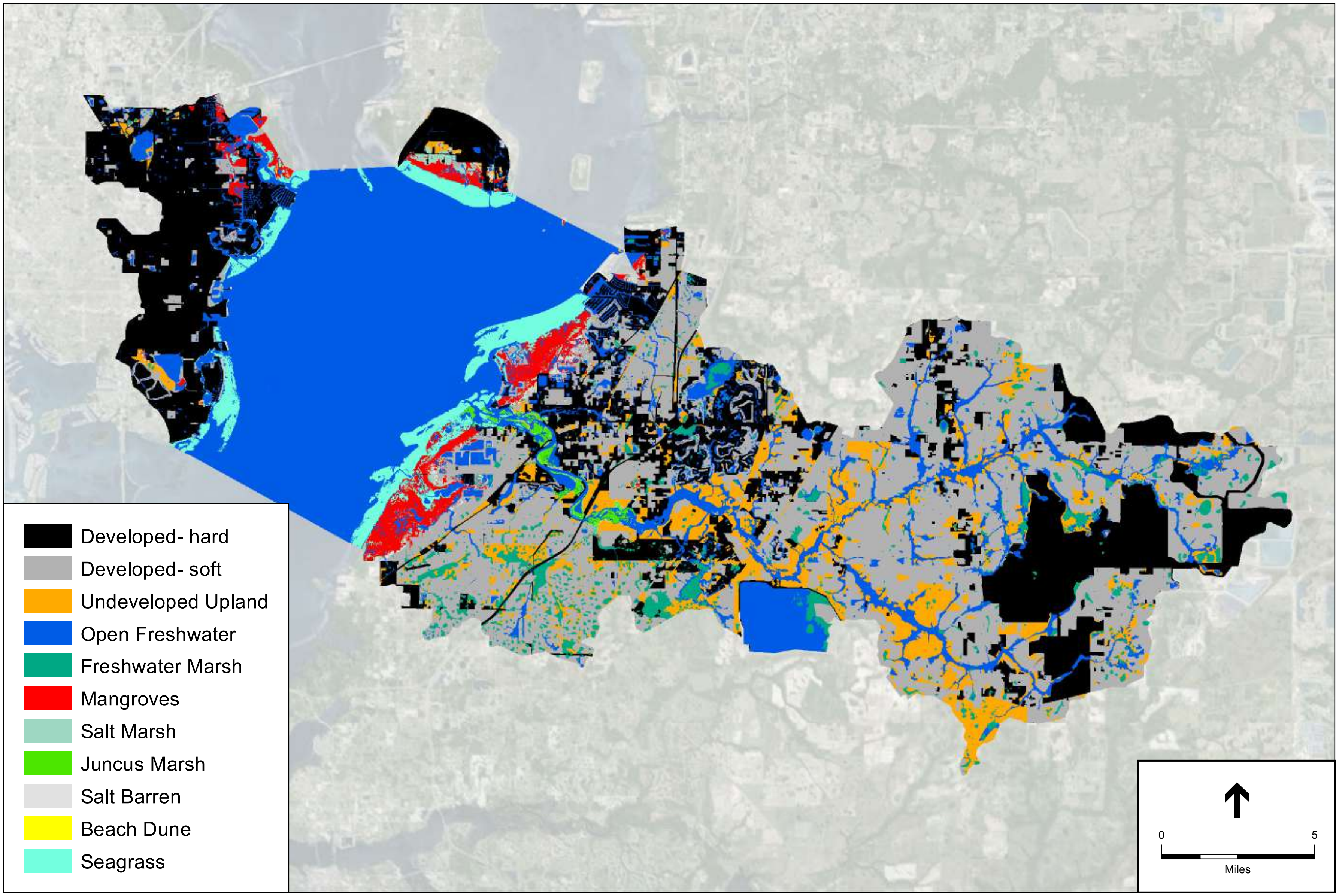
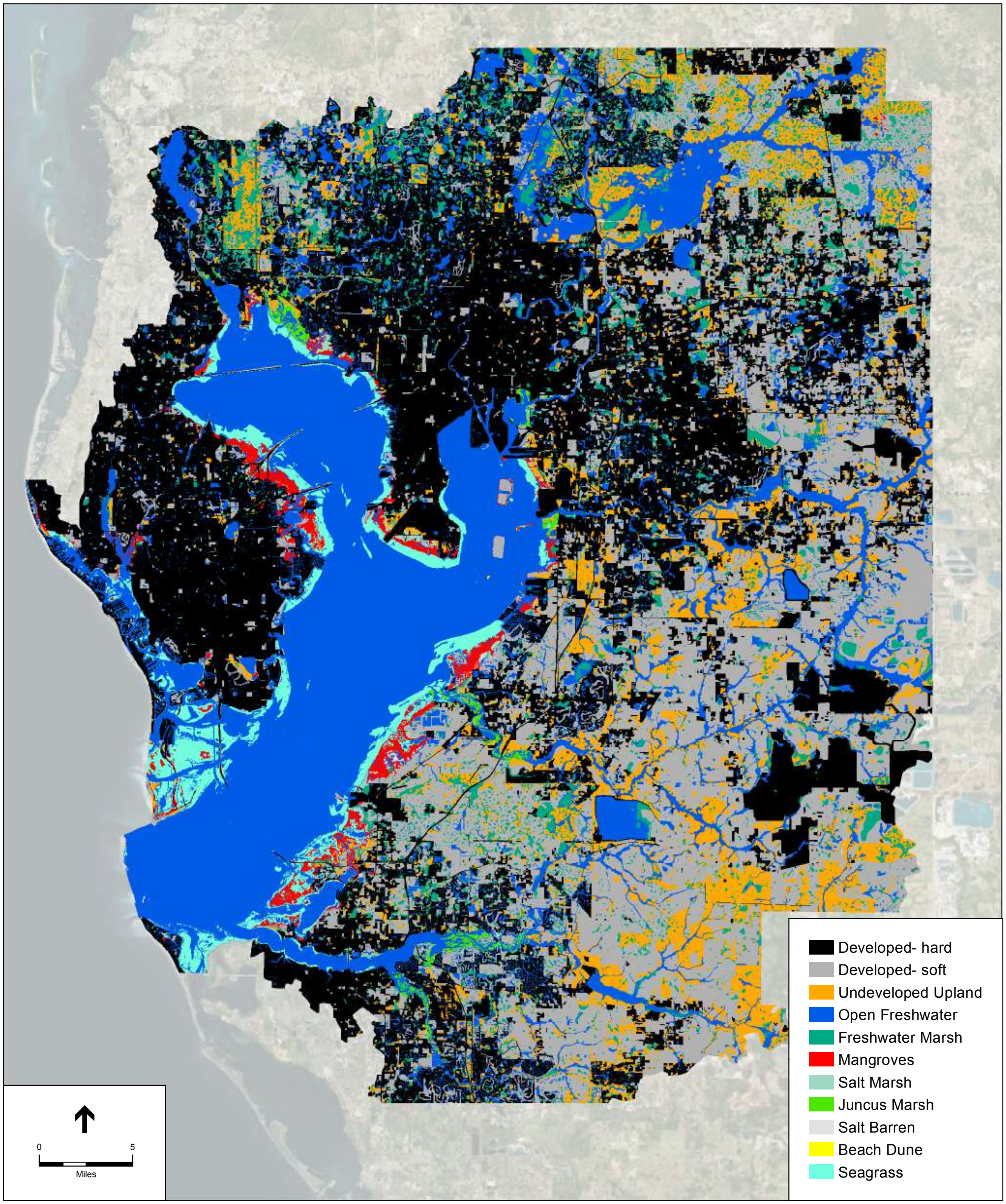


Figure G-10
Tampa Bay Habitat Evolution Modeling Results
Run 1: Low Sea-Level Rise, Low Accretion, MTB 2100



Tampa Bay Blue Carbon Assessment .D140671

Figure G-11
Tampa Bay Habitat Evolution Modeling Results
Run 2: Low Sea-Level Rise, High Accretion, 2007

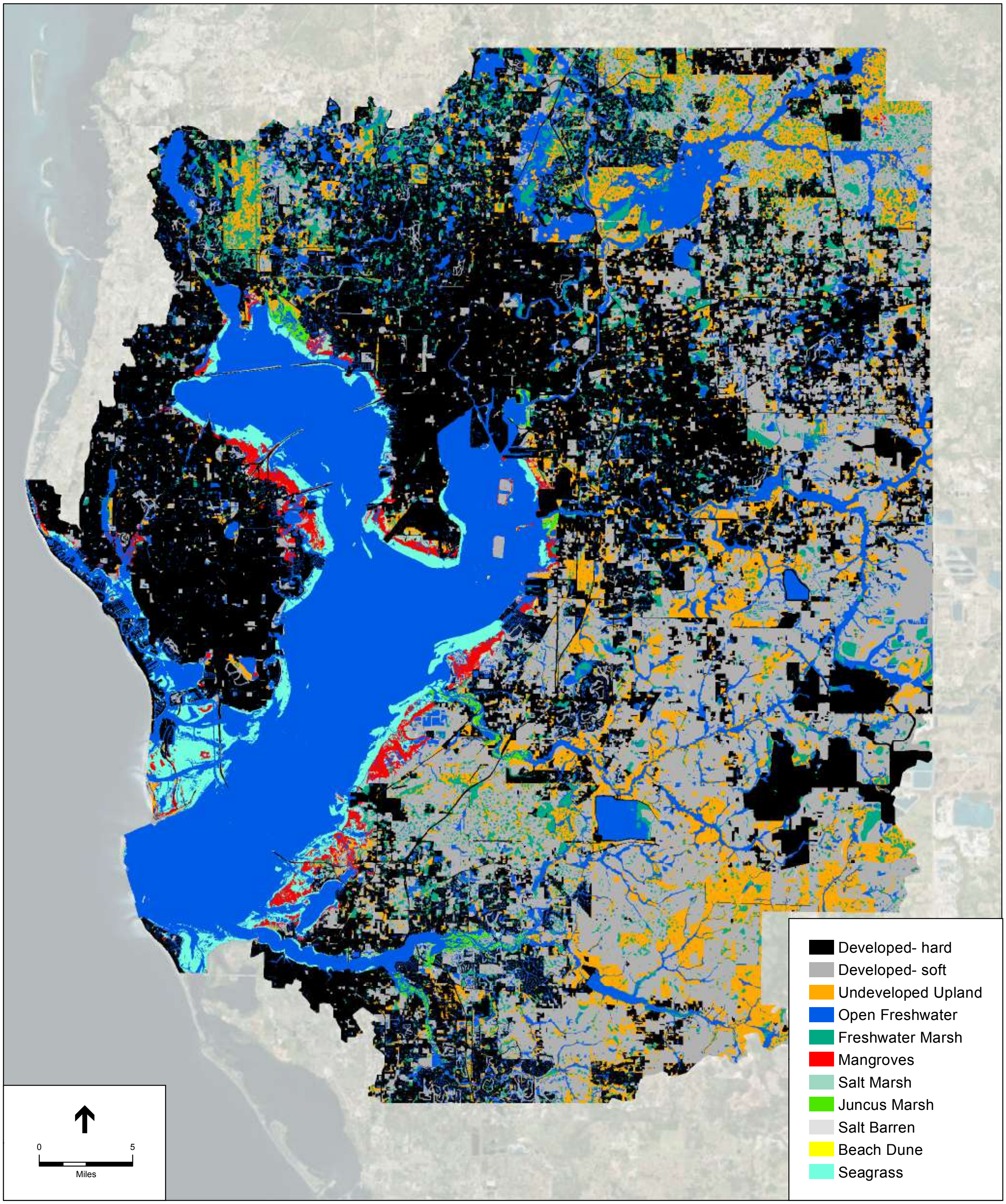


Figure G-12
Tampa Bay Habitat Evolution Modeling Results
Run 2: Low Sea-Level Rise, High Accretion, 2025

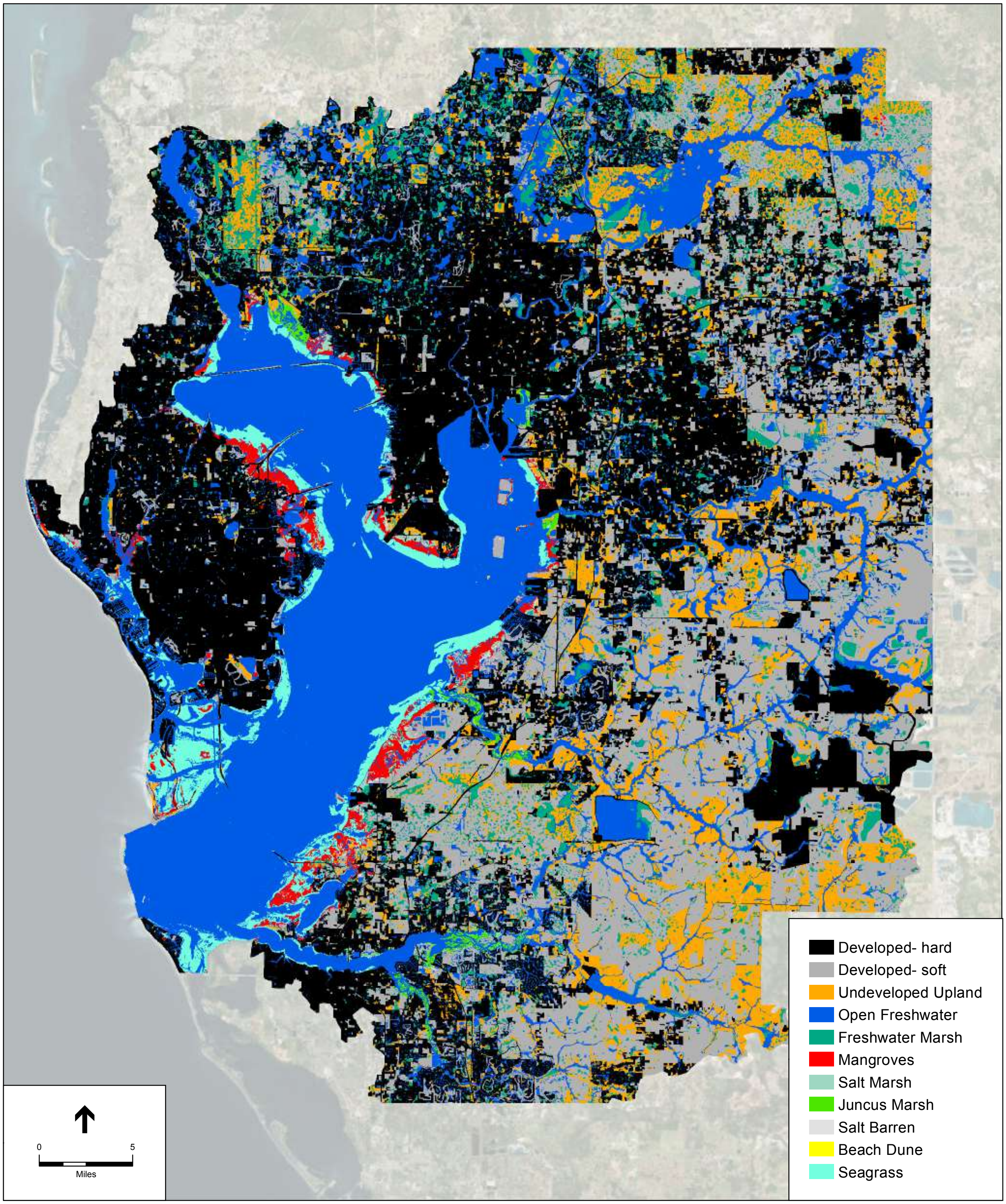


Figure G-13
Tampa Bay Habitat Evolution Modeling Results
Run 2: Low Sea-Level Rise, High Accretion, 2050

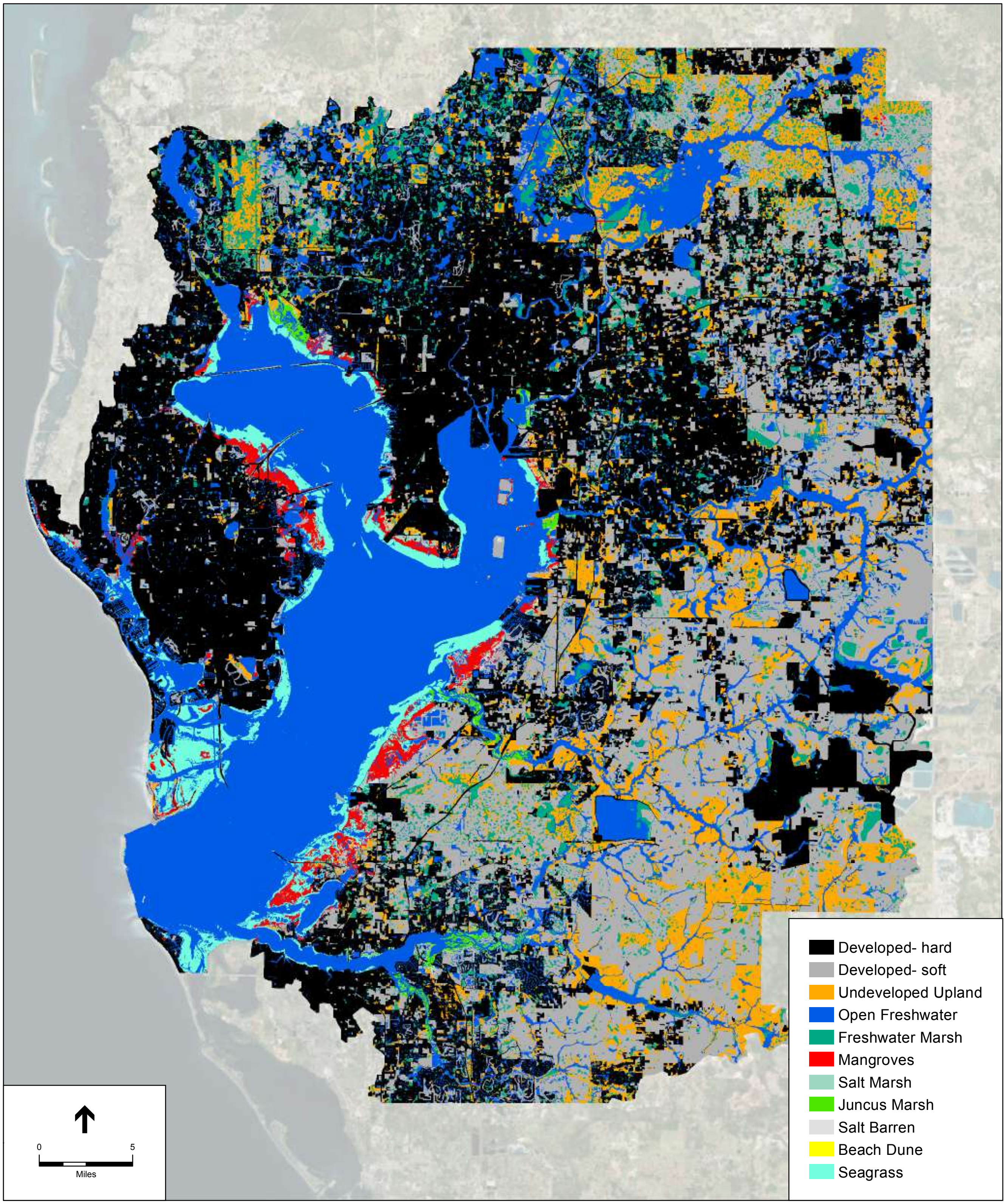
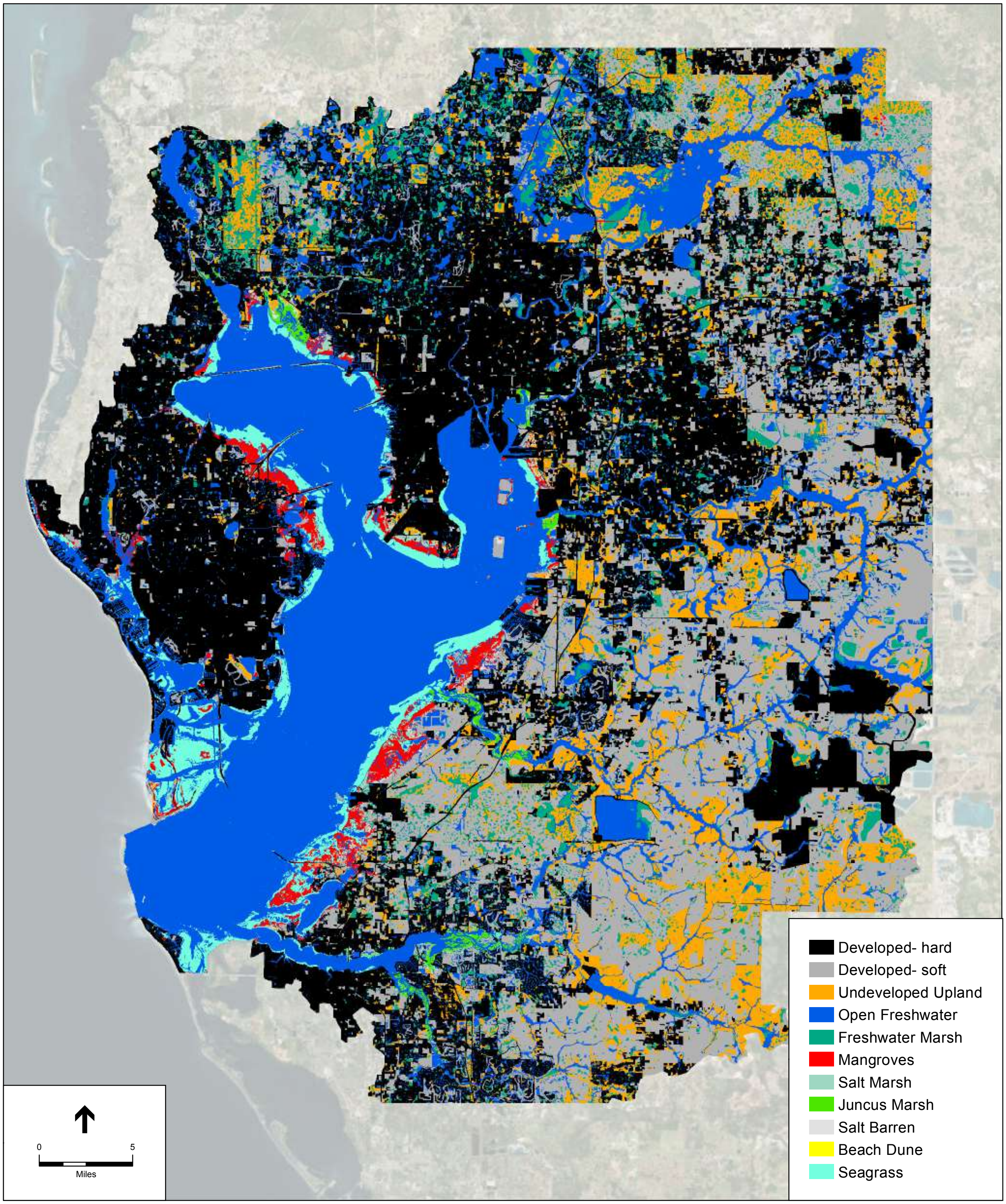


Figure G-14
Tampa Bay Habitat Evolution Modeling Results
Run 2: Low Sea-Level Rise, High Accretion, 2075



Tampa Bay Blue Carbon Assessment .D140671

Figure G-15
Tampa Bay Habitat Evolution Modeling Results
Run 2: Low Sea-Level Rise, High Accretion, 2100

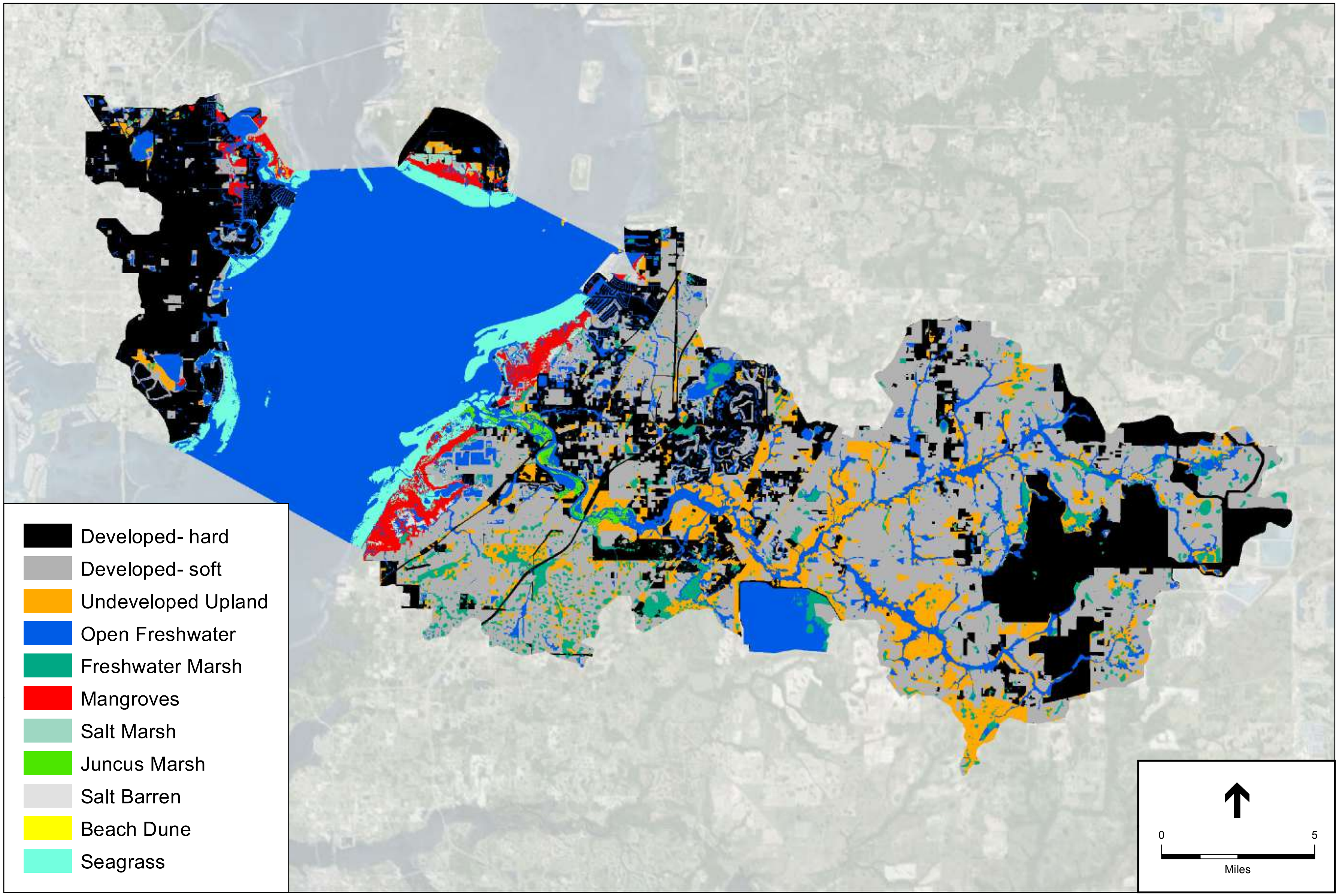
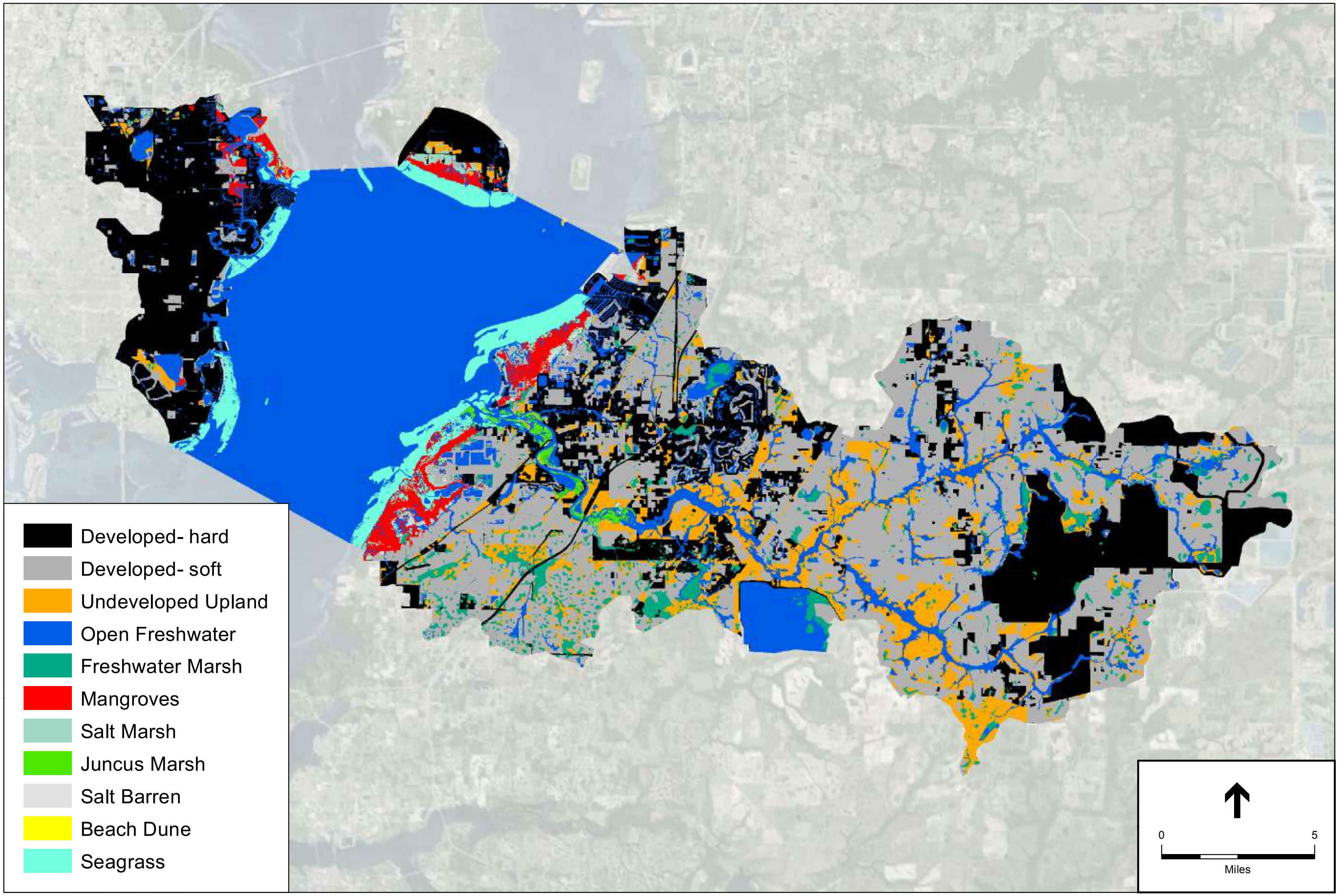


Figure G-16
Tampa Bay Habitat Evolution Modeling Results
Run 2: Low Sea-Level Rise, High Accretion, MTB 2007



Tampa Bay Blue Carbon Assessment. .D140671

Figure G-17

Tampa Bay Habitat Evolution Modeling Results

Run 2: Low Sea-Level Rise, High Accretion, MTB 2025

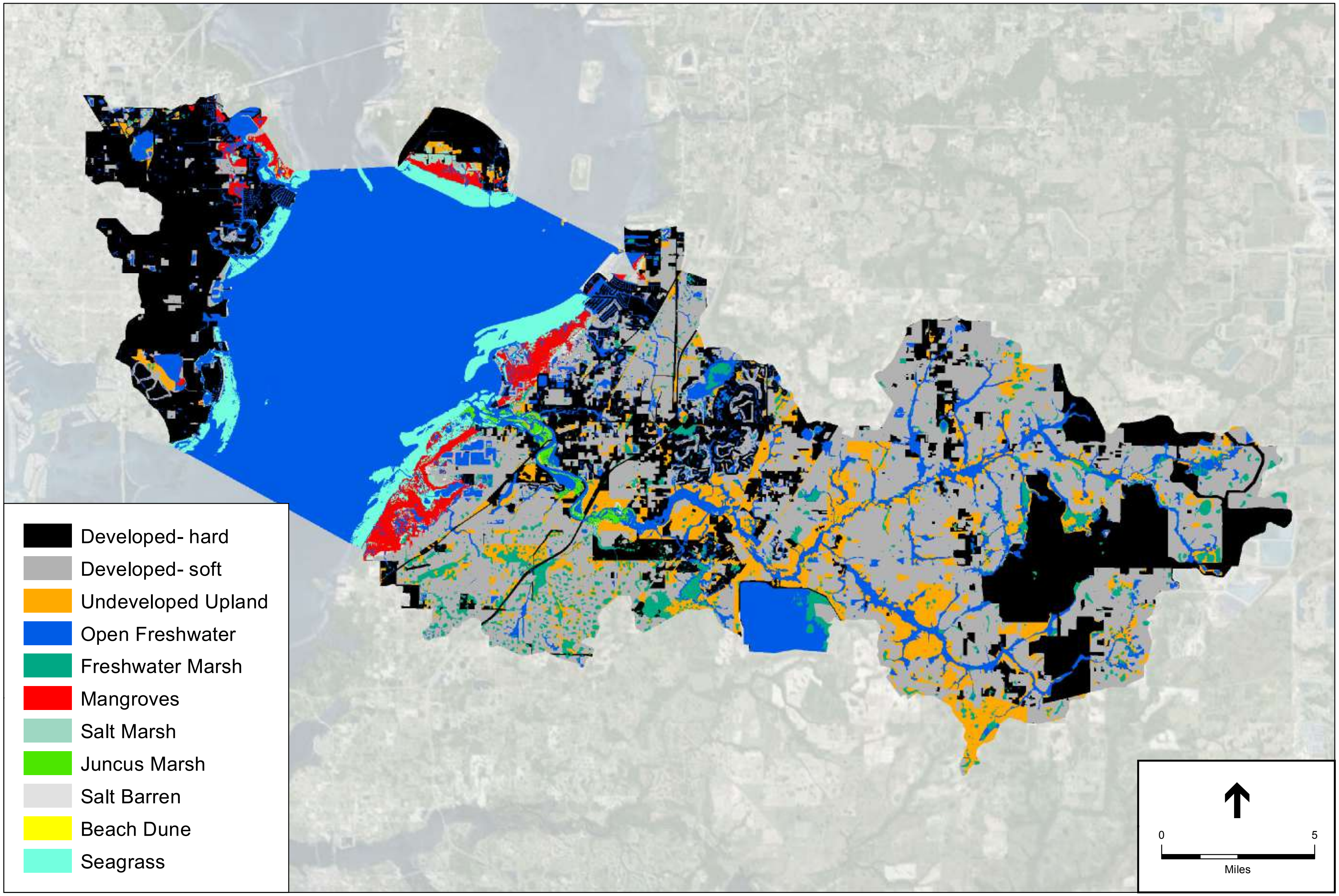
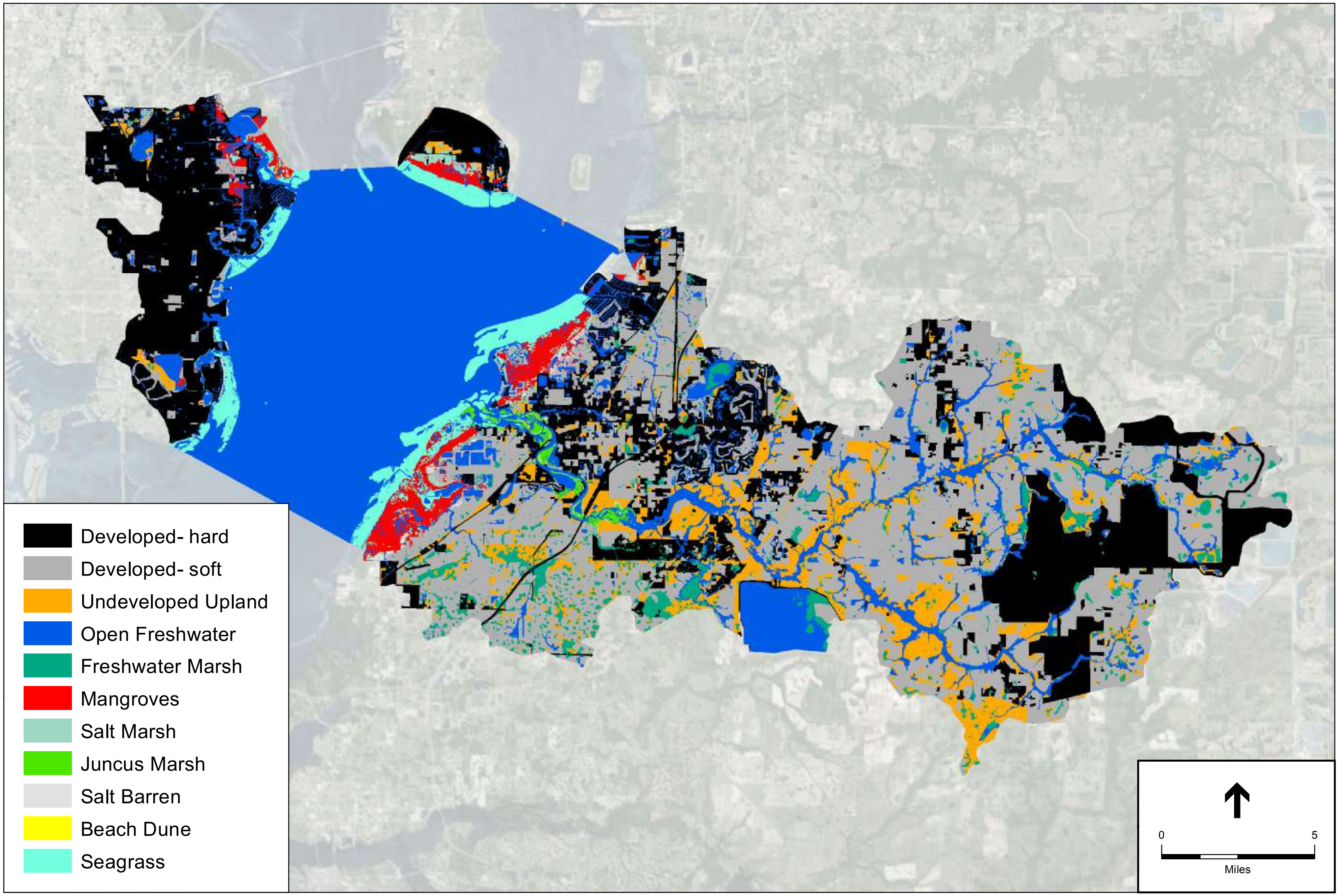
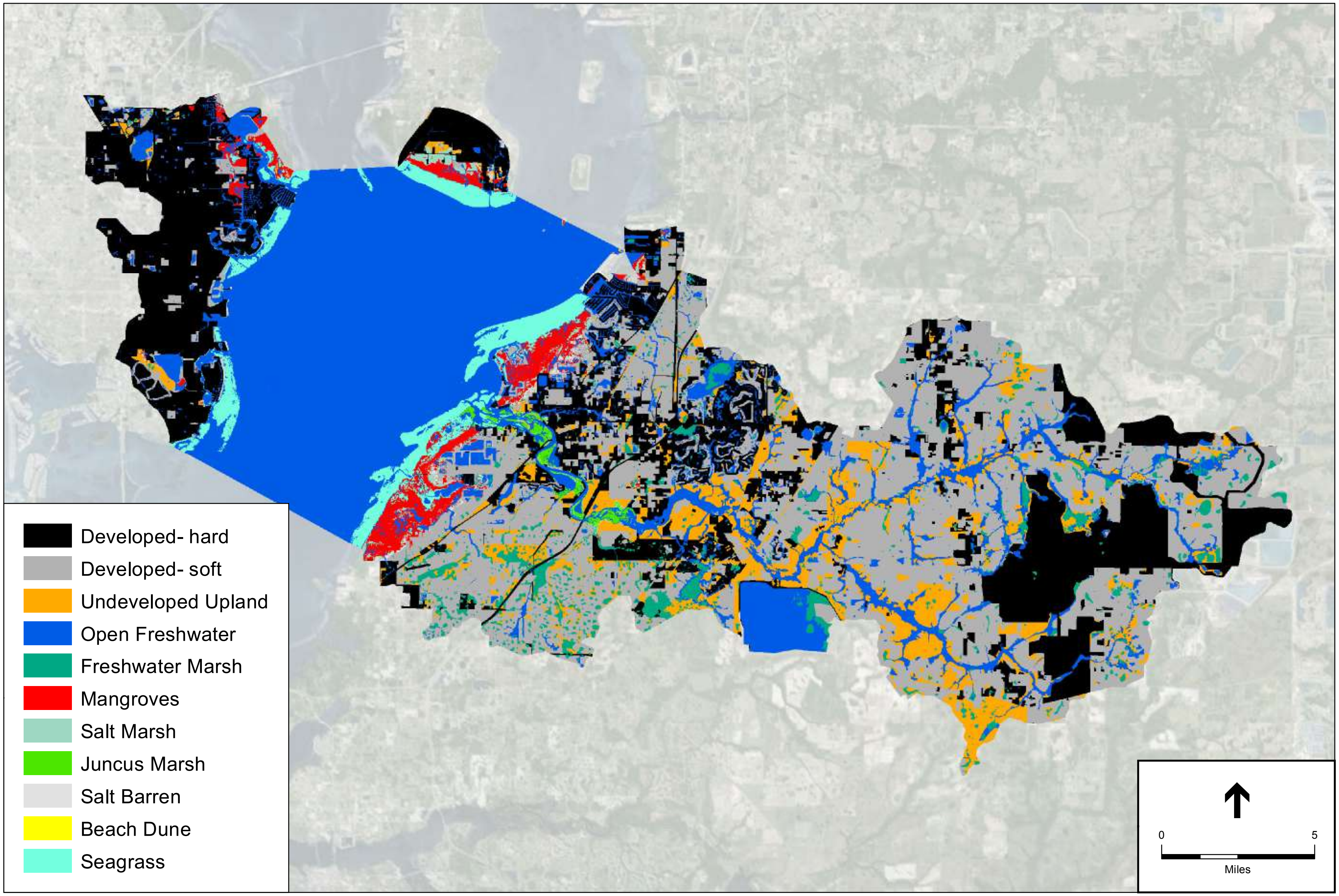


Figure G-18
Tampa Bay Habitat Evolution Modeling Results
Run 2: Low Sea-Level Rise, High Accretion, MTB 2050



Tampa Bay Blue Carbon Assessment. .D140671

Figure G-19
Tampa Bay Habitat Evolution Modeling Results
Run 2: Low Sea-Level Rise, High Accretion, MTB 2075



Tampa Bay Blue Carbon Assessment. .D140671

Figure G-20

Tampa Bay Habitat Evolution Modeling Results

Run 2: Low Sea-Level Rise, High Accretion, MTB 2100

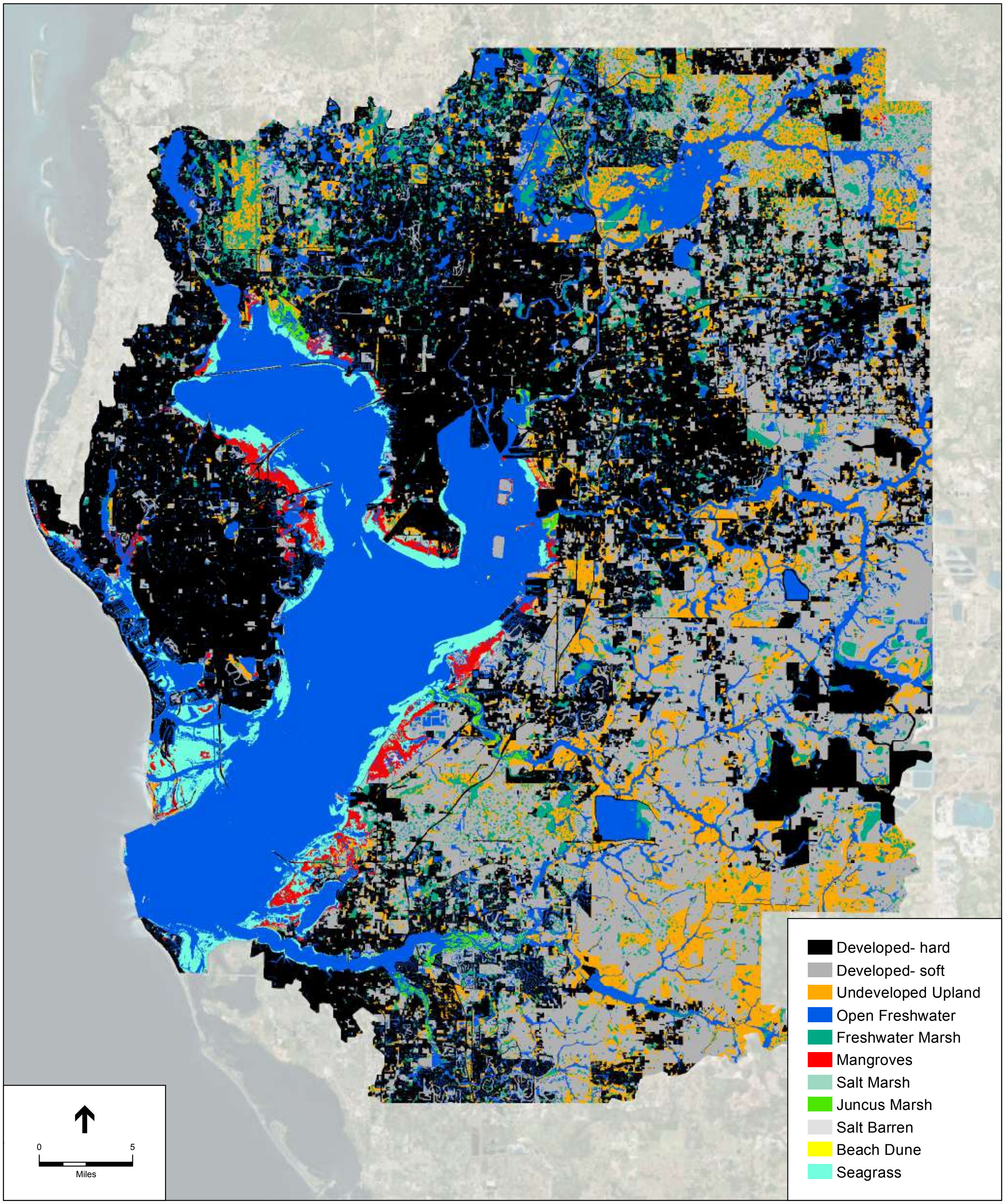


Figure G-1
Tampa Bay Habitat Evolution Modeling Results
Run 3: High Sea-Level Rise, Low Accretion, 2007

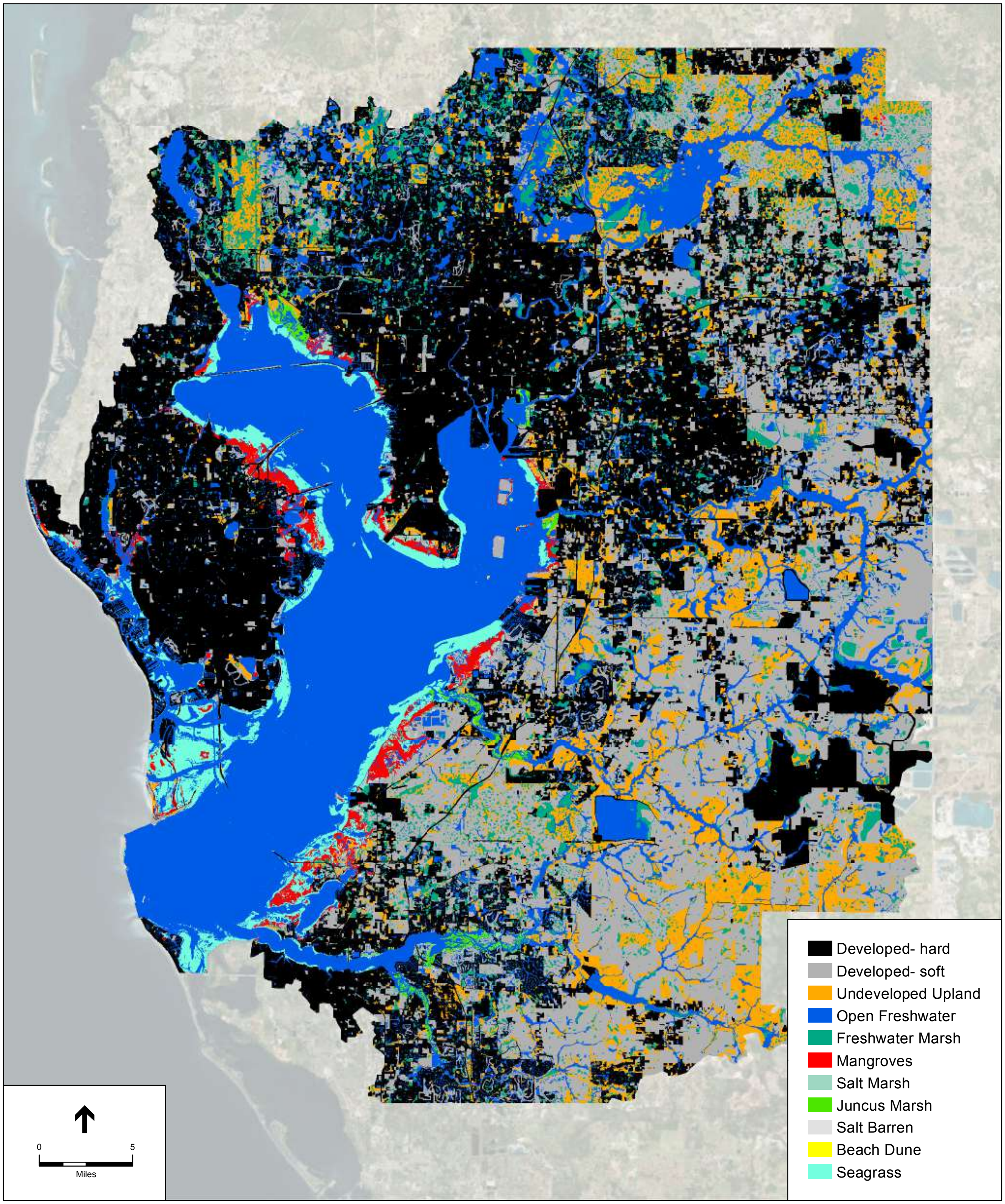
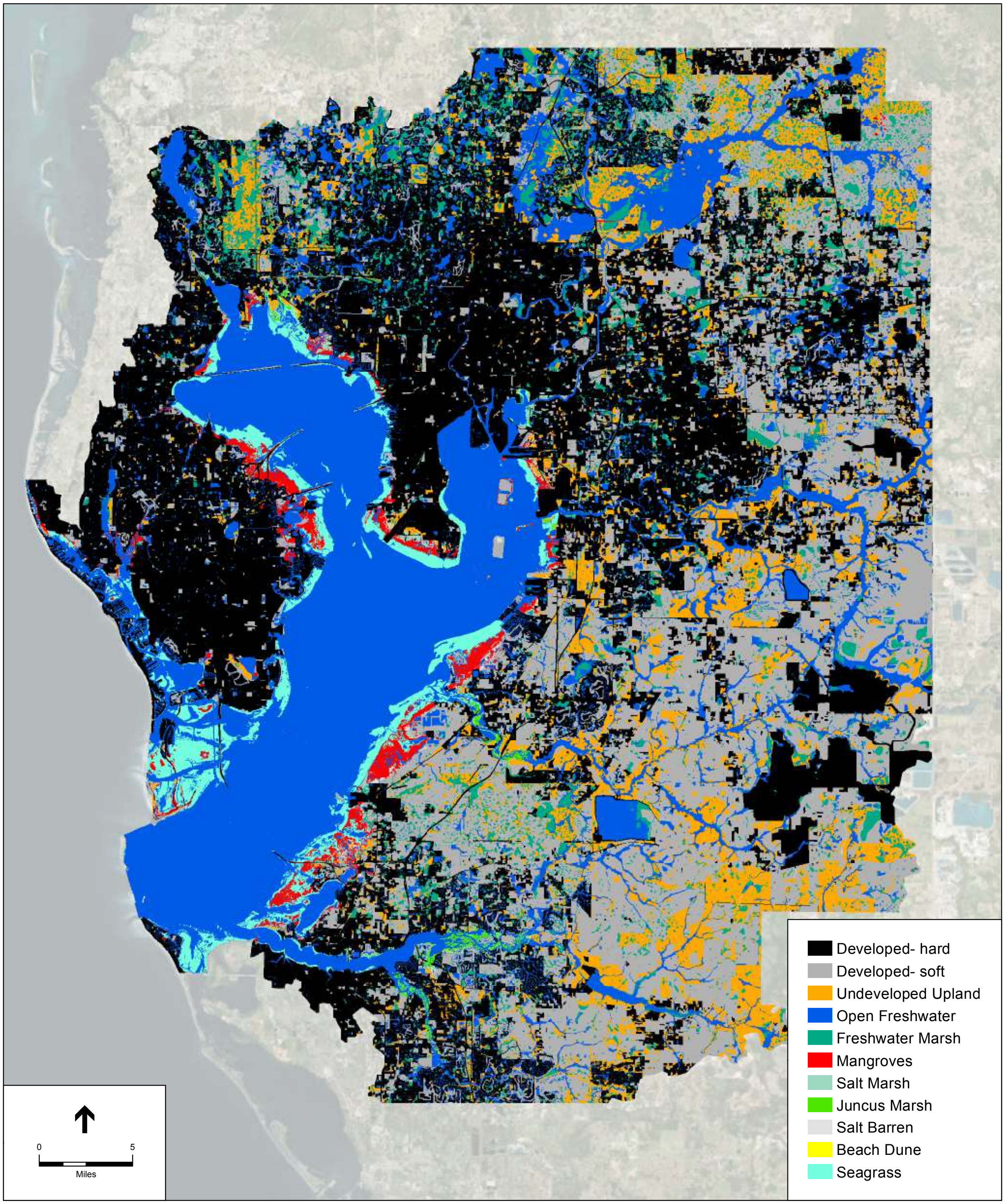


Figure G-22
Tampa Bay Habitat Evolution Modeling Results
Run 3: High Sea-Level Rise, Low Accretion, 2025



ESA

Figure G-23
Tampa Bay Habitat Evolution Modeling Results
Run 3: High Sea-Level Rise, Low Accretion, 2050

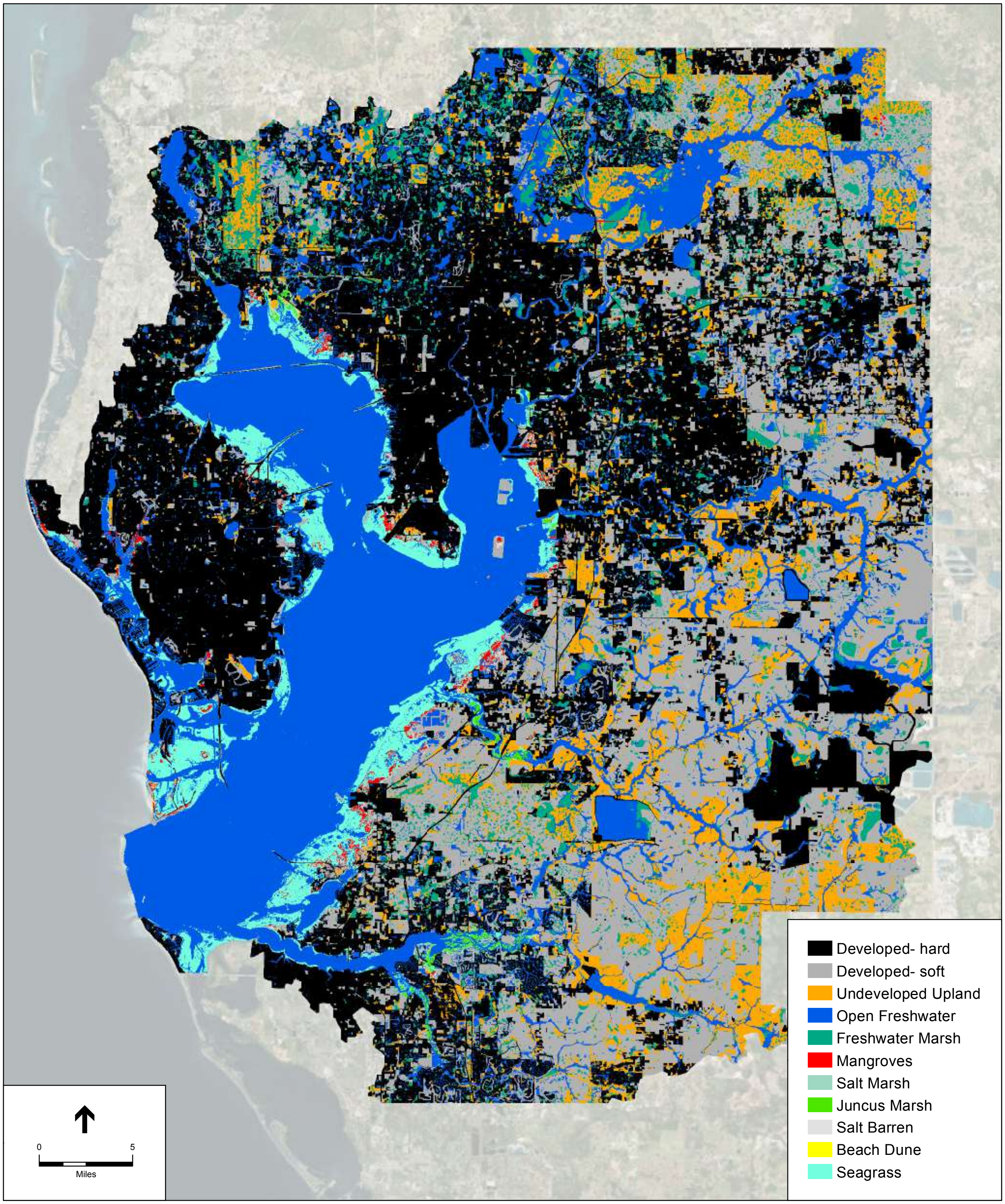


Figure G-24
Tampa Bay Habitat Evolution Modeling Results
Run 3: High Sea-Level Rise, Low Accretion, 2075

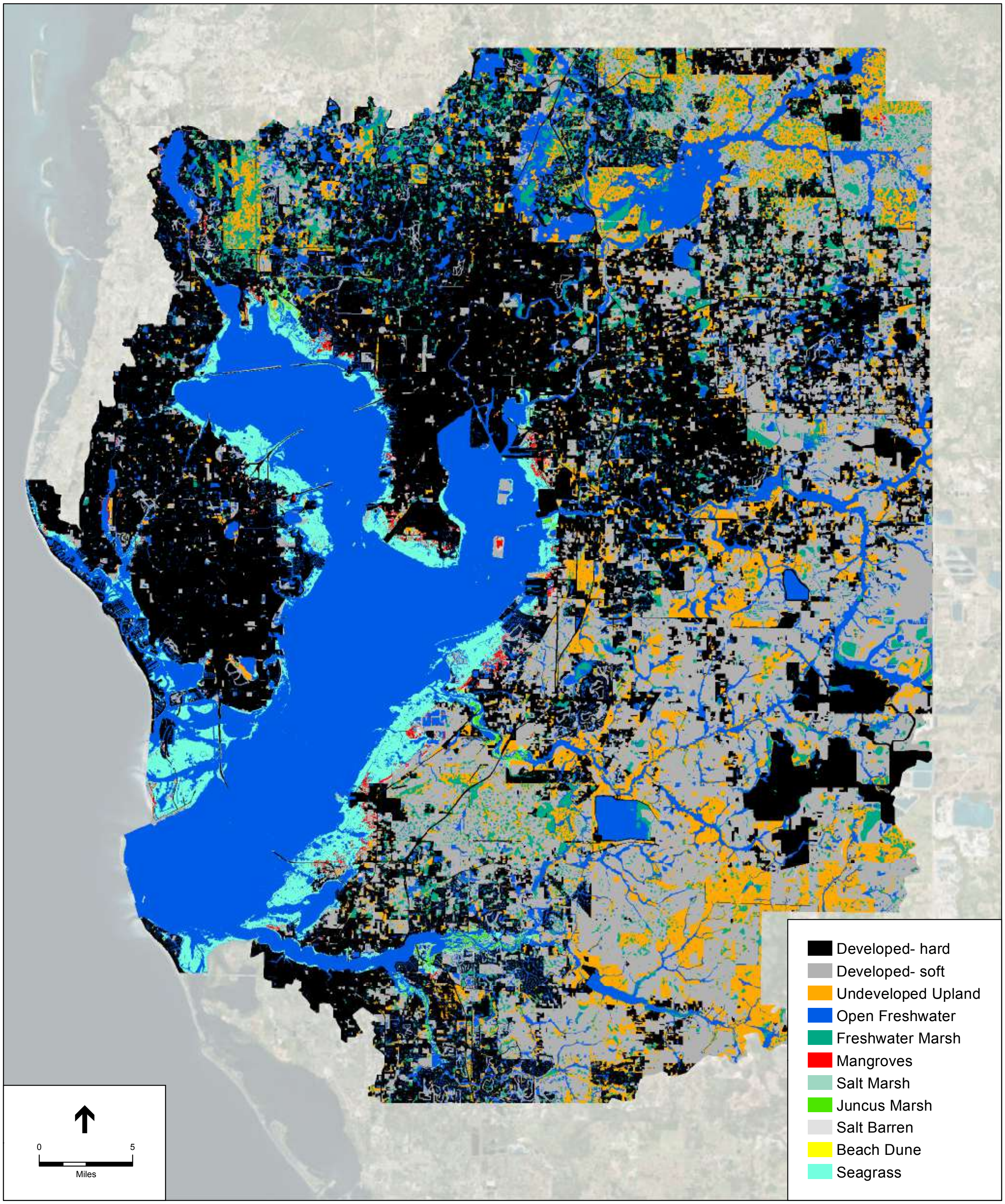
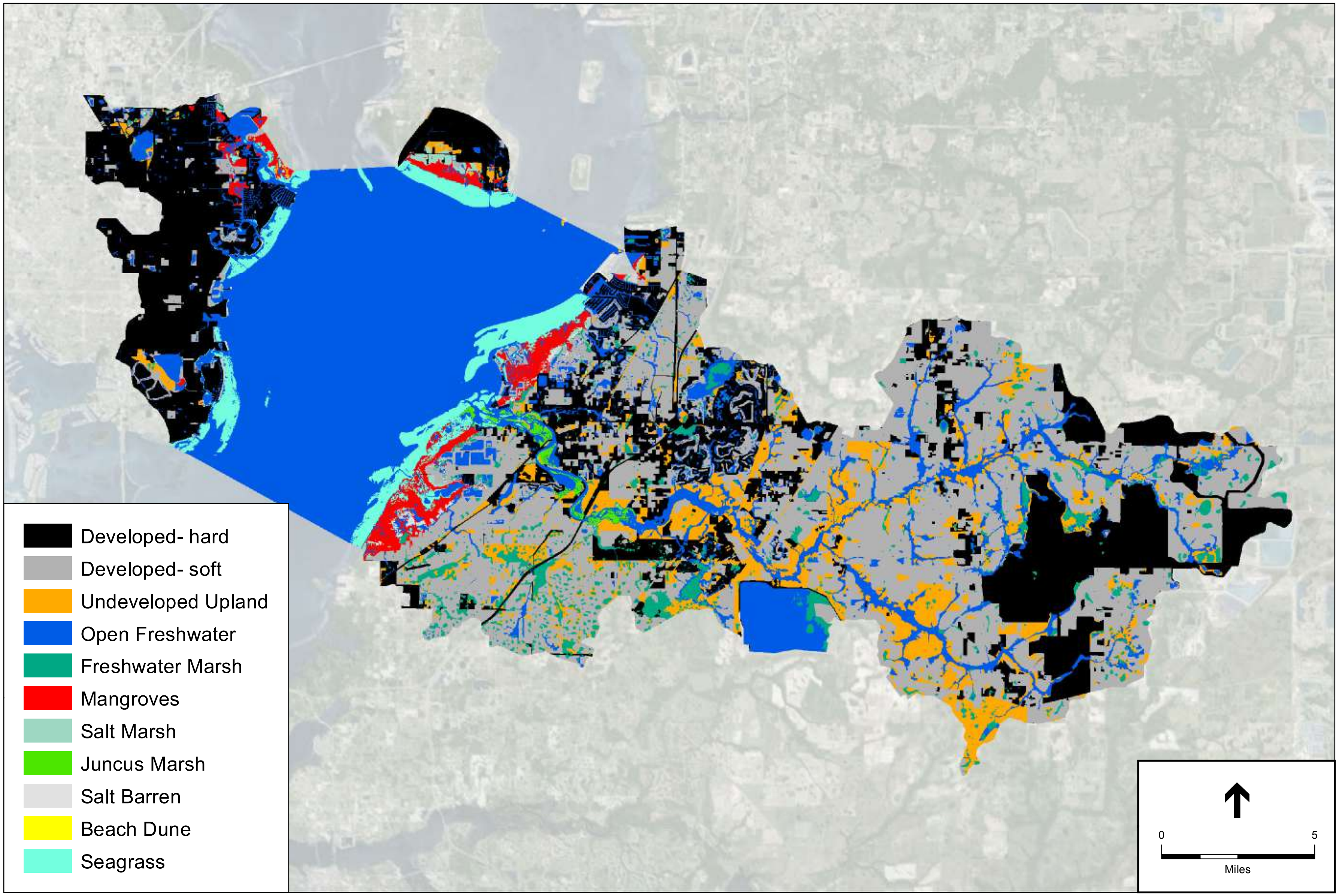
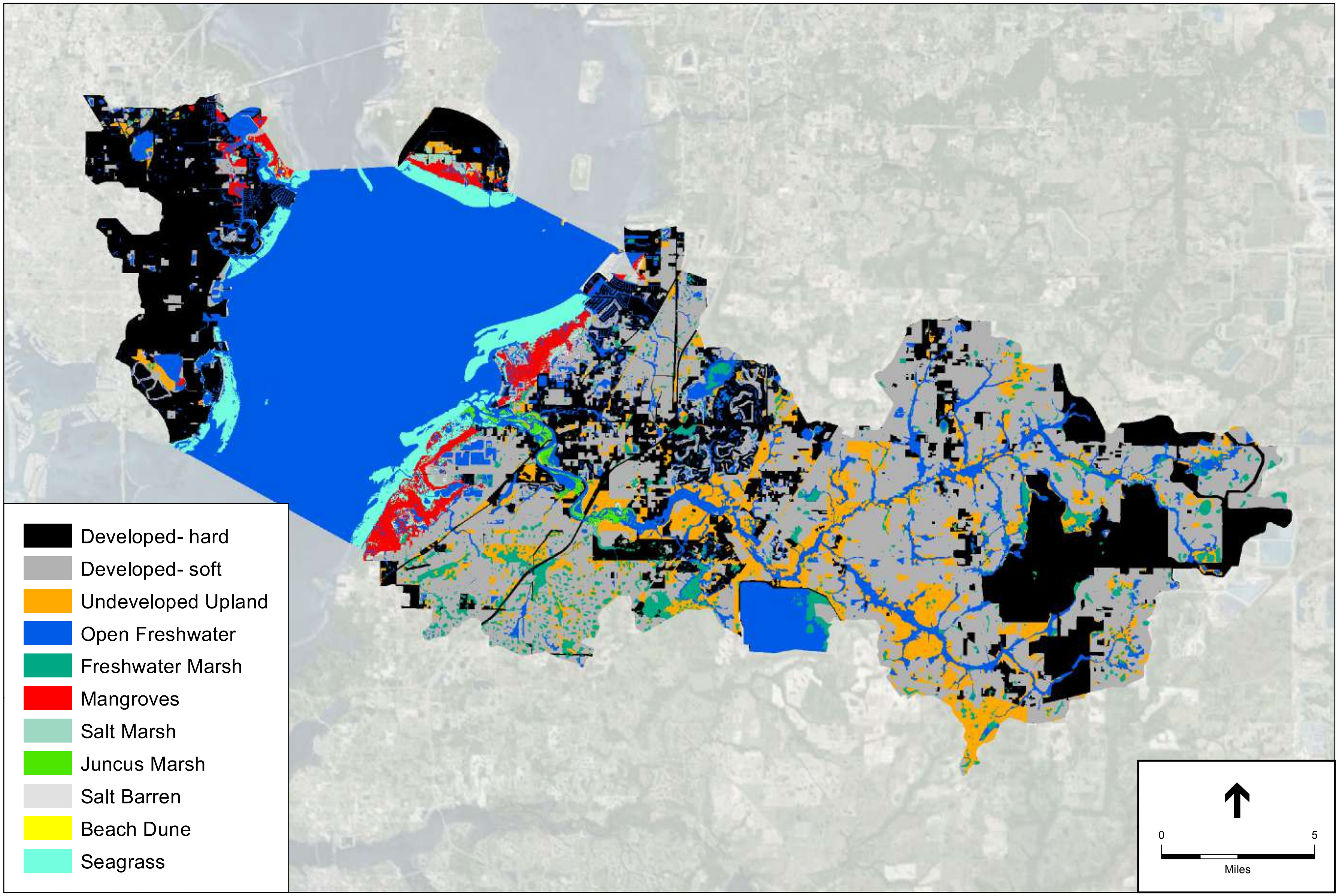


Figure G-25
Tampa Bay Habitat Evolution Modeling Results
Run 3: High Sea-Level Rise, Low Accretion, 2100



ESA

Figure G-26
Tampa Bay Habitat Evolution Modeling Results
Run 3: High Sea-Level Rise, Low Accretion, MTB 2007



Tampa Bay Blue Carbon Assessment. .D140671

Figure G-27

Tampa Bay Habitat Evolution Modeling Results

Run 3: High Sea-Level Rise, Low Accretion, MTB 2025

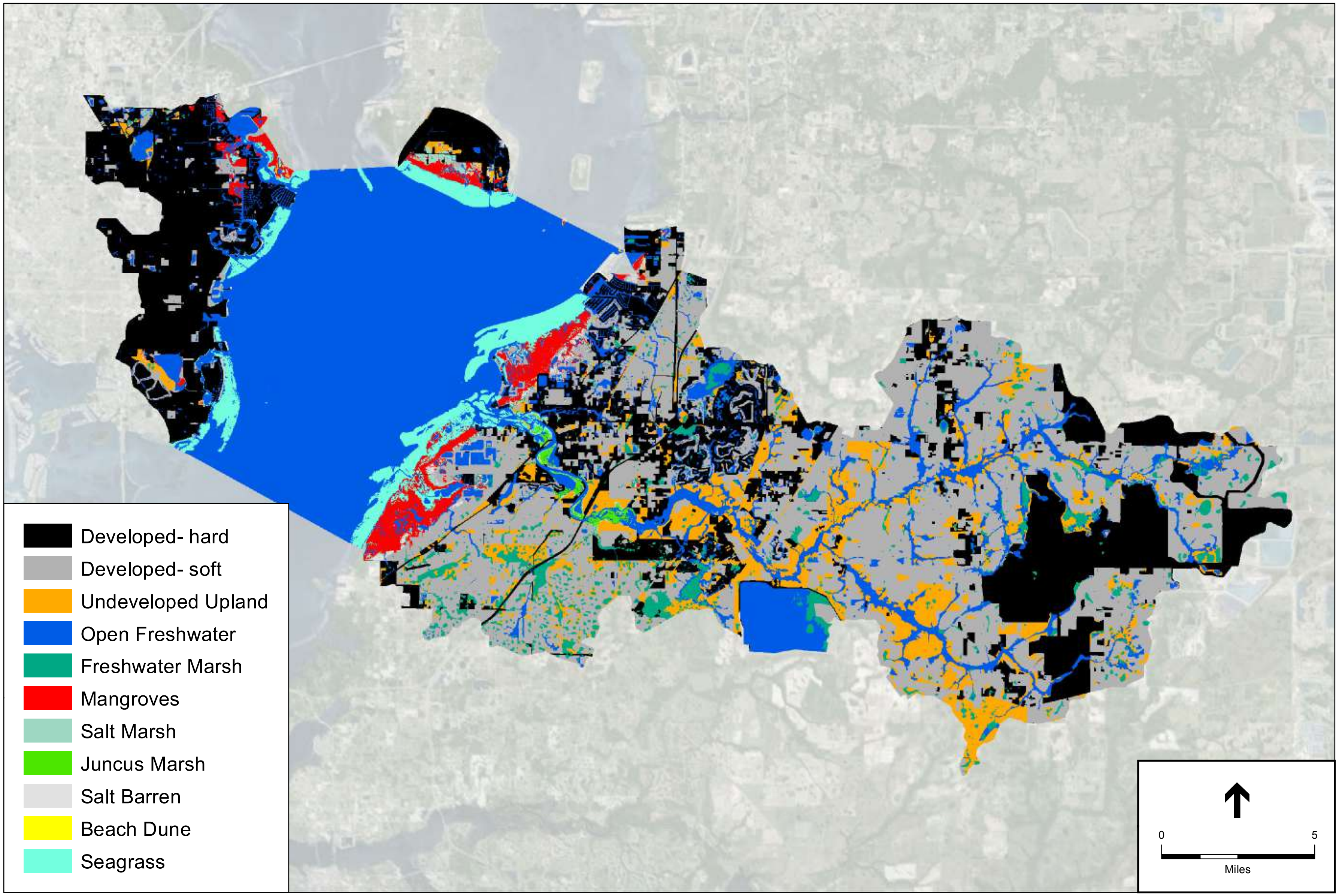


Figure G-28

Tampa Bay Habitat Evolution Modeling Results

Run 3: High Sea-Level Rise, Low Accretion, MTB 2050

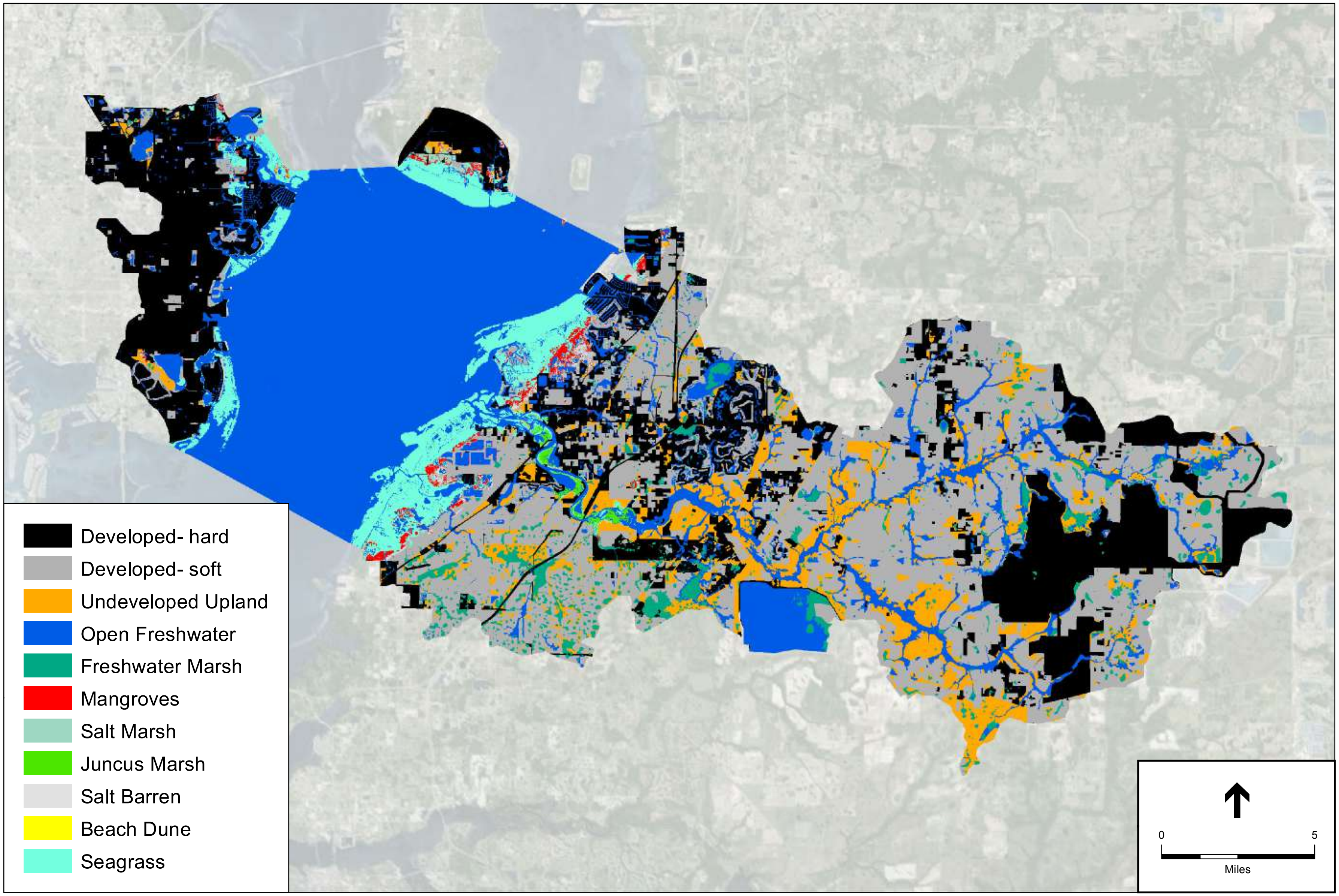


Figure G-29
Tampa Bay Habitat Evolution Modeling Results
Run 3: High Sea-Level Rise, Low Accretion, MTB 2075

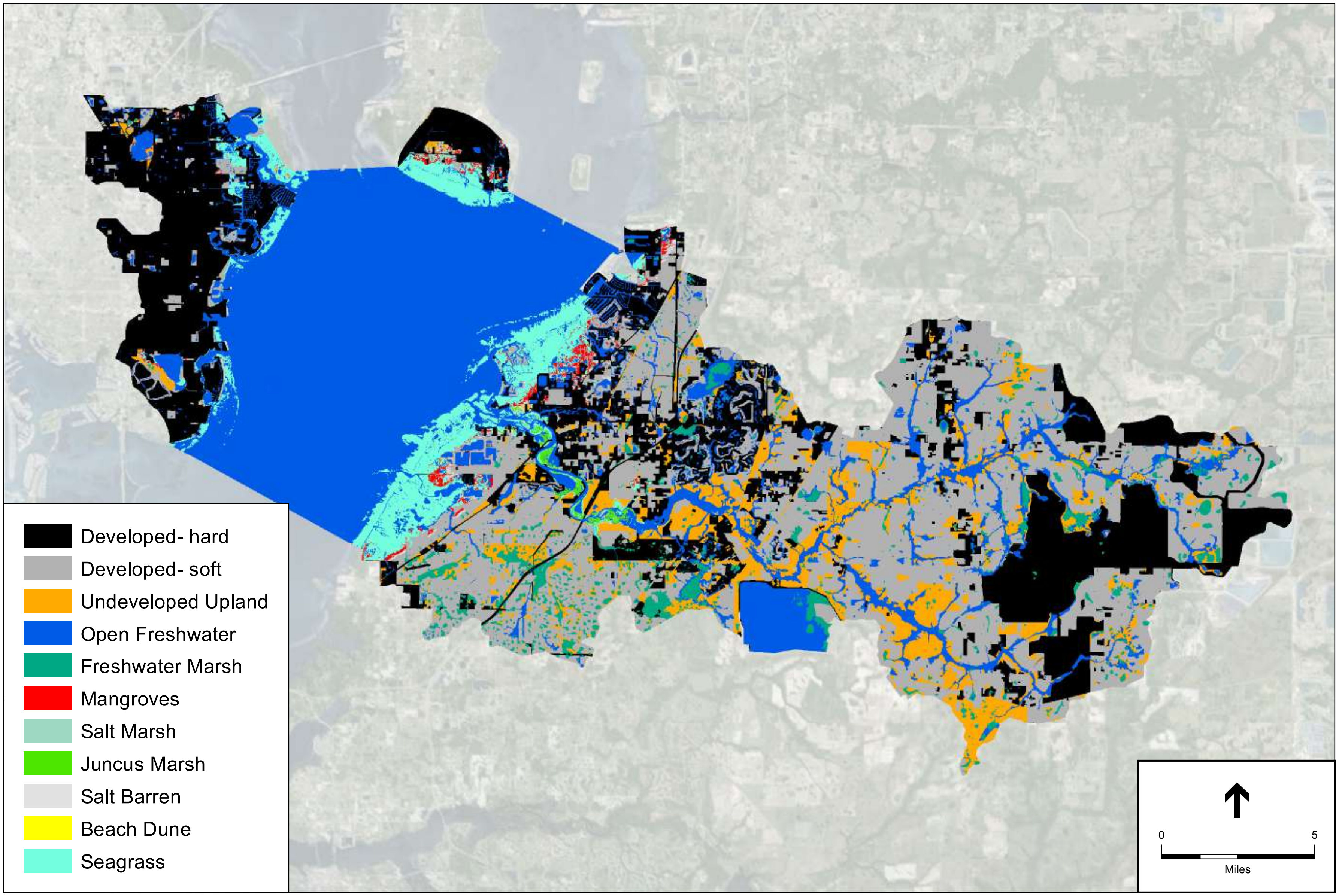
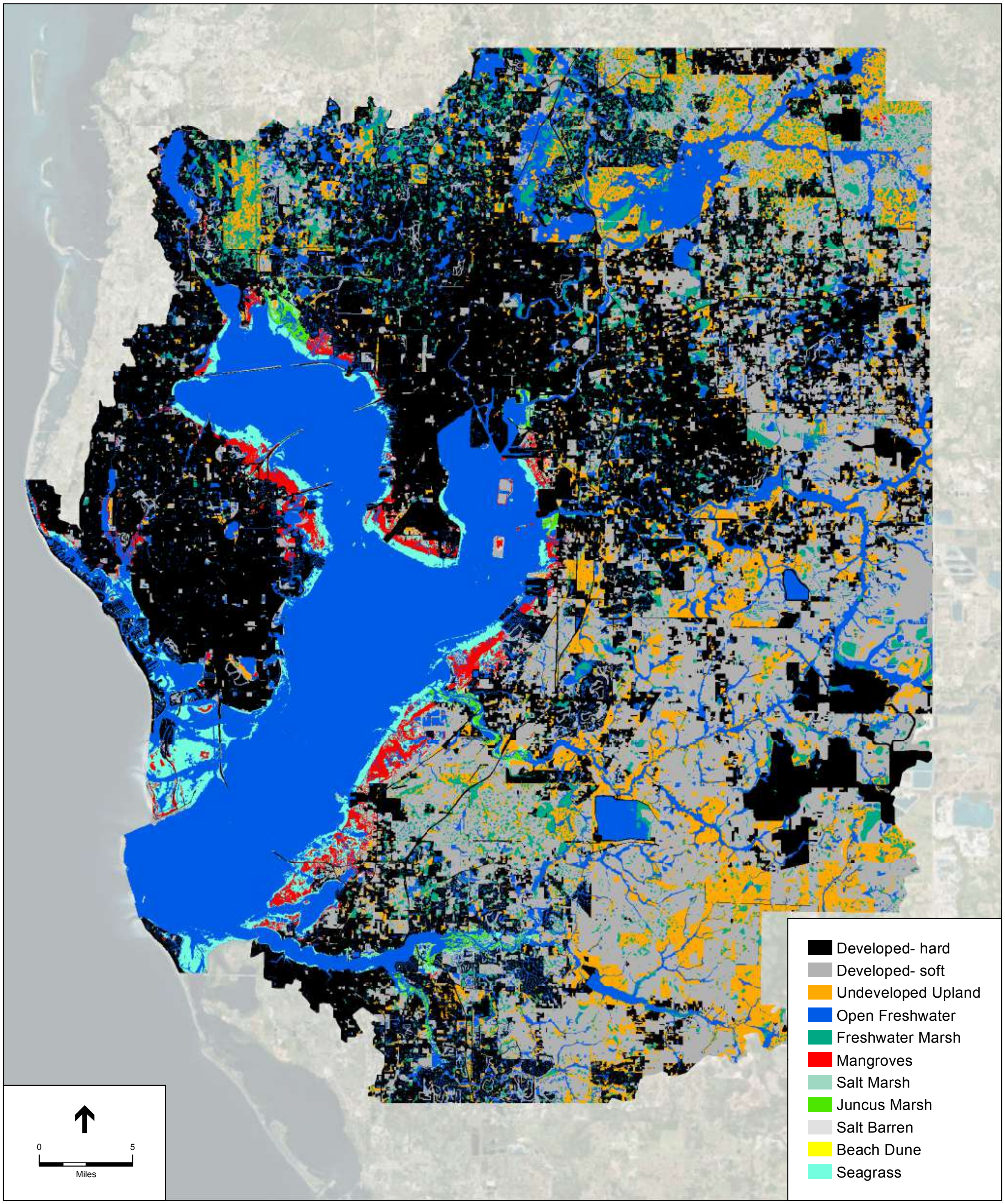


Figure G-30
Tampa Bay Habitat Evolution Modeling Results
Run 3: High Sea-Level Rise, Low Accretion, MTB 2100



Tampa Bay Blue Carbon Assessment .D140671

Figure G-31
Tampa Bay Habitat Evolution Modeling Results
Run 4: High Sea-Level Rise, High Accretion, 2007

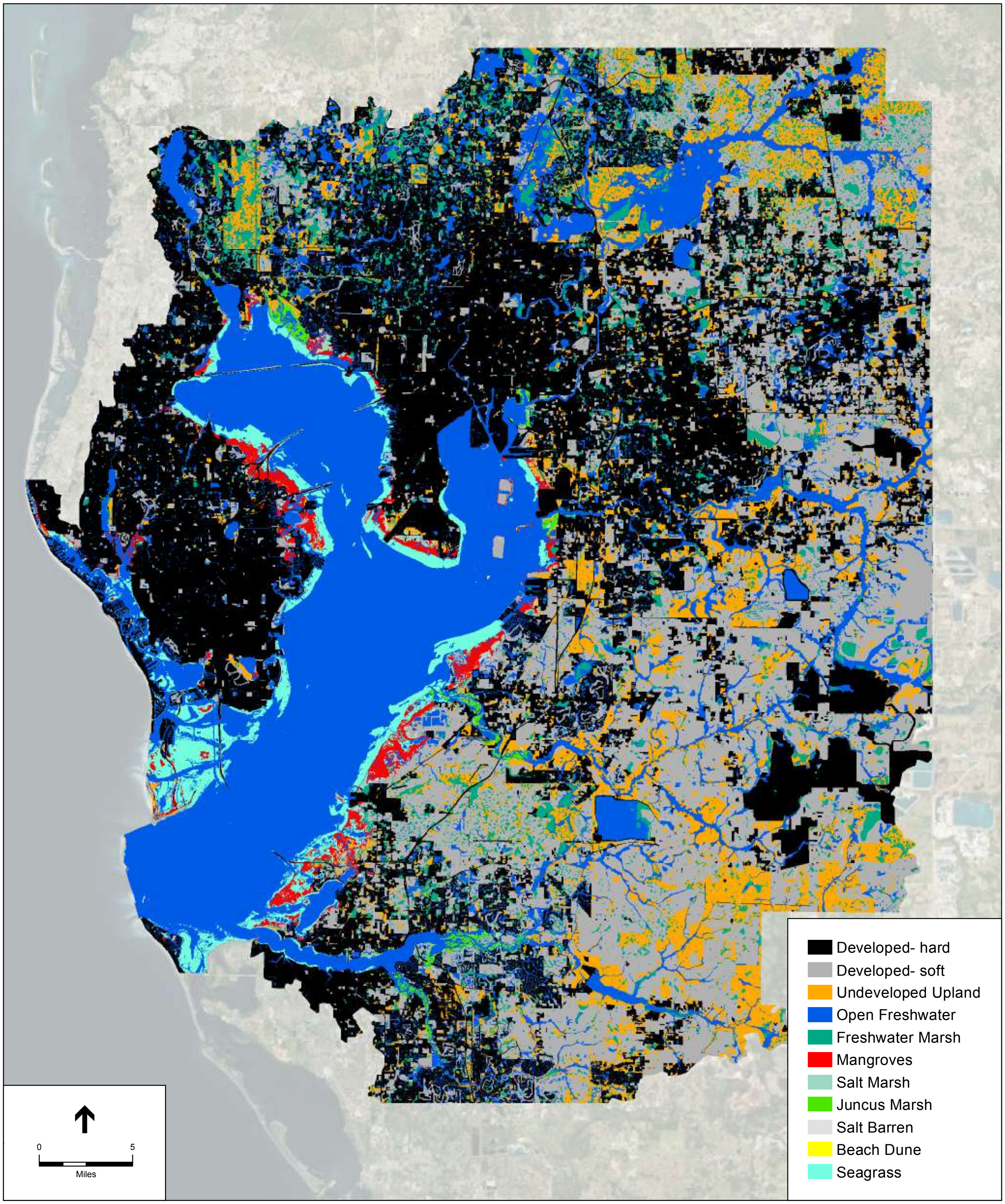


Figure G-32
Tampa Bay Habitat Evolution Modeling Results
Run 4: High Sea-Level Rise, High Accretion, 2025

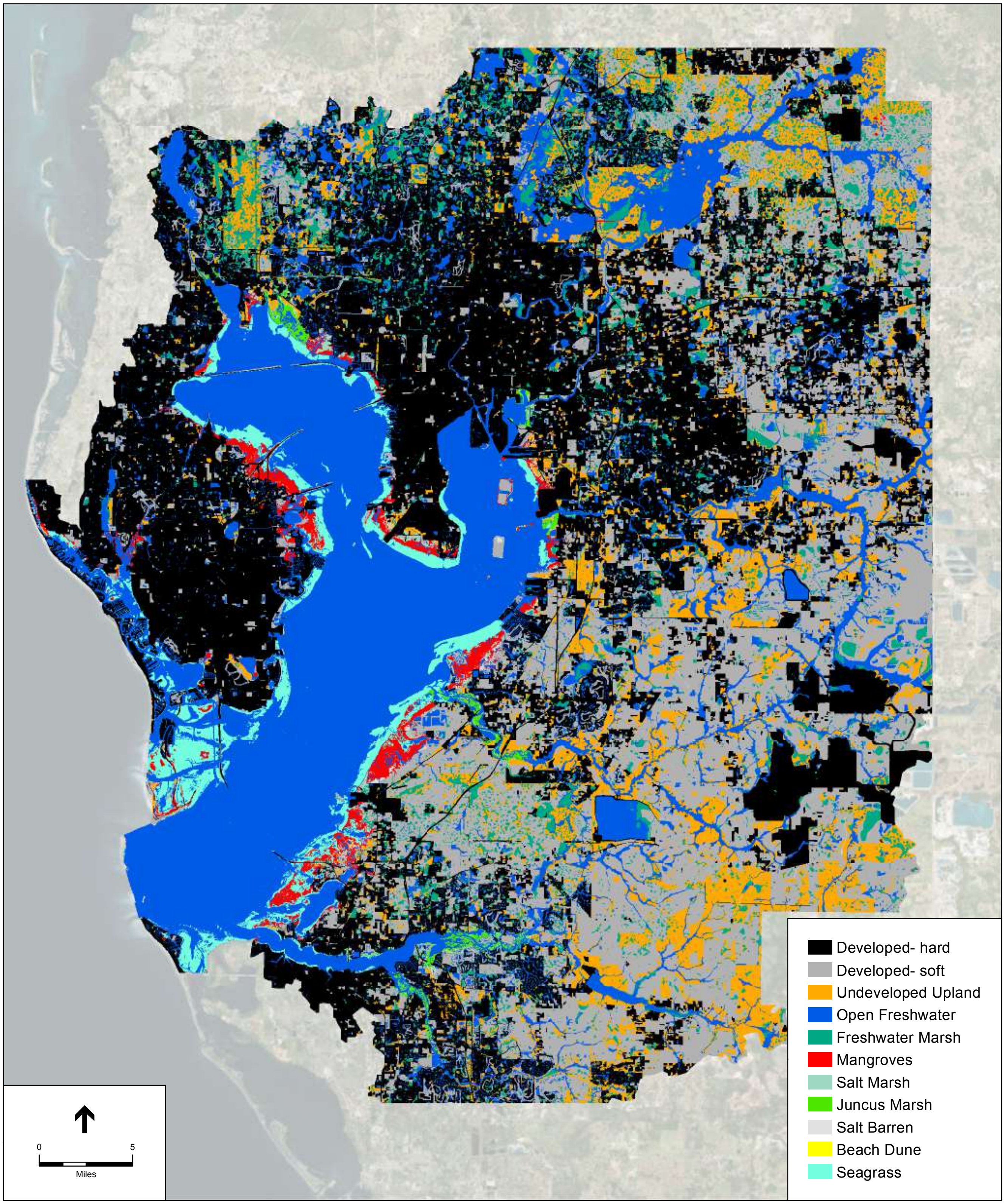


Figure G-33
Tampa Bay Habitat Evolution Modeling Results
Run 4: High Sea-Level Rise, High Accretion, 2050

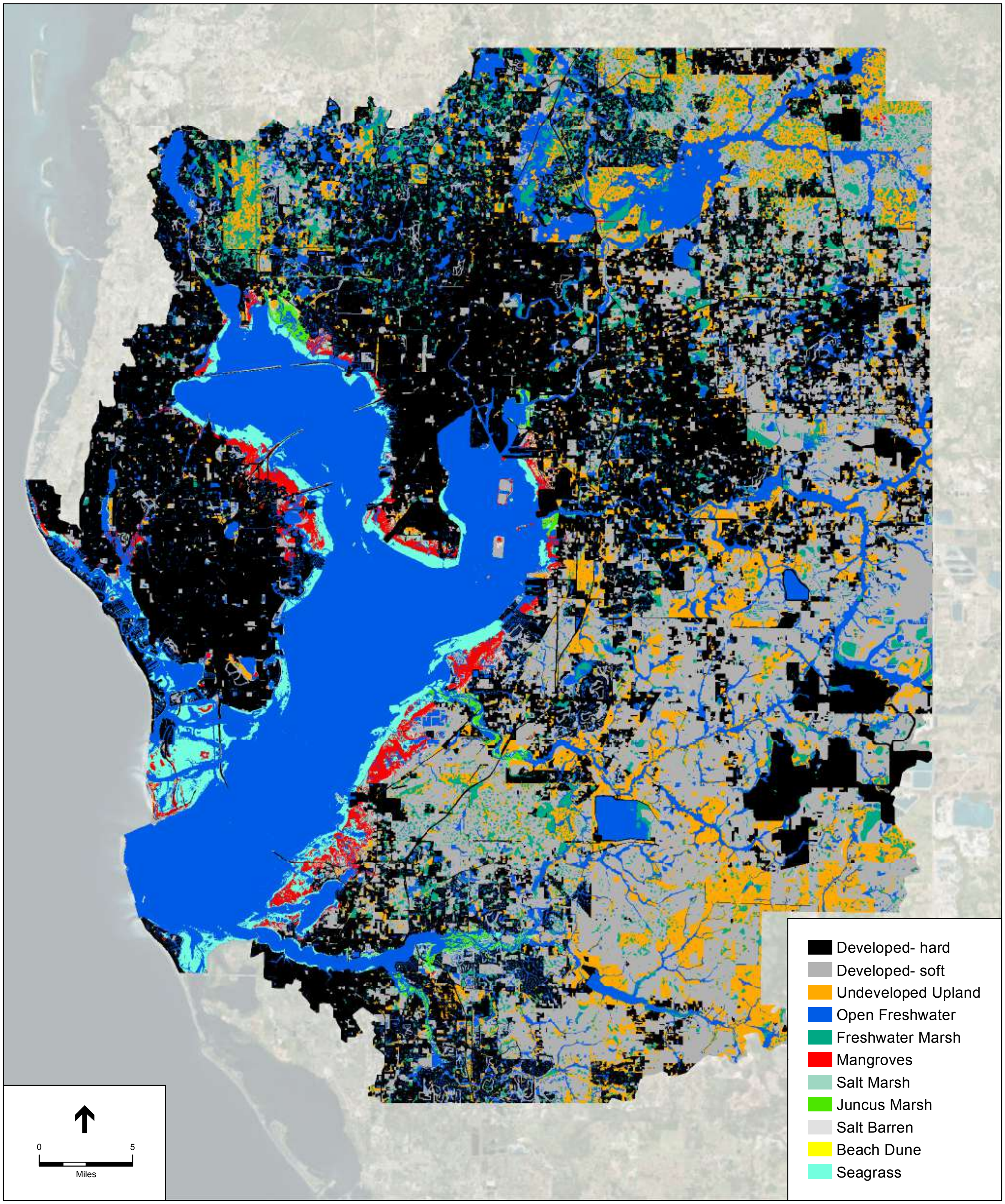
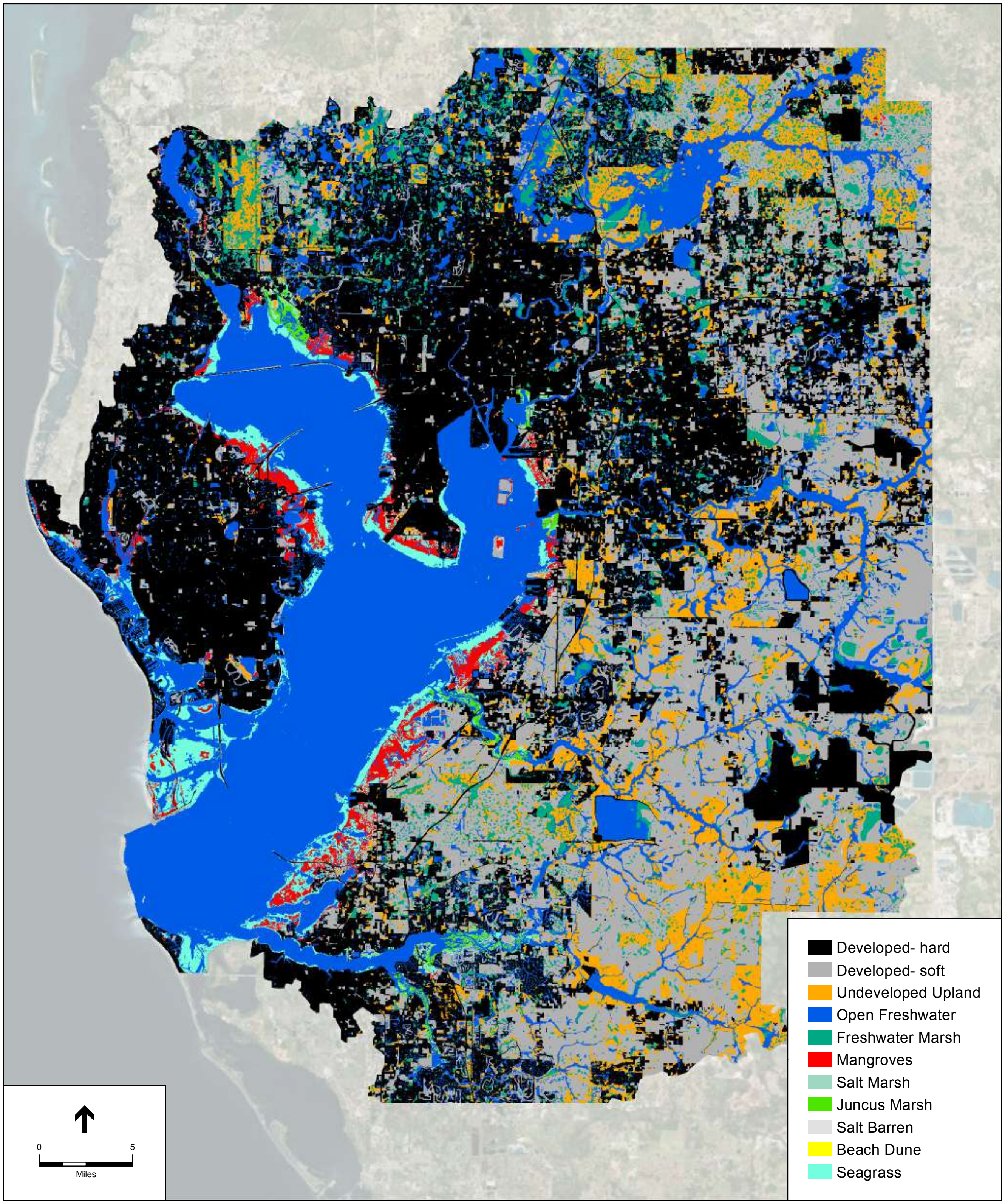
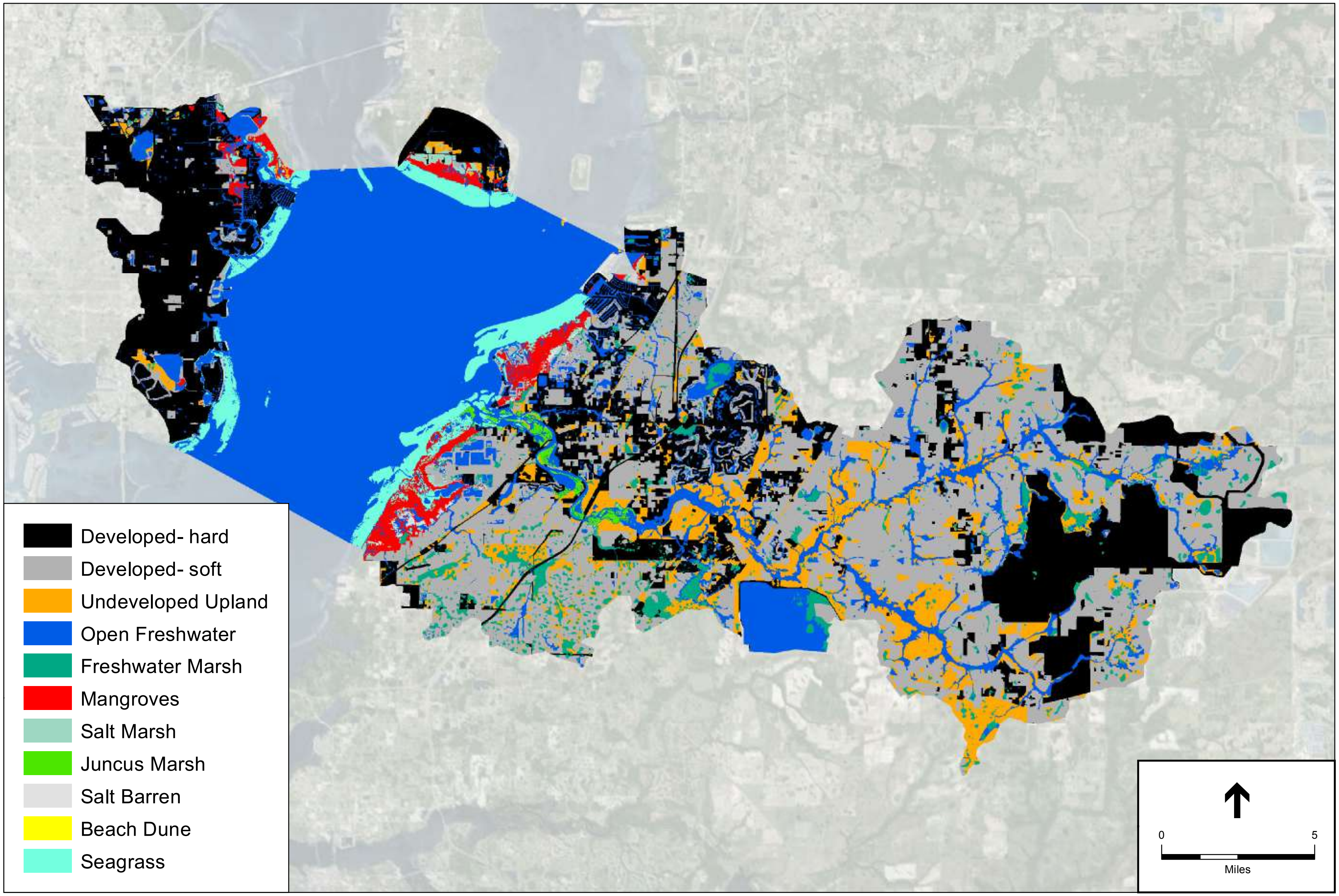


Figure G-34
Tampa Bay Habitat Evolution Modeling Results
Run 4: High Sea-Level Rise, High Accretion, 2075



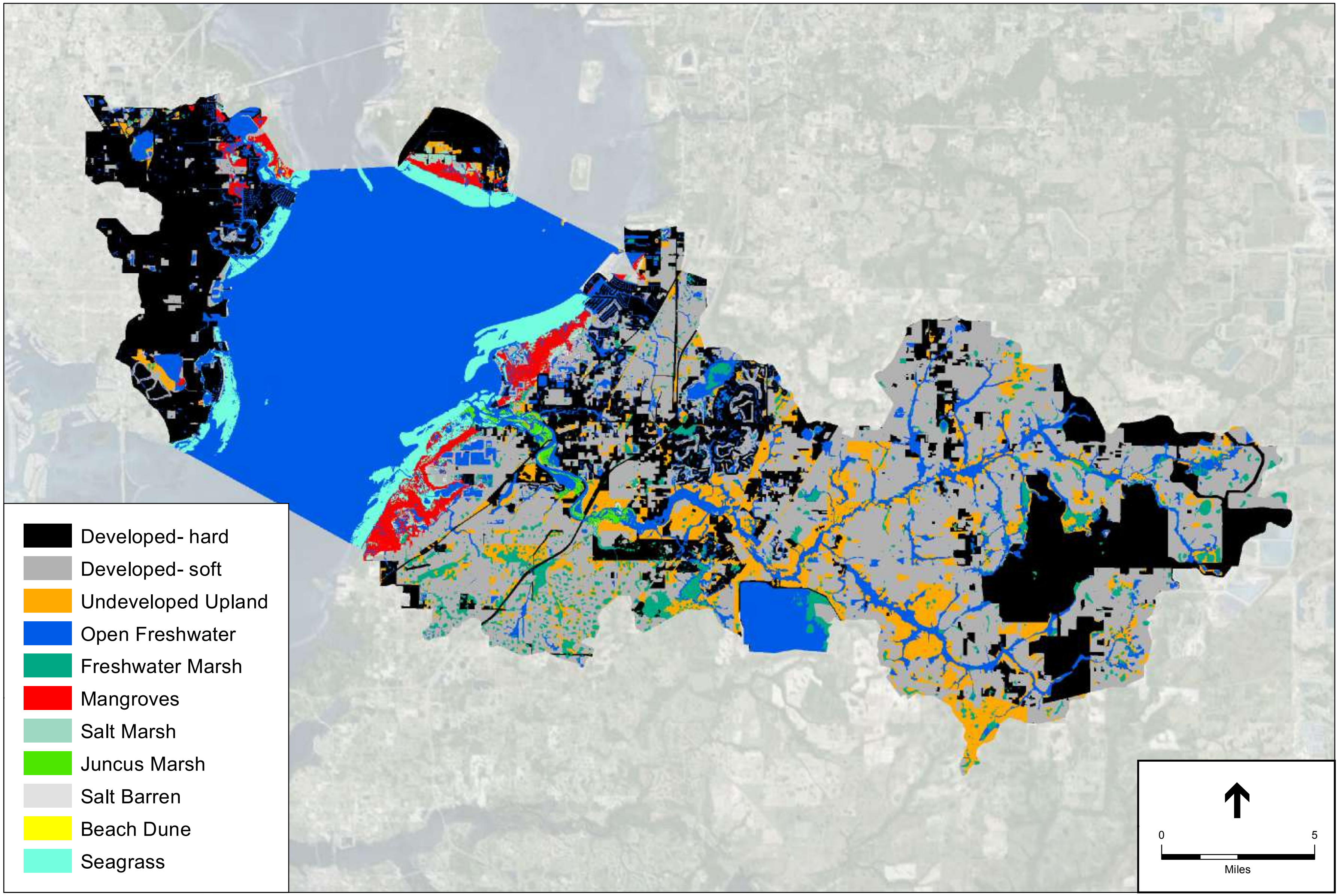
ESA

Figure G-35
Tampa Bay Habitat Evolution Modeling Results
Run 4: High Sea-Level Rise, High Accretion, 2100



ESA

Figure G-36
Tampa Bay Habitat Evolution Modeling Results
Run 4: High Sea-Level Rise, High Accretion, MTB 2007



Tampa Bay Blue Carbon Assessment .D140671

Figure G-37

Tampa Bay Habitat Evolution Modeling Results

Run 4: High Sea-Level Rise, High Accretion, MTB 2025

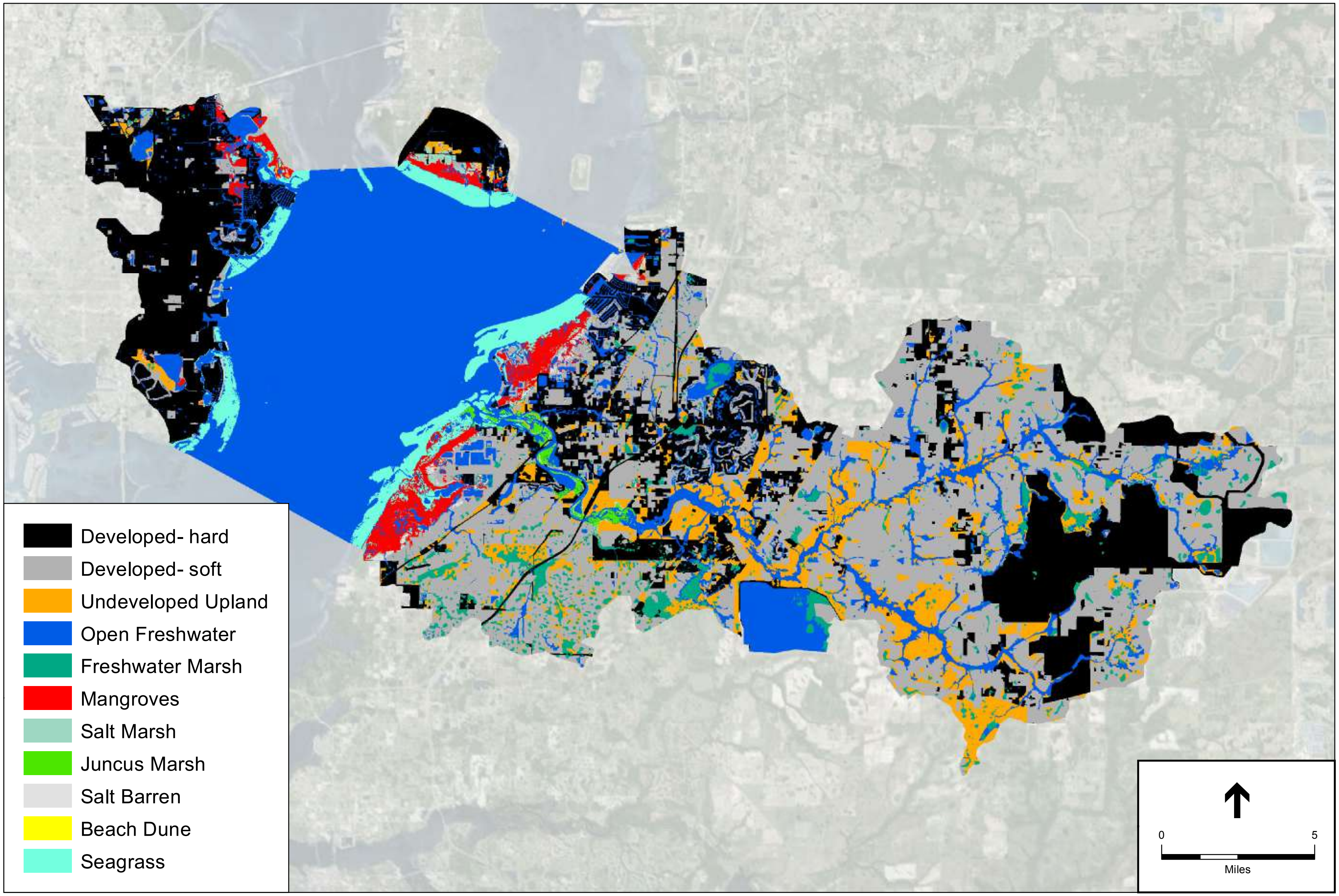
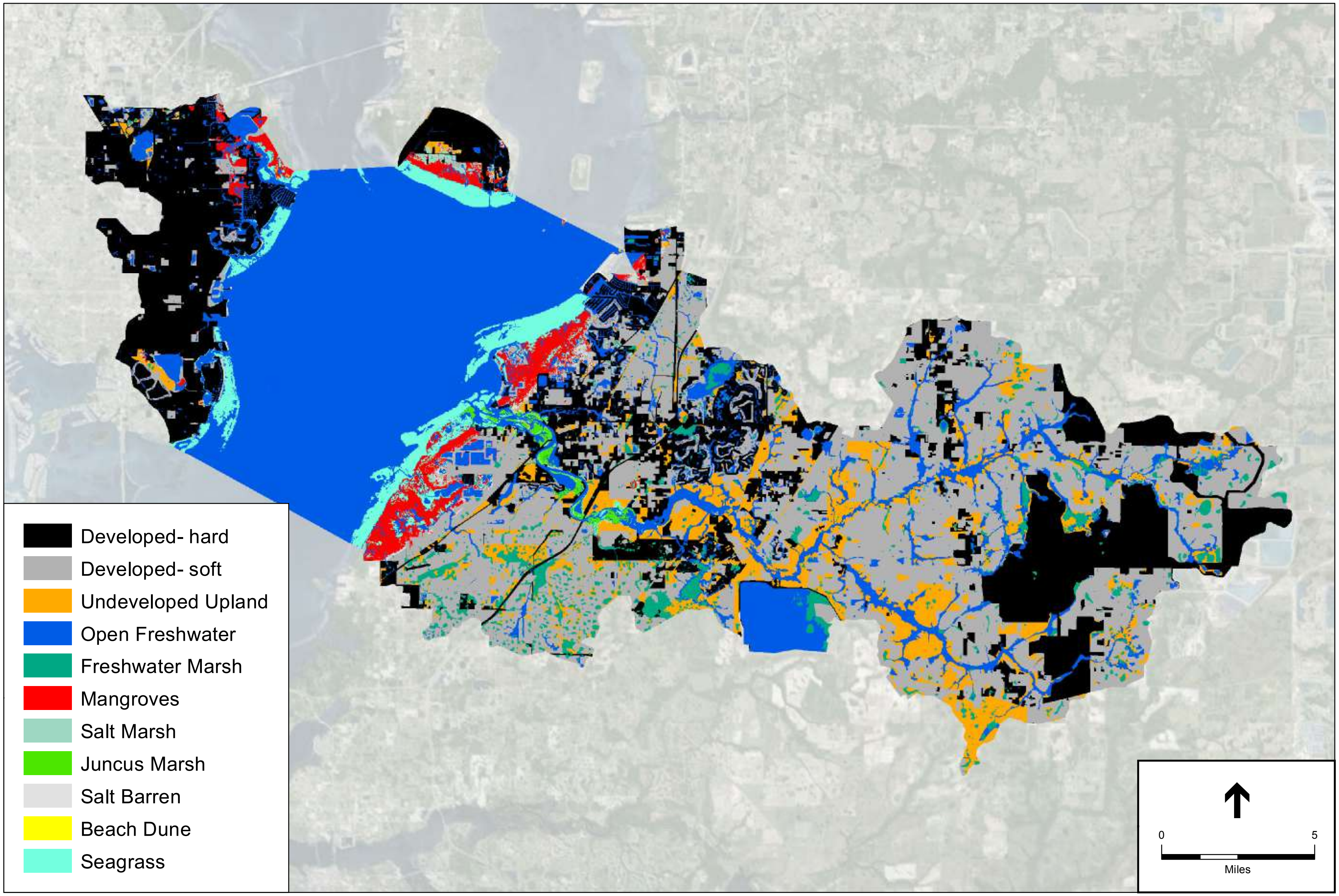


Figure G-38
Tampa Bay Habitat Evolution Modeling Results
Run 4: High Sea-Level Rise, High Accretion, MTB 2050

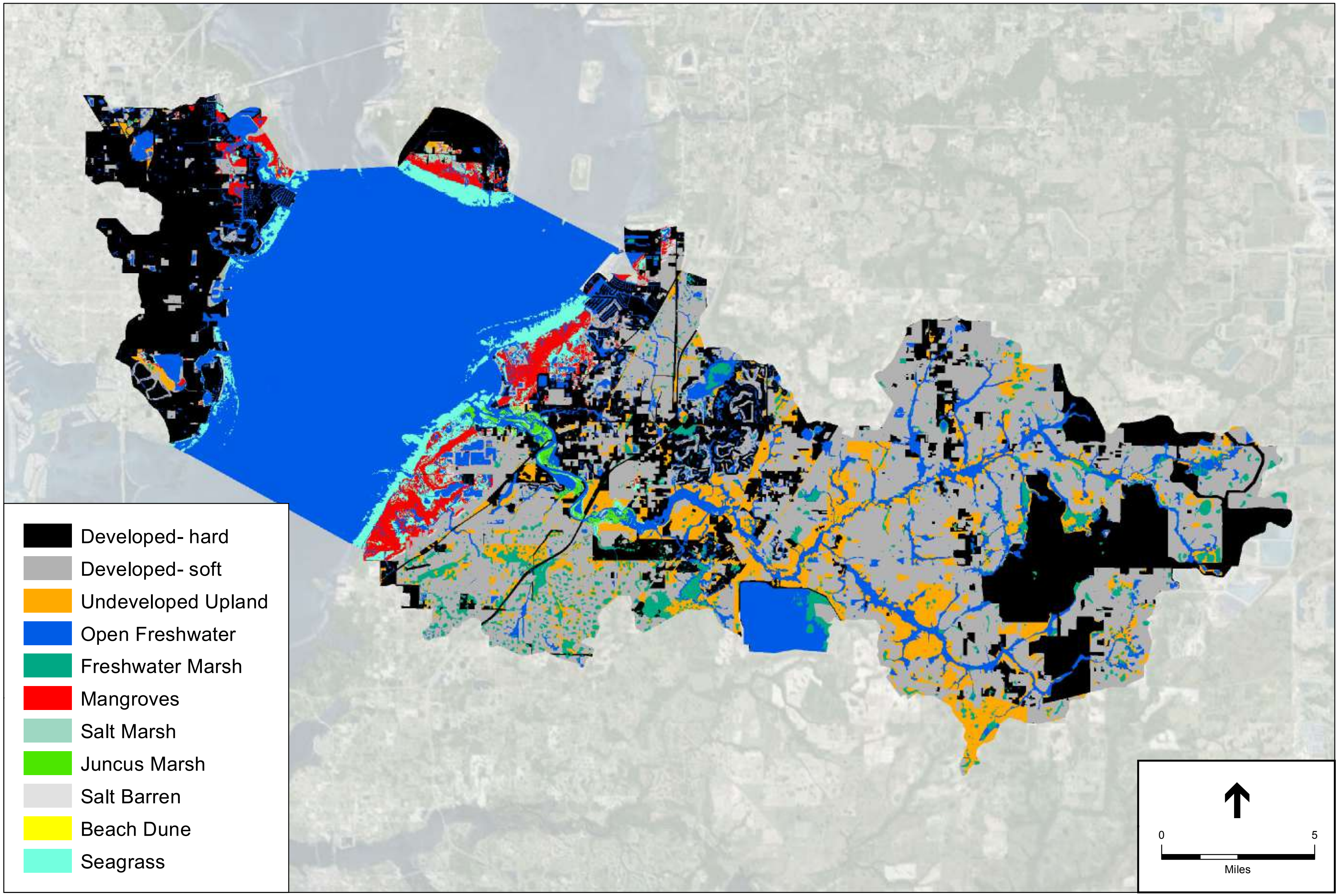


Tampa Bay Blue Carbon Assessment .D140671

Figure G-39

Tampa Bay Habitat Evolution Modeling Results

Run 4: High Sea-Level Rise, High Accretion, MTB 2075



Tampa Bay Blue Carbon Assessment .D140671

Figure G-40

Tampa Bay Habitat Evolution Modeling Results

Run 4: High Sea-Level Rise, High Accretion, MTB 2100

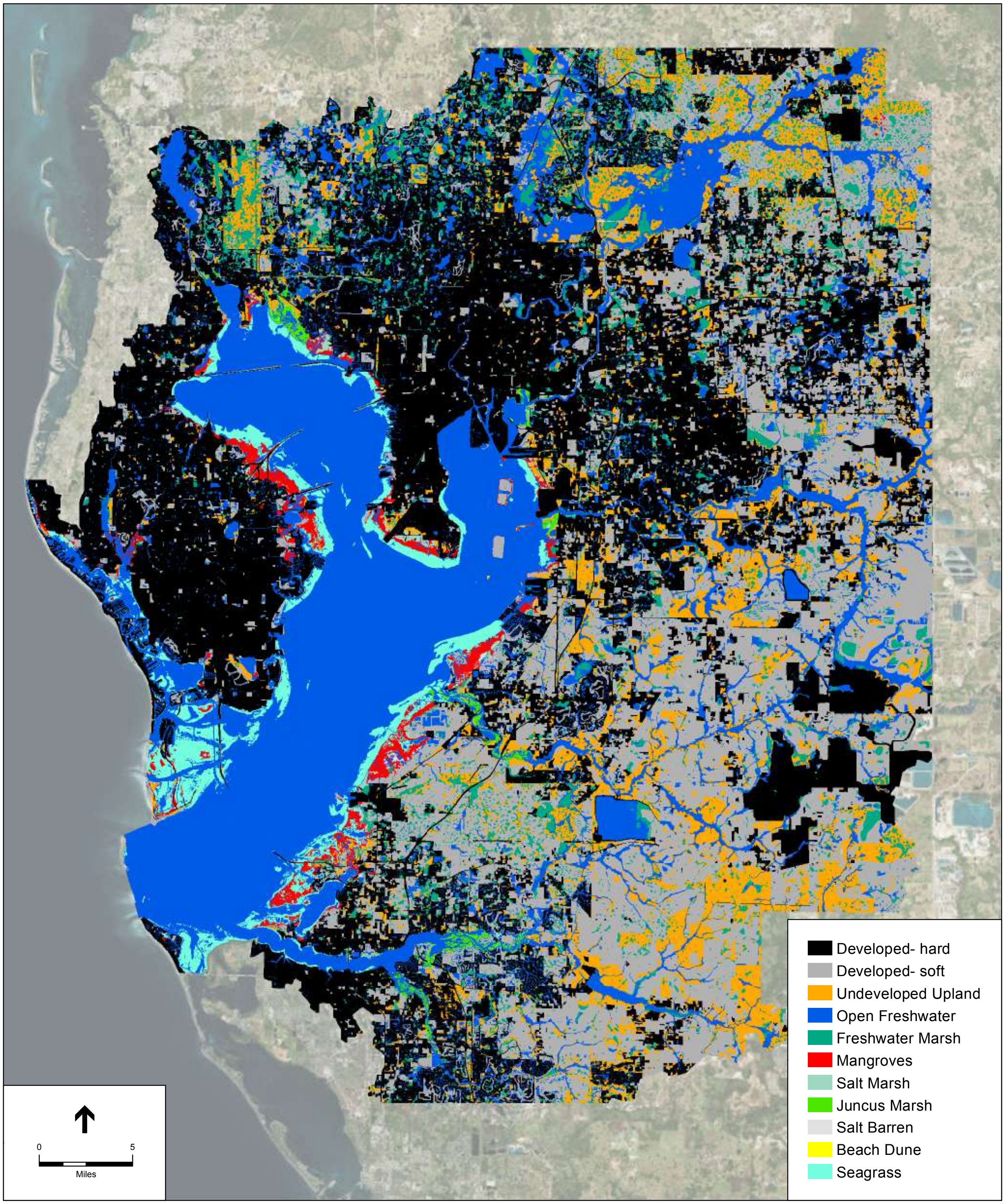


Figure G-41
Tampa Bay Habitat Evolution Modeling Results
Run 5: High Sea-Level Rise, Low Accretion, No Protection, 2007

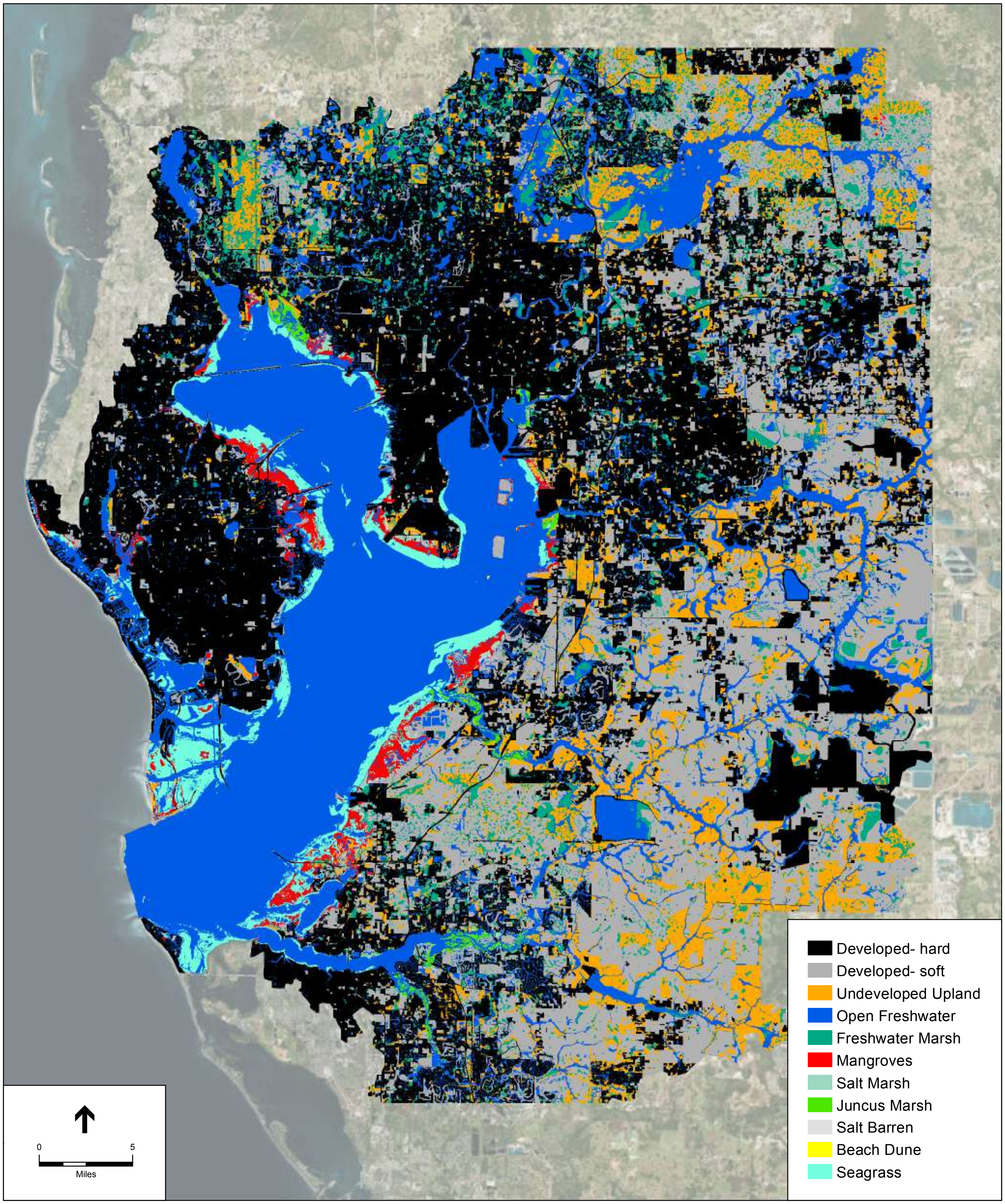
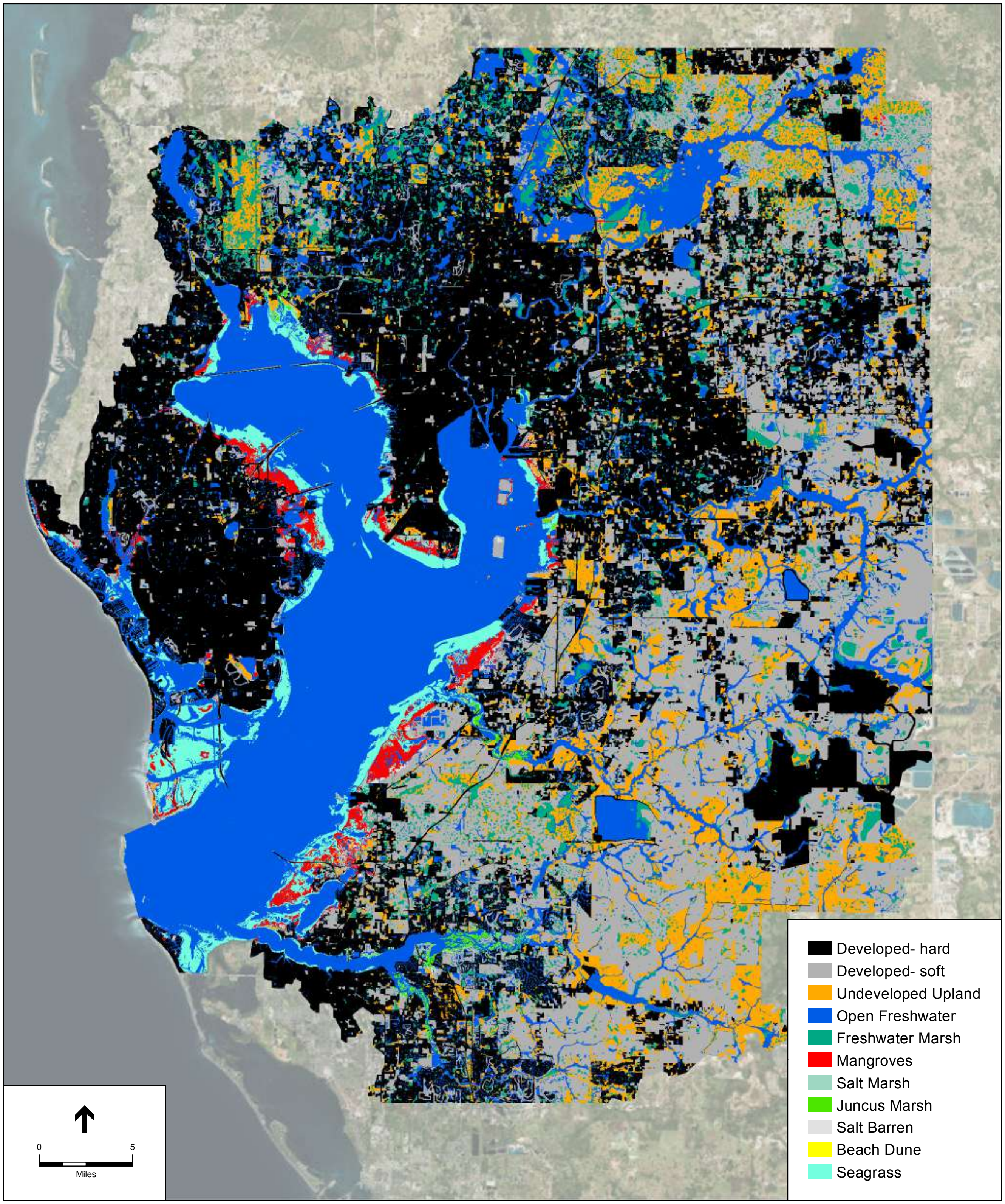
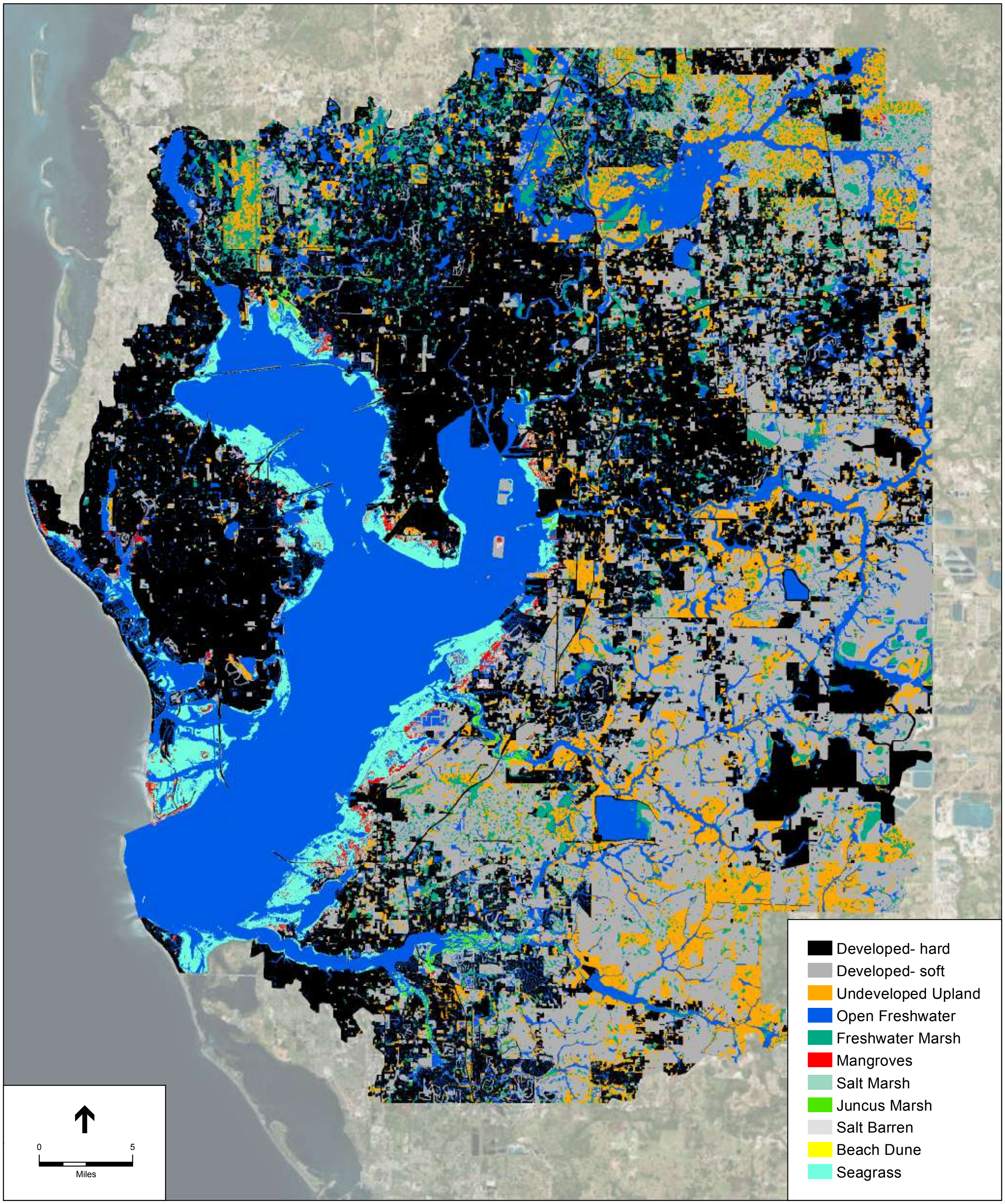


Figure G-42
Tampa Bay Habitat Evolution Modeling Results
Run 5: High Sea-Level Rise, Low Accretion, No Protection, 2025



ESA

Figure G-43
Tampa Bay Habitat Evolution Modeling Results
Run 5: High Sea-Level Rise, Low Accretion, No Protection, 2050



ESA

Figure G-44
Tampa Bay Habitat Evolution Modeling Results
Run 5: High Sea-Level Rise, Low Accretion, No Protection, 2075

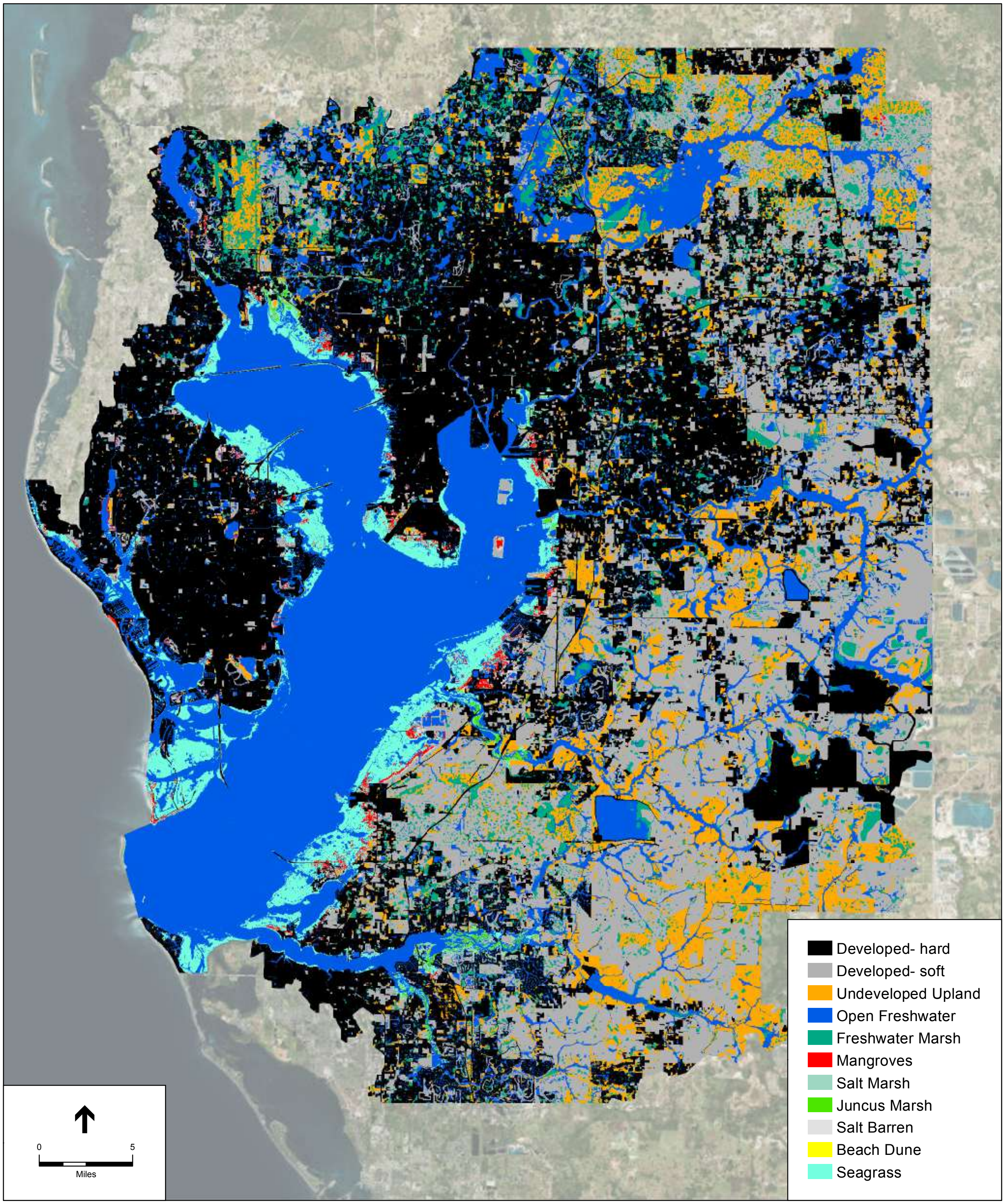


Figure G-45
Tampa Bay Habitat Evolution Modeling Results
Run 5: High Sea-Level Rise, Low Accretion, No Protection, 2100

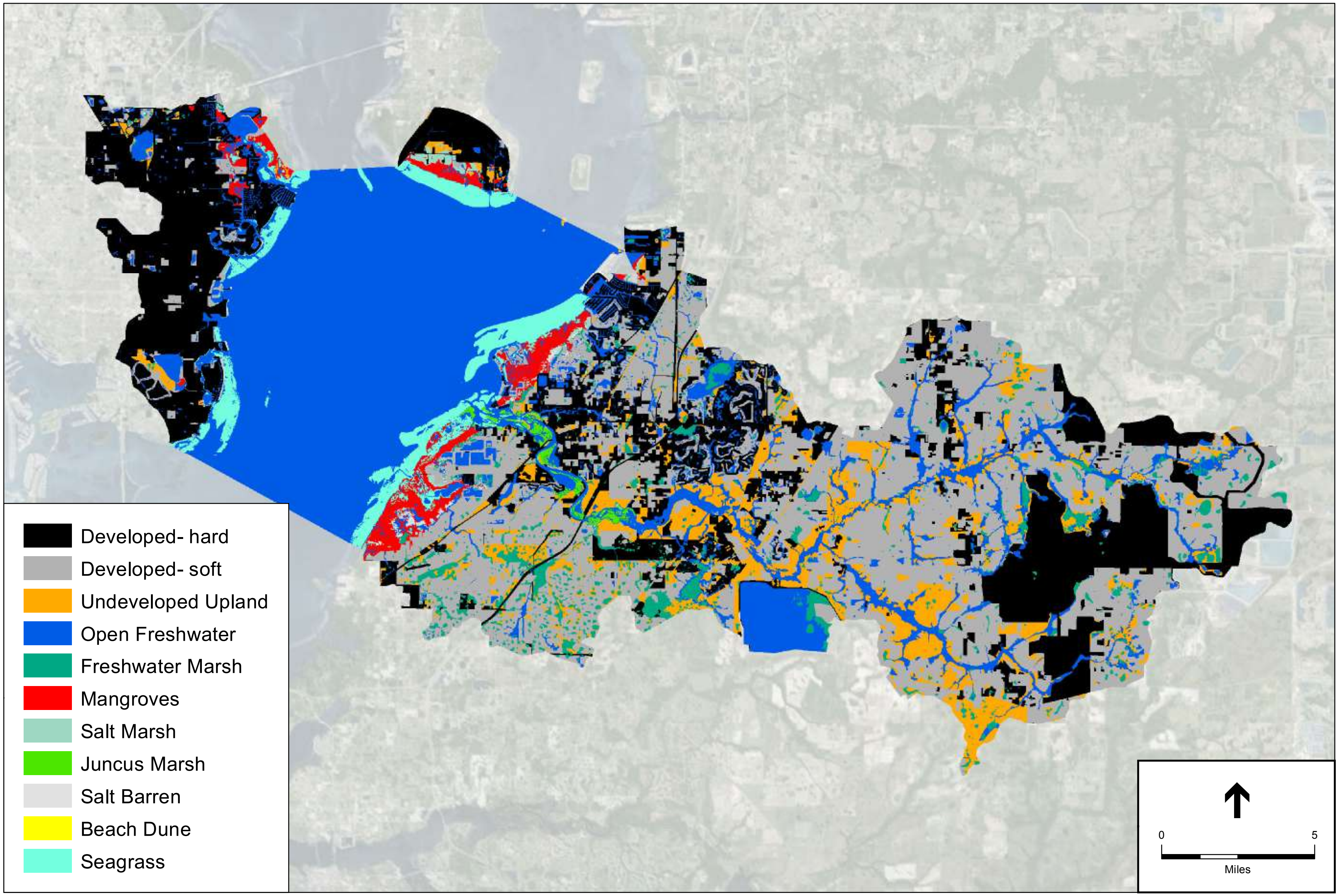
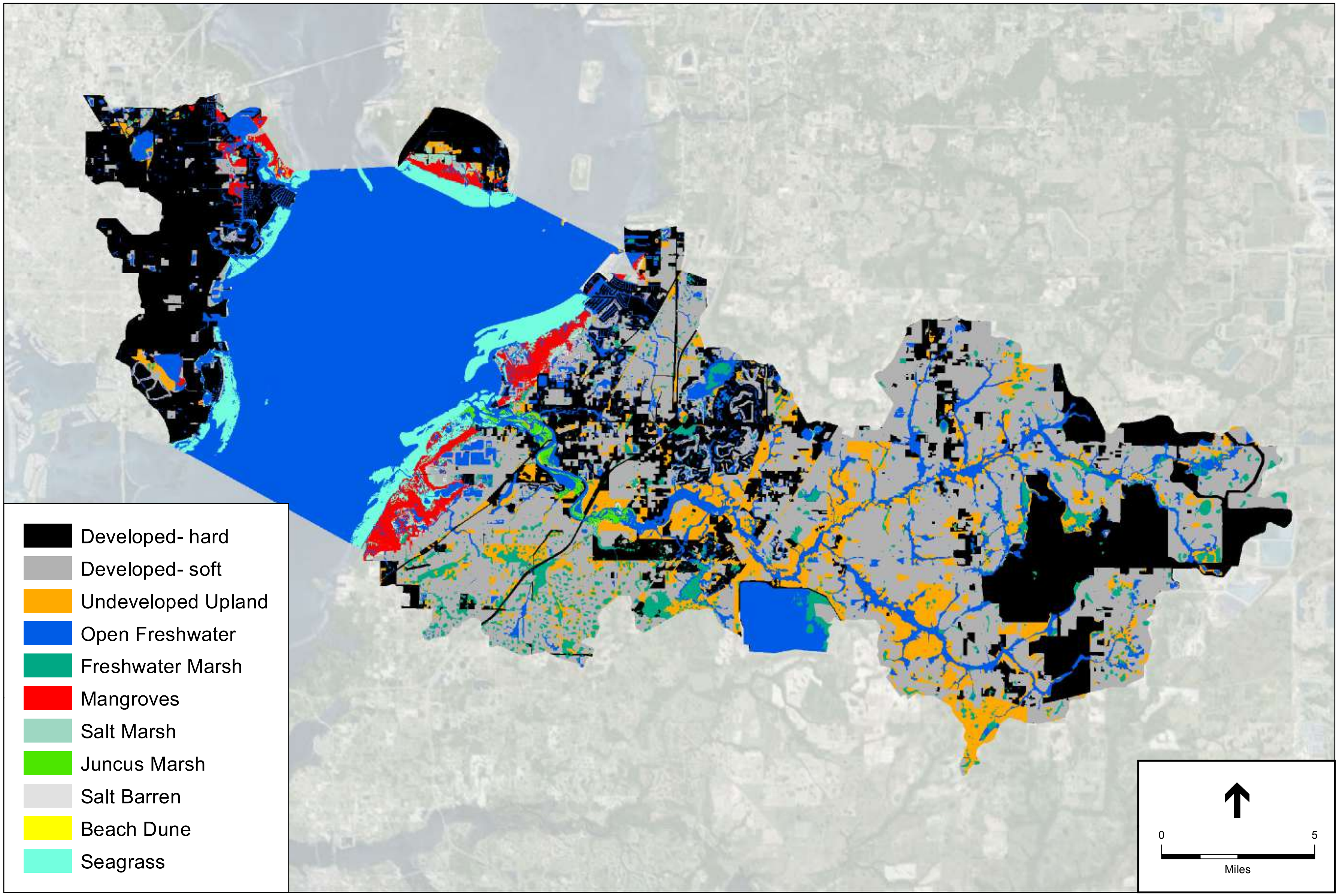


Figure G-46
Tampa Bay Habitat Evolution Modeling Results
Run 5: High Sea-Level Rise, Low Accretion, No Protection
Middle Tampa Bay 2007



Tampa Bay Blue Carbon Assessment. .D140671

Figure G-47

Tampa Bay Habitat Evolution Modeling Results
Run 5: High Sea-Level Rise, Low Accretion, No Protection
Middle Tampa Bay 2025

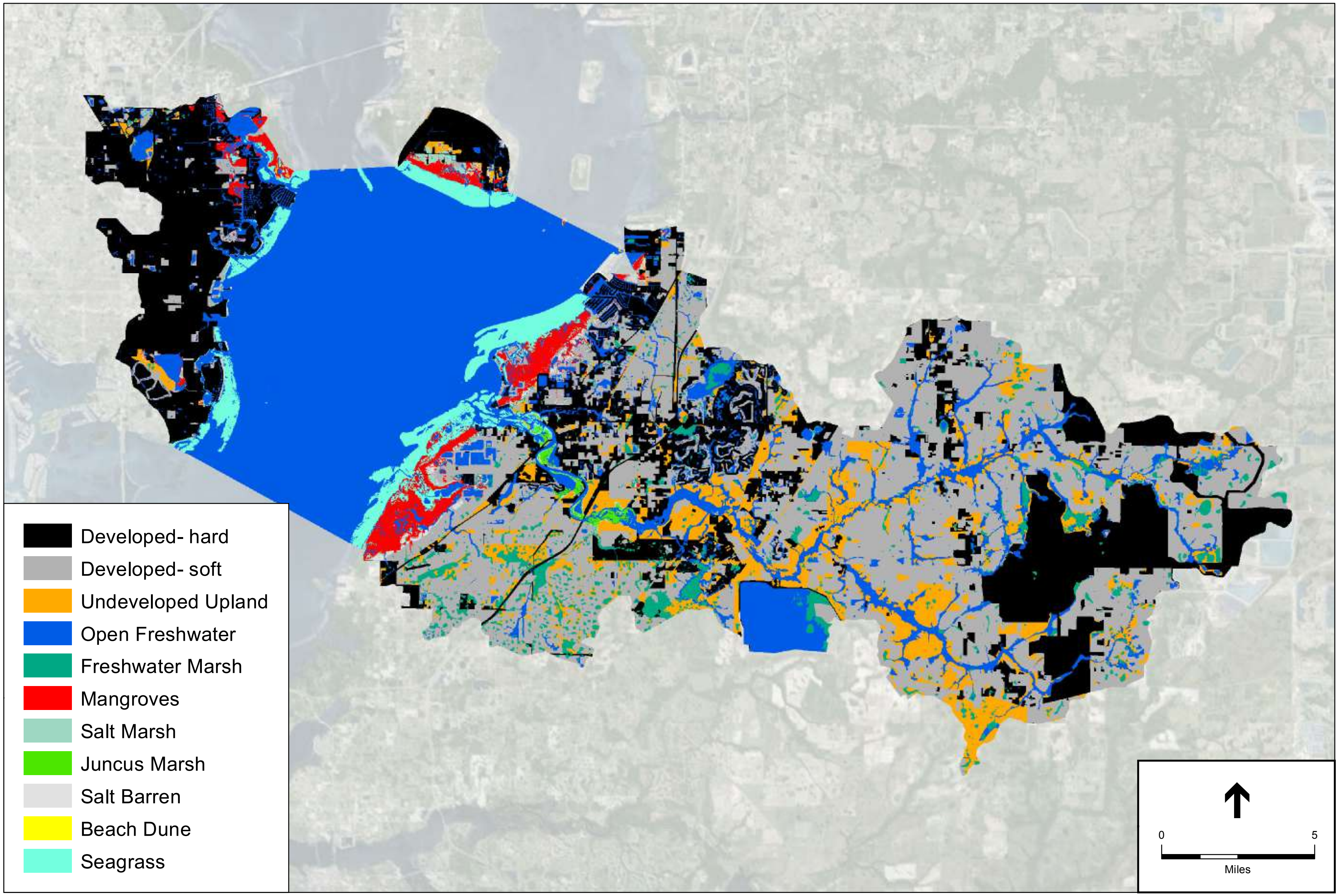


Figure G-48
Tampa Bay Habitat Evolution Modeling Results
Run 5: High Sea-Level Rise, Low Accretion, No Protection, MTB 2050

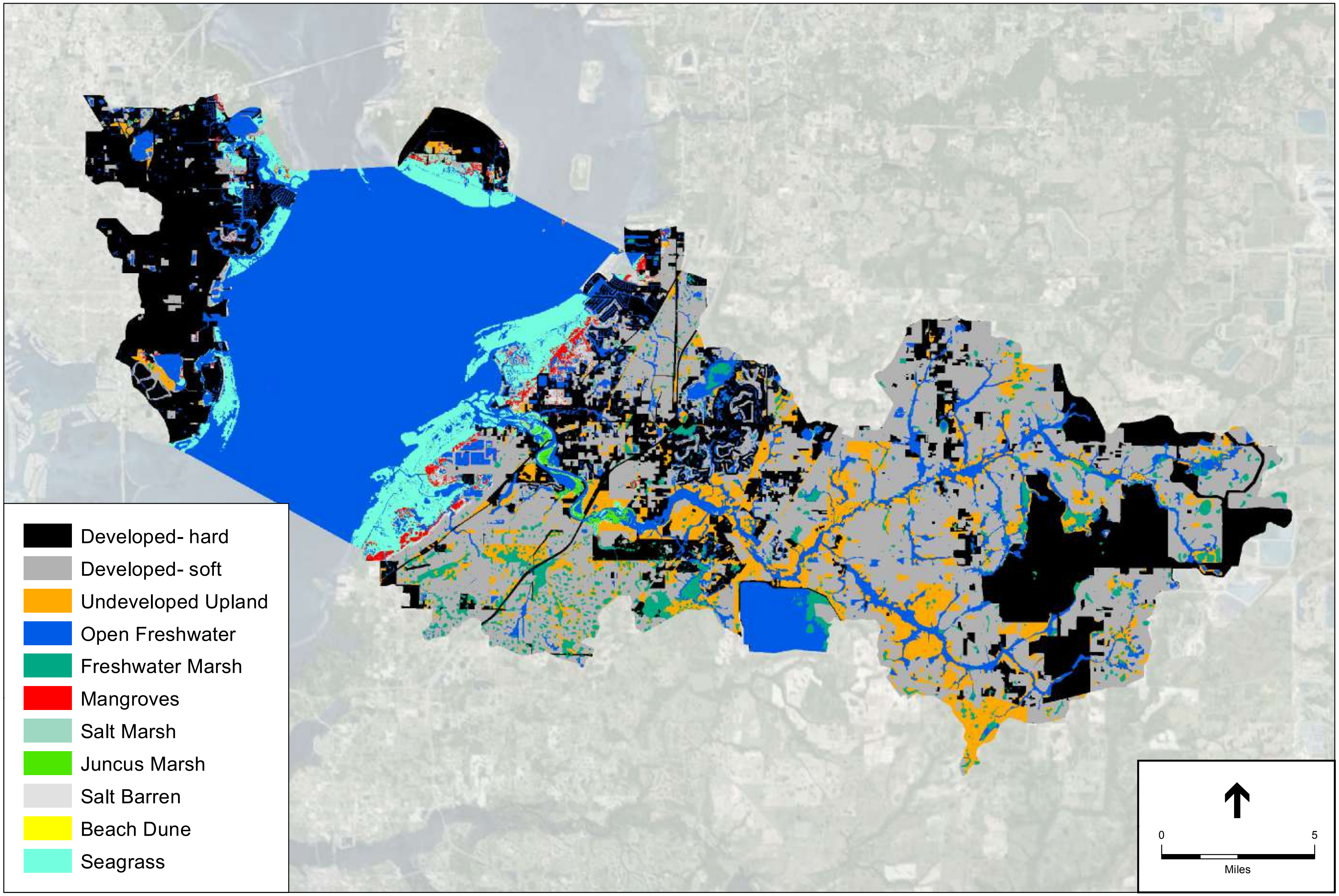


Figure G-49
Tampa Bay Habitat Evolution Modeling Results
Run 5: High Sea-Level Rise, Low Accretion, No Protection, MTB 2075

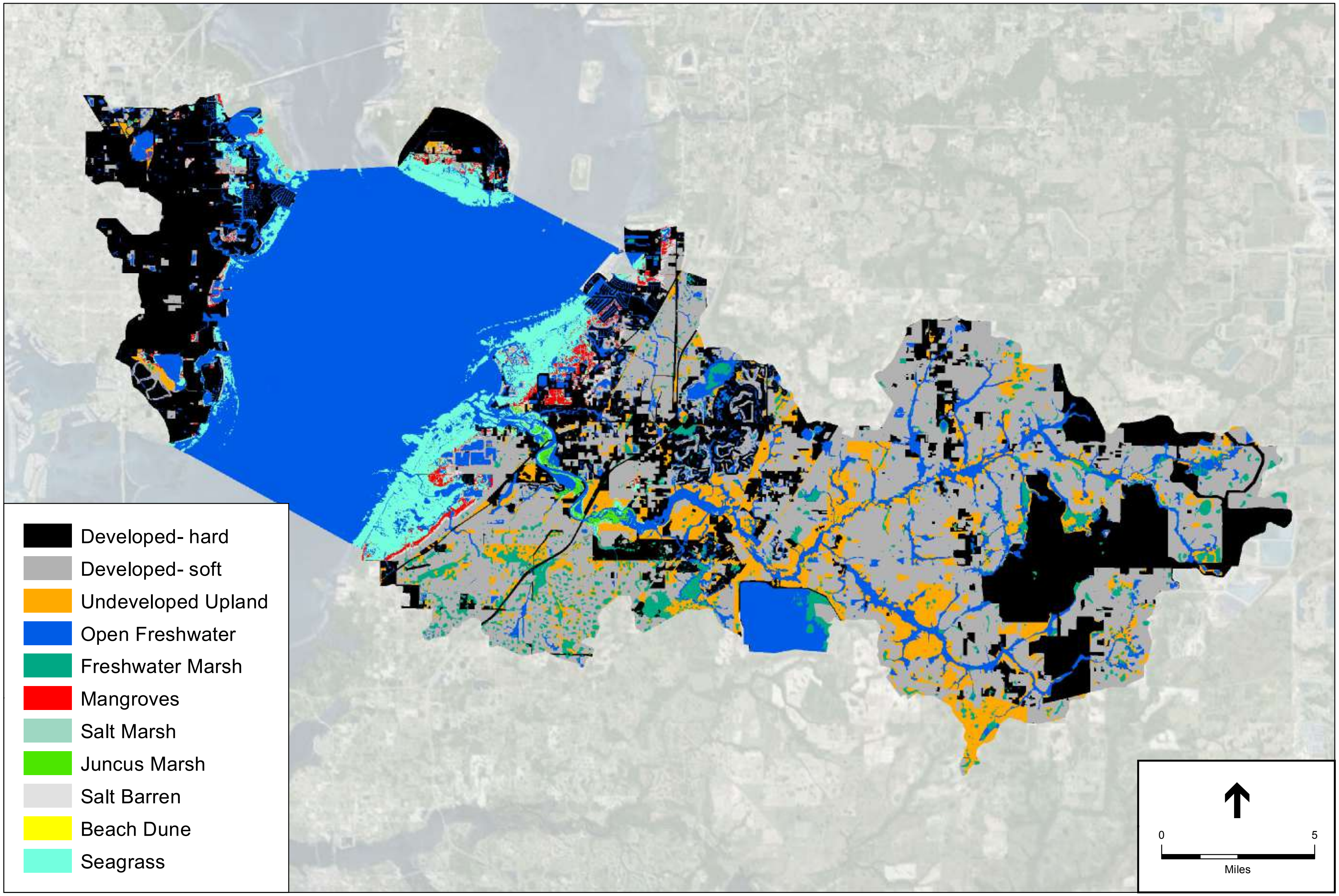
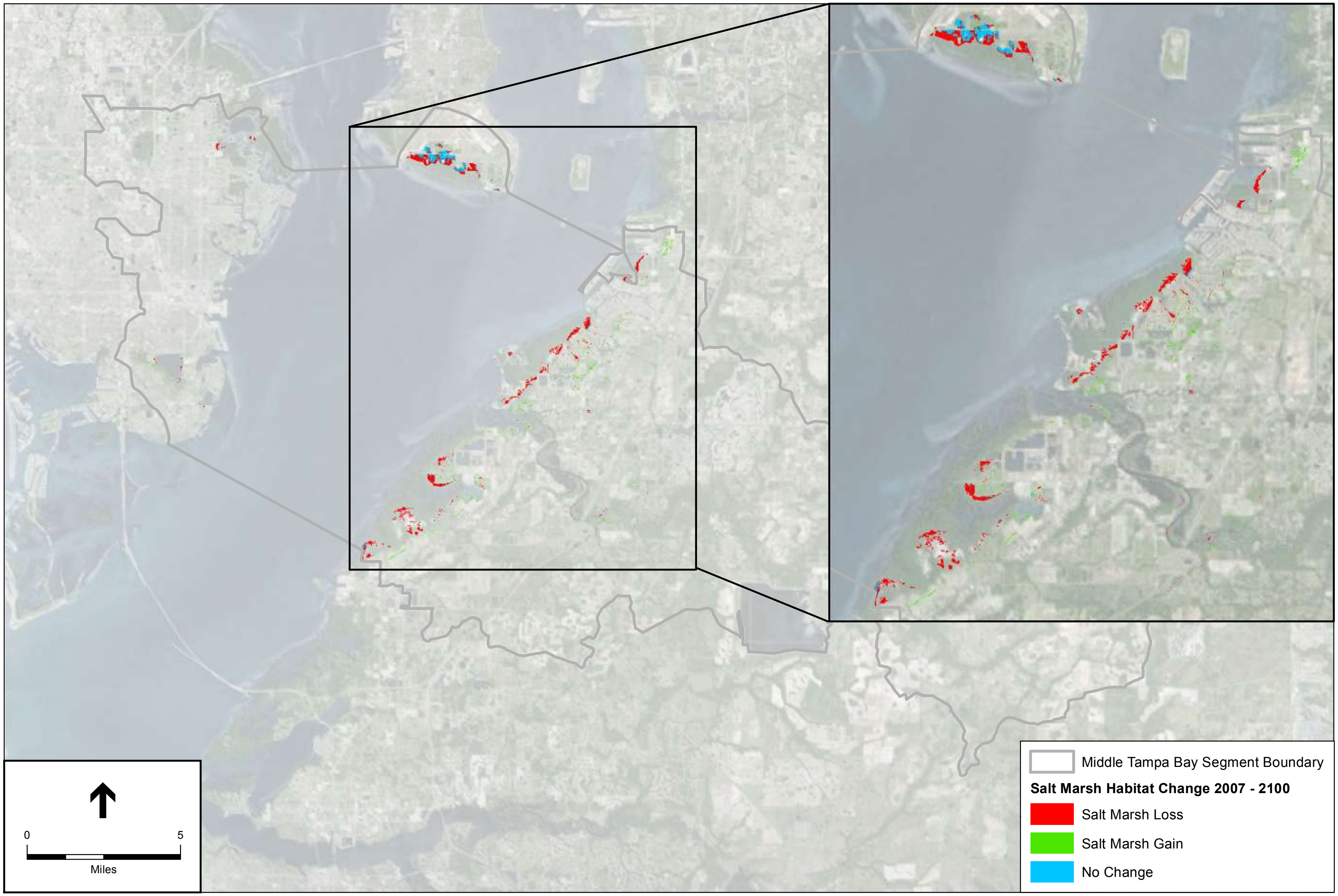


Figure G-50
Tampa Bay Habitat Evolution Modeling Results
Run 5: High Sea-Level Rise, Low Accretion, No Protection, MTB 2100

APPENDIX H

Habitat Change Maps



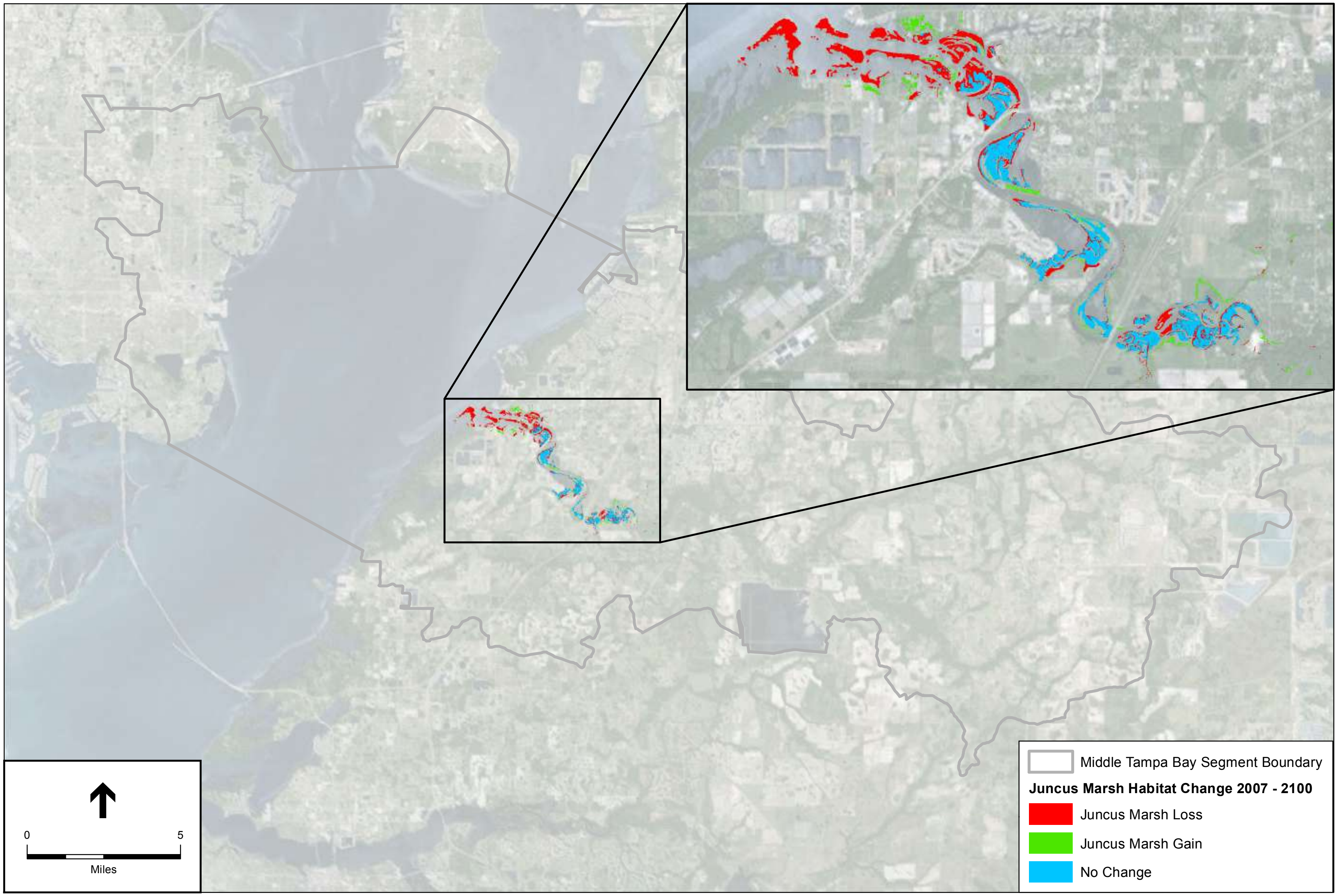
SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management

ESA

Tampa Bay Blue Carbon Assessment. .D140671

Figure H-1

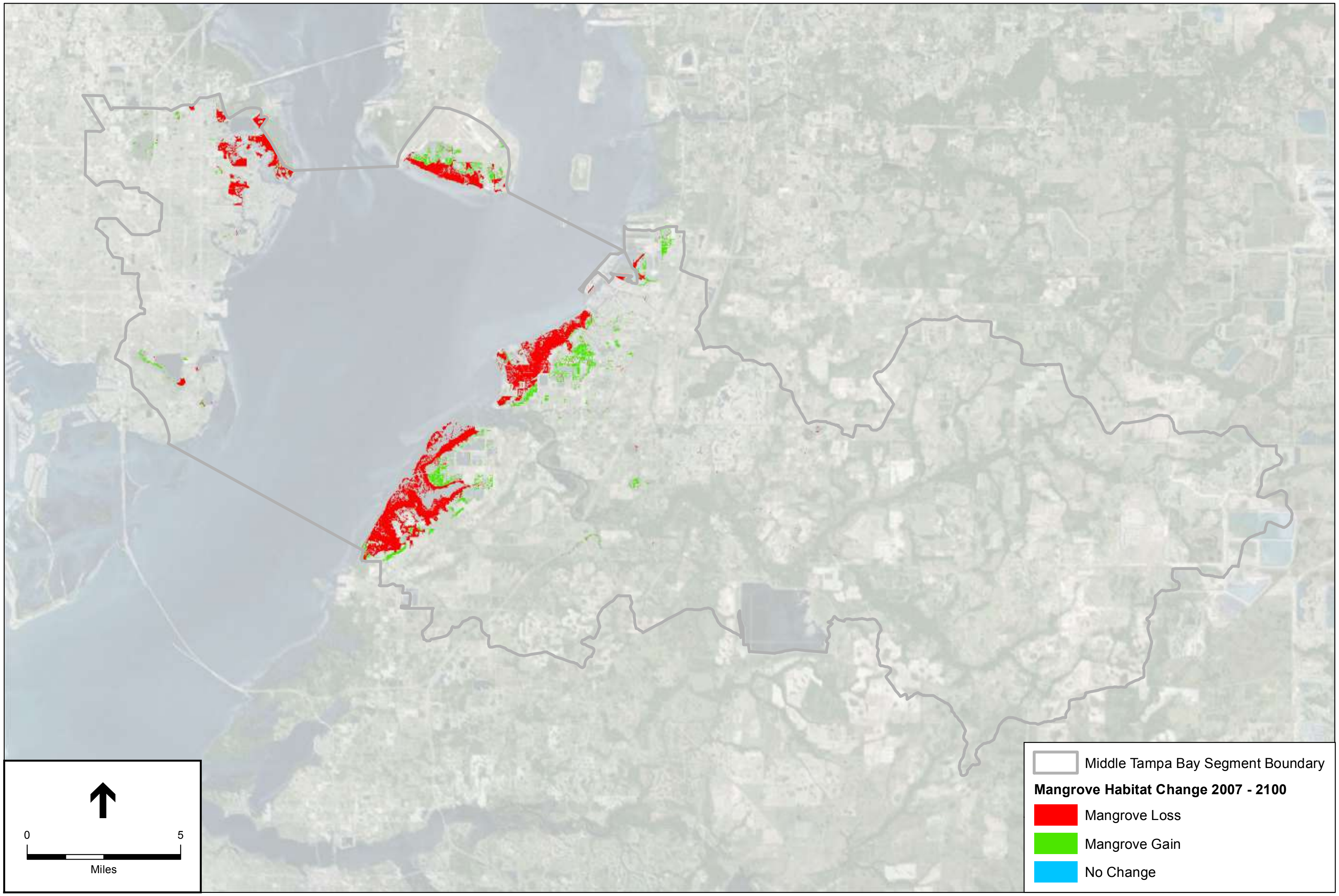
Change in Salt Marsh Habitat
Middle Tampa Bay 2007 - 2100



SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management

Tampa Bay Blue Carbon Assessment. .D140671

Figure H-2
Change in Juncus Marsh Habitat
Middle Tampa Bay 2007 - 2100



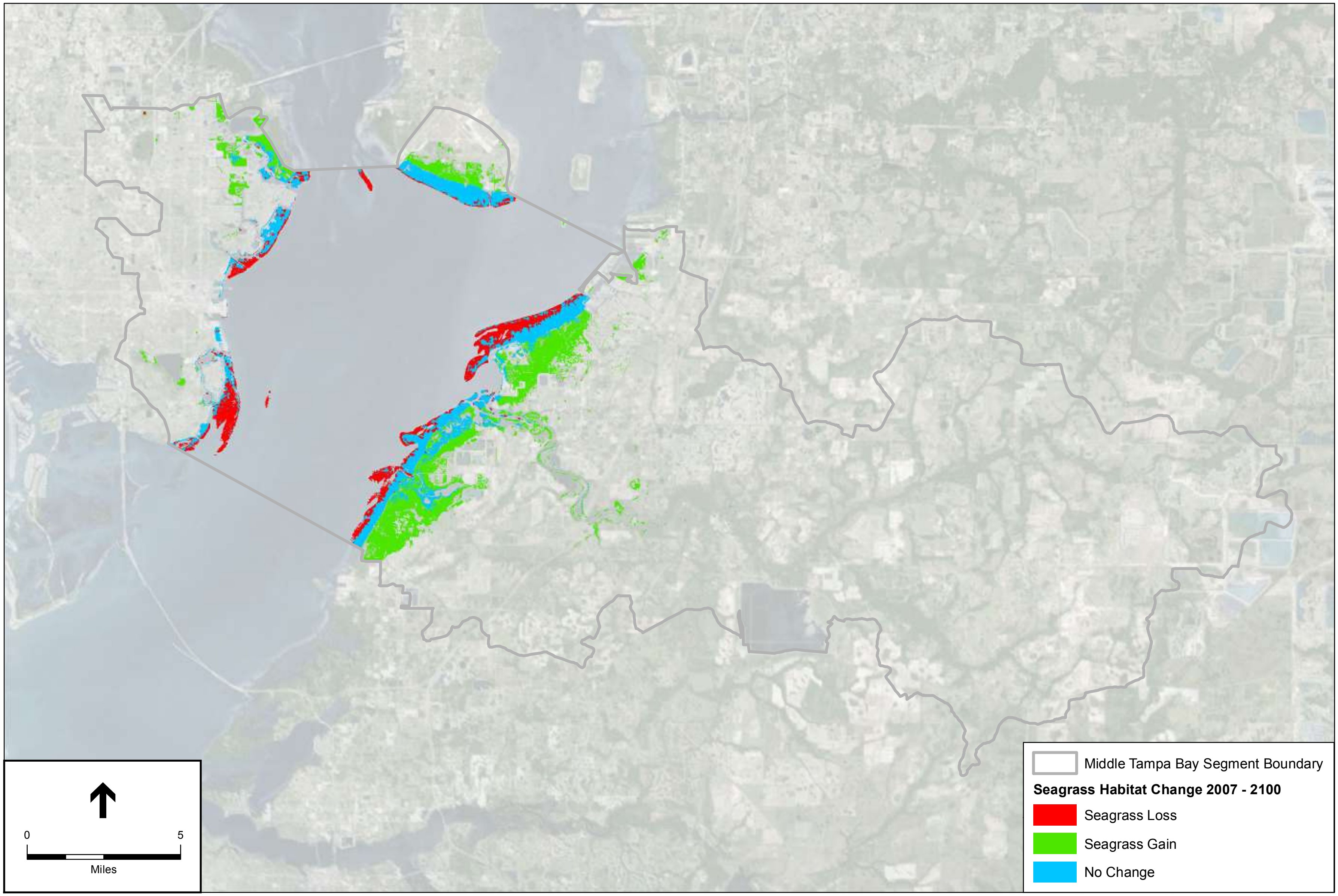
SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management

ESA

Tampa Bay Blue Carbon Assessment. .D140671

Figure H-3

Change in Mangrove Habitat
Middle Tampa Bay 2007 - 2100



SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management

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Figure H-4
Change in Seagrass Habitat Middle Tampa Bay 2007 - 2100

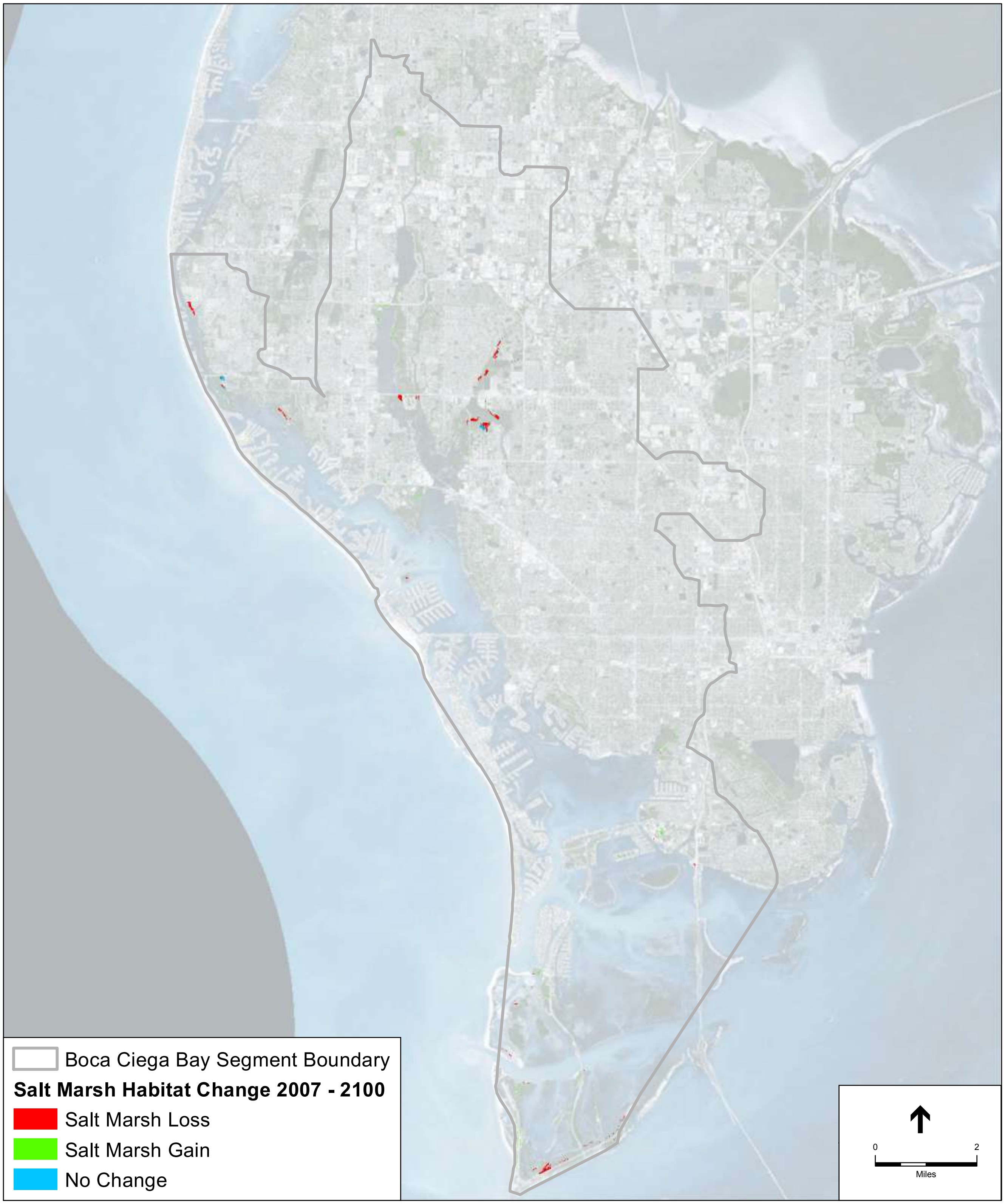


Figure H-5
Change in Salt Marsh Habitat Boca Ciega Bay 2007-2100

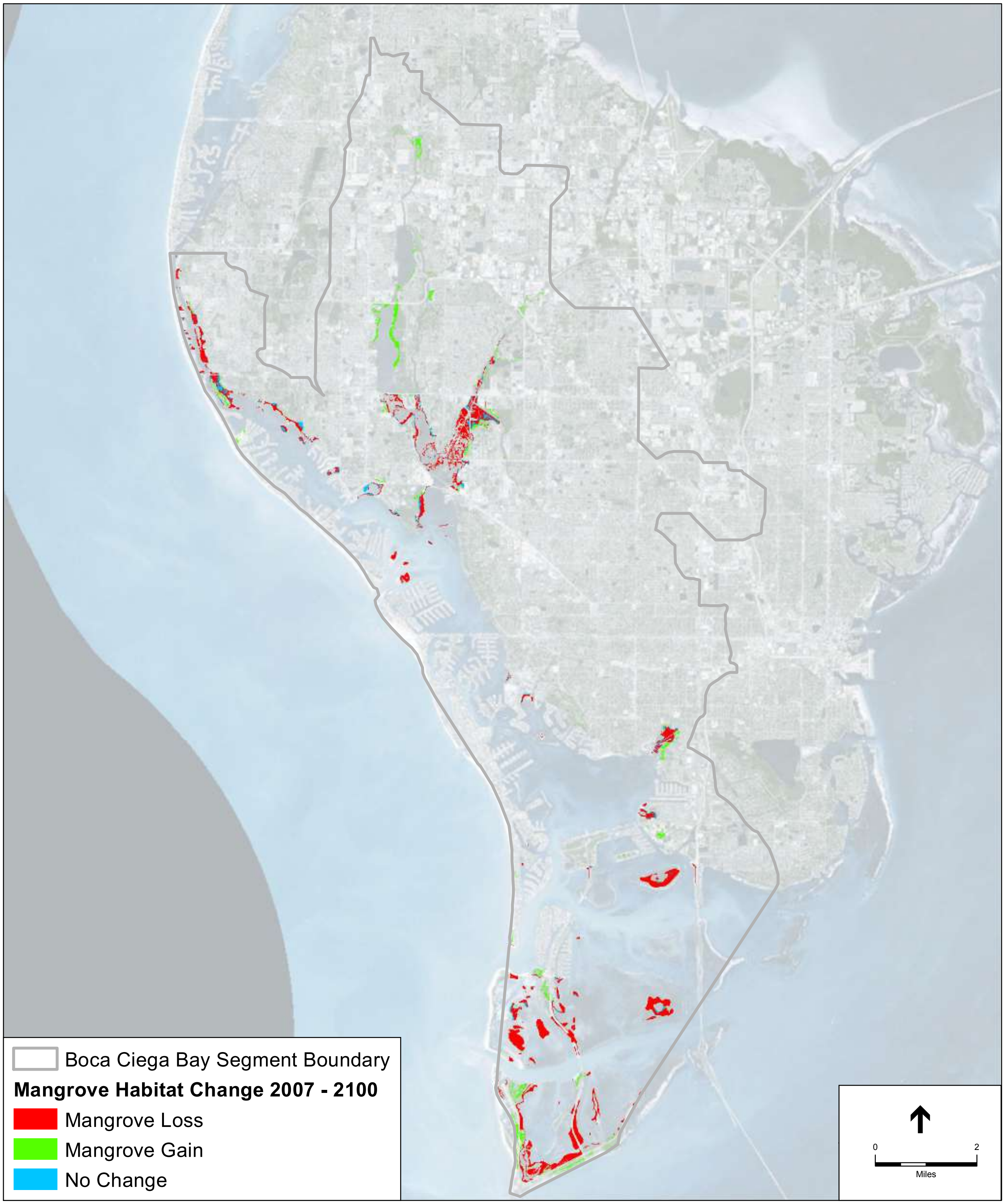


Figure H-6
Change in Mangrove Habitat
Boca Ciega Bay 2007-2100

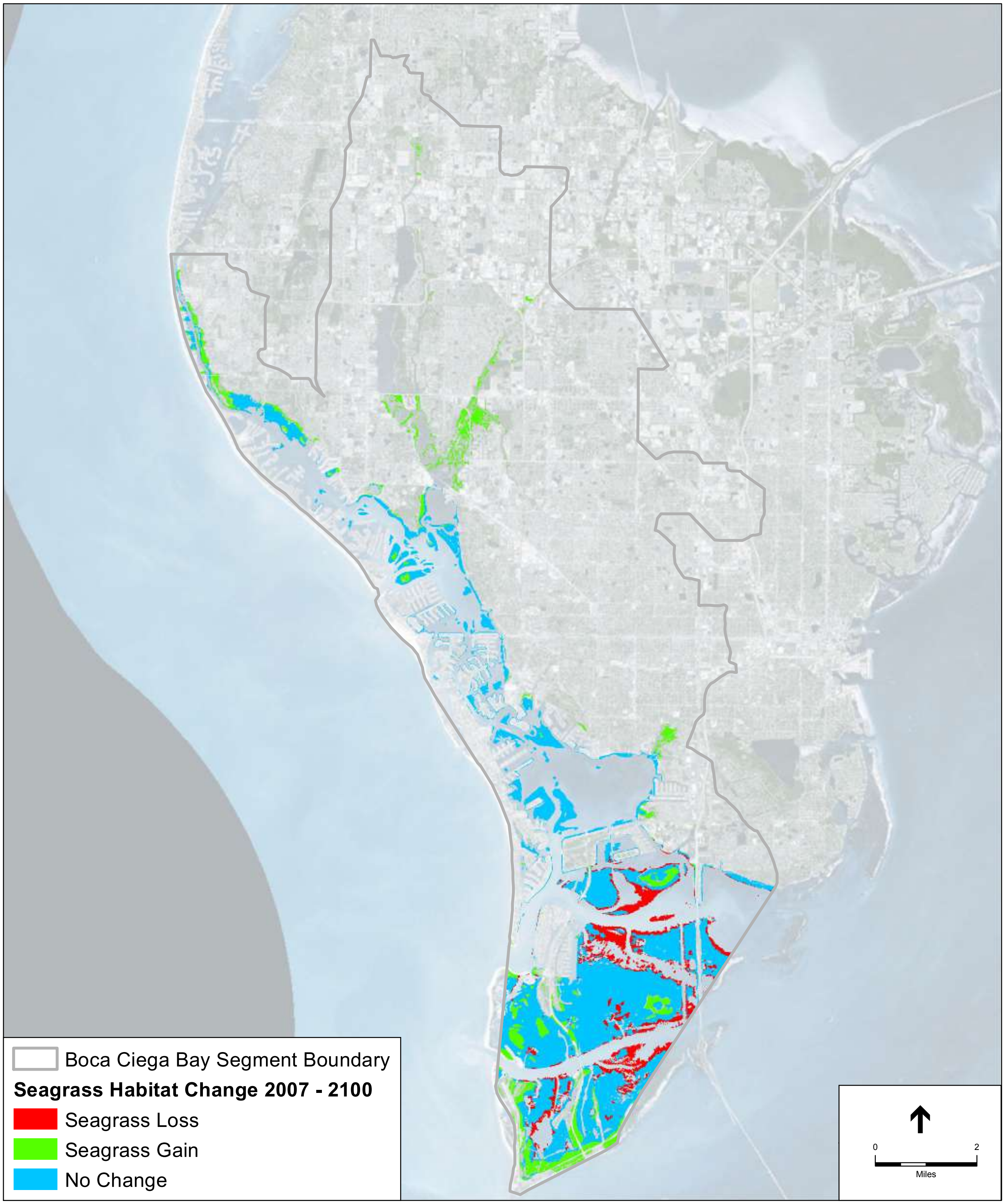


Figure H-7
Change in Seagrass Habitat Boca Ciega Bay 2007-2100

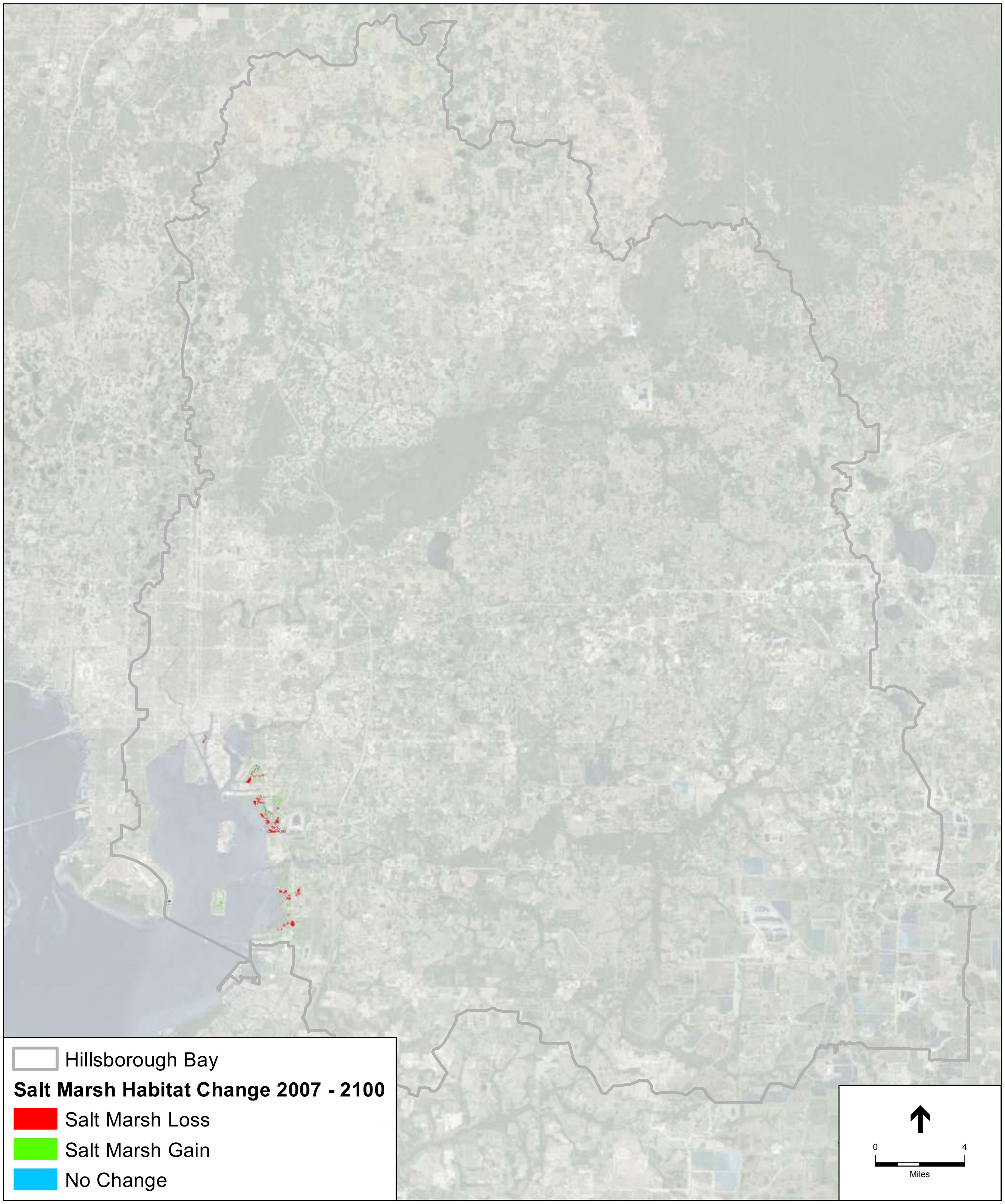


Figure H-8
Change in Salt Marsh
Hillsborough Bay 2007-2100

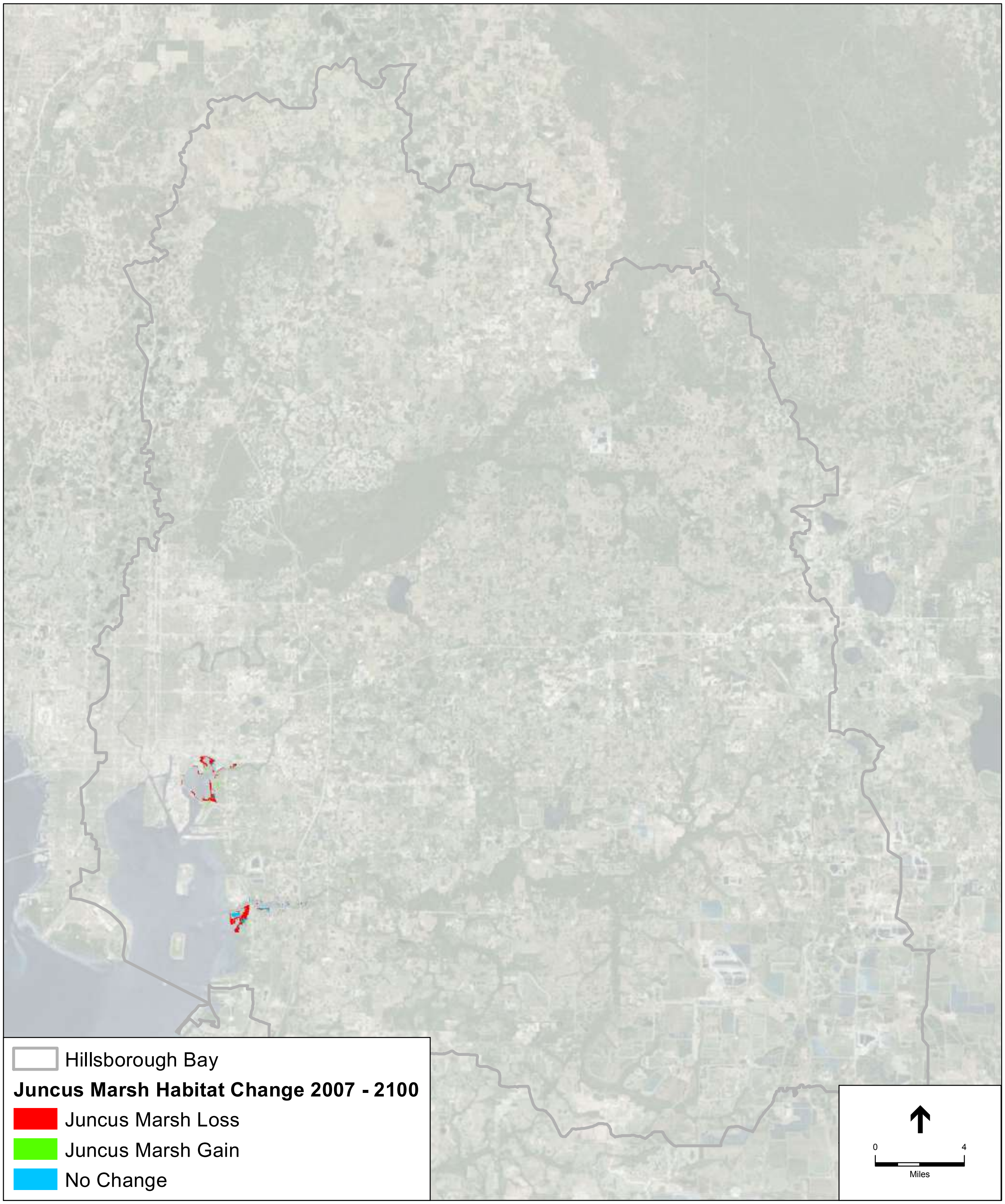


Figure H-9
Change in Juncus Marsh Habitat
Hillsborough Bay 2007-2100

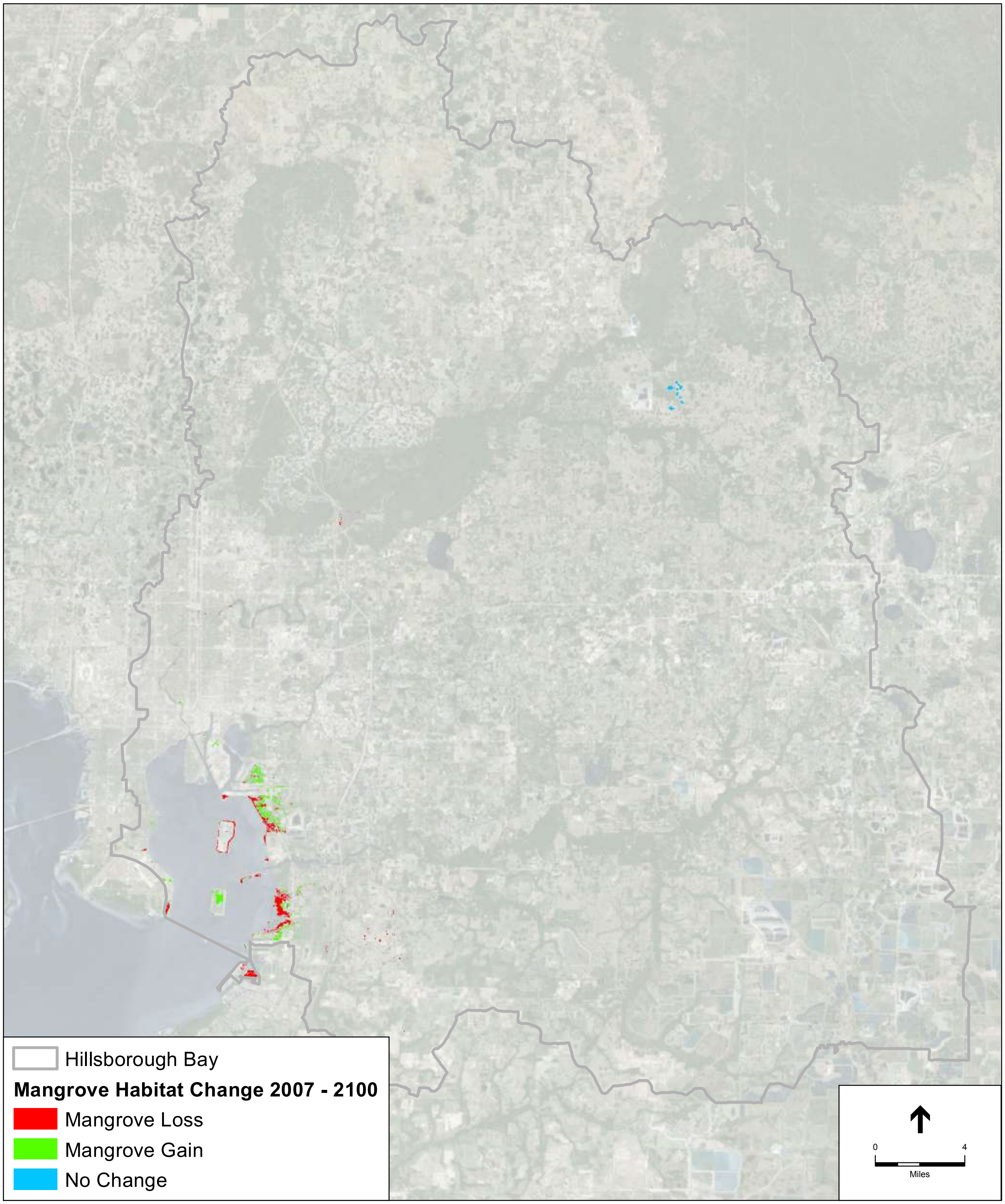


Figure H-10
Change in Mangrove Habitat
Hillsborough Bay 2007-2100

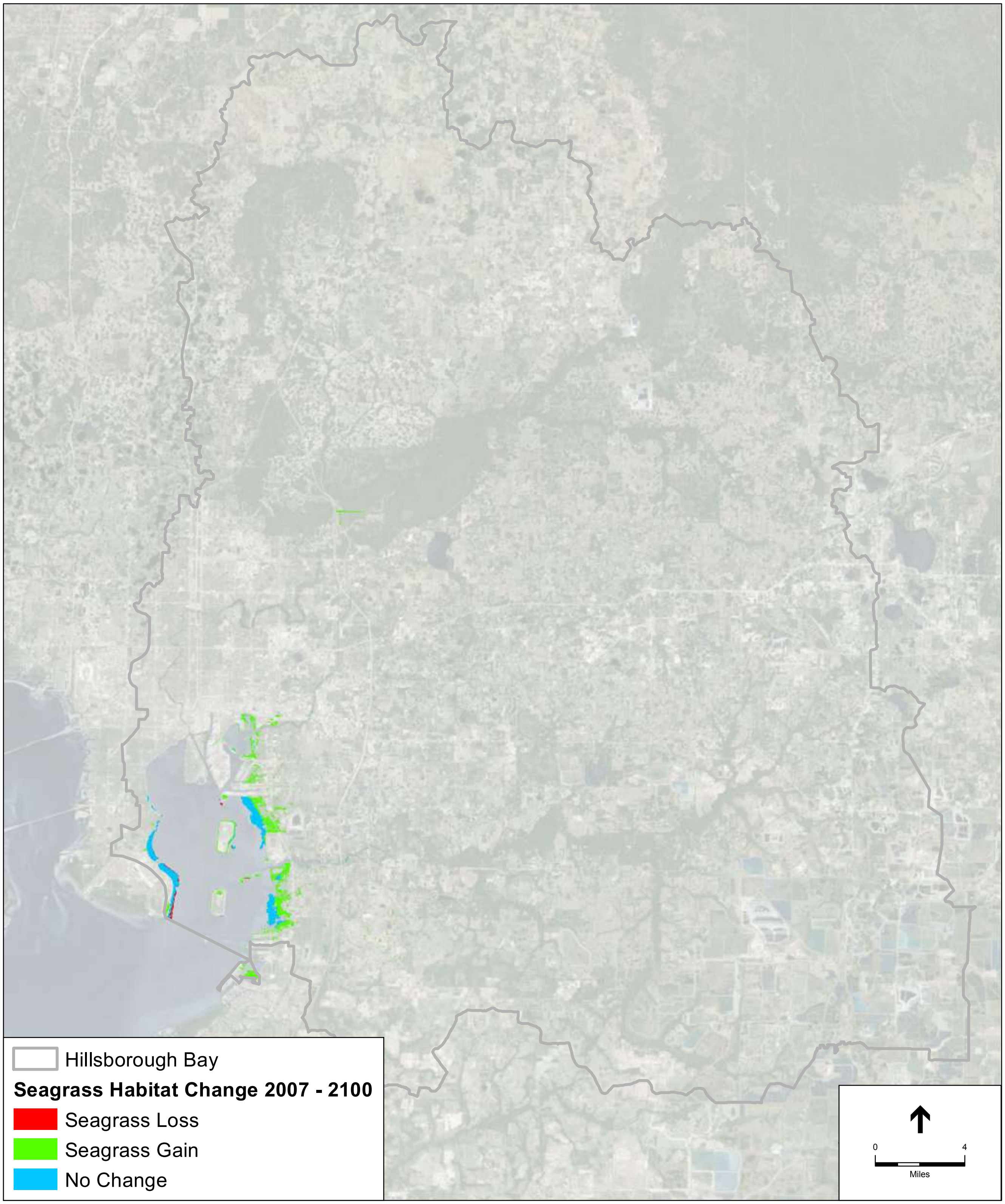
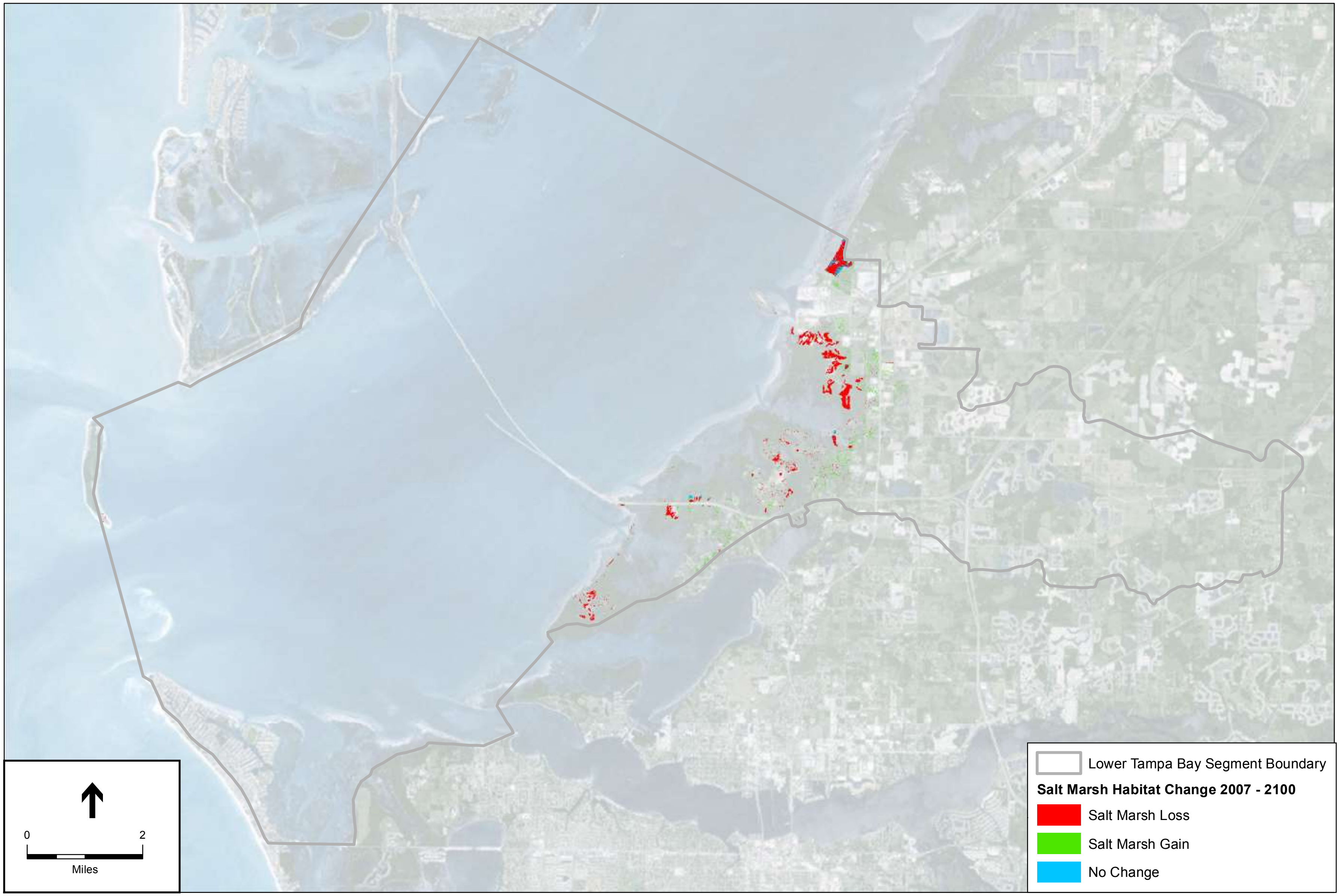


Figure H-11
Change in Seagrass Habitat
Hillsborough Bay 2007-2100



SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management

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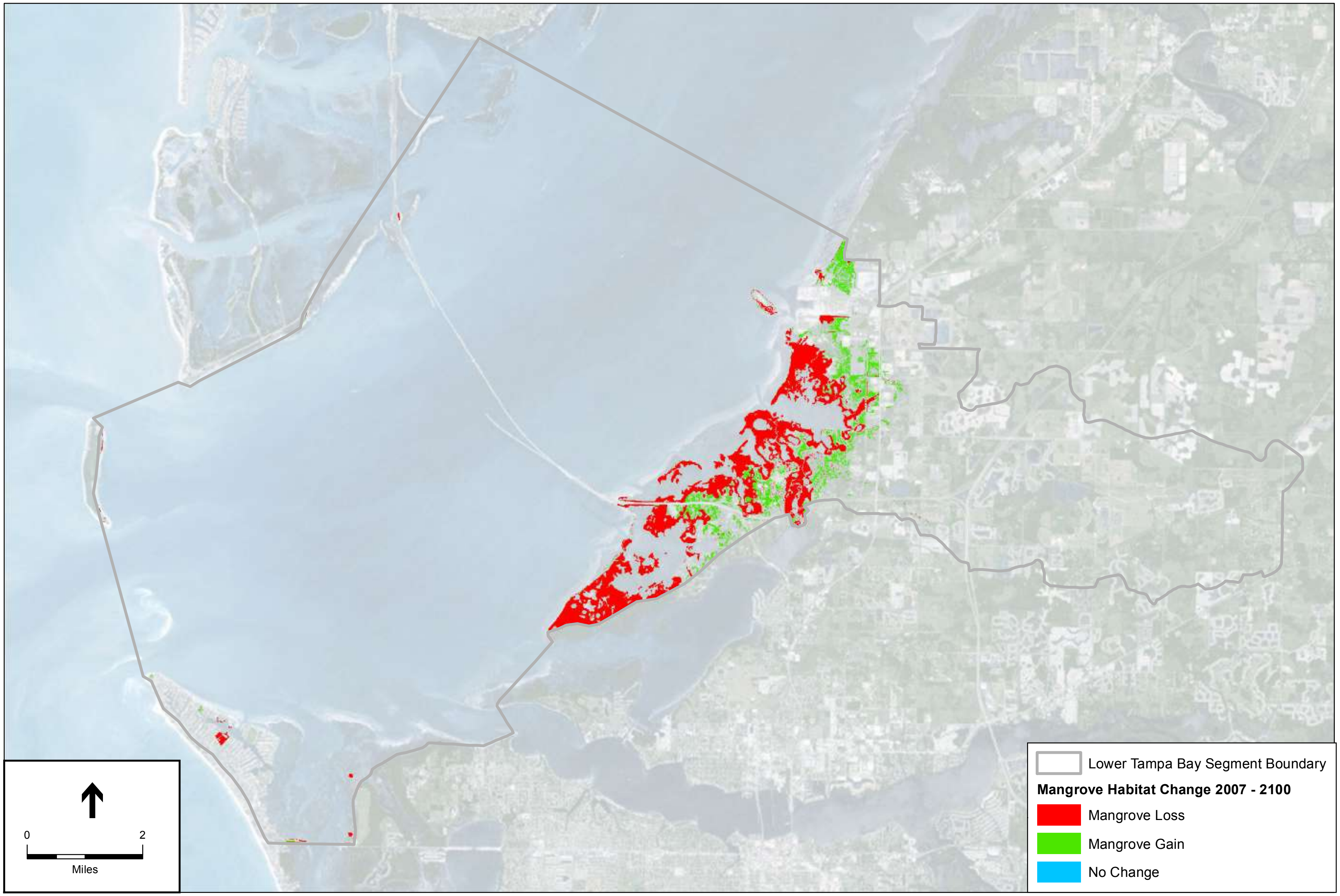
Figure H-12

Change in Salt Marsh Habitat
Lower Tampa Bay 2007 - 2100

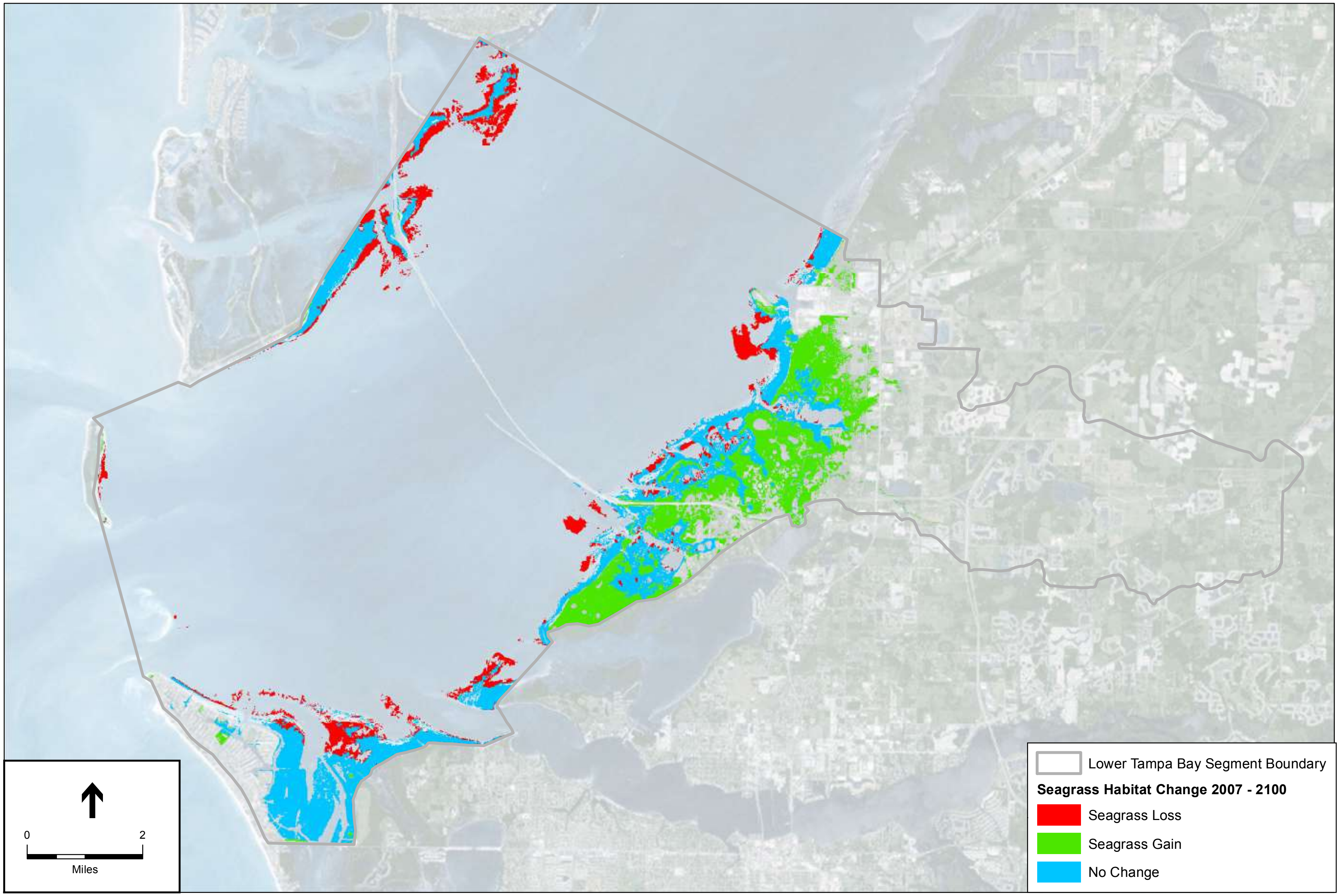


SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management

ESA

Tampa Bay Blue Carbon Assessment. .D140671

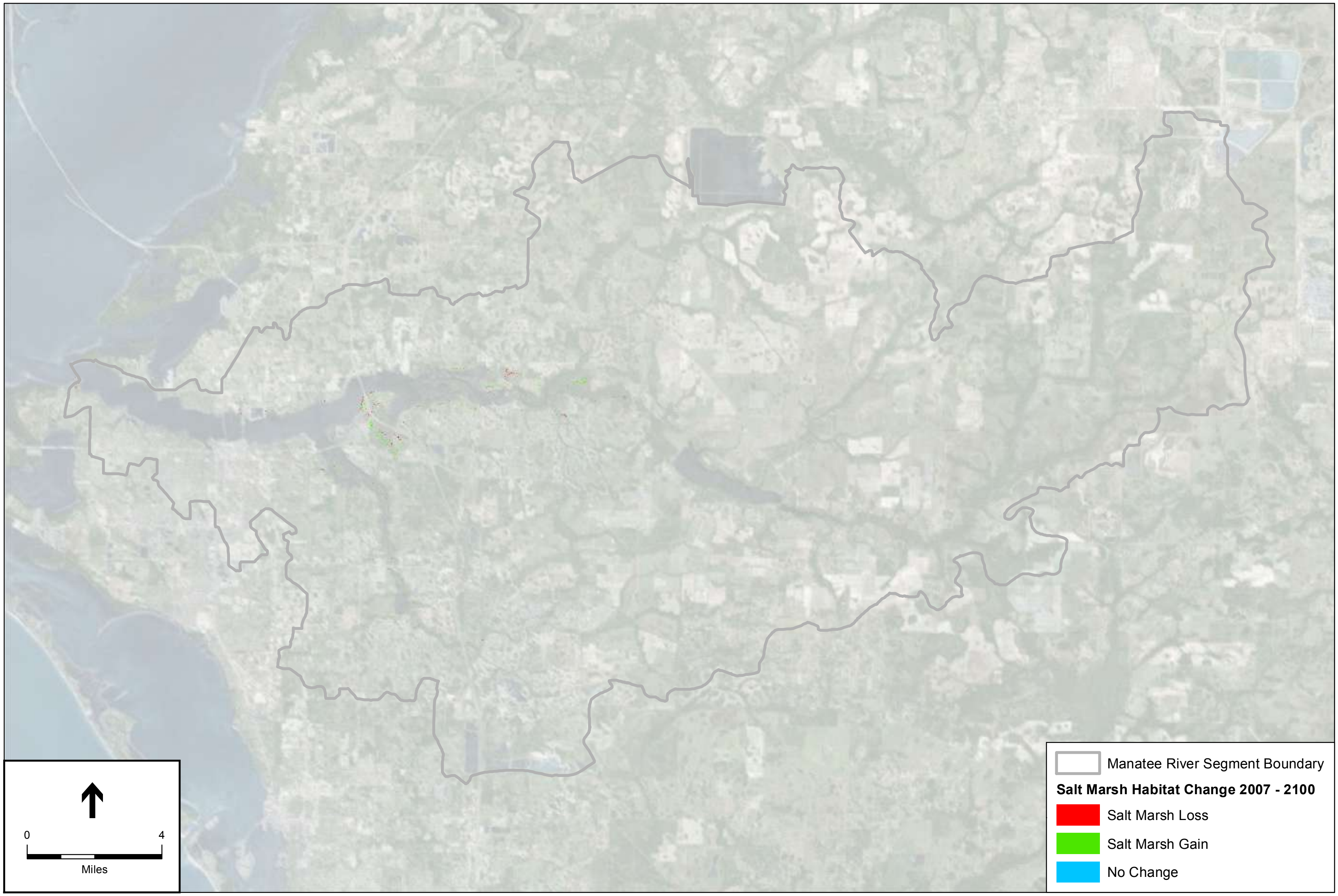
Figure H-13
Change in Mangrove Habitat
Lower Tampa Bay 2007 - 2100



SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management

Tampa Bay Blue Carbon Assessment. .D140671

Figure H-14
Change in Seagrass Habitat Lower Tampa Bay 2007 - 2100



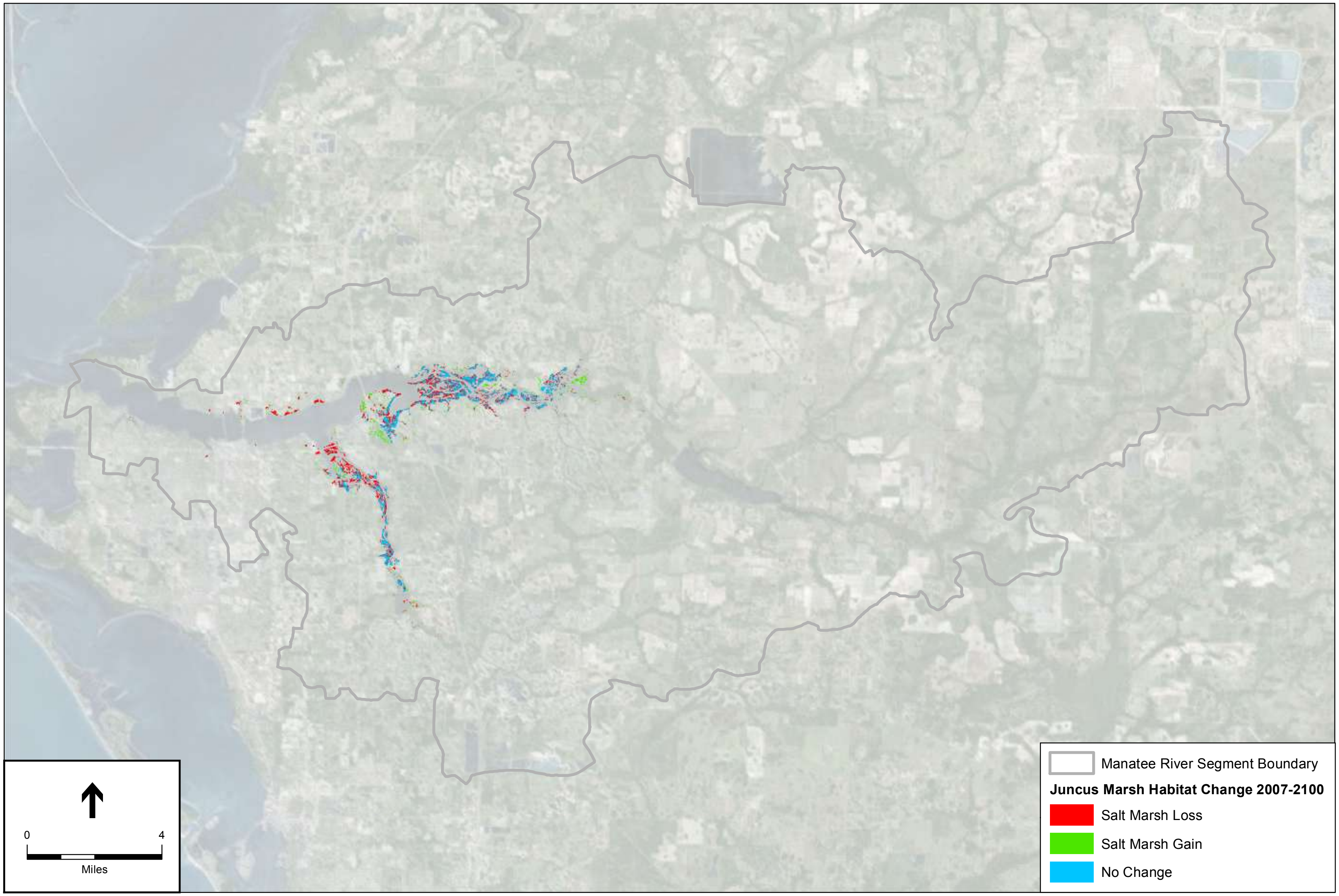
SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management

ESA

Tampa Bay Blue Carbon Assessment. .D140671

Figure H-15

Change in Salt Marsh Habitat
Manatee River 2007 - 2100



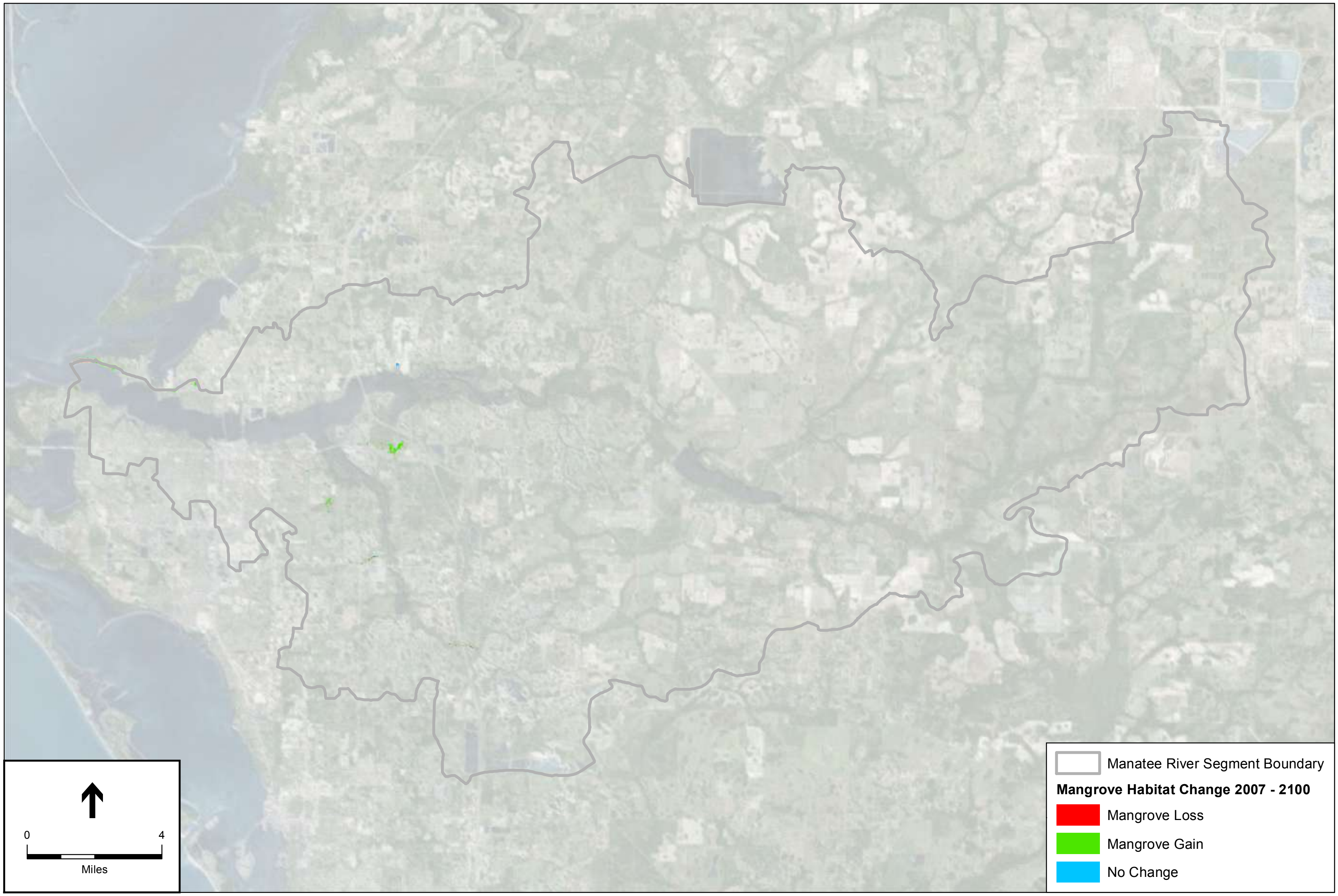
SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management

Tampa Bay Blue Carbon Assessment. .D140671

Figure H-16

Change in Juncus Marsh Habitat

Manatee River 2007 - 2100

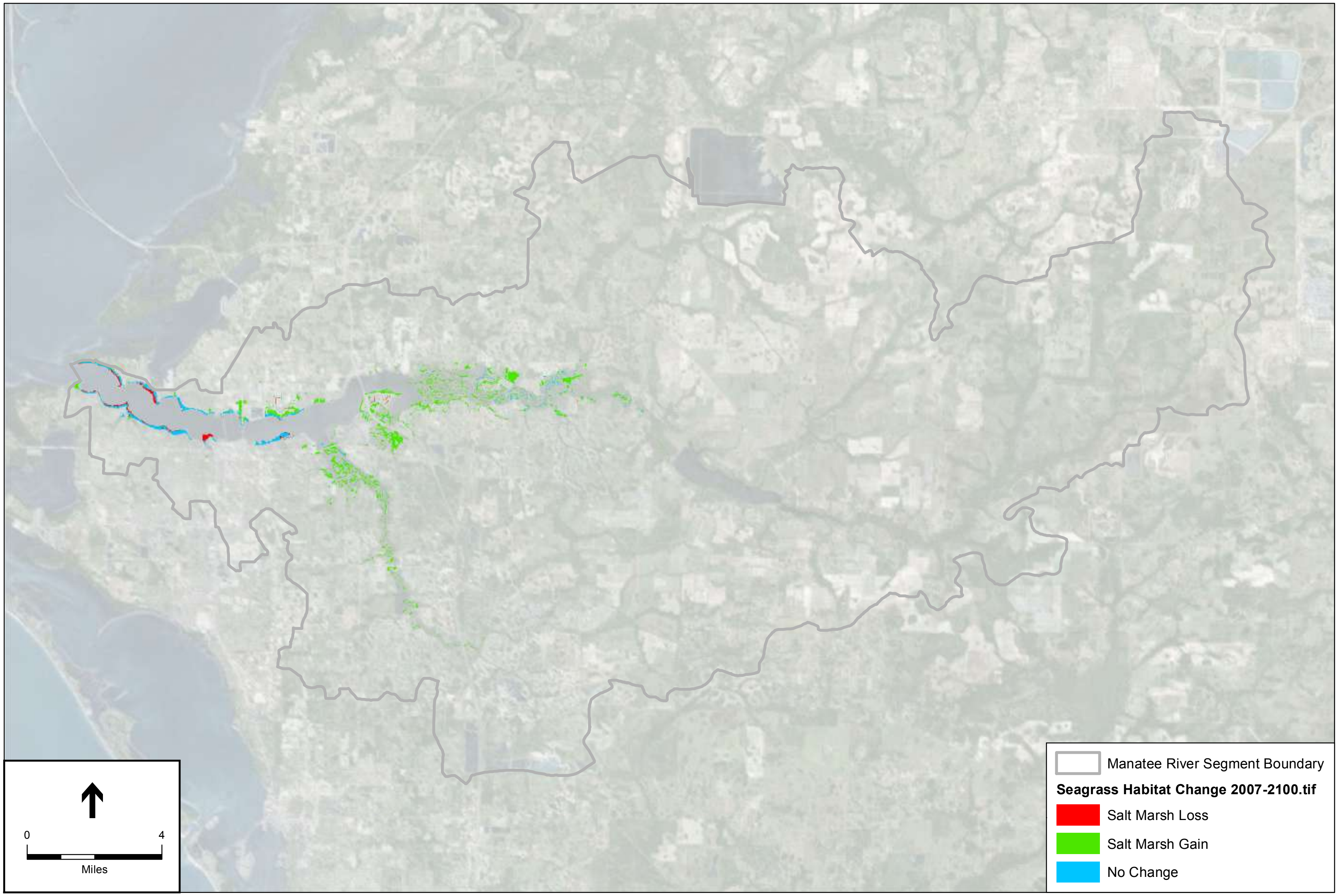


SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management

ESA

Tampa Bay Blue Carbon Assessment. .D140671

Figure H-17
Change in Mangrove Habitat
Manatee River 2007 - 2100



SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management

Tampa Bay Blue Carbon Assessment. .D140671

Figure H-18
Change in Seagrass Habitat
Manatee River 2007 - 2100

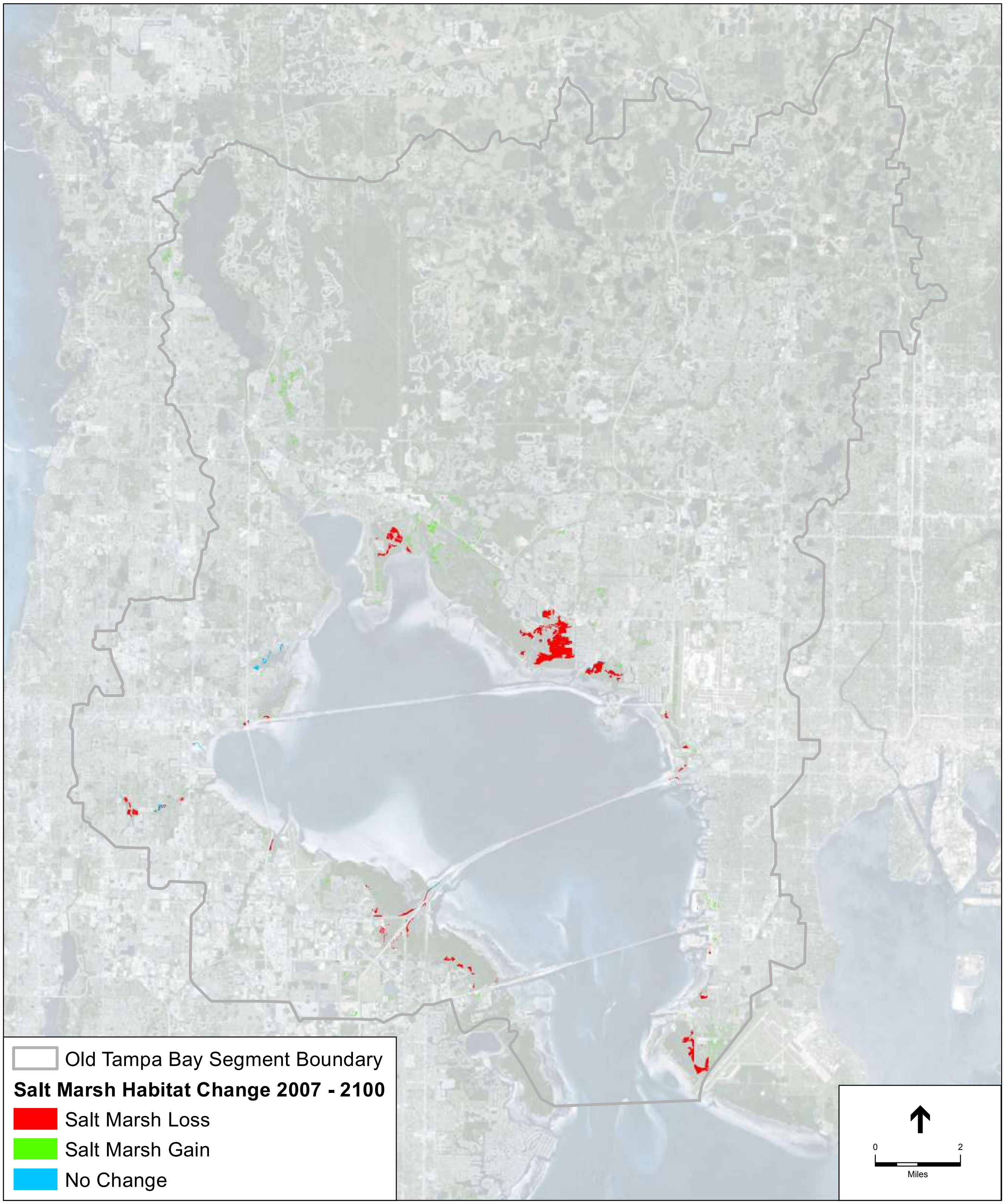


Figure H-19
Change in Salt Marsh Habitat
Old Tampa Bay 2007-2100

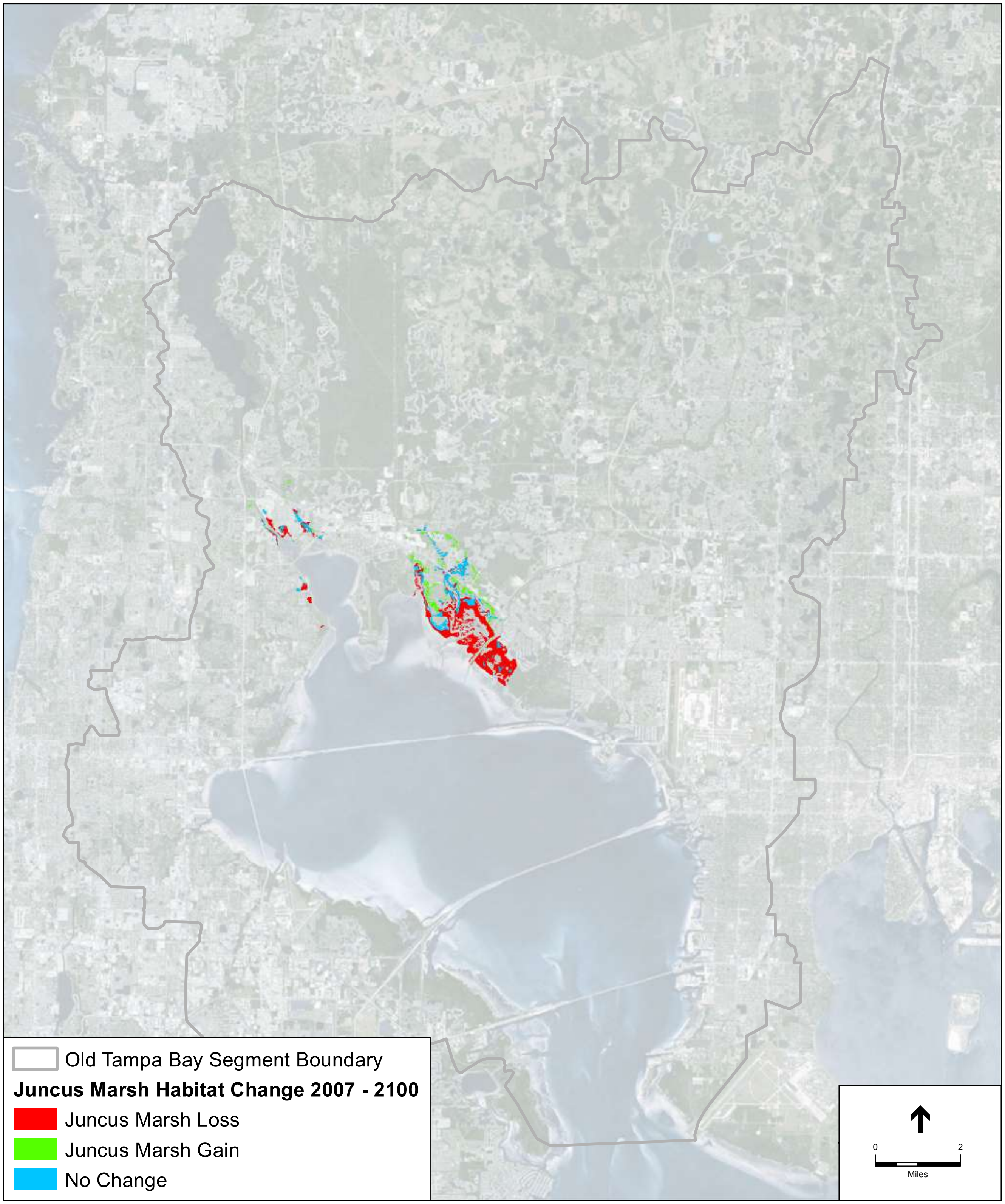
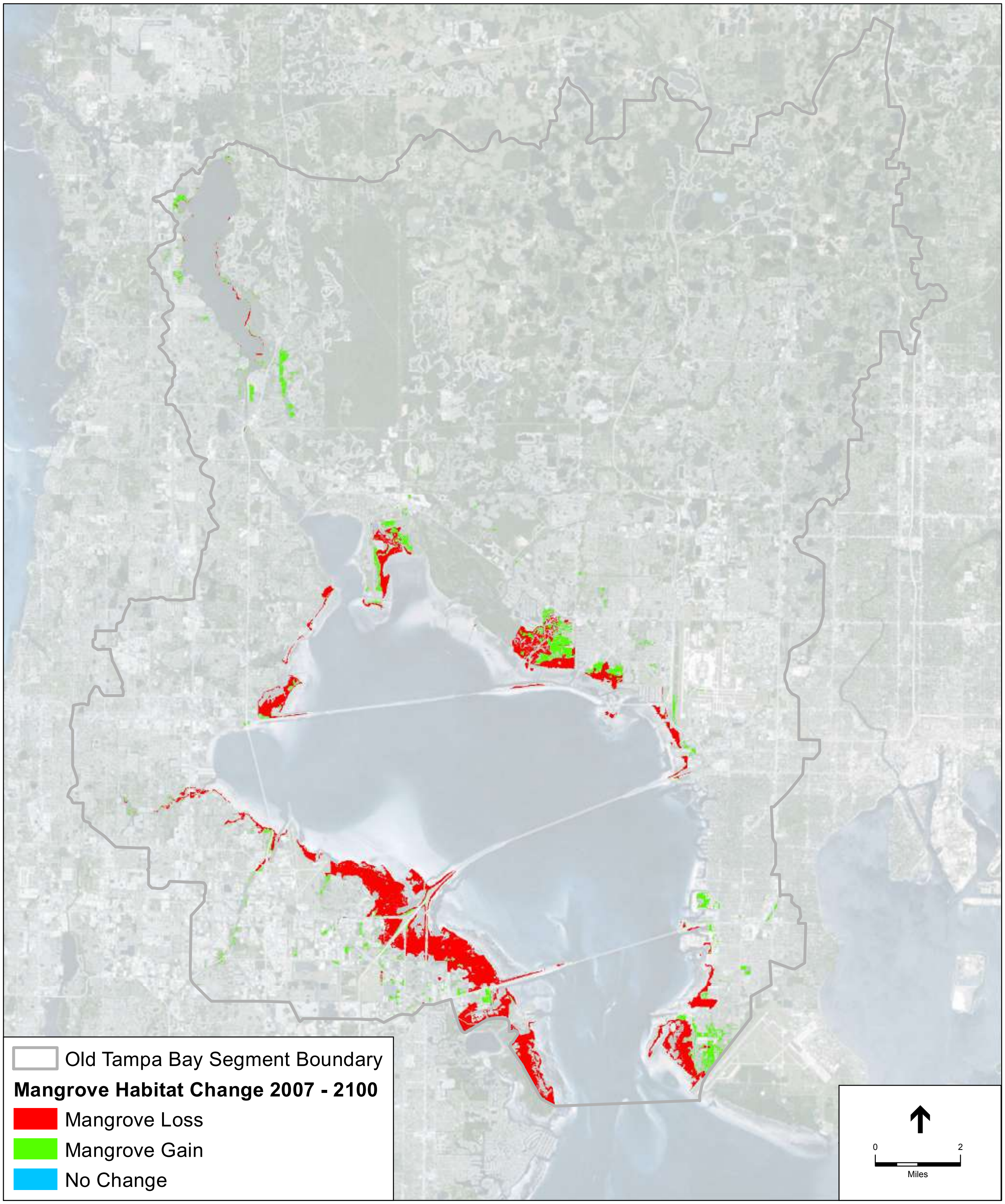


Figure H-20
Change in Juncus Marsh Habitat
Old Tampa Bay 2007-2100



ESA

Figure H-21
Change in Mangrove Habitat
Old Tampa Bay 2007-2100

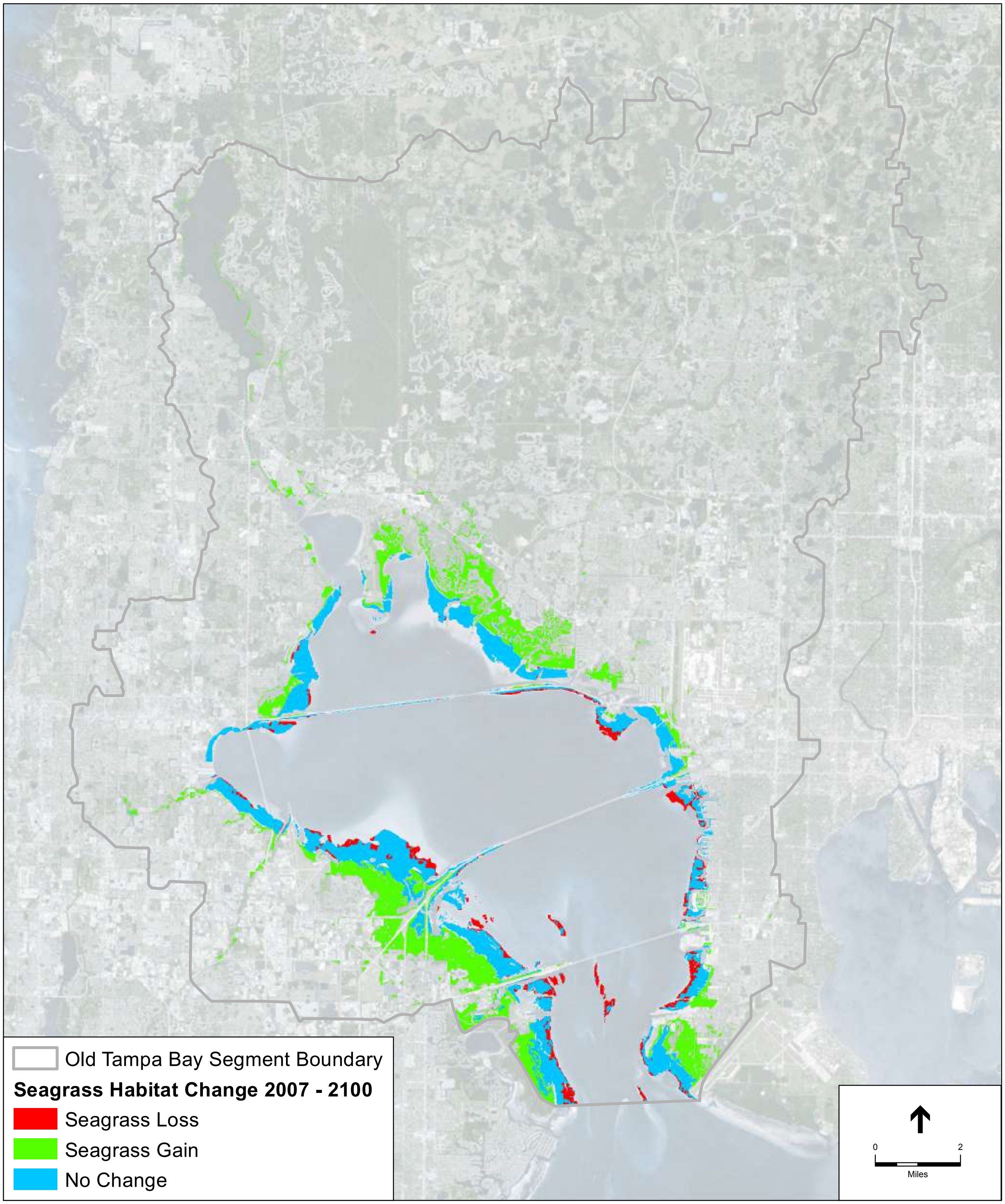
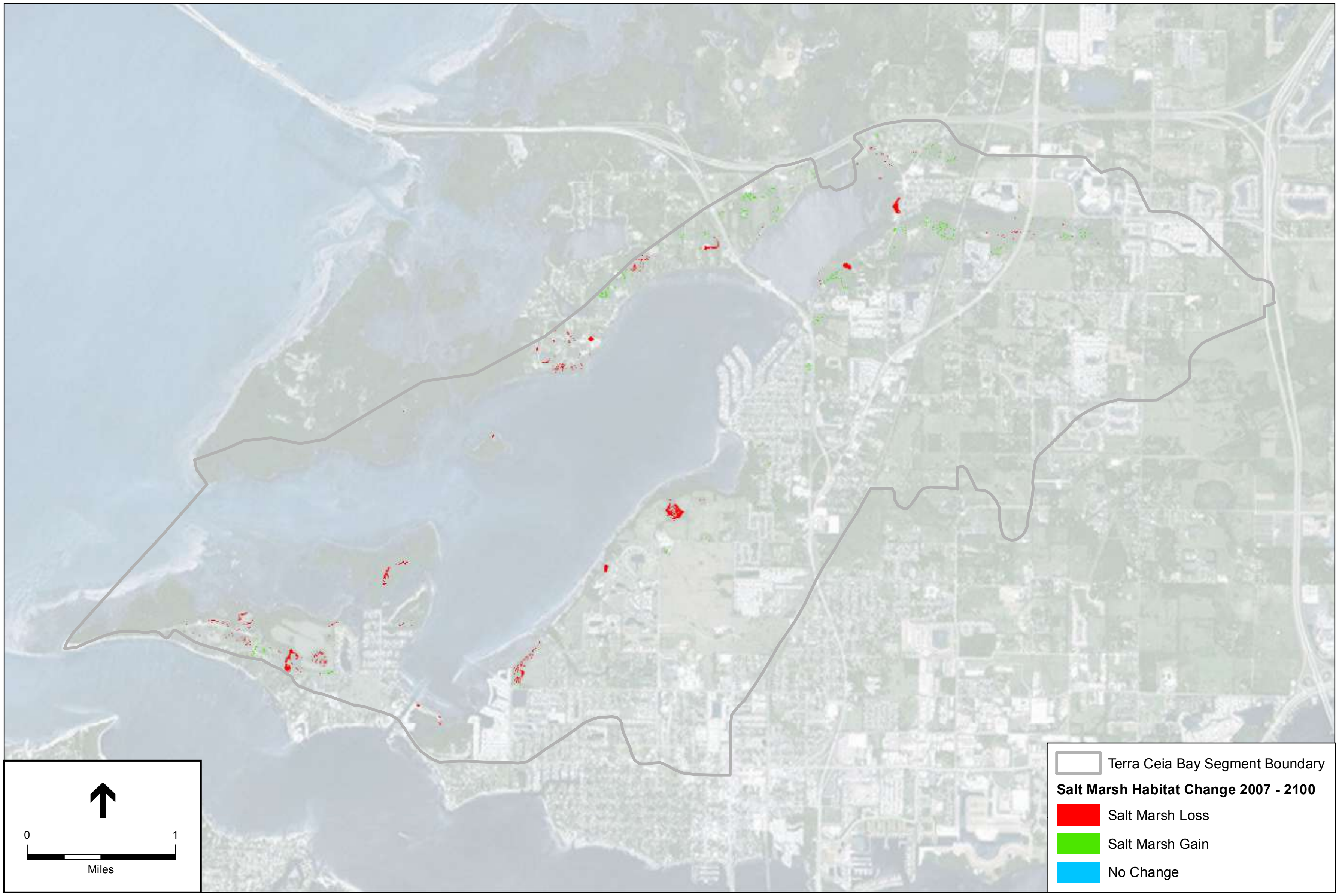


Figure H-22
Change in Seagrass Habitat
Old Tampa Bay 2007-2100



SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management

ESA

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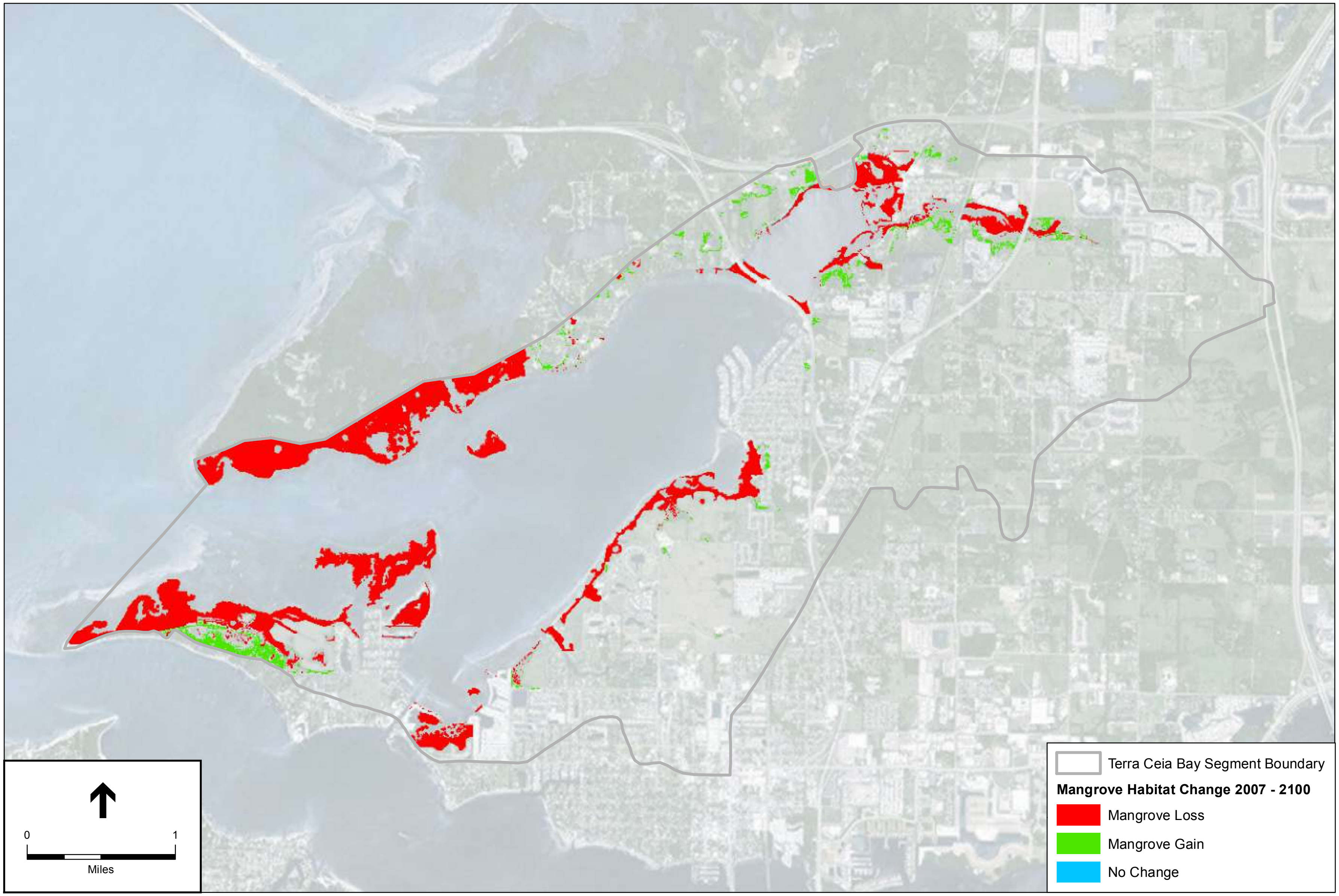
Figure H-23

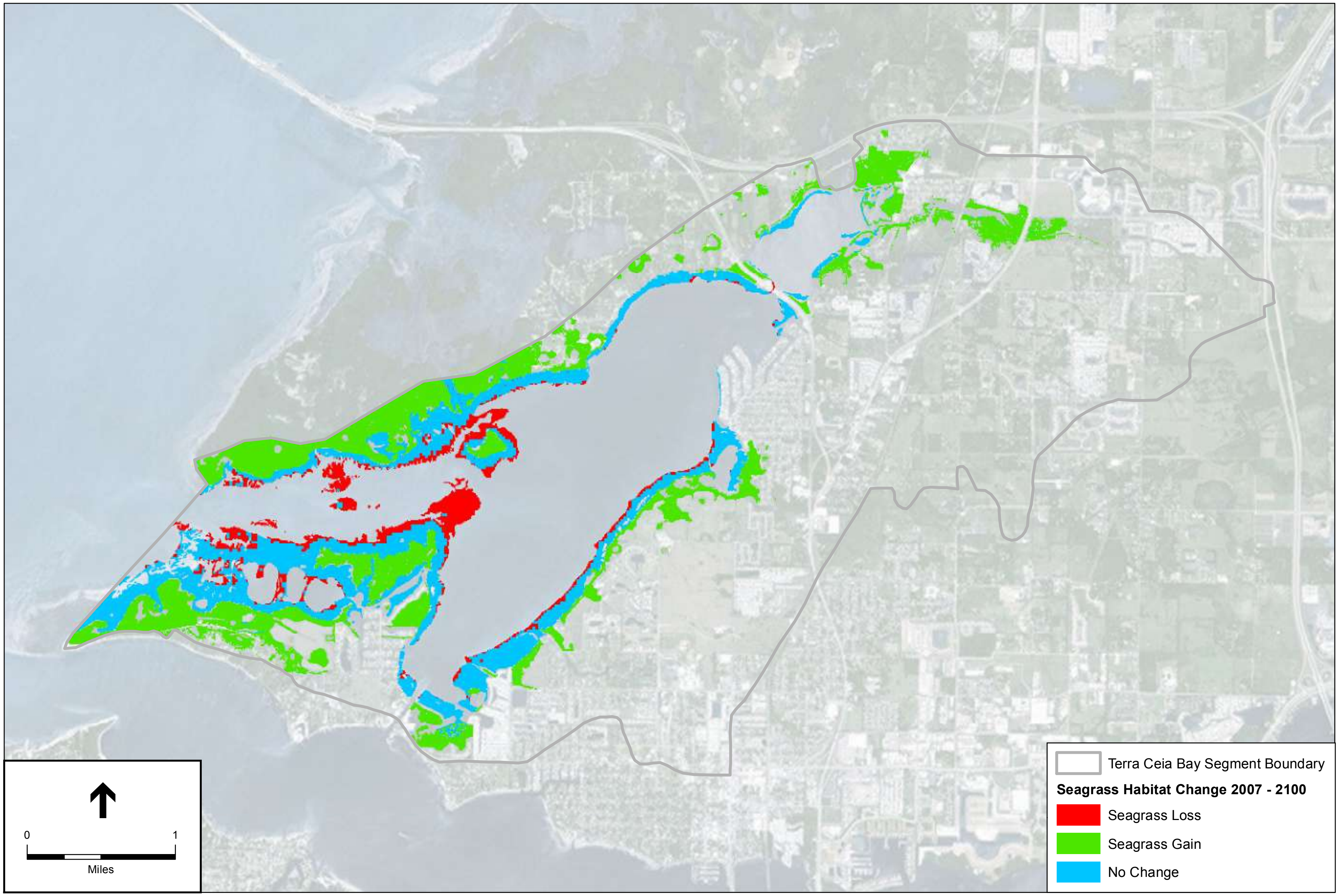
Change in Salt Marsh Habitat Terra Ceia Bay 2007 - 2100



SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management

Tampa Bay Blue Carbon Assessment. .D140671

Figure H-24
Change in Mangrove Habitat Terra Ceia Bay 2007 - 2100



SOURCE: ESRI, SFWFMD, Florida Division of Emergency Management

ESA

Tampa Bay Blue Carbon Assessment. .D140671

Figure H-25

Change in Seagrass Habitat Terra Ceia Bay 2007 - 2100

APPENDIX I

HEM Habitat Acreage Results

Appendix I. HEM Acreages

Run 1	Lower Tampa Bay					Manatee River					Terra Ceia					Middle Tampa Bay					Boca Ciega Bay					Hillsborough Bay					Old Tampa Bay					All of Tampa Bay				
	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100
Mudflat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
Developed - Low Intensity	1581.37	1581.37	1581.37	1581.37	1581.37	13467.3	13467.3	13467.3	13467.3	13467.3	805.711	805.711	805.711	805.711	805.711	9061.45	9061.45	9061.45	9061.45	9061.45	852.167	852.167	852.167	852.167	852.167	56196.1	56196.1	56196.1	56196.1	56196.1	10911.7	10911.7	10911.7	10911.7	10911.7	92875.8	92875.8	92875.8	92875.8	92875.8
Developed - Mid/High Intensity	5055.06	5055.06	5055.06	5055.06	5055.06	35475.2	35475.2	35475.2	35475.2	35475.2	2604.36	2604.36	2604.36	2604.36	2604.36	52265	52265	52265	52265	52265	42545.4	42545.4	42545.4	42545.4	42545.4	145545	145545	145545	145545	145545	85277.1	85277.1	85277.1	85277.1	85277.1	368767	368767	368767	368767	368767
Recreational	206.333	206.333	206.333	206.333	206.333	654.631	654.631	654.631	654.631	654.631	28.8372	28.8372	28.8372	28.8372	28.8372	1312.85	1312.85	1312.85	1312.85	1312.85	1763.96	1763.96	1763.96	1763.96	1763.96	3647.94	3647.94	3647.94	3647.94	3647.94	2904.87	2904.87	2904.87	2904.87	2904.87	10519.4	10519.4	10519.4	10519.4	10519.4
Developed - Rangeland	323.683	323.683	323.683	323.683	323.683	2914.14	2914.14	2914.14	2914.14	2914.14	122.712	122.712	122.712	122.712	122.712	1969.95	1969.95	1969.95	1969.95	1969.95	906.901	906.901	906.901	906.901	906.901	2482.05	2482.05	2482.05	2482.05	2482.05	3112.31	3112.31	3112.31	3112.31	3112.31	11831.7	11831.7	11831.7	11831.7	11831.7
Rangeland - Grassland/Herbaceous/Open Land	2827.82	2814.9	2790.76	2751.66	2698.83	18935	18907.8	18863.7	18804.1	18728.6	484.771	478.643	468.338	454.303	440.638	25399.4	25304.7	25148.1	24900.9	24607.6	742.403	734.94	727.725	718.162	691.573	53369	53348.1	53321.5	53268.4	53191.8	5493.02	5468.44	5438.86	5393.44	5312.79	107251	107057	106759	106291	105672
Agriculture - Cropland and Pastureland	2362.65	2362.65	2362.65	2362.65	2362.65	43453.5	43453.5	43453.5	43453.5	43453.5	1005.94	1005.94	1005.94	1005.94	1005.94	34157.8	34157.8	34157.8	34157.8	34157.8	5.04095	5.04095	5.04095	5.04095	5.04095	70737.3	70737.3	70737.3	70737.3	70737.3	3314.25	3314.25	3314.25	3314.25	3314.25	155036	155036	155036	155036	155036
Agriculture - Tree Crops	901.563	901.563	901.563	901.563	901.563	9508.53	9508.53	9508.53	9508.53	9508.53	0	0	0	0	0	6353.62	6353.62	6353.62	6353.62	6353.62	0	0	0	0	0	4422.24	4422.24	4422.24	4422.24	4422.24	483.733	483.733	483.733	483.733	483.733	21669.7	21669.7	21669.7	21669.7	21669.7
Agriculture - Vineyards	475.159	475.159	475.159	475.159	475.159	2377.42	2377.42	2377.42	2377.42	2377.42	193.335	193.335	193.335	193.335	193.335	3520.48	3520.48	3520.48	3520.48	3520.48	34.6689	34.6689	34.6689	34.6689	34.6689	3158.03	3158.03	3158.03	3158.03	3158.03	386.547	386.547	386.547	386.547	386.547	10145.6	10145.6	10145.6	10145.6	10145.6
Aquiculture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	462.877	462.877	462.877	462.877	462.877	0	0	0	0	0	647.341	647.341	647.341	647.341	647.341	0	0	0	0	0	1110.22	1110.22	1110.22	1110.22	1110.22
Rangeland - Shrub and Brushland	291.93	280.316	254.37	202.157	138.305	18149	18148.1	18145.9	18140.9	18133.7	31.0117	30.7893	30.2951	29.4796	23.7962	8372.39	8368.78	8364.93	8356.7	8341.08	188.344	176.705	159.383	135.957	102.129	15146.1	15144	15140.5	15132.4	15114.6	1246.2	1241.43	1234.19	1221.69	1205.72	43425	43390.1	43329.6	43219.3	43059.3
Upland Forest	691.079	682.356	671.755	656.608	631.057	14722.1	14706.6	14679.6	14644.6	14599.3	316.566	313.008	306.806	298.379	286.42	11565.9	11529.4	11472.8	11389.3	11292.9	459.196	447.68	429.222	404.165	373.401	34746.2	34705.6	34642.3	34545.3	34415.4	8185.78	8154.5	8100.18	7977.27	7812.77	70686.8	70539.1	70302.7	69915.7	69411.2
Tree Plantations	0	0	0	0	0	1319.54	1319.54	1319.54	1319.54	1319.54	0	0	0	0	0	658.634	657.473	655.372	651.468	645.562	0	0	0	0	0	6831.42	6831.42	6831.42	6831.42	6831.42	431.94	431.94	431.94	431.94	431.94	9241.54	9240.37	9238.27	9234.37	9228.46
Open Freshwater	668.84	667.209	656.212	647.49	643.931	6127.32	6093.59	6042.46	5983.58	5940.61	140.034	133.19	126.37	120.958	104.649	6035.89	5975.67	5713.69	5401.69	5317.8	1563.41	1520.12	1472.05	1440.43	1411.22	16359.4	16342.5	16321.4	16296.3	16247.7	9782.28	9658.92	9564.33	9434.45	9271.88	40677.1	40391.2	39896.5	39324.9	38937.7
Subtidal	54675.5	54745	54921.2	55103.4	55368.8	20190.5	20224.8	20276.4	20336.3	20383.5	2882.73	2889.85	2897.28	2904.75	2943.76	76162	76246.4	76535.4	76900.4	77126.1	13463.2	13519.1	13591.6	13671	13816.5	76295.4	76314.3	76337.3	76365.4	76423.6	54358.6	54490.2	54600.2	54756.5	54962.2	298028	298430	299159	300038	301024
Freshwater Swamp	1781.31	1696.65	1599.98	1475.64	1304.42	3044.78	2993.33	2930.77	2868.45	2809.93	219.009	204.43	186.515	165.462	143.173	3746.46	3686.51	3597.09	3476.74	3393.42	157.727	138.305	123.676	112.285	104.254	16067.5	16056	16038	16010.8	15979.3	12269.4	12250.8	12214	12125.3	11989.7	37286.2	37026	36690.1	36234.6	35724.2
Mangroves	2162.52	2223.8	2314.26	2427.73	2572.96	17.7916	22.3136	31.3082	38.5978	48.4326	772.55	787.401	786.659	803.512	820.315	4895.82	4981.44	5223.56	5517.81	5891.98	1249.88	1254.36	1262.24	1305.73	1374.74	977.153	1055.09	1056.28	1141.87	1236.17	3916.91	3913.28	3914.84	3977.63	4095.35	13992.6	14237.7	14589.1	15212.9	16039.9
Freshwater Marsh	479.656	475.9	469.846	458.578	450.226	9748.5	9729.84	9712.96	9696.11	9674.54	62.6659	61.5786	60.0713	58.5886	56.2164	5675.91	5637.83	5589.74	5547.66	5506.47	220.788	218.416	216.958	214.907	211.497	23584.2	23571.3	23556.7	23533.6	23509.9	4330.69	4301.95	4264.02	4211.51	4123.96	44102.4	43996.8	43870.3	43721	43532.8
Salt Marsh	299.739	318.222	314.639	321.756	331.146	32.1237	53.7948	73.6373	92.3185	99.7811	22.5854	26.2179	21.8194	25.5507	27.3298	886.984	973.545	967.516	951.602	970.703	80.3586	91.2806	93.0598	103.191	93.0104	310.018	261.042	283.677	239.544	251.207	653.346	653.766	671.088	687.644	730.295	2285.15	2377.87	2425.44	2421.61	2503.47
Juncus Marsh	0	0	0	0	0	1731.89	1748.24	1741.99	1812.71	1880.72	0	0	0	0	0	893.952	883.327	887.478	911.373	958.817	0	0	0	0	0	521.342	513.682	520.527	528.904	551.984	1100.95	1098.95	1109.43	1128.48	1136.12	4248.13	4244.2	4259.43	4381.47	4527.63
Salt Barren	275.127	301.839	348.591	413.629	461.197	182.586	233.687	285.53	302.63	279.624	68.4481	67.9045	78.5547	86.4868	87.0057	555.344	588.58	652.951	799.879	746.752	72.2288	98.6197	119.204	116.782	134.351	183.945	228.078	251.948	349.679	429.296	180.659	250.589	339.424	521.664	736.596	1518.34	1769.3	2076.2	2590.75	2874.82
Beach - Dune	11.6139	11.5892	11.2927	7.63555	6.42473	0	0	0	0	0	0	0	0	0	0	8.10505	7.93208	7.61084	5.93052	4.9421	21.8194	18.7306	13.3931	10.3784	8.67339	22.3383	21.2263	20.6827	19.0765	11.8363	6.07879	5.90581	4.9421	2.69345	2.05097	69.9555	65.384	57.9215	45.7145	33.9275
Seagrass	6444.08	6391.42	6256.28	6143.01	6002.01	616.28	635.703	713.566	777.541	919.009	1025.96	1033.32	1063.61	1078.86	1093.02	8459.94	8475.19	8500.52	8505.24	8512.6	7888.17	7889.23	7899.04	7874.57	7786.38	1524.1	1545.87	1615.85	1675.37	1744.07	7350.24	7385.5	7418.69	7435.99	7494.75	33308.8	33356.2	33467.6	33490.6	33551.8
Total	81515.1	81515.1	81515.1	81515.1	81515.1	202668	202668	202668	202668	202668	10787.2	10787.2	10787.2	10787.2	10787.2	262421	262421	262421	262421	262421	72215.7	72215.7	72215.7	72215.7	72215.8	532775	532775	532775	532775	532775	215697	215697	215697	215697	215697	1378078	1378078	1378078	1378078	1378078

Run 2	Lower Tampa Bay					Manatee River					Terra Ceia					Middle Tampa Bay					Boca Ciega Bay					Hillsborough Bay					Old Tampa Bay					All of Tampa Bay				
	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100
Mudflat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Developed - Low Intensity	1581.37	1581.37	1581.37	1581.37	1581.37	13467.3	13467.3	13467.3	13467.3	13467.3	805.711	805.711	805.711	805.711	805.711	9061.45	9061.45	9061.45	9061.45	9061.45	852.167	852.167	852.167	852.167	852.167	56196.1	56196.1	56196.1	56196.1	56196.1	10911.7	10911.7	10911.7	10911.7	10911.7	92875.8	92875.8	92875.8	92875.8	92875.8
Developed - Mid/High Intensity	5055.06	5055.06	5055.06	5055.06	5055.06	35475.2	35475.2	35475.2	35475.2	35475.2	2604.36	2604.36	2604.36	2604.36	2604.36	52265	52265	52265	52265	52265	42545.4	42545.4	42545.4	42545.4	42545.4	145545	145545	145545	145545	145545	85277.1	85277.1	85277.1	85277.1	85277.1	368767	368767	368767	368767	368767
Recreational	206.333	206.333	206.333	206.333	206.333	654.631	654.631	654.631	654.631	654.631	28.8372	28.8372	28.8372	28.8372	28.8372	1312.85	1312.85	1312.85	1312.85	1312.85	1763.96	1763.96	1763.96	1763.96	1763.96	3647.94	3647.94	3647.94	3647.94	3647.94	2904.87	2904.87	2904.87	2904.87	2904.87	10519.4	10519.4	10519.4	10519.4	10519.4
Developed - Rangeland	323.683	323.683	323.683	323.683	323.683	2914.14	2914.14	2914.14	2914.14	2914.14	122.712	122.712	122.712	122.712	122.712	1969.95	1969.95	1969.95	1969.95	1969.95	906.901	906.901	906.901	906.901	906.901	2482.05	2482.05	2482.05	2482.05	2482.05	3112.31	3112.31	3112.31	3112.31	3112.31	11831.7	11831.7	11831.7	11831.7	11831.7
Rangeland - Grassland/Herbaceous/Open Land	2827.82	2814.9	2790.76	2751.66	2698.83	18935	18907.8	18863.7	18804.1	18728.6	484.771	478.643	468.338	454.303	440.638	25399.4	25304.7	25148.1	24900.9	24607.6	742.403	734.94	727.725	718.162	691.573	53369	53348.1	53321.5	53268.4	53191.8	5493.02	5468.44	5438.86	5393.44	5312.79	107251	107057	106759	106291	105672
Agriculture - Cropland and Pastureland	2362.65	2362.65	2362.65	2362.65	2362.65	43453.5	43453.5	43453.5	43453.5	43453.5	1005.94	1005.94	1005.94	1005.94	1005.94	34157.8	34157.8	34157.8	34157.8	34157.8	5.04095	5.04095	5.04095	5.04095	5.04095	70737.3	70737.3	70737.3	70737.3	70737.3	3314.25	3314.25	3314.25	3314.25	3314.25	155036	155036	155036	155036	155036
Agriculture - Tree Crops	901.563	901.563	901.563	901.563	901.563	9508.53	9508.53	9508.53	9508.53	9508.53	0	0	0	0	0	6353.62	6353.62	6353.62	6353.62	6353.62	0	0	0	0	0	4422.24	4422.24	4422.24	4422.24	4422.24	483.733	483.733	483.733	483.733	483.733	21669.7	21669.7	21669.7	21669.7	21669.7
Agriculture - Vineyards	475.159	475.159	475.159	475.159	475.159	2377.42	2377.42	2377.42	2377.42	2377.42	193.335	193.335	193.335	193.335	193.335	3520.48	3520.48	3520.48	3520.48	3520.48	34.6689	34.6689	34.6689	34.6689	34.6689	3158.03	3158.03	3158.03	3158.03	3158.03	386.547	386.547	386.547	386.547	386.547	10145.6	10145.6	10145.6	10145.6	10145.6
Aquiculture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	462.877	462.877	462.877	462.877	462.877	0	0	0	0	0	647.341	647.341	647.341	647.341	647.341	0	0	0	0	0	1110.22	1110.22	1110.22	1110.22	1110.22
Rangeland - Shrub and Brushland	291.93	280.316	254.37	202.157	138.305	18149	18148.1	18145.9	18140.9	18133.7	31.0117	30.7893	30.2951	29.4796	23.7962	8372.39	8368.78	8364.93	8356.7	8341.08	188.344	176.705	159.383	135.957	102.129	15146.1	15144	15140.5	15132.4	15114.6	1246.2	1241.43	1234.19	1221.69	1205.72	43425	43390.1	43329.6	43219.3	43059.3
Upland Forest	691.079	682.356	671.755	656.608	631.057	14722.1	14706.6	14679.6	14644.6	14599.3	316.566	313.008	306.806	298.379	286.42	11565.9	11529.4	11472.8	11389.3	11292.9	459.196	447.68	429.222	404.165	373.401	34746.2	34705.6	34642.3	34545.3	34415.4	8185.78	8154.5	8100.18	7977.27	7812.77	70686.8	70539.1	70302.7	69915.7	69411.2
Tree Plantations	0	0	0	0	0	1319.54	1319.54	1319.54	1319.54	1319.54	0	0	0	0	0	658.634	657.473	655.372	651.468	645.562	0	0	0	0	0	6831.42	6831.42	6831.42	6831.42	6831.42	431.94	431.94	431.94	431.94	431.94	9241.54	9240.37	9238.27	9234.37	9228.46
Open Freshwater	668.84	667.209	656.212	647.49	643.931	6127.32	6093.59	6042.46	5983.58	5940.61	140.034	133.19	126.37	120.958	104.649	6035.89	5975.67	5713.69	5401.69	5317.8	1563.41	1520.12	1472.05	1440.43	1411.22	16359.4	16342.5	16321.4	16296.3	16247.7	9782.28	9658.92	9564.33	9434.45	9271.88	40677.1	40391.2	39896.5	39324.9	38937.7
Subtidal	54675.5	54744.8	54920.8	55102.9	55368.3	20190.5	20224.8	20276.4	20336.2	20383.5	2882.73	2889.85	2897.28	2904.75	2943.76	76162	76246.4	76535.4	76900.4	77126.1	13463.2	13519.1	13591.6	13671	13816.5	76295.4	76314.3	76337.3	76365.4	76423.2	54358.6	54490.2	54600.2	54756.4	54962	298028	298429	299159	300037	301023
Freshwater Swamp	1781.31	1696.65	1599.98	1475.64	1304.42	3044.78	2993.33	2930.77	2868.45	2809.93	219.009	204.43	186.515	165.462	143.173	3746.46	3686.51	3597.09	3476.74	3393.42	157.727	138.305	123.676	112.285	104.254	16067.5	16056	16038	16010.8	15979.3	12269.4	12250.8	12214	12125.3	11989.7	37286.2	37026	36690.1	36234.6	35724.2
Mangroves	2162.52	2232.15	2339.99	2464.11	2613.14	17.7916	22.2889	31.2835	38.5237	48.3338	772.55	790.885	818.363	846.607	872.429	4895.82	4979.84	5206.85	5466.51	5798.03	1249.88	1257.27	1286.33	1336.37	1408.15	977.153	1043.13	1021.88	1055.83	1105.6	3916.91	3918.74	3946.15	4015.34	4133.92	13992.6	14244.3	14650.8	15223.3	15979.6
Freshwater Marsh	479.656	475.9	469.846	458.578	450.226	9748.5	9729.84	9712.96	9696.11	9674.54	62.6659	61.5786	60.0713	58.5886	56.2164	5675.91	5637.83	5589.74	5547.66	5506.47	220.788	218.416	216.958	214.907	211.497	23584.2	23571.3	23556.7	23533.6	23509.9	4330.69	4301.95	4264.02	4211.51	4123.96	44102.4	43996.8	43870.3	43721	43532.8
Salt Marsh	299.739	319.606	324.276	345.107	372.338	32.1237	53.8442	73.9092	92.8374	100.547	22.5854	26.9592	24.7599	30.814	34.5453	886.984	977.054	1006.14	1033.81	1104.76	80.3586	92.615	98.4714	114.459	109.418	310.018	274.361	326.08	338.386	402.633	653.346	657.572	684.63	719.397	786.684	2285.15	2402.01	2538.26	2674.81	2910.92
Juncus Marsh	0	0	0	0	0	1731.89	1750.67	1785.51	1873.67	1952.13	0	0	0	0	0	893.952	901.39	911.744	945.449	995.265	0	0	0	0	0	521.342	525.519	548.598	581.167	619.987	1100.95	1101.32	1120.5	1146.86	1159.62	4248.13	4278.9	4366.35	4547.16	4727
Salt Barren	275.127	301.839	348.591	413.629	461.197	182.586	233.687	285.53	302.63	279.624	68.4481	67.9045	78.5547	86.4868	87.0057	555.344	588.58	652.951	799.879	746.752	72.2288	98.6197	119.204	116.782	134.351	183.945	228.078	251.948	349.679	429.296	180.659	250.589	339.424	521.664	736.596	1518.34	1769.3	2076.2	2590.75	2874.82
Beach - Dune	11.6139	11.5892	11.2927	7.63555	6.42473	0	0	0	0	0	0	0	0	0	0	8.10505	7.93208	7.61084	5.93052	4.9421	21.8194	18.7306	13.3931	10.3784	8.67339	22.3383	21.2263	20.6827	19.0765	11.8363	6.07879	5.90581	4.9421	2.69345	2.05097	69.9555	65.384	57.9215	45.7145	33.9275
Seagrass	6444.08	6381.91	6221.34	6083.75	5921.18	616.28	633.256	669.803	716.16	846.953	1025.96	1029.09	1028.97	1030.5	1033.69	8459.94	8455.22	8454.33	8440.25	8436.05	7888.17	7884.98	7869.53	7832.67	7736.57	1524.1	1532.67	1579.77	1610.31	1655.63	7350.24	7373.87	7362.84	7348.22	7376.48	33308.8	33291	33186.6	33061.9	33006.6
Total	81515.1	81515.1	81515.1	81515.1	81515.1	202668	202668	202668	202668	202668	10787.2	10787.2	10787.2	10787.2	10787.2	262421	262421	262421	262421	262421	72215.7	72215.7	72215.7	72215.7	72215.8	532775	532775	532775	532775	532775	215697	215697	215697	215697	215697	1378078	1378078	1378078	1378078	1378078

Run 3	Lower Tampa Bay					Manatee River					Terra Ceia					Middle Tampa Bay					Boca Ciega Bay					Hillsborough Bay					Old Tampa Bay					All of Tampa Bay				
	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100
Mudflat	0	0	0	0	0	0	0	0	0	406.093	0	0	0	0	0	0	0	0	0	148.51	0	0	0	0	0	0	0	0	0	101.758	0	0	0	0	179.028	0	0	0	0	835.388
Developed - Low Intensity	1581.37	1581.37	1581.37	1581.37	1581.37	13467.3	13467.3	13467.3	13467.3	13467.3	805.711	805.711	805.711	805.711	805.711	9061.45	9061.45	9061.45	9061.45	9061.45	852.167	852.167	852.167	852.167	852.167	56196.1	56196.1	56196.1	56196.1	56196.1	10911.7	10911.7	10911.7	10911.7	10911.7	92875.8	92875.8	92875.8	92875.8	92875.8
Developed - Mid/High Intensity	5055.06	5055.06	5055.06	5055.06	5055.06	35475.2	35475.2	35475.2	35475.2	35475.2	2604.36	2604.36	2604.36	2604.36	2604.36	52265	52265	52265	52265	52265	42545.4	42545.4	42545.4	42545.4	42545.4	145545	145545	145545	145545	145545	85277.1	85277.1	85277.1	85277.1	85277.1	368767	368767	368767	368767	368767
Recreational	206.333	206.333	206.333	206.333	206.333	654.631	654.631	654.631	654.631	654.631	28.8372	28.8372	28.8372	28.8372	28.8372	1312.85	1312.85	1312.85	1312.85	1312.85	1763.96	1763.96	1763.96	1763.96	1763.96	3647.94	3647.94	3647.94	3647.94	3647.94	2904.87	2904.87	2904.87	2904.87	2904.87	10519.4	10519.4	10519.4	10519.4	10519.4
Developed - Rangeland	323.683	323.683	323.683	323.683	323.683	2914.14	2914.14	2914.14	2914.14	2914.14	122.712	122.712	122.712	122.712	122.712	1969.95	1969.95	1969.95	1969.95	1969.95	906.901	906.901	906.901	906.901	906.901	2482.05	2482.05	2482.05	2482.05	2482.05	3112.31	3112.31	3112.31	3112.31	3112.31	11831.7	11831.7	11831.7	11831.7	11831.7
Rangeland - Grassland/Herbaceous/Open Land	2827.82	2803.51	2741.93	2630.85	2508.66	18935	18887.1	18789	18625.7	18361	484.771	473.379	451.165	428.456	402.04	25399.4	25231.8	24839.6	24240.6	23496.8	742.403	731.11	714.48	662.958	583.687	53369	53333.9	53251.1	53097.4	52856.2	5493.02	5454.43	5378.02	5232.03	5034.22	107251	106915	106165	104918	103243
Agriculture - Cropland and Pastureland	2362.65	2362.65	2362.65	2362.65	2362.65	43453.5	43453.5	43453.5	43453.5	43453.5	1005.94	1005.94	1005.94	1005.94	1005.94	34157.8	34157.8	34157.8	34157.8	34157.8	5.04095	5.04095	5.04095	5.04095	5.04095	70737.3	70737.3	70737.3	70737.3	70737.3	3314.25	3314.25	3314.25	3314.25	3314.25	155036	155036	155036	155036	155036
Agriculture - Tree Crops	901.563	901.563	901.563	901.563	901.563	9508.53	9508.53	9508.53	9508.53	9508.53	0	0	0	0	0	6353.62	6353.62	6353.62	6353.62	6353.62	0	0	0	0	0	4422.24	4422.24	4422.24	4422.24	4422.24	483.733	483.733	483.733	483.733	483.733	21669.7	21669.7	21669.7	21669.7	21669.7
Agriculture - Vineyards	475.159	475.159	475.159	475.159	475.159	2377.42	2377.42	2377.42	2377.42	2377.42	193.335	193.335	193.335	193.335	193.335	3520.48	3520.48	3520.48	3520.48	3520.48	34.6689	34.6689	34.6689	34.6689	34.6689	3158.03	3158.03	3158.03	3158.03	3158.03	386.547	386.547	386.547	386.547	386.547	10145.6	10145.6	10145.6	10145.6	10145.6
Aquiculture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	462.877	462.877	462.877	462.877	462.877	0	0	0	0	0	647.341	647.341	647.341	647.341	647.341	0	0	0	0	0	1110.22	1110.22	1110.22	1110.22	1110.22
Rangeland - Shrub and Brushland	291.93	268.603	188.368	91.4289	54.3878	18149	18147.1	18139.7	18124.5	18105.4	31.0117	30.6163	29.0349	20.1144	19.0024	8372.39	8366.81	8354.06	8315.06	8243.08	188.344	167.142	129.409	73.2667	34.7924	15146.1	15142.5	15129.3	15094.2	14975	1246.2	1237.97	1218.43	1185.76	1121.09	43425	43360.7	43188.3	42904.4	42552.7
Upland Forest	691.079	676.673	652.086	602.393	560.756	14722.1	14692.5	14635.1	14536.6	14404.4	316.566	309.944	296.403	275.522	250.787	11565.9	11502.1	11369.8	11187.6	10985.1	459.196	438.933	397.691	344.44	281.206	34746.2	34674.7	34518.3	34287.4	34112.6	8185.78	8130.33	7942.53	7626.68	7287.7	70686.8	70425.2	69812	68860.6	67882.5
Tree Plantations	0	0	0	0	0	1319.54	1319.54	1319.54	1319.54	1319.54	0	0	0	0	0	658.634	656.509	650.48	638.717	609.46	0	0	0	0	0	6831.42	6831.42	6831.42	6831.42	6831.42	431.94	431.94	431.94	431.94	431.94	9241.54	9239.41	9233.38	9221.62	9192.36
Open Freshwater	668.84	656.904	647.02	640.497	601.232	6127.32	6068.73	5977.89	5873.2	5758.96	140.034	127.061	112.482	101.857	63.0859	6035.89	5790.19	5388.84	5231.54	5112.93	1563.41	1489.43	1435.98	759.181	648.157	16359.4	16328.8	16272.5	16223.6	16156.2	9782.28	9607.65	9400.84	9135.77	8777.05	40677.1	40068.7	39235.6	37965.6	37117.6
Subtidal	54675.5	54874.5	55152.2	55633.7	56429.7	20190.5	20249.7	20343.2	20464.4	20679.7	2882.73	2896.25	2914.14	3000.28	3184.44	76162	76446.5	76935.7	77637.4	79917.6	13463.2	13563.7	13689.2	14700.2	15534.2	76295.4	76329.3	76390.5	76458.7	76608.1	54358.6	54549.6	54798	55228.2	56407.9	298028	298910	300223	303123	308762
Freshwater Swamp	1781.31	1646.21	1438.67	1166.51	1021.21	3044.78	2960.15	2854.63	2755.22	2675.01	219.009	195.51	160.223	126.122	97.5324	3746.46	3645.39	3452.73	3335.55	3240.76	157.727	129.854	110.481	97.9525	86.1161	16067.5	16047.1	16003.6	15949.3	15905.8	12269.4	12233.8	12096.7	11879	11603.9	37286.2	36858	36117	35309.6	34630.3
Mangroves	2162.52	2268.4	2445.82	828.692	731.481	17.7916	27.3298	40.8712	58.218	102.326	772.55	774.576	771.709	143.395	109.641	4895.82	5084.36	5597.67	1662.13	1470.28	1249.88	1243.78	1312.35	938.159	472.49	977.153	1090.9	1190.63	717	782.483	3916.91	3900.98	3988.1	934.947	1198.04	13992.6	14390.3	15347.2	5282.54	4866.74
Freshwater Marsh	479.656	473.799	456.23	444.345	432.286	9748.5	9719.91	9691.71	9652.13	9608.09	62.6659	60.6643	58.045	54.5361	50.4342	5675.91	5608.27	5538.29	5457.74	5400.29	220.788	217.724	214.067	161.014	111.519	23584.2	23562.6	23529.2	23484.4	23431.2	4330.69	4282.41	4196.12	4040.81	3926.8	44102.4	43925.4	43683.7	43295	42960.6
Salt Marsh	299.739	307.72	267.491	231.488	92.3432	32.1237	62.8141	99.0892	90.3416	91.5525	22.5854	20.8063	25.1553	24.9576	13.739	886.984	997.341	807.12	597.401	420.474	80.3586	89.5756	84.51	65.5076	52.4604	310.018	235.812	182.808	192.89	163.411	653.346	659.054	600.194	442.639	253.555	2285.15	2373.12	2066.37	1645.23	1087.53
Juncus Marsh	0	0	0	0	0	1731.89	1705.12	1676.36	1416.01	1169.1	0	0	0	0	0	893.952	879.892	609.905	585.417	560.212	0	0	0	0	0	521.342	509.63	211.398	230.722	194.744	1100.95	1099.54	388.919	479.779	502.291	4248.13	4194.19	2886.58	2711.93	2426.35
Salt Barren	275.127	324.671	430.111	382.815	175.025	182.586	263.933	298.528	301.938	295.217	68.4481	73.6126	87.4999	69.3871	59.3052	555.344	593.843	809.912	733.235	613.34	72.2288	112.285	119.5	167.784	125.48	183.945	260.226	371.177	426.405	401.323	180.659	290.695	574.297	711.811	608.447	1518.34	1919.27	2691.02	2793.38	2278.14
Beach - Dune	11.6139	11.5151	7.56142	5.8811	4.81855	0	0	0	0	0	0	0	0	0	0	8.10505	7.63555	5.13979	4.29963	2.22395	21.8194	14.9252	9.83479	5.95523	0.76603	22.3383	20.9298	18.1869	7.66026	0.96371	6.07879	5.55987	2.64403	1.38379	0.27182	69.9555	60.5655	43.367	25.18	9.04405
Seagrass	6444.08	6296.71	6181.76	7950.76	7997.56	616.28	713.294	951.676	1599.39	1840.96	1025.96	1063.91	1120.47	1781.7	1776.32	8459.94	8506.2	8957.54	13690	13095.7	7888.17	7909.09	7890.14	8131.32	8177.15	1524.1	1570.38	2037.98	2937.04	3417.07	7350.24	7422.15	8289.37	11975.4	11973.9	33308.8	33481.7	35428.9	48065.7	48278.7
Total	81515.1	81515.1	81515.1	81515.1	81515.2	202668	202668	202668	202668	202668	10787.2	10787.2	10787.2	10787.2	10787.2	262421	262421	262421	262421	262421	72215.7	72215.7	72215.7	72215.9	72216.2	532775	532775	532775	532775	532775	215697	215697	215697	215697	215697	1378078	1378078	1378078	1378078	1378079

Run 4	Lower Tampa Bay					Manatee River					Terra Ceia					Middle Tampa Bay					Boca Ciega Bay					Hillsborough Bay					Old Tampa Bay					All of Tampa Bay				
	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100
Mudflat	0	0	0	0	0	0	0	0	0	374.438	0	0	0	0	0	0	0	0	0	155.355	0	0	0	0	0	0	0	0	0	120.81	0	0	0	0	183.105	0	0	0	0	833.708
Developed - Low Intensity	1581.37	1581.37	1581.37	1581.37	1581.37	13467.3	13467.3	13467.3	13467.3	13467.3	805.711	805.711	805.711	805.711	805.711	9061.45	9061.45	9061.45	9061.45	9061.45	852.167	852.167	852.167	852.167	852.167	56196.1	56196.1	56196.1	56196.1	56196.1	10911.7	10911.7	10911.7	10911.7	10911.7	92875.8	92875.8	92875.8	92875.8	92875.8
Developed - Mid/High Intensity	5055.06	5055.06	5055.06	5055.06	5055.06	35475.2	35475.2	35475.2	35475.2	35475.2	2604.36	2604.36	2604.36	2604.36	2604.36	52265	52265	52265	52265	52265	42545.4	42545.4	42545.4	42545.4	42545.4	145545	145545	145545	145545	145545	85277.1	85277.1	85277.1	85277.1	85277.1	368767	368767	368767	368767	368767
Recreational	206.333	206.333	206.333	206.333	206.333	654.631	654.631	654.631	654.631	654.631	28.8372	28.8372	28.8372	28.8372	28.8372	1312.85	1312.85	1312.85	1312.85	1312.85	1763.96	1763.96	1763.96	1763.96	1763.96	3647.94	3647.94	3647.94	3647.94	3647.94	2904.87	2904.87	2904.87	2904.87	2904.87	10519.4	10519.4	10519.4	10519.4	10519.4
Developed - Rangeland	323.683	323.683	323.683	323.683	323.683	2914.14	2914.14	2914.14	2914.14	2914.14	122.712	122.712	122.712	122.712	122.712	1969.95	1969.95	1969.95	1969.95	1969.95	906.901	906.901	906.901	906.901	906.901	2482.05	2482.05	2482.05	2482.05	2482.05	3112.31	3112.31	3112.31	3112.31	3112.31	11831.7	11831.7	11831.7	11831.7	11831.7
Rangeland - Grassland/Herbaceous/Open Land	2827.82	2803.51	2741.93	2630.85	2508.66	18935	18887.1	18789	18625.7	18361	484.771	473.379	451.165	428.456	402.04	25399.4	25231.8	24839.6	24240.6	23496.8	742.403	731.11	714.48	662.958	583.687	53369	53333.9	53251.1	53097.4	52856.2	5493.02	5454.43	5378.02	5232.03	5034.22	107251	106915	106165	104918	103243
Agriculture - Cropland and Pastureland	2362.65	2362.65	2362.65	2362.65	2362.65	43453.5	43453.5	43453.5	43453.5	43453.5	1005.94	1005.94	1005.94	1005.94	1005.94	34157.8	34157.8	34157.8	34157.8	34157.8	5.04095	5.04095	5.04095	5.04095	5.04095	70737.3	70737.3	70737.3	70737.3	70737.3	3314.25	3314.25	3314.25	3314.25	3314.25	155036	155036	155036	155036	155036
Agriculture - Tree Crops	901.563	901.563	901.563	901.563	901.563	9508.53	9508.53	9508.53	9508.53	9508.53	0	0	0	0	0	6353.62	6353.62	6353.62	6353.62	6353.62	0	0	0	0	0	4422.24	4422.24	4422.24	4422.24	4422.24	483.733	483.733	483.733	483.733	483.733	21669.7	21669.7	21669.7	21669.7	21669.7
Agriculture - Vineyards	475.159	475.159	475.159	475.159	475.159	2377.42	2377.42	2377.42	2377.42	2377.42	193.335	193.335	193.335	193.335	193.335	3520.48	3520.48	3520.48	3520.48	3520.48	34.6689	34.6689	34.6689	34.6689	34.6689	3158.03	3158.03	3158.03	3158.03	3158.03	386.547	386.547	386.547	386.547	386.547	10145.6	10145.6	10145.6	10145.6	10145.6
Aquiculture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	462.877	462.877	462.877	462.877	462.877	0	0	0	0	0	647.341	647.341	647.341	647.341	647.341	0	0	0	0	0	1110.22	1110.22	1110.22	1110.22	1110.22
Rangeland - Shrub and Brushland	291.93	268.603	188.368	91.4289	54.3878	18149	18147.1	18139.7	18124.5	18105.4	31.0117	30.6163	29.0349	20.1144	19.0024	8372.39	8366.81	8354.06	8315.06	8243.08	188.344	167.142	129.409	73.2667	34.7924	15146.1	15142.5	15129.3	15094.2	14975	1246.2	1237.97	1218.43	1185.76	1121.09	43425	43360.7	43188.3	42904.4	42552.7
Upland Forest	691.079	676.673	652.086	602.393	560.756	14722.1	14692.5	14635.1	14536.6	14404.4	316.566	309.944	296.403	275.522	250.787	11565.9	11502.1	11369.8	11187.6	10985.1	459.196	438.933	397.691	344.44	281.206	34746.2	34674.7	34518.3	34287.4	34112.6	8185.78	8130.33	7942.53	7626.68	7287.7	70686.8	70425.2	69812	68860.6	67882.5
Tree Plantations	0	0	0	0	0	1319.54	1319.54	1319.54	1319.54	1319.54	0	0	0	0	0	658.634	656.509	650.48	638.717	609.46	0	0	0	0	0	6831.42	6831.42	6831.42	6831.42	6831.42	431.94	431.94	431.94	431.94	431.94	9241.54	9239.41	9233.38	9221.62	9192.36
Open Freshwater	668.84	656.904	647.02	640.497	601.232	6127.32	6068.73	5977.89	5873.2	5758.96	140.034	127.061	112.482	101.857	63.0859	6035.89	5790.19	5388.84	5231.54	5112.93	1563.41	1489.43	1435.98	759.181	648.157	16359.4	16328.8	16272.5	16223.6	16156.2	9782.28	9607.65	9400.84	9135.77	8777.05	40677.1	40068.7	39235.6	37965.6	37117.6
Subtidal	54675.5	54874.3	55152.2	55633.6	56429.3	20190.5	20249.7	20343.2	20464.3	20679.6	2882.73	2896.25	2914.14	3000.28	3184.44	76162	76446.5	76935.7	77637.3	79917.2	13463.2	13563.7	13689.2	14700.2	15534.2	76295.4	76329.3	76390.3	76458.5	76606.8	54358.6	54549.6	54797.9	55228	56407.7	298028	298909	300222	303122	308759
Freshwater Swamp	1781.31	1646.21	1438.67	1166.51	1021.21	3044.78	2960.15	2854.63	2755.22	2675.01	219.009	195.51	160.223	126.122	97.5324	3746.46	3645.39	3452.73	3335.55	3240.76	157.727	129.854	110.481	97.9525	86.1161	16067.5	16047.1	16003.6	15949.3	15905.8	12269.4	12233.8	12096.7	11879	11603.9	37286.2	36858	36117	35309.6	34630.3
Mangroves	2162.52	2283.52	2502.53	2816.58	2816.8	17.7916	27.3298	40.8218	65.4087	109.937	772.55	799.138	819.302	850.981	819.129	4895.82	5089.48	5659.05	6260.93	6369.38	1249.88	1267.58	1341.19	1447.42	1518.39	977.153	1081.26	1187.74	1427.5	1589.6	3916.91	3921.53	4046.17	4525.21	5040.65	13992.6	14469.8	15596.8	17394	18263.9
Freshwater Marsh	479.656	473.799	456.23	444.345	432.286	9748.5	9719.91	9691.71	9652.13	9608.09	62.6659	60.6643	58.045	54.5361	50.4342	5675.91	5608.27	5538.29	5457.74	5400.29	220.788	217.724	214.067	161.014	111.519	23584.2	23562.6	23529.2	23484.4	23431.2	4330.69	4282.41	4196.12	4040.81	3926.8	44102.4	43925.4	43683.7	43295	42960.6
Salt Marsh	299.739	312.514	303.025	275.473	149.894	32.1237	62.9377	99.5834	91.3795	92.2444	22.5854	21.8688	26.119	26.0696	13.9862	886.984	1008.56	900.328	735.607	569.281	80.3586	91.6266	95.3085	78.5053	59.3299	310.018	249.008	217.601	221.11	181.672	653.346	664.54	670.396	641.386	391.711	2285.15	2411.05	2312.36	2069.53	1458.12
Juncus Marsh	0	0	0	0	0	1731.89	1742.17	1754.42	1714.86	1596.37	0	0	0	0	0	893.952	883.994	922.295	902.996	896.547	0	0	0	0	0	521.342	515.214	525.222	552.305	517.636	1100.95	1103.28	1136.02	1226.58	1255.79	4248.13	4244.65	4337.96	4396.74	4266.34
Salt Barren	275.127	324.671	430.111	382.815	175.025	182.586	263.933	298.528	301.938	295.217	68.4481	73.6126	87.4999	69.3871	59.3052	555.344	593.843	809.912	733.235	613.34	72.2288	112.285	119.5	167.784	125.48	183.945	260.226	371.177	426.405	401.323	180.659	290.695	574.297	711.811	608.447	1518.34	1919.27	2691.02	2793.38	2278.14
Beach - Dune	11.6139	11.5151	7.56142	5.8811	4.81855	0	0	0	0	0	0	0	0	0	0	8.10505	7.63555	5.13979	4.29963	2.22395	21.8194	14.9252	9.83479	5.95523	0.76603	22.3383	20.9298	18.1869	7.66026	0.96371	6.07879	5.55987	2.64403	1.38379	0.27182	69.9555	60.5655	43.367	25.18	9.04405
Seagrass	6444.08	6276.99	6089.54	5918.93	5855.01	616.28	676.129	873.196	1292.41	1437.14	1025.96	1038.29	1071.92	1073	1066.58	8459.94	8485.76	8490.56	8635.51	7705.06	7888.17	7883.25	7850.51	7609.06	7124.39	1524.1	1561.24	1692.5	1876.99	2251.05	7350.24	7392.4	7414.17	7439.77	7235.83	33308.8	33314.1	33482.4	33845.7	32675.1
Total	81515.1	81515.1	81515.1	81515.1	81515.2	202668	202668	202668	202668	202668	10787.2	10787.2	10787.2	10787.2	10787.2	262421	262421	262421	262421	262421	72215.7	72215.7	72215.7	72215.9	72216.2	532775	532775	532775	532775	532775	215697	215697	215697	215697	215697	1378078	1378078	1378078	1378078	1378079

Run 5

	Lower Tampa Bay					Manatee River				
	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100
Mudflat	0	0	0	0	0	0	0	0	0	445.629
Developed - Low Intensity	1581.37	1581.37	1581.37	1581.37	1581.37	13467.3	13467.3	13467.3	13467.3	13467.3
Developed - Mid/High Intensity	5055.06	5055.06	5055.06	5055.06	5055.06	35475.2	35475.2	35475.2	35475.2	35475.2
Recreational	206.333	157.727	143.445	120.464	103.463	654.631	644.623	638.94	629.5	617.541
Developed - Rangeland	323.683	319.482	303.989	297.564	294.08	2914.14	2899.48	2881.1	2857.28	2813.74
Rangeland - Grassland/Herbaceous/Open Land	2827.82	2803.51	2741.93	2630.85	2508.66	18935	18887.1	18789	18625.7	18361
Agriculture - Cropland and Pastureland	2362.65	2361.36	2354.76	2295.58	2257.73	43453.5	43432.3	43402.1	43344.5	43252.4
Agriculture - Tree Crops	901.563	901.563	901.563	901.563	901.563	9508.53	9508.26	9508.01	9507.1	9505.37
Agriculture - Vineyards	475.159	472.144	466.708	442.936	416.323	2377.42	2377	2375.84	2368.21	2351.87
Aquiculture	0	0	0	0	0	0	0	0	0	0
Rangeland - Shrub and Brushland	291.93	268.603	188.368	91.4289	54.3878	18149	18147.1	18139.7	18124.5	18105.4
Upland Forest	691.079	676.673	652.086	602.393	560.756	14722.1	14692.5	14635.1	14536.6	14404.4
Tree Plantations	0	0	0	0	0	1319.54	1319.54	1319.54	1319.54	1319.54
Open Freshwater	668.84	656.904	647.02	640.497	601.232	6127.32	6068.73	5977.89	5873.2	5758.96
Subtidal	54675.5	54884.2	55162.5	55644.9	56444.5	20190.5	20249.8	20343.4	20464.7	20680.6
Freshwater Swamp	1781.31	1646.21	1438.67	1166.51	1021.21	3044.78	2960.15	2854.63	2755.22	2675.01
Mangroves	2162.52	2281.37	2466.48	891.704	866.82	17.7916	28.2441	42.2056	61.8998	117.919
Freshwater Marsh	479.656	473.799	456.23	444.345	432.286	9748.5	9719.91	9691.71	9652.13	9608.09
Salt Marsh	299.739	311.056	275.547	260.968	109.492	32.1237	67.0643	111.148	111.37	118.314
Juncus Marsh	0	0	0	0	0	1731.89	1710.86	1692.92	1465.88	1228.26
Salt Barren	275.127	343.723	471.971	459.64	211.25	182.586	290.695	354.349	372.931	395.714
Beach - Dune	11.6139	11.5151	7.56142	5.8811	4.81855	0	0	0	0	0
Seagrass	6444.08	6308.72	6199.67	7981.25	8089.95	616.28	722.066	967.886	1655.06	1965.47
Total	81515.1	81515	81514.9	81514.9	81515	202668	202668	202668	202668	202668

	Terra Ceia					Middle Tampa Bay				
	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100
Mudflat	0	0	0	0	0	0	0	0	0	151.599
Developed - Low Intensity	805.711	805.711	805.711	805.711	805.711	9061.45	9061.45	9061.45	9061.45	9061.45
Developed - Mid/High Intensity	2604.36	2604.36	2604.36	2604.36	2604.36	52265	52265	52265	52265	52265
Recreational	28.8372	28.1206	27.8488	27.6511	27.4534	1312.85	1214.89	1150.13	989.879	757.773
Developed - Rangeland	122.712	119.525	117.622	111.939	97.8536	1969.95	1916.89	1893.54	1808.83	1724.77
Rangeland - Grassland/Herbaceous/Open Land	484.771	473.379	451.165	428.456	402.04	25399.4	25231.8	24839.6	24240.6	23496.8
Agriculture - Cropland and Pastureland	1005.94	972.581	907.691	831.435	763.654	34157.8	34129.3	34031.4	33769.6	33355.8
Agriculture - Tree Crops	0	0	0	0	0	6353.62	6353.62	6353.62	6353.62	6353.1
Agriculture - Vineyards	193.335	192.841	189.801	176.013	143.667	3520.48	3518.26	3511.61	3488.31	3440.37
Aquiculture	0	0	0	0	0	462.877	460.431	458.874	455.44	448.298
Rangeland - Shrub and Brushland	31.0117	30.6163	29.0349	20.1144	19.0024	8372.39	8366.81	8354.06	8315.06	8243.08
Upland Forest	316.566	309.944	296.403	275.522	250.787	11565.9	11502.1	11369.8	11187.6	10985.1
Tree Plantations	0	0	0	0	0	658.634	656.509	650.48	638.717	609.46
Open Freshwater	140.034	127.061	112.482	101.857	63.0859	6035.89	5790.19	5388.84	5231.54	5112.93
Subtidal	2882.73	2896.25	2914.14	3000.28	3184.44	76162	76446.6	76935.8	77637.6	79917.8
Freshwater Swamp	219.009	195.51	160.223	126.122	97.5324	3746.46	3645.39	3452.73	3335.55	3240.76
Mangroves	772.55	783.62	793.084	242.188	230.154	4895.82	5147.2	5693.06	1932.24	2190.46
Freshwater Marsh	62.6659	60.6643	58.045	54.5361	50.4342	5675.91	5608.27	5538.29	5457.74	5400.29
Salt Marsh	22.5854	23.4256	37.8812	50.706	34.1252	886.984	1012.29	833.683	704.225	549.858
Juncus Marsh	0	0	0	0	0	893.952	880.609	611.388	587.245	563.77
Salt Barren	68.4481	98.2984	157.9	132.004	119.031	555.344	659.771	1004.14	1134.9	1054.99
Beach - Dune	0	0	0	0	0	8.10505	7.63555	5.13979	4.29963	2.22395
Seagrass	1025.96	1065.3	1123.78	1798.28	1893.84	8459.94	8545.71	9018.05	13821.1	13494.9
Total	10787.2	10787.2	10787.2	10787.2	10787.2	262421	262421	262421	262421	262421

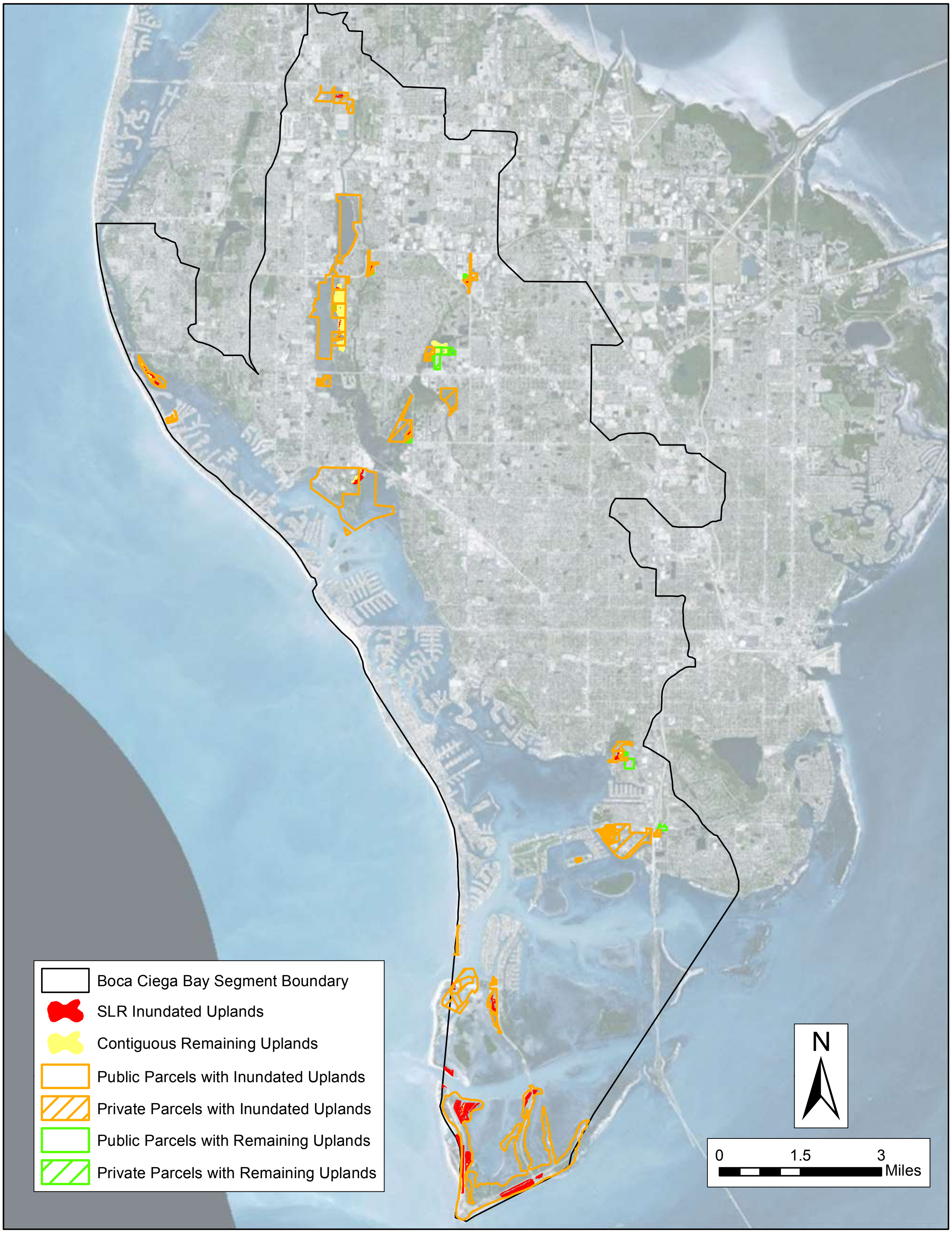
	Boca Ciega Bay					Hillsborough Bay				
	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100
Mudflat	0	0	0	0	0	0	0	0	0	106.675
Developed - Low Intensity	852.167	852.167	852.167	852.167	852.167	56196.1	56196.1	56196.1	56196.1	56196.1
Developed - Mid/High Intensity	42545.4	42545.4	42545.4	42545.4	42545.4	145545	145545	145545	145545	145545
Recreational	1763.96	1589.55	1459.18	1196.33	940.235	3647.94	3620.39	3612.43	3585.27	3526.36
Developed - Rangeland	906.901	892.692	871.466	811.666	680.429	2482.05	2475.35	2473.97	2473.25	2472.56
Rangeland - Grassland/Herbaceous/Open Land	742.403	731.11	714.48	662.958	583.687	53369	53333.9	53251.1	53097.4	52856.2
Agriculture - Cropland and Pastureland	5.04095	5.04095	5.04095	5.04095	5.04095	70737.3	70728.6	70727.3	70717	70703.1
Agriculture - Tree Crops	0	0	0	0	0	4422.24	4422.14	4422.14	4422.14	4422.14
Agriculture - Vineyards	34.6689	34.6689	34.6689	34.6689	33.9522	3158.03	3156.3	3155.85	3154.57	3153.93
Aquiculture	0	0	0	0	0	647.341	642.053	638.915	631.897	618.85
Rangeland - Shrub and Brushland	188.344	167.142	129.409	73.2667	34.7924	15146.1	15142.5	15129.3	15094.2	14975
Upland Forest	459.196	438.933	397.691	344.44	281.206	34746.2	34674.7	34518.3	34287.4	34112.6
Tree Plantations	0	0	0	0	0	6831.42	6831.42	6831.42	6831.42	6831.42
Open Freshwater	1563.41	1489.43	1435.98	759.181	648.157	16359.4	16328.8	16272.5	16223.6	16156.2
Subtidal	13463.2	13563.7	13689.2	14700.4	15534.7	76295.4	76329.4	76390.8	76459.1	76608.8
Freshwater Swamp	157.727	129.854	110.481	97.9525	86.1161	16067.5	16047.1	16003.6	15949.3	15905.8
Mangroves	1249.88	1292.38	1418.58	1184.52	878.039	977.153	1120.05	1202.69	737.782	834.276
Freshwater Marsh	220.788	217.724	214.067	161.014	111.519	23584.2	23562.6	23529.2	23484.4	23431.2
Salt Marsh	80.3586	108.133	121.452	134.351	123.454	310.018	237.147	186.935	200.649	181.499
Juncus Marsh	0	0	0	0	0	521.342	510.322	212.461	234.503	201.168
Salt Barren	72.2288	207.964	271.247	399.816	330.478	183.945	273.916	387.609	467.375	459.962
Beach - Dune	21.8194	14.9252	9.83479	5.95523	0.76603	22.3383	20.9298	18.1869	7.66026	0.96371
Seagrass	7888.17	7934.27	7934.47	8245.7	8544.65	1524.1	1575.47	2068.32	2974.08	3474.35
Total	72215.7	72215.1	72214.8	72214.8	72214.8	532775	532775	532775	532775	532775

	Old Tampa Bay					Tampa Bay ALL				
	2007	2025	2050	2075	2100	2007	2025	2050	2075	2100
Mudflat	0	0	0	0	186.169	0	0	0	0	890.073
Developed - Low Intensity	10911.7	10911.7	10911.7	10911.7	10911.7	92875.8	92875.8	92875.8	92875.8	92875.8
Developed - Mid/High Intensity	85277.1	85277.1	85277.1	85277.1	85277.1	368767	368767	368767	368767	368767
Recreational	2904.87	2823.25	2776.23	2674.39	2520.35	10519.4	10078.6	9808.2	9223.5	8493.18
Developed - Rangeland	3112.31	3094.75	3069.07	2988.39	2830.61	11831.7	11718.2	11610.8	11348.9	10914
Rangeland - Grassland/Herbaceous/Open Land	5493.02	5454.43	5378.02	5232.03	5034.22	107251	106915	106165	104918	103243
Agriculture - Cropland and Pastureland	3314.25	3313.78	3312.91	3307.3	3285.66	155036	154943	154741	154270	153623
Agriculture - Tree Crops	483.733	483.733	483.708	483.634	482.868	21669.7	21669.3	21669	21668.1	21665
Agriculture - Vineyards	386.547	386.547	386.547	386.547	386.547	10145.6	10137.8	10121	10051.2	9926.66
Aquiculture	0	0	0	0	0	1110.22	1102.48	1097.79	1087.34	1067.15
Rangeland - Shrub and Brushland	1246.2	1237.97	1218.43	1185.76	1121.09	43425	43360.7	43188.3	42904.4	42552.7
Upland Forest	8185.78	8130.33	7942.53	7626.68	7287.7	70686.8	70425.2	69812	68860.6	67882.5
Tree Plantations	431.94	431.94	431.94	431.94	431.94	9241.54	9239.41	9233.38	9221.62	9192.36
Open Freshwater	9782.28	9607.65	9400.84	9135.77	8777.05	40677.1	40068.7	39235.6	37965.6	37117.6
Subtidal	54358.6	54550	54798.5	55228.7	56409.2	298028	298920	300234	303136	308780
Freshwater Swamp	12269.4	12233.8	12096.7	11879	11603.9	37286.2	36858	36117	35309.6	34630.3
Mangroves	3916.91	3929.49	4037.72	1026.94	1426.37	13992.6	14582.4	15653.8	6077.28	6544.04
Freshwater Marsh	4330.69	4282.41	4196.12	4040.81	3926.8	44102.4	43925.4	43683.7	43295	42960.6
Salt Marsh	653.346	672.274	618.208	478.569	319.581	2285.15	2431.39	2184.85	1940.84	1436.32
Juncus Marsh	1100.95	1100.83	391.711	492.406	522.207	4248.13	4202.62	2908.48	2780.03	2515.41
Salt Barren	180.659	339.844	656.212	874.629	829.433	1518.34	2214.21	3303.43	3841.3	3400.86
Beach - Dune	6.07879	5.55987	2.64403	1.38379	0.27182	69.9555	60.5655	43.367	25.18	9.04405
Seagrass	7350.24	7429.19	8309.83	12032.8	12125.7	33308.8	33580.7	35622	48508.3	49588.8
Total	215697	215697	215697	215696	215696	1378078	1378077	1378077	1378076	1378076

Appendix I

APPENDIX J

Parcel Prioritization Maps

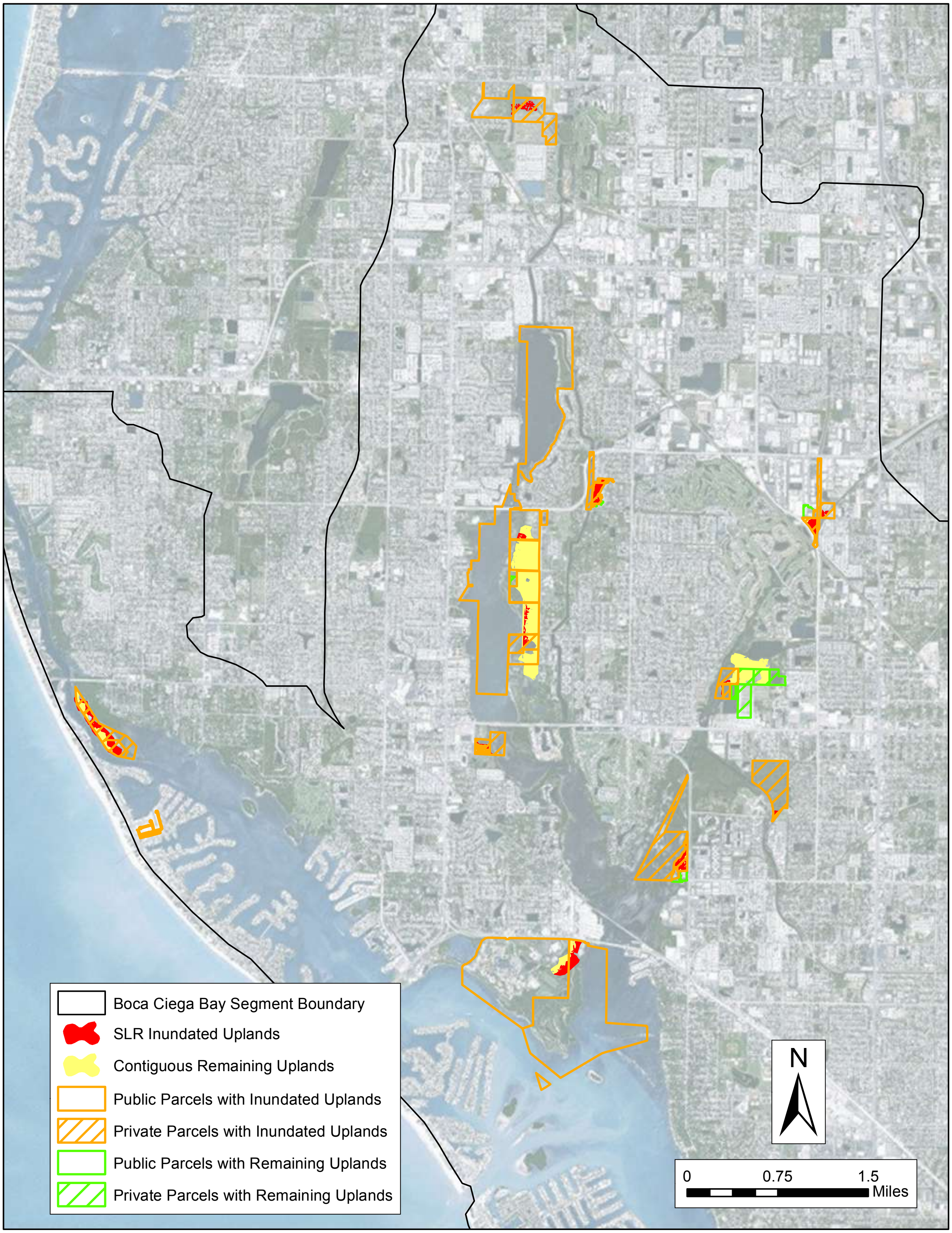


SOURCE: FDOR 2010, ESA 2016

ESA

Tampa Bay Blue Carbon Asessment . D140671

Figure J-1
Parcel Prioritization in Boca Ciega Bay



SOURCE: FDOR 2010, ESA 2016

ESA

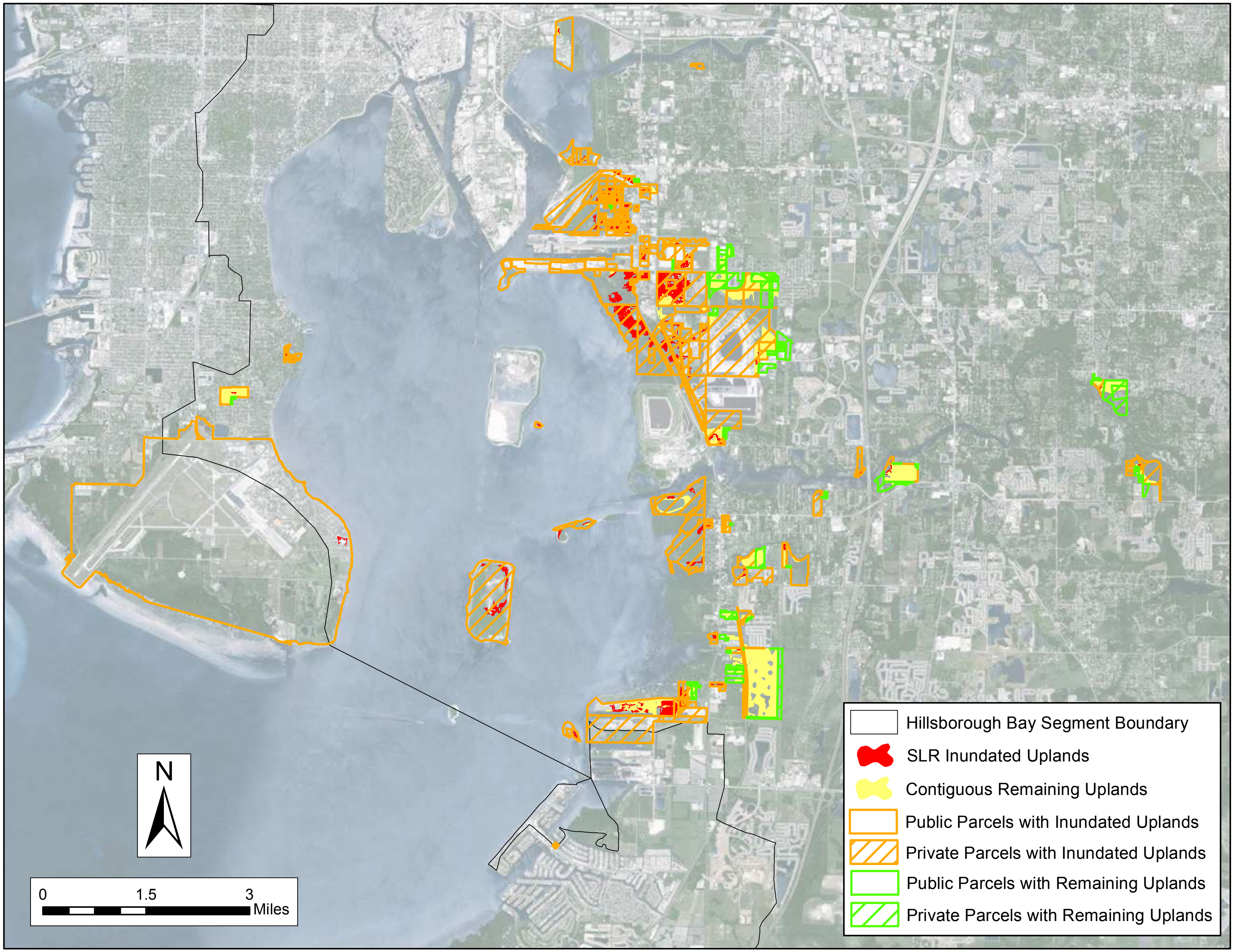
Tampa Bay Blue Carbon Asessment . D140671

Figure J-2

Parcel Prioritization in Boca Ciega Bay, North

SOURCE: FDOR 2010, ESA 2016

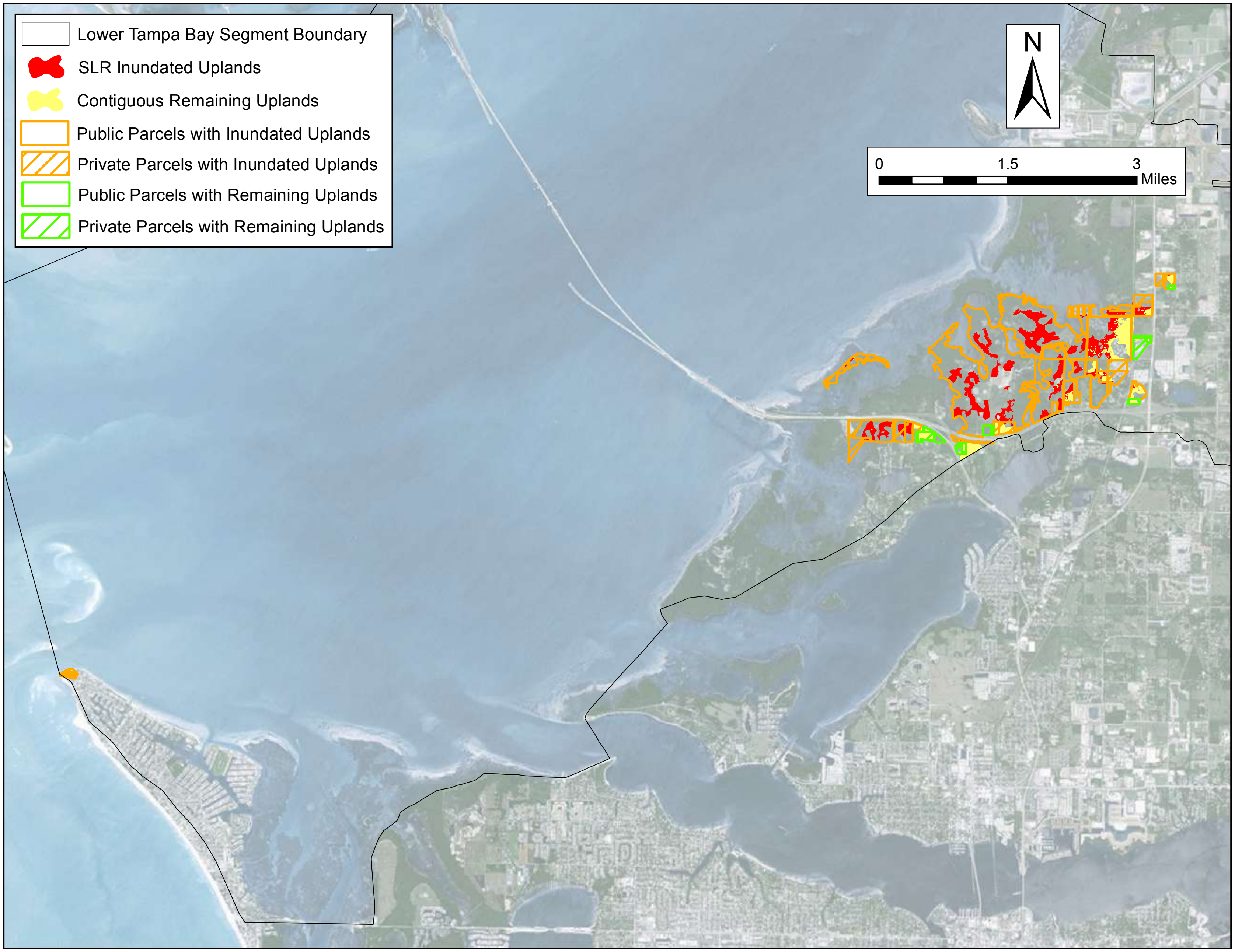
Figure J-3
Parcel Prioritization in Boca Ciega Bay, South



SOURCE: FDOR 2010, ESA 2016

ESA

Figure J-4
Parcel Prioritization in Hillsborough Bay

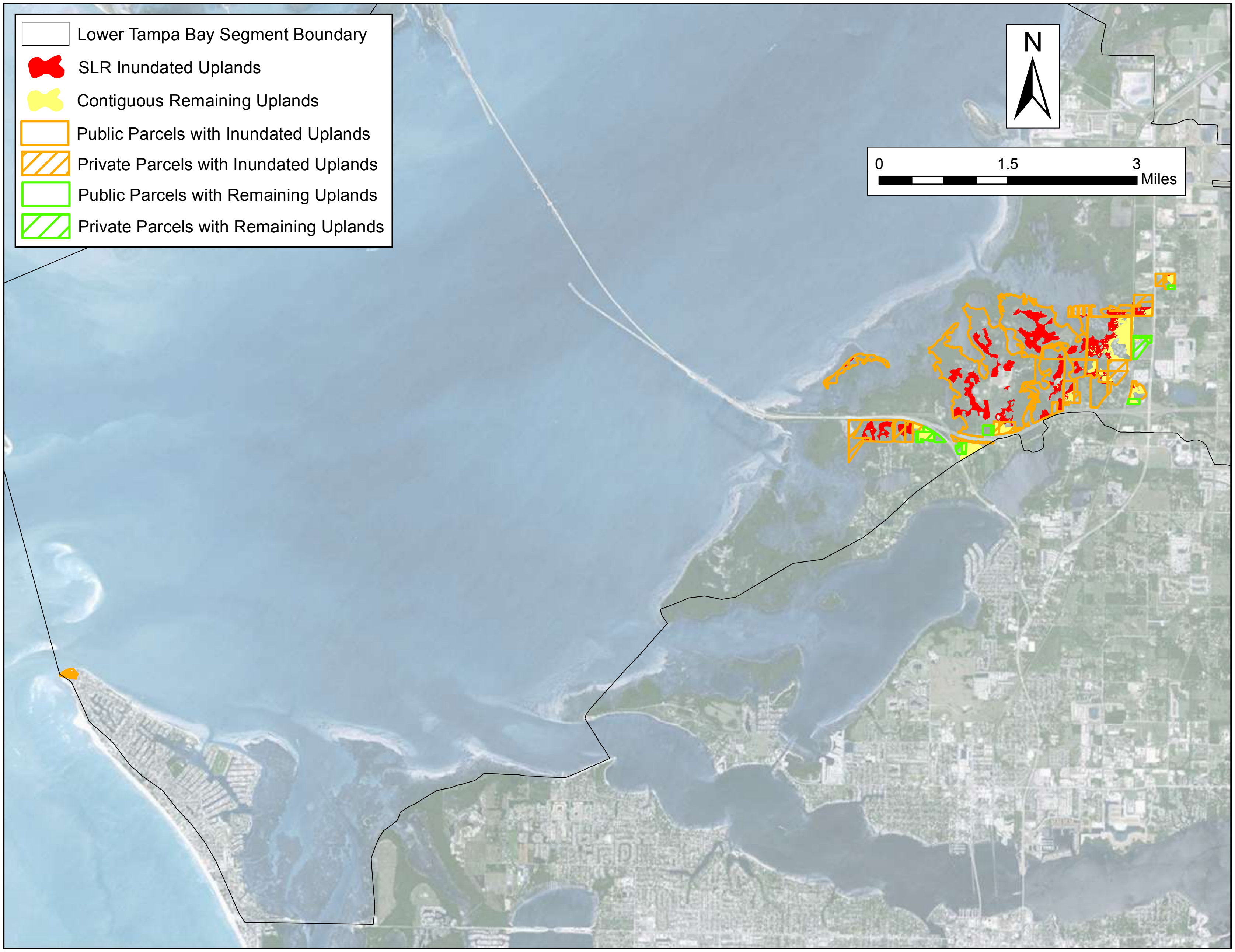


SOURCE: FDOR 2010, ESA 2016

ESA

Tampa Bay Blue Carbon Asessment . D140671

Figure J-5
Parcel Prioritization in Lower Tampa Bay



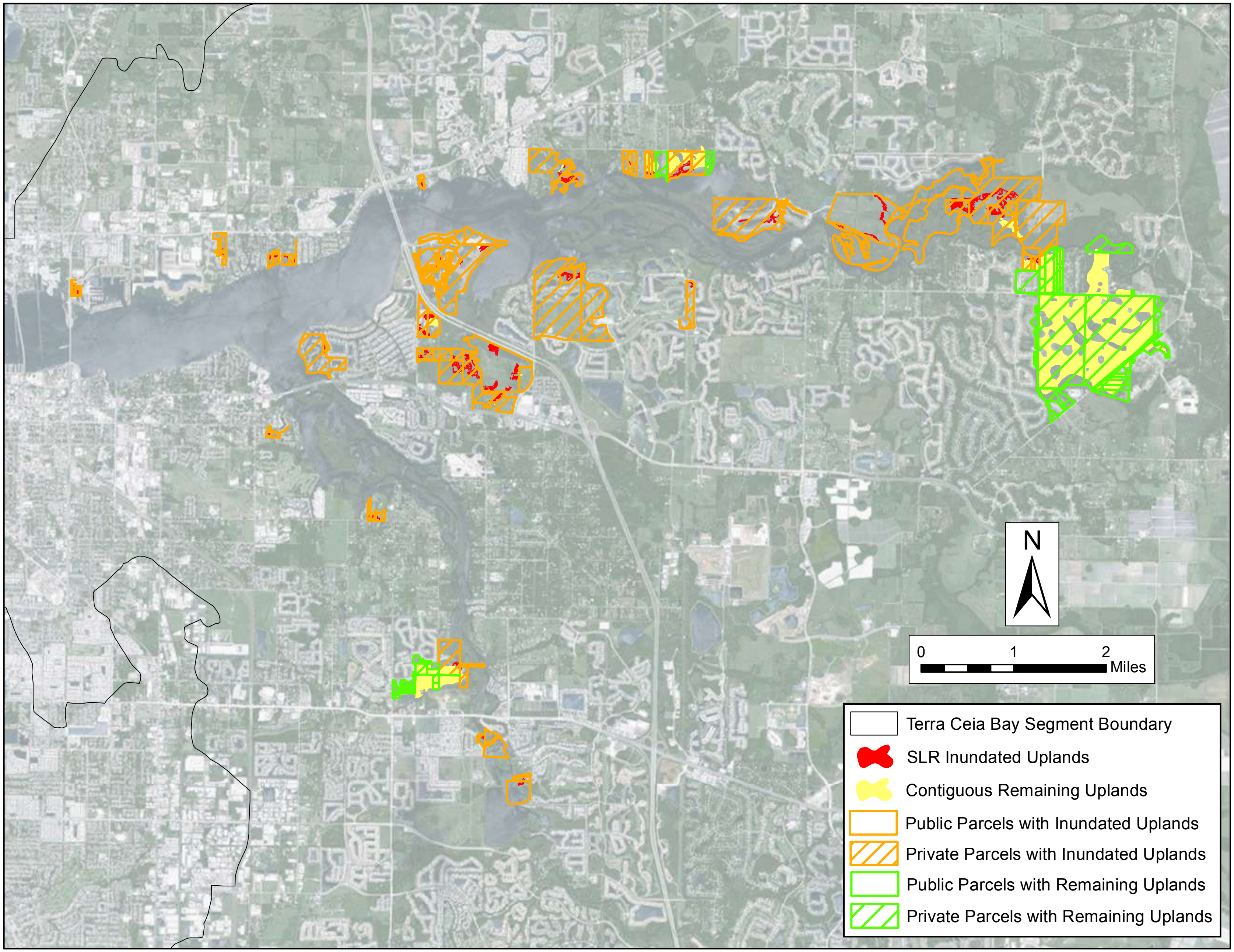
SOURCE: FDOR 2010, ESA 2016

ESA

Tampa Bay Blue Carbon Asessment . D140671

Figure J-6

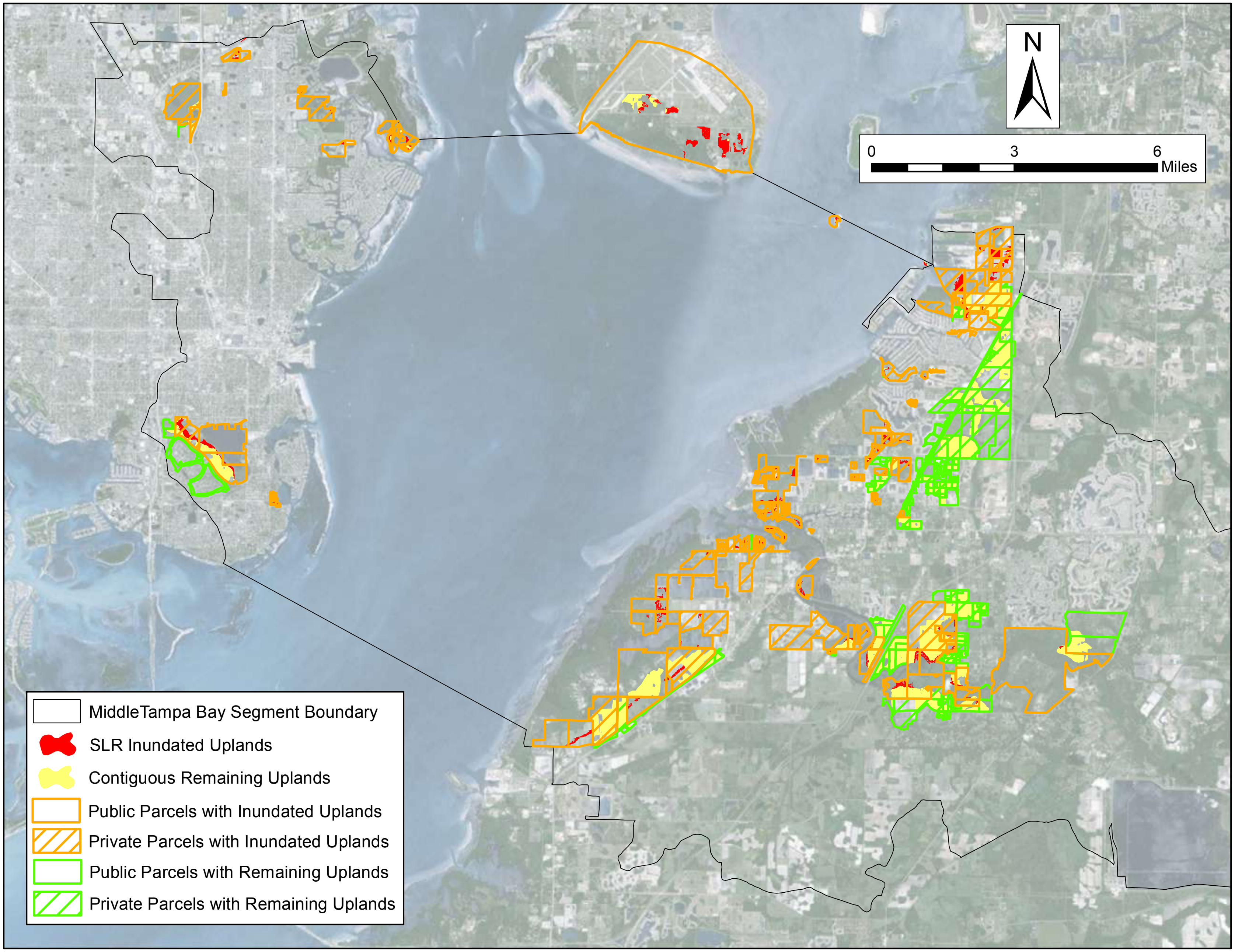
Parcel Prioritization in Lower Tampa Bay - Zoomed



SOURCE: FDOR 2010, ESA 2016

ESA

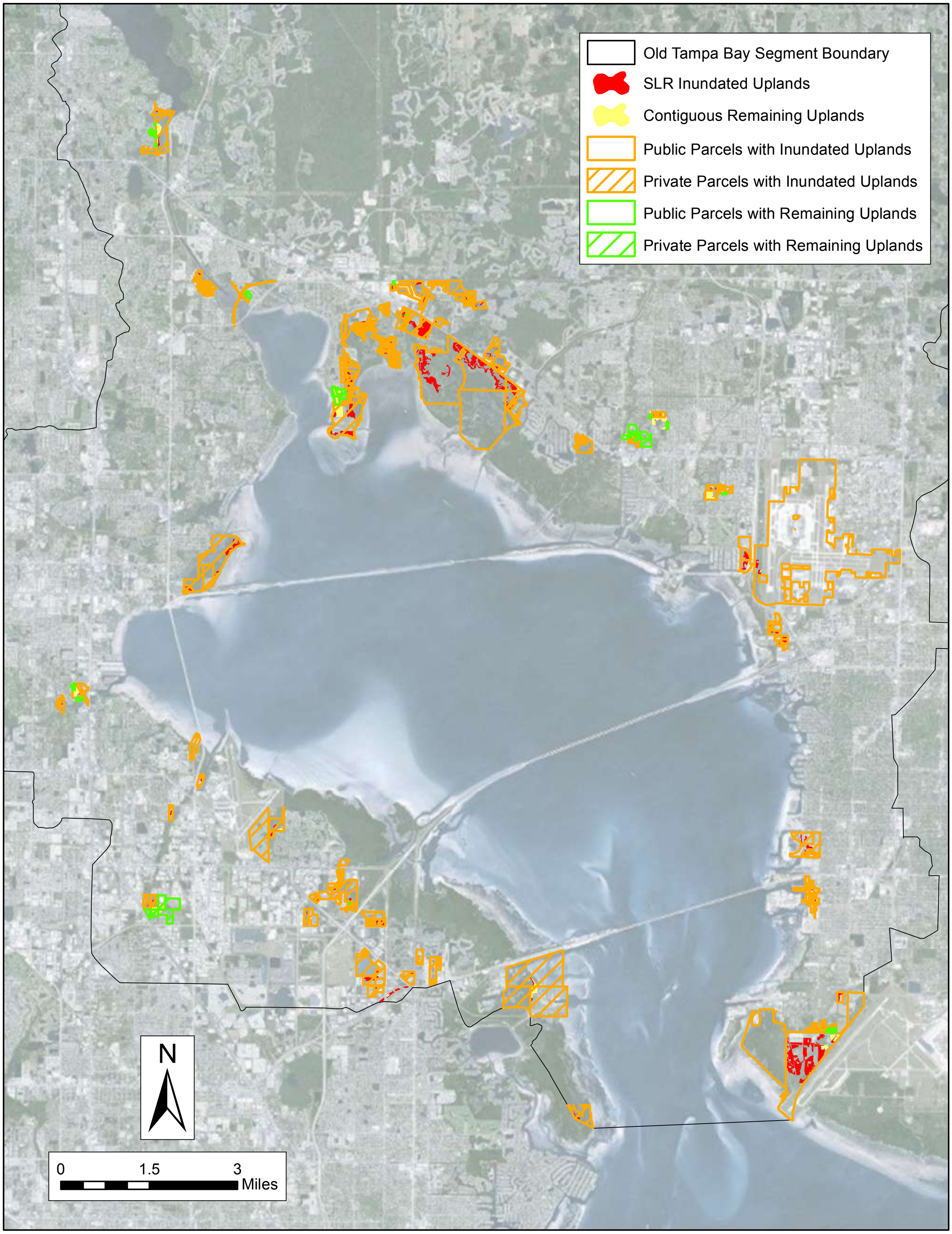
Figure J-7
Parcel Prioritization in Manatee River



SOURCE: FDOR 2010, ESA 2016

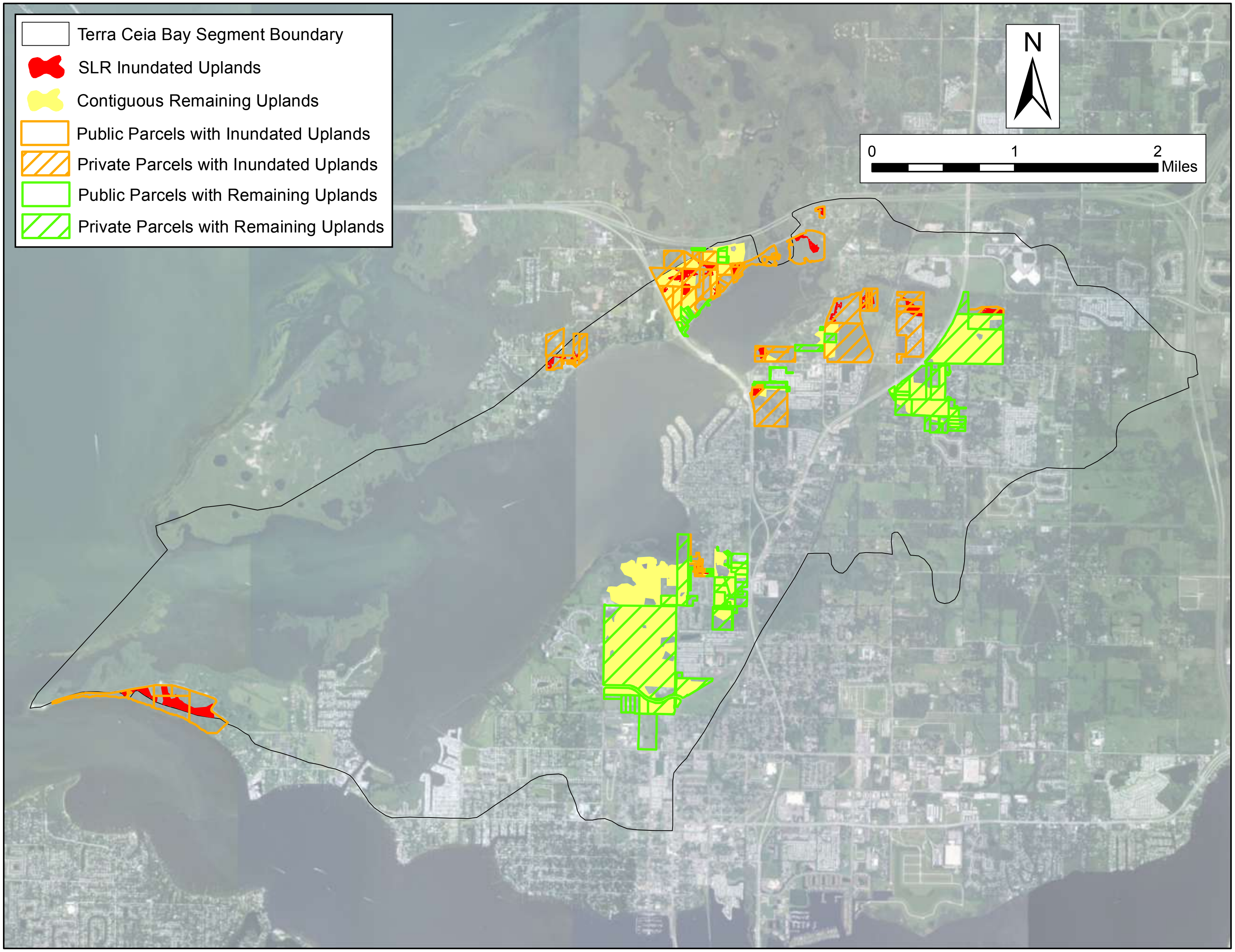
ESA

Figure J-8
Parcel Prioritization in Middle Tampa Bay



SOURCE: FDOR 2010, ESA 2016

Figure J-9
Parcel Prioritization in Old Tampa Bay



SOURCE: FDOR 2010, ESA 2016

ESA

Figure J-10
Parcel Prioritization in Terra Ceia Bay

APPENDIX K

Parcel Prioritization Tables-
Not Included for General Distribution

Appendix K. Parcel Prioritization Tables

Boca Ciega Bay

Public Parcels with Inundated Uplands		No Public Parcels with Remaining Uplands
PARCELID	Parcel Type	
15 30 26 70740 200 1100	C	
15 31 02 00000 400 0000	C	
16 33 05 00000 100 0000	C	
15 31 02 00000 300 0000	F	
15 29 34 50117 000 0040	M	
16 31 34 99582 001 0010	P	
16 32 30 00000 140 0100	C	
15 30 27 00000 110 0100	C	

Private Parcels with Inundated Uplands	Private Parcels with Remaining Uplands
PARCELID	PARCELID
15 30 25 00000 140 0200	15 30 25 00000 140 0100
15 30 25 19368 000 0011	16 30 30 69894 200 2302
15 30 30 00000 310 0100	16 30 30 00000 230 0100
15 30 14 99088 000 0420	15 30 25 00000 140 0300
15 30 14 99088 000 0430	15 30 25 19368 000 0110
15 30 26 70740 200 0500	15 30 25 19368 000 0111
16 30 19 00000 210 0100	15 30 14 99088 000 0470
16 32 11 95203 000 0001	15 30 23 59787 000 0010
16 32 11 95203 000 6190	15 30 14 99088 000 0500
16 32 11 95203 000 6200	15 30 14 99088 000 0460
16 32 11 95203 000 6220	15 30 36 00000 340 0200
16 32 11 95203 000 6210	16 31 34 96724 002 0014
15 30 14 70578 400 0600	16 30 18 12575 000 0200
15 30 14 99088 000 0510	16 31 34 73188 002 0052
15 30 14 99088 000 0520	16 31 34 73188 002 0051
16 30 18 69768 400 6100	16 31 34 73208 000 0012
16 30 31 00000 220 0100	16 31 34 73206 003 0001
15 30 27 03843 012 0060	16 31 34 73188 002 0050
15 30 27 03843 012 0050	16 32 11 69630 001 0010
15 30 27 03843 012 0040	
15 30 27 03843 012 0030	
16 32 11 95203 000 1110	
16 32 11 95203 000 3010	
16 32 11 95203 000 3020	
16 32 11 95203 000 3030	
16 32 11 95203 000 3040	
16 32 11 95203 000 3050	
16 32 11 95203 000 1010	
16 32 11 95203 000 1020	
16 32 11 95203 000 1030	
16 32 11 95203 000 1040	
16 32 11 95203 000 1050	
16 32 11 95203 000 1060	
16 32 11 95203 000 1070	
16 32 11 95203 000 1080	
16 32 11 95203 000 1090	

Boca Ciega Bay

16 32 11 95203 000 1100
16 32 11 95203 000 3060
16 32 11 95203 000 3070
16 32 11 95203 000 3080
16 32 11 95203 000 1120
16 32 11 95203 000 1130
16 32 11 95203 000 2200
16 32 11 95203 000 2210
16 32 11 95203 000 2170
16 32 11 95203 000 2180
16 32 11 95203 000 2190
16 32 11 95203 000 2220
16 32 11 95203 000 3090
16 32 11 95203 000 3100
16 32 11 95203 000 3110
16 32 11 95203 000 3120
16 32 11 95203 000 3130
16 32 11 95203 000 3140
16 32 11 95203 000 3150
16 32 11 95203 000 3160
16 32 11 95203 000 3170
16 32 11 95203 000 3180
16 32 11 95203 000 3190
16 32 11 95203 000 3200
16 32 11 95203 000 3210
15 29 35 00000 320 0100
15 30 14 99088 000 0001
15 30 14 99088 000 0340
15 30 14 99088 000 0330
15 30 14 99088 000 0002
15 30 14 85158 005 0250
15 30 36 00000 340 0300
15 30 36 00000 340 0100
15 30 36 00000 310 0100
15 30 32 74008 000 0100
16 32 09 05635 000 0600
16 32 09 05635 000 0610
16 32 09 05635 000 0690
16 32 30 90910 001 0010
16 32 20 90864 026 0002
16 32 30 00000 220 0100
16 32 20 90864 025 0101
16 32 09 05635 000 0700
16 32 29 22441 000 2070
16 32 29 22441 000 2150
16 32 29 22441 000 1150
16 32 29 22441 000 1140
16 32 29 22441 000 1120
16 32 29 22441 000 2020

Boca Ciega Bay

16 32 29 22441 000 2060
16 32 10 17230 000 0001
16 32 10 24283 001 0106
16 31 34 96724 002 0012
16 32 10 55254 018 0030
16 32 10 55254 019 0010
16 32 10 55254 017 0030
16 32 10 55254 016 0010
16 32 10 55254 015 0010
16 32 10 55254 015 0020
16 32 10 55254 015 0040
16 32 10 55254 014 0010
16 32 10 55254 014 0020
16 32 10 55254 014 0040
16 32 10 55254 000 0001
16 32 20 85360 001 0111
16 32 20 85360 001 0103
16 32 20 85360 001 0081
16 32 20 85360 001 0091
16 32 20 85360 001 0113
16 32 20 85360 001 0121
16 32 20 85360 001 0104
16 32 20 85360 001 0084
16 32 20 85360 001 0093
16 32 20 85360 001 0072
16 32 20 85360 001 0102
16 32 20 85360 001 0101
16 32 20 85360 001 0123
16 32 20 85360 001 0082
16 32 20 85360 000 0001
16 32 20 85360 001 0074
16 32 20 85360 001 0114
16 32 20 85360 001 0094
16 32 20 85360 001 0112
16 32 20 85360 001 0083
16 32 20 85360 001 0073
16 32 20 85360 001 0092
16 32 20 85360 001 0071
16 32 11 95203 000 2010
16 32 11 95203 000 2020
16 32 11 95203 000 1140
16 32 19 00000 210 0100
16 32 11 95203 000 1150
16 32 11 95203 000 1160
16 32 11 95203 000 1180
16 32 11 95203 000 1200
16 32 11 95203 000 2030
16 32 11 95203 000 2040
16 32 11 95203 000 2050

Boca Ciega Bay

16 32 11 95203 000 2060
16 32 11 95203 000 2070
16 32 11 95203 000 2080
16 32 11 95203 000 2090
16 32 11 95203 000 2100
16 32 11 95203 000 2110
16 32 11 95203 000 2120
16 32 11 95203 000 2130
16 32 11 95203 000 2140
16 32 11 95203 000 2150
16 32 11 95203 000 2160
16 30 18 12575 000 0300
16 30 18 12569 000 0030
16 32 10 00000 120 0200
16 30 19 00000 210 0500
16 32 11 00000 220 0500
16 32 20 85360 001 0124
15 30 27 70758 400 3100
15 30 27 03843 000 0001
15 30 27 03843 012 0020
16 32 29 22441 000 1090
16 32 29 22441 000 2100
16 32 29 22441 000 1050
16 32 29 22441 000 1060
16 32 29 22441 000 1130
16 32 29 22441 000 0001
16 32 29 22441 000 2130
16 32 29 22441 000 2010
16 32 29 22441 000 1100
16 32 29 22441 000 2080
16 32 29 22441 000 1110
16 32 29 22441 000 2140
16 32 29 22441 000 1010
16 32 29 22441 000 2040
16 32 29 22441 000 1020
16 32 29 22441 000 1080
16 32 29 22441 000 2110
16 32 29 22441 000 2050
16 32 29 22441 000 2090
16 32 29 22441 000 1030
16 32 29 22441 000 2120
16 32 29 22441 000 2000
16 32 29 22441 000 1070
16 32 29 22441 000 1040
16 32 29 22441 000 2030
16 32 29 22441 000 1000
15 30 30 00000 430 0100
15 30 31 00000 110 0100
16 32 11 95203 000 4050

Boca Ciega Bay

16 32 11 95203 000 4060
16 32 11 95203 000 3220
16 32 11 95203 000 4010
16 32 11 95203 000 4020
16 32 11 95203 000 4030
16 32 11 95203 000 4040
16 32 11 95203 000 4070
16 32 11 95203 000 4080
16 32 11 95203 000 4090
16 32 11 95203 000 4100
16 32 11 95203 000 4110
16 32 11 95203 000 4160
16 32 11 95203 000 5140
16 32 11 95203 000 6070
16 32 11 95203 000 4170
16 32 11 95203 000 4180
16 32 11 95203 000 4190
16 32 11 95203 000 4120
16 32 11 95203 000 4130
16 32 11 95203 000 4140
16 32 11 95203 000 5020
16 32 11 95203 000 5030
16 32 11 95203 000 4150
16 32 11 95203 000 4200
16 32 11 95203 000 4210
16 32 11 95203 000 4220
16 32 11 95203 000 5010
16 32 11 95203 000 5040
16 32 11 95203 000 5050
16 32 11 95203 000 5060
16 32 11 95203 000 5070
16 32 11 95203 000 5080
16 32 11 95203 000 5090
16 32 11 95203 000 5100
16 32 11 95203 000 5110
16 32 11 95203 000 5120
16 32 11 95203 000 5130
16 32 11 95203 000 5150
16 32 11 95203 000 5160
16 32 11 95203 000 5170
16 32 11 95203 000 5180
16 32 11 95203 000 6020
16 32 11 95203 000 6030
16 32 11 95203 000 5190
16 32 11 95203 000 5200
16 32 11 95203 000 5210
16 32 11 95203 000 5220
16 32 11 95203 000 6010
16 32 11 95203 000 6040

Boca Ciega Bay

16 32 11 95203 000 6050
16 32 11 95203 000 6060
16 32 11 95203 000 6080
16 32 11 95203 000 6090
16 32 11 95203 000 6100
16 32 11 95203 000 6110
16 32 11 95203 000 6120
16 32 11 95203 000 6130
16 32 11 95203 000 6140
16 32 11 95203 000 6150
16 32 11 95203 000 6160
16 32 11 95203 000 6170
16 32 11 95203 000 6180
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16 30 19 00000 210 0200
16 32 10 24283 001 0104
15 30 25 19368 000 0010
15 30 32 74008 000 0110
15 30 32 74008 000 0120
15 30 32 74008 000 0040
15 30 32 74008 000 0050
15 30 32 74008 000 0060
15 30 32 74008 000 0080
15 30 32 74008 000 0090
16 32 10 24283 001 0107
16 31 34 73188 002 0080
15 30 32 74008 000 0070
16 32 30 90910 000 0040
15 30 32 74008 000 0140
15 30 32 74008 000 0020
15 30 32 74008 000 0010
15 30 32 74008 000 0001
15 30 32 74008 000 0130
15 30 32 74008 000 0150
16 32 10 24283 001 0126
16 32 10 55251 000 0002
16 32 10 24283 001 0129
16 32 10 72400 002 0010
16 32 10 72400 000 0001
16 32 10 72400 002 0020
16 32 10 72400 002 0030
16 32 10 55254 018 0010
16 32 10 55254 018 0020
16 32 10 55254 019 0020
16 32 10 55254 019 0030
16 32 10 55254 017 0020
16 32 10 55254 016 0020
16 32 10 55254 016 0030
16 32 10 55254 015 0030

Boca Ciega Bay

16 32 10 55254 014 0030
16 32 10 17230 000 0470
15 30 32 74008 000 0030
16 32 20 85360 001 0122

Hillsborough Bay

Public Parcels with Inundated Uplands		Public Parcels with Remaining Uplands	
PARCELID	Parcel Type	PARCELID	Parcel Type
193017ZZZ000000000100U	C	19300266300000166680OU	C
1930251RR000000000660U	S	193002663000001668400U	C
1931031RR000000001040U	C	193002663000001667300U	C
1931031RR000000001053U	C		
193117ZZZ000001748200U	C		
193103ZZZ000001735700U	C		
1930351S1000000000440U	C		
193002663000001668400U	C		
1930251RR000000000720U	S		
183015ZZZ000005543300A	M		
193002663000001667300U	C		
203019ZZZ000002985300U	C		
193010663000001675800U	C		
183020ZZZ000005565000A	P		
193004ZZZ000001672100U	C		
192920ZZZ000005902800A	M		
193004ZZZ000001675001U	C		
1930261RR000000I00001U	C		

Private Parcels with Inundated Uplands	Private Parcels with Remaining Uplands
PARCELID	PARCELID
1929294DH000000000002A	1929331Q3000031000050U
192928ZZZ000005814700A	193002663000001666300U
192928ZZZ000005814800A	1930021QU000000000330U
192928ZZZ000005815400A	1930021QU000000000320U
1929294DH000000000001A	19300294U000000000040U
192934ZZZ000001621200U	19300294U000000000060U
1929331Q3000029000060U	193003942000000I00000U
1929331Q3000028000010U	1930021QU000000000350U
1929331Q3000029000020U	1930021QU000000000370U
1929331Q3000025000060U	193002663000001667901U
1929331Q3000024000060U	1930021QU000000000360U
1929331Q3000029000010U	1930021QU000000000010U
1929331Q3000031000010U	1930021QU000000000340U
1929331Q3000030000010U	19300294U000000000050U
192934663000001621300U	193002663000001667100U
192934663000001621500U	193002663000001667500U
1929331Q3000031000020U	193002663000001668300U
1929331Q3000040000010U	193011663000001681000U
1929331Q3000051000010U	193012663000001684700U
1929331Q3000038000050U	193012663000001684800U
1929331Q3000030000060U	193011ZZZ000001681400U
1929331Q3000031000060U	193011663000001681500U
1929331Q3000024000040U	2030102OI000001000300U
1929331Q3000031000040U	2030102OI000001000310U
1929331Q3000031000030U	18301541J000000000210A
1929331Q3000060000000U	18301541J000000000230A

Hillsborough Bay

1929331Q3000056000030U	2030152OJ000012000090U
1929331Q3000054000060U	18301541J000000000200A
19300366300000166910 0U	193014ZZZ000001694300U
1929331Q3000039000060U	2030102OI000001000290U
192933ZZZ000001607400U	203015ZZZ000002889400U
1929331Q3000041000010U	18301541J000000000220A
1929331Q3000051000060U	203023ZZZ000003037400U
193003942000000J00000U	203023ZZZ000003037300U
19300266300000166720 0U	203023ZZZ000003037600U
193010ZZZ000001679800U	1930261RR000000000600U
193010ZZZ000001679200U	1930251RR000000000670U
193010ZZZ000001679400U	203023ZZZ000003037500U
193010ZZZ000001679000U	1930261RR000000K00009U
193010ZZZ000001679600U	1930261RR000000K00008U
193010ZZZ000001678200U	1931021SD000000A00000U
19301066300000167780 0U	1931021SC000000000400U
18301140H000001000030A	1931031RR000000001000U
193011ZZZ000001681300U	1931021RR000000001600U
18301140H000001000020A	1931031RR000000000993U
18301140O000003000020A	193102ZZZ000001735100U
193010ZZZ000001679000U	1931021RR000000001620U
193010ZZZ000001679100U	1931031RR000000000992U
193010ZZZ000001679900U	1931031RR000000001003U
193010ZZZ000001679700U	1931021SD000000B00000U
203015ZZZ000002889000U	193102ZZZ000001734400U
193015ZZZ000001696600U	1930351S2000000000020U
193010ZZZ000001680600U	193102ZZZ000001734600U
1930241RJ000000000010U	1931031RR000000000990U
1930261RR000000I00002U	19300294U000000000031U
203019ZZZ000002998000U	19300294U000000A00000U
203019ZZZ000002997500U	1931021SD000000C00000U
203019ZZZ000002997900U	1930351S1000000000250U
193022ZZZ000001696900U	1930351S1000000000130U
1930261RR000000000593U	1931031RR000000000980U
203019ZZZ000002987100U	1929331Q3000011000050U
193026ZZZ000001728500U	19302486W000000000010U
1930261RR000000J00000U	19300266300000166690 0U
203023ZZZ000003037100U	1930125EU000000UL0000U
1930261RR000000J00002U	19302486W000000000020U
193026ZZZ000001727400U	19300266300000166790 2U
1931021RR000000001811U	19300266300000166700 0U
1931031RR000000001020U	19300266300000166770 0U
1931031RR000000001010U	1930241RJ000000000490U
193102ZZZ000001735000U	193014ZZZ000001694700U
1931031RR000000001002U	19300266300000167190 2U
1931031RR000000001011U	18301541K000001000250A
1931031RR000000001050U	1930351S0000000000200U
1930351S1000000000431U	193014ZZZ000001694800U
1931021RR000000001820U	18301541J000000000500A

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1931031RR000000001001U
193117ZZZ000001748300U
193117ZZZ000001748100U
193102ZZZ000001735300U
193109ZZZ000001736500U
193109ZZZ000001736700U
1931031RR000000001051U
193117ZZZ000001748000U
1931171T4000000000740U
1930351S1000000000490U
1931031RR000000001052U
1931031RR000000001072U
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1929331Q3000020000010U
192933ZZZ000001607400U
1929331Q3000032000010U
1929221O4000001000030U
19292280U000000000010U
1929331Q3000012000000U
1929331Q3000037000010U
1929331Q3000032000010U
1929331Q3000021000000U
1929331Q3000024000010U
192933ZZZ000001607400U
1929331Q3000036000010U
1929331Q3000021000000U
192933ZZZ000001607400U
192932ZZZ000001607000U
1929331Q3000026000010U
1929331Q3000029000030U
1929331Q3000028000040U
1929331Q3000026000010U
1929331Q3000035000000U
1929331Q3000027000010U
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1929331Q3000025000010U
1929331Q3000011000021U
1929331Q3000021000000U
1929331Q3000021000000U
192932ZZZ000001606900U
1929331Q3000026000010U
1929331Q3000026000010U
1929331Q3000028000020U
1929331Q3000049000020U
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1929331Q3000054000010U
18301140P000000000010A
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1930026630000016678000U
1930026630000016664000U
1930021QU000000000310U
1930021QU000000000300U
1930026630000016666000U
1930026630000016680000U
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1930126630000016846000U
18301541J000000000240A
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2030192RW000000A00000U
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19303589Z000011000800U
19303589Z000011000810U
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19303589Z000011000790U
19303589Z000011000840U
19303589Z000011000830U
19301261G000000000020U
19301180D000001682100U
1930351S0000000000220U
18301541K000002000240A

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193003663000001669800U
193004ZZZ000001673600U
1929331Q3000041000020U
1929331Q3000050000010U
1930041Q3000111000011U
193004ZZZ000001675000U
193011663000001680800U
1929331Q3000053000010U
1930031Q3000070000001U
193003942000000000170U
193015ZZZ000001696600U
193024ZZZ000001717600U
1930261RR000000F00002U
192932ZZZ000001606900U
1929331Q3000051000020U
1929331Q3000043000020U
1929331Q3000043000010U
1929331Q3000050000020U
192933ZZZ000001607400U
193003663000001670000U
193003942000000000110U
1929331Q3000049000031U
18301140H000001000010A
1930031Q3000103000050U
18301140P000000000020A
19302486W000000000040U
1930261RR000000I00000U
193027ZZZ000001728700U
193010663000001677300U
1929331Q3000056000040U
1929331Q3000050000030U
193003942000000000100U
19300394200000000011AU
193010663000001676900U
193010ZZZ000001679300U
1929331Q3000060000000U
1929331Q3000060000000U
193026ZZZ000001727300U
1929331Q3000044002340U
1930031Q3000069000010U
1929331Q3000059000021U
193014ZZZ000001694700U
1930031Q3000103000051U
1929331Q3000038000040U
1929331Q3000052000010U
1930031Q3000081000020U
1930261RS000000000010U
193010ZZZ000001679300U
193004ZZZ000001673600U

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1929331Q3000044000050U
1930261RR000000I00000U
192933ZZZ000001607400U
1929331Q3000049000010U
1929331Q3000048000010U
1930261RS000000000051U
1930031Q3000094000030U
193003942000000H00000U
1929331Q3000043000030U
1929331Q3000048000010U
1929331Q3000055000010U
193010ZZZ000001679300U
192933ZZZ000001607400U
1929331Q3000043000040U
1929331Q3000055000010U
193002663000001668300U
193010663000001677400U
18301140O000001000010A
18301140O000004000080A
19302486W000000000030U
1930261RS000000000020U
193009ZZZ000001675300U
1930041Q3000111000010U
193010663000001676900U
183011ZZZ000005540600A
193003942000000D00000U
193003663000001670800U
2030192RW000000000050U
203023ZZZ000003035500U
193003942000000000050U
193010663000001677200U
193014ZZZ000001691900U
193003663000001671900U
193003663000001671901U
193010663000001675500U
203023ZZZ000003034901U
1929331Q3000032000020U
19303589Z000011000710U
19303589Z000011000720U
19303589Z000000F00000U
1930041Q3000114000050U
192928ZZZ000005814900A

Manatee River

Public Parcels with Inundated Uplands		Public Parcels with Remaining Uplands	
PARCELID	Parcel Type	PARCELID	Parcel Type
622500007	S	637900002	F
2122700309	S	2122700309	S
2122700309	S	2123915007	F
2122700309	S		
2122700309	S		
637300104	F		
2070000059	S		
2122700309	S		
2122700359	S		
2070400109	S		
2069200000	S		
2122700309	S		
2069800007	S		
2122700152	C		
2122700309	S		
2138800004	S		
2138500000	S		
2122700309	S		

Private Parcels with Inundated Uplands	Private Parcels with Remaining Uplands
PARCELID	PARCELID
623600053	625210059
625200001	632800059
625210000	632100109
625500004	632100209
635700008	2143500003
2065700003	2143200000
2065900009	2123100006
637310053	2143210009
2070610059	2144000003
635900004	637200007
633400007	2122100007
2121900001	2121900001
2122100007	2142610100
2137500050	2142610050
2138510058	2123900009
2120900002	
2121000059	
2143000004	
2137500019	
2139110056	
2082000106	
2138810003	
2070610259	
2072300102	
6866600106	
6864600009	

Manatee River

6866600205
6866600155
6866600056

Middle Tampa Bay

Public Parcels with Inundated Uplands		No Public Parcels with Remaining Uplands
PARCELID	Parcel Type	
505410259	C	
497700209	C	
505410309	C	
1111100059	C	
1111101009	C	
1111300659	C	
1734100059	M	
1739300059	M	

Private Parcels with Inundated Uplands	Private Parcels with Remaining Uplands
PARCELID	PARCELID
852900000	860510155
497700219	860500008
860000058	859902009
859302721	521500009
859302804	535530000
859302903	535520001
859901209	535500003
853200004	535510002
859901109	535535009
859901309	535800502
856300009	535530059
825100100	526500004
817810059	535800205
545912759	524411459
545900059	556320559
545913909	556600259
545913159	556200059
497707959	556700059
545912859	556320609
545912809	556320509
545912909	556600159
497700219	556320659
525100059	556600759
525100059	556326259
537000059	556326509
545911209	556903059
505410159	556321359
505410159	556904609
862000007	556321309
1036301009	556927002
1100001809	556303009
1100001759	556303109
1100001709	556902459
526300009	556912359

Middle Tampa Bay

1100001859	556916609
969700004	556302859
1101600079	556302959
526310008	556303059
526400007	556912309
1100007809	556302809
965000052	556302909
948000005	556303159
968000000	556925105
968410050	556927051
968410506	556920007
968400051	561615006
1100007059	556910057
964900500	562219402
535800205	562219451
1100007159	1697717009
1100007759	1697714559
1036306159	1697714609
1101800059	1697714659
1100007559	1703300002
1100007109	1697714709
1100007309	1697735159
2581600589	1697735209
2581600879	1697735259
1100005659	1703100006
1102083209	1697735309
1100005909	1703410058
2581600709	1730210000
1100006009	1697723209
1100005959	1697713059
1100006059	1697723109
1100700109	1697723259
2581600759	1697723159
1100800109	1703200004
1094500259	1697723059
1093901401	1697713009
1129100002	1697712969
1093903456	1697713109
1094500459	1703400000
1093903407	1703810509
1093903654	1697707909
1094500359	1697707859
1093903704	1697707809
1093901203	1697707759
1111300609	1703810109
1093901351	1703810059
1123710509	556925154

Middle Tampa Bay

1123800003	556903109
1111900005	
1123710210	
1112000003	
1093901153	
1093901302	
1093901252	
1126400009	
1112100001	
1123901009	
1111300509	
1393810054	
1393810104	
1394000002	
1179302109	
1393810161	
1415900008	
1414700102	
1414000008	
1414710051	
1415500055	
1730200001	
1735710409	
1732200280	
1734100159	
1739100152	
1739100053	
3133700169	
2581600809	
1729900009	

Old Tampa Bay

Public Parcels with Inundated Uplands		Public Parcels with Remaining Uplands	
PARCELID	Parcel Type	PARCELID	Parcel Type
193132ZZZ000001760100U	C	193122ZZZ000001752500U	C
1932061V4000000007400U	C	19313272X000000A00050U	C
1932061V4000000006811U	C	193224ZZZ000001811000U	P
183212ZZZ000001092704U	M	193220ZZZ000001805400U	S
183202953000000A00000U	M	193227ZZZ000001826300U	C
183212ZZZ000001092702U	M	193220ZZZ000001805700U	S
193132ZZZ000001760101U	C	193220ZZZ000001802600U	S
183212ZZZ000001092703U	M	193232ZZZ000001834100U	S
183211ZZZ000001083801U	M	183232ZZZ000001116600U	S
183211ZZZ000001083802U	M	193234ZZZ000001837600U	S
183202ZZZ000001072643U	M	193234ZZZ000001837800U	S
183212ZZZ000001095300U	C	193224ZZZ000001811600U	S
183212ZZZ000001095200U	S	193234ZZZ000001837900U	P
183212ZZZ000001092701U	M	193229ZZZ000001829900U	S
183222ZZZ000001109000U	S	183226ZZZ000001114400U	C
193220ZZZ000001805300U	S	193227ZZZ000001815700U	P
193228ZZZ000001829300U	C	193229ZZZ000001830200U	S
183227ZZZ000001114700U	S	193220ZZZ000001805600U	S
193227ZZZ000001826600U	C	193220ZZZ000001801900U	S
183228ZZZ000001115500U	S	193220ZZZ000001805500U	S
183212ZZZ000001095200U	S	193220ZZZ000001805500U	S
193219ZZZ000001801200U	C	193229ZZZ000001830100U	S
193234ZZZ000001837700U	S	193229ZZZ000001830300U	S
183222ZZZ000001109300U	C	193229ZZZ000001830000U	S
183221ZZZ000001107900U	C	193220ZZZ000001805600U	S
193219ZZZ000001801100U	C	193224ZZZ000001811700U	S
193228ZZZ000001827100U	S	1932041UU000000002631U	C
193220ZZZ000001805200U	S	1932041UU000000002051U	M
193227ZZZ000001826800U	S	16 31 35 00000 240 0300	M
183221ZZZ000001107700U	C		
183232ZZZ000001116700U	S		
183202ZZZ000001092705U	C		
193229ZZZ000001830200U	S		
193229ZZZ000001830600U	S		
183213ZZZ000001102900U	C		
183201ZZZ000001070900U	C		
193227ZZZ000001826100U	C		
183221ZZZ000001107700U	C		
183216ZZZ000001106800U	C		
18323119A000000000060U	S		
183233ZZZ000001117800U	S		
193219ZZZ000001801300U	C		
193228ZZZ000001829000U	S		
193132ZZZ000001758400U	C		
193228ZZZ000001827000U	S		
193223ZZZ000001810900U	P		
183020ZZZ000005565000A	P		

17 30 33 00000 230 0100	C	
16 32 01 00000 410 0100	M	
16 32 01 00000 110 0100	M	
16 31 36 00000 400 0000	M	
17 30 32 59748 001 0010	M	

Private Parcels with Inundated Uplands	Private Parcels with Remaining Uplands
PARCELID	PARCELID
193110ZZZ000001738000U	19311597J000000000020U
1931151SF000000001000U	193122ZZZ000001752401U
1931211TA000039000040U	19311597J000000000030U
193116ZZZ000001744800U	193116ZZZ000001745900U
1931151SF000000004000U	193122ZZZ0000175240WU
193116ZZZ000001746000U	193122ZZZ000001752900U
193110ZZZ000001738100U	193122ZZZ000001752402U
1931291TA000039000680U	193127ZZZ000001755100U
19312992600040600002OU	1931291TA000039000660U
19312992600040600003OU	1931291TA000039000650U
19312992600040400001OU	193115ZZZ000001743900U
19312992600040400002OU	193128ZZZ00000175610NU
19312883X000039000300U	193133ZZZ000001760500U
193116ZZZ000001745400U	193128ZZZ000001756000U
193132ZZZ000001758510U	193128ZZZ000001756000U
19312992600040600001OU	193134ZZZ000001761201U
19312892600040200001OU	193133ZZZ000001761000U
19312992600030700002OU	193128ZZZ00000175610NU
19312892600030400001OU	193128ZZZ000001756200U
19312992600030500001OU	193127ZZZ000001755200U
19312992600030600002OU	193127ZZZ000001755201U
193132ZZZ000001758500U	193122ZZZ000001752600U
193110ZZZ000001738300U	1932049FI000014000020U
19312892600040200003OU	1932041UU000000002160U
19312992600030500002OU	193205ZZZ000001767000U
19312892600040200002OU	1932041UU000000002010U
19312899K000000D014A0U	1932041UU000000002011U
19312892600030400002OU	193205ZZZ000001767200U
193205ZZZ000001766900U	193122ZZZ000001752400U
193205ZZZ000001766800U	1932041UU000000002110U
18320182200000002AD0U	193205ZZZ000001767100U
1932061V4000000007270U	193134ZZZ000001761200U
1931291TA000039000690U	1932049FI000014000030U
19312992600030700003OU	19320482O000000D00000U
193132ZZZ000001759601U	1932041UU000000002231U
1932061V4000000006800U	193115ZZZ000001743700U
18320179F0000000001B0U	193205ZZZ000001767900U
183211ZZZ000001083800U	1932041UU000000002360U
183212ZZZ000001092700U	19320485K000001000120U
193132ZZZ000001759602U	1932041UU000000002350U
1932051UU000000000260U	1932041UU000000002370U

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183212ZZZ000001092200U
1932051UU000000000161U
19312992600040400030U
19312992600030500040U
1931299260000000B00250U
19312992600030500030U
19312992600030700010U
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1931291TA000039000670U
1931281SF000000670000U
1932081UU000000000420U
183212ZZZ000001092500U
183212ZZZ000001092100U
1932061V4000000006820U
183212ZZZ000001092401U
183212ZZZ000001092300U
1932081UU000000000412U
183211ZZZ000001087300U
18321118W000003000000U
183211ZZZ000001087100U
183211ZZZ000001087200U
1832119CM000000E00000U
1832119CM000000A00000U
183211ZZZ000001085900U
18321219400001200131U
183211ZZZ000001087000U
18321196Z000000E00000U
18321196Z000000D00000U
1932061V4000000006810U
1932051UU000000000250U
183214ZZZ000001103101U
183213ZZZ000001095800U
18321196Z000000A00000U
193221ZZZ000001806700U
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18321196Z000000B00000U
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193221ZZZ000001806400U
193230ZZZ000001832400U
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183232ZZZ000001116500U
193103ZZZ000001736300U
1832119CM000000B00000U
183201ZZZ000001070700U
18321196Z000000C00000U
193220ZZZ000001805000U
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1932041UU000000002361U
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19320482O000000E00000U
1932041UU000000002510U
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1932041UY000001000050U
19320485J000000A00000U
1932041UY000001000040U
1932041UY000001000090U
1932051V4000000006750U
193128ZZZ00000175620NU
1932049FI000014000040U
1932081UU000000000390U
193134ZZZ000001761200U
1932081UU000000000380U
19313272XB00001000200U
1932081UU000000000440U
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1932051V4000000007630U
1932041UU000000002020U
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1932041UU000000002362U
19320485K000000A00000U
193205ZZZ000001767300U
19320485K000000C00000U
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1932081UU000000000383U
1932081UU000000000370U
1932041UU000000002573U
1932051UU000000000050U
183212ZZZ000001092400U
1932041UU000000002261U
1932041UY000001000100U
1932081UU000000000430U
193133ZZZ000001761001U
183211ZZZ000001086400U
1932041UU000000002450U
193222ZZZ000001807700U
1932041UY000001000070U
1932041UY000001000060U
1932051UU000000000360U
193222ZZZ000001807200U
1932041UU000000002570U
1932051UU000000000351U
193208ZZZ000001773500U

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183227ZZZ000001114800U
1932051V3000002000040U
18321196Z000000F00000U
193230ZZZ000001831400U
193221ZZZ000001806000U
193230ZZZ000001831500U
193128926000304000030U
1932061V4000000007260U
193128926000401000020U
183211886000000000310U
193205ZZZ000001767601U
18321118W000003000002U
183201953000001000920U
183211886000000000340U
1932051V3000001000010U
183201953000001000940U
183213195000000000030U
183211886000000000170U
193221ZZZ000001806000U
1932051V3000002000010U
1931151SF000000008000U
183211886000000000110U
183211886000000000150U
193128926000000B00240U
183211886000000000120U
183211680000000000020U
183211886000000000260U
1931151SF000000003000U
183211886000000000130U
19313297F000000B032A0U
193128926000401000010U
1932061V4000000007401U
183202ZZZ000001072300U
193132ZZZ000001759400U
183211886000000000140U
1832119CM000000D00000U
183211ZZZ000001086300U
19322020Y000002000010U
1931151SF000000006000U
183211886000000000330U
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193219ZZZ000001799400U
183212194000012000010U
183211886000000000280U
193220ZZZ000001804900U
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Terra Ceia Bay

Public Parcels with Inundated Uplands	
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16 30 10 71010 300 1200	S
16 30 04 77515 000 0300	D
16 28 35 00000 110 0100	P
16 29 09 00000 120 0300	P
16 28 25 18432 000 0001	M
16 28 35 00000 230 0100	P
16 29 16 00000 130 0100	S
17281906J000000010000U	S
172823ZZZ000000352200U	C
172823ZZZ000000351700U	C
172829ZZZ000000394300U	S
172827ZZZ000000389600U	C
172829ZZZ000000394100U	S
172829ZZZ000000394600U	S
172833ZZZ000000395800U	S
1728260A1000077A00000U	C
172828ZZZ000000392100U	S
1729010EF000000000440U	C
182919ZZZ000005492800A	M
182919ZZZ000005493000A	M
182919ZZZ000005494300A	M
182919ZZZ000005493200A	M
183008ZZZ000005529701A	C
183005ZZZ000005527800A	M
1830083XJ000009000011A	M
183005ZZZ000005528200A	M
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	16 30 08 70974 400 1401
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	16 30 12 94177 027 0010
	16 30 12 94177 027 0020
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2387600006	S	2423510052	C
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2387400001	S		

Private Parcels with Inundated Uplands	Private Parcels with Remaining Uplands
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2135400006	2199700200
2132000007	2137200159
	2239600006
2123700059	679500058
2123700509	2136410053
2123700459	2136700008
2132500055	2136400005
2132500006	2233900006
2132300001	2199700150
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2131700003	681400057
2134810059	2243120009
2133800058	698302304
2134810509	698302353
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2132801009	698900503
680900008	698900057
2130600055	2263500007
2199700101	698301405
2136200009	2243622350
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2423300359
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APPENDIX L

Analysis and Recommendation for Grouping Blue Carbon Projects in Tampa Bay

Analysis and Recommendation for Grouping Blue Carbon Projects in Tampa Bay

By Stefanie Simpson, Restore America's Estuaries
May 2016

The ability of coastal wetlands to sequester and store carbon long term in the soil presents new opportunities to promote and value coastal restoration. In the absence of compliance markets, voluntary carbon markets provide a platform for connecting investors looking to reduce their carbon footprint, with projects yielding a climate benefit. A 2016 study assessed past and potential carbon sequestration and storage values of restoring Tampa Bay habitats (Sheehan et al. 2016), providing local data that can be used to prioritize restoration, enhance coastal management, and develop carbon offset projects. However, cost and scalability are major barriers for coastal offset project development. An alternative project design method called "grouping" allows project developers to aggregate smaller projects in order to achieve economies of scale. This paper describes how to use a grouped project approach and makes recommendations for Tampa Bay stakeholders considering carbon offset projects to support restoration.

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I. Terms to Know

Baseline Scenario – a projection of the status quo or business-as-usual, i.e. during the crediting period without the project.

Carbon Offset/Credit – a unit of measurement equal to one metric ton of carbon dioxide equivalent; results from project activities that reduce and/or prevent atmospheric greenhouse gases and are available to compensate carbon emissions elsewhere through transactions on a carbon market (voluntary or compliance).

Coastal Blue Carbon (Blue Carbon) – the greenhouse gases (GHGs) sequestered by, stored in and released by tidal wetlands including mangroves, marshes, salt barrens, seagrass, and other emergent tidal wetlands; usually refers to the flux of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) within tidal wetland and seagrass systems.

Crediting Period – the time period for which GHG emission reductions or removals generated by the project are eligible for offset/credit issuance.

Grouped Project – a project to which additional instances of the project activity, which meet pre-established eligibility criteria, may be added after initial project validation.

Project Activity Instance (Instance) – a particular set of implemented technologies and/or measures that constitute the minimum unit of activity necessary to comply with the criteria and procedures to the project activity under the methodology applied to the project.

Project Description (PD) – the document describing the geographic areas within which new project instances may be developed and general eligibility criteria for inclusion as a carbon project (i.e. baseline scenario, additionality, non-permanence risk, etc.)

Project Proponent(s) – the individual(s) or organization(s) that has overall control and responsibility for the project together with the owners of the project.

Validation – assessment by a standard-approved validation/verification body (VVB) of a project description to meet rules and requirements.

Verification – periodic independent assessment by a VVB to assess the GHG reductions and removals that have resulted from the project during a monitoring period.

With-project Scenario – a projection of change in GHG reductions or removals due to project activity(s). The estimated climate benefit is determined by comparing the with-project scenario to the baseline scenario for a given geographic area.

II. Introduction

Fueled by an increased understanding of global climate change impacts, companies and governments across the world are investing in ways to reduce greenhouse gas emissions. For those emissions that cannot be avoided, companies, organizations, and individuals may choose to purchase carbon offsets. Carbon offsets or credits are generated by projects that reduce and/or prevent emissions of atmospheric greenhouse gases (GHGs). Increasing interest in carbon offsets has led to the development of standards to provide accounting and verification requirements ensuring generated offsets represent achievable and real emission reductions.

Coastal wetland restoration is among the newest project type established to generate carbon offsets on the voluntary carbon market. Coastal wetlands – seagrass, salt marsh, mangrove and other forested tidal wetlands – are some of the most productive habitats in the world, improving water quality, providing critical habitat, and protecting shorelines from storms. In addition, coastal wetlands are also efficient at sequestering and storing carbon in their soils, where it can remain locked for centuries or more (referred to as 'blue carbon'). Alternatively, the degradation or draining of coastal systems can result in the release of these soil carbon stocks, converting a natural carbon sink to a carbon source. Therefore restoring coastal habitat and preventing habitat degradation can yield a climate benefit. Blue carbon ecosystem services provide an opportunity to add additional value to coastal wetlands and to incorporate coastal restoration and conservation activities into the carbon market. It also has the potential to attract a new type of investor – those interested in global climate benefits.

The Verified Carbon Standard VM0033 Methodology for Tidal Wetland and Seagrass Restoration (Emmer et al. 2015) provides the procedures for measuring, accounting, and verifying GHG reductions in coastal wetlands, allowing coastal restoration activities with a climate benefit to generate offsets. Though not all coastal restoration activities will be appropriate as offset projects, and the potential revenue generated through offset sales generally will not cover the full cost of restoration, blue carbon offset projects can provide support for typically underfunded project components such as monitoring and management and bring additional investors to the table.

One of the barriers for blue carbon offset projects coming to market is the transaction cost associated with registering, monitoring, and verifying project activities. This barrier is particularly relevant for coastal wetlands, as projects can be smaller on an individual parcel scale and geographically dispersed. An aggregated or "grouped" project approach provides an opportunity for projects which may have otherwise been too small to justify the costs needed to receive verified carbon offsets. Smaller projects grouped together can achieve a larger climate benefit than stand-alone projects at a lower overall cost, thus benefiting from economies of scale. In addition to reducing costs, grouping together smaller projects under one project description document also helps streamline the expansion of a project over time. This analysis provides an overview of the benefits of designing a grouped project, specific considerations for planning a grouped project using the VCS VM0033 Methodology, and recommendations for resource managers in Tampa Bay considering the application of blue carbon market incentives.

III. Blue Carbon Potential in Tampa Bay

Coastal wetland activities that can have a climate benefit include conserving the carbon already stored in the ground (avoided conversion), increasing sequestration by restoring or creating new wetlands, and reducing methane emissions by restoring tidal flow to impounded wetlands (increasing salinity to 18-20ppt or higher). It is with these activities in mind that project developers can consider the opportunities for restoration activities in Tampa Bay.

Figure 1: Tampa Bay Estuary Watershed. Courtesy Tampa Bay Estuary Program.

Tampa Bay's coastal wetlands span 400 square miles, stretching from the headwaters of the Hillsborough River to the shorelines of Anna Maria Island. As Florida's largest open-water estuary, Tampa Bay is substantially segmented due to coastal development and infrastructure. Tampa Bay has lost 16,000 acres of seagrass and 5,400 acres of emergent tidal wetlands since the 1950s[i], due primarily to developmental pressures. Sea-level rise is also threatening Tampa's coastal habitats and has been rising at a rate of about an inch per decade[ii]. With the possibility of accelerated sea-level rise due to increased impacts from global climate change, Tampa Bay has set a goal of "restoring the balance" of coastal habitats to levels that existed before the 1950s. One management strategy is to allow room for coastal habitats to migrate landward to keep pace with rising seas; however increasing population and development pressures are squeezing out available land for coastal wetland migration.

Through management efforts and strong community engagement, restoration and habitat quality have improved over the past decade. In 2015, the Tampa Bay Estuary Program announced the recent return of more than 5,000 acres of seagrass meadows, bringing total seagrass extent in Tampa Bay to more than 40,000 acres, exceeding the 38,000-acre restoration goal[iii]. In addition, restoration targets have been defined for salt marsh (6,313 acres), salt barren (1,287 acres), non-forested (17,088 acres) and forested (1,615 acres) freshwater wetlands; while protection targets have been established for existing mangrove and coastal upland habitats (Tampa Bay Estuary Program Habitat Master Plan Update, June 2010; and Master Plan, 2014). The restoration plan specifically targets salt marsh and salt barrens as priorities for restoration as loss of these habitats has been disproportionate compared to other emergent tidal wetlands. However, restoration costs are anticipated to be high for most habitats, and although carbon finance will not pay full restoration costs, it can lead to increased funding from additional sources, provide incentive to land owners to restore or conserve habitat, and support other project components such as monitoring and management.

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[i] Tampa Bay Watch strategic plan: http://www.tampabaywatch.org/PDFs/tbw%20strategic%20plan%20web.pdf
[ii] Tampa Bay Estuary Program: http://www.tbep.org/pdfs/Tampa-Bay-and-Sea-Level-Rise.pdf
[iii] Tampa Bay Estuary Program website; posted 10/02/15 <http://www.tbep.org/news_and_events-whats_new.html>

IV. Process Overview for Developing a Carbon Offset Project

The process of developing a carbon offset project involves many steps. This section provides an overview of this process to serve as a review before detailing additional steps and considerations particular to using a grouped approach. For additional details and information on developing blue carbon offset projects, read *Coastal Blue Carbon in Practice: A manual for using the VCS Methodology for Tidal Wetland and Seagrass Restoration VM0033 (Emmer et al. 2015)*.

Carbon credits are generated by project activities that have a net GHG benefit (projects that result in increased sequestration and/or reduction of GHG emissions). Standard-approved methodologies provide the procedures to account for GHG reductions; the only currently available methodology for tidal wetland activities with application to Tampa Bay is the Verified Carbon Standard VM0033 Methodology for Tidal Wetland and Seagrass Restoration. Tidal wetland restoration projects typically include multiple partners, therefore a project proponent will need to be identified to lead project coordination and development. The project proponent can be an individual, organization, or group of organizations that work together to develop the project description (PD) document. Project activity instance(s) is a particular set of implemented technologies and/or measures applied to the project (i.e. project activities). The project proponent would typically begin with a feasibility study to assess the technical, financial, and legal feasibility of the project. The feasibility study can also help accelerate development of the PD if the project proceeds. The PD details the location, project activity instance(s), and monitoring procedures. The PD also includes demonstration of additionality (the project goes beyond business-as-usual) and that the project meets applicability conditions for the methodology being used. The PD must then be validated by a 3rd party that has been approved by the carbon standard. Once validated, the project can begin generating credits.

V. Benefits of a Grouped Project Approach

The cost for developing and validating a PD as well as all costs to monitor GHG changes will add to the overall cost of a project. Because these costs are largely fixed and do not vary by size of the project, larger projects will have greater economies of scale. However, coastal restoration projects are typically smaller in size (a few hundred acres or smaller), thus transaction costs may be prohibitive for entry into the carbon market. Given the fragmentation of remaining habitat in Tampa Bay, opportunities to develop a carbon offset project will necessitate grouping together multiple projects at smaller scales. Grouping smaller projects can help reduce the burden of transaction costs by allowing a single validation for multiple project instances in a similar or the same geographic area and by combining monitoring and verification procedures.

Using a grouped approach can be advantageous for many reasons. A grouped project approach is ideal for projects that, separately, have small GHG reduction potential, but when grouped together have larger GHG offset potential. Land-use projects like coastal restoration typically include multiple partners, and arranging for all project partners to undertake project activities at the same time can be difficult. Project proponents using a grouped approach can allow the addition of project instances over time, avoiding the need for a single start date; however all grouped project instances must share the same crediting period (typically at least 30 years for land-use projects, but can be up to 100 years) – meaning if the project has a 30 year crediting period starting in year one, project instances starting in year three will be able to generate credits for 27 years. In addition, instead of monitoring each individual project instance, monitoring is performed over the entire area of project instances, spreading this largely fixed cost over a larger project area. This can have a significant impact on reducing overall monitoring costs.

VI. Requirements for Grouping Offset Projects Using VCS Methodologies

Before embarking on developing a blue carbon offset project, restoration sites and activities will need to be clearly identified. Not all restoration projects will yield a climate benefit. Determining if a project will be appropriate as a carbon project is part of the feasibility study, during which time project developers determine the most likely baseline and with-project scenarios. The baseline scenario is the projection of GHG emissions/removals for the project area in the absence of the project activities (business-as-usual). The with-project scenario is a projection of GHG emissions/removals that will occur as a result of project activities. Both scenarios must assess the emissions/removals of greenhouse gases in the project area (e.g. carbon dioxide, methane and/or nitrous oxide). By comparing the with-project scenario to the baseline scenario, the project developer can demonstrate if there will be a net climate benefit (i.e. an increase in GHG removals and/or a decrease in GHG emissions).

Carbon offset projects must also meet general criteria, as established by the standard. The Verified Carbon Standard (VCS) sets the following criteria for methodologies:

- Offsets must be *real* – representing an actual reduction of emissions (demonstrated by rigorous and scientifically sound accounting procedures);
- Offsets must be *additional* – outside of business-as-usual and not part of a regulatory or compliance measure;
- Offsets must be *permanent*, taking sea-level rise into account and mitigating for risk of emission reversals (E.g. VCS requires a portion of the credits to be set aside in a buffer pool to mitigate future risks of emissions reversals due to storms, sea-level rise, etc.); and
- Project methods must be *verified* by an independent 3rd party to ensure proper methods of accounting are followed.

Following a standard-approved methodology (e.g. VM0033 Methodology) will ensure the above criteria are being met. Additionally, the VCS provides a set of rules and procedures for grouping project instances.

Process/requirement	**Details**
Predetermine eligibility	Includes (1) the geographic boundaries for the grouped project, including where any new project activity instances may be added, and (2) establishes criteria for determining eligibility of future project instances.
Complete Initial Validation	Validation is contracted to an approved validation/verification body (VVB) to ensure the requirements of the standard and follows an approved methodology.
Verification	Verification by a VVB of the monitored emission reductions/removals for a specified time period (to verify generated credits).
Add New Instances	New project instances are included during a verification event. The VVB will verify the new instances comply with eligibility criteria and fall with-in the predetermined geographic boundaries (as set out in the PD). New instances are then monitored with other project activities.

Table 1: Summary of general requirements for grouped projects under the Verified Carbon Standard[iv].

Coastal restoration projects will often involve many project partners. Grouped projects require a designated "project aggregator" to lead efforts and keep track of all project documentation. The project aggregator may also be the project proponent. New project proponents may be added to the grouped project, following VCS requirements[v].

For grouped projects, the geographic scope, baseline scenario and eligibility criteria for all instances (initial and future) must be provided in the PD for validation. After validation and project implementation, new project instances can only be added that meet the pre-established criteria.

Geographic Boundaries and Baseline Scenarios

All carbon offset projects require a well-defined geographic area using geodetic polygons. Grouped projects require geographic areas of where initial project instances occur *and* areas where future project instances may occur (even if no initial instance occurs there). A baseline scenario is needed for each geographic area. Since baseline scenarios can vary depending on existing land uses and/or management activities, multiple baseline scenarios may be required. If the geographic area where project activities will take place require multiple baseline scenarios, the area will need to be delineated appropriately so there is only one baseline scenario per defined geographic area. For example, one area may be abandoned with high water tables, thus not emitting CO_2 but emitting CH_4; another area may be drained to varying depths, and thus have various CO_2 emissions. Project developers grouping such areas together for the whole estuary would need to delineate according to existing land use and subsequent baseline. Those instances with a common land use may be grouped together under a common (or as conservative) baseline, and

[iv] VCS Grouped Project requirements listed online at: http://www.v-c-s.org/grouped-projects/
[v] See VCS document: *Registration and Issuance Process* at: http://database.v-c-s.org/program-documents

areas with differing baselines will need to be defined as separate geographic areas. The PD will also designate which instances are permitted to occur in which geographic areas.

Pre-set Eligibility Criteria

The project proponent is responsible for including a set (or several sets) of eligibility criteria upon which the inclusion of new project instances will be determined. As project instances and geographic boundaries can vary, it may be necessary to establish multiple sets of eligibility criteria as well. At minimum, eligibility criteria is to include:

1. Applicability conditions set out in the applied methodology (see Applicability Conditions in the VCS VM0033 Methodology[1]);
2. A baseline (business-as-usual) scenario;
3. Clearly defined geographic boundaries;
4. Technical characteristics, including restoration techniques and measures, quantification, and monitoring criteria, for all project instances; and
5. Demonstration of additionality. (The VCS VM0033 Methodology uses a standardized activity method for demonstrating additionality of projects in the U.S., and has already established additionality for all tidal wetland and seagrass restoration projects in the U.S. which are eligible to use the methodology, and which are not part of a regulatory or compliance measure.)

Assessing Risks

As with all forestry and land use projects, blue carbon projects are subject to non-permanence risks (natural or man-made which are outside the control of the project proponent), such as sea-level rise, that could result in a reversal of emission reductions that have been previously achieved and credited. The VCS requires credits issued to have a permanence of at least 100 years. The project proponent must conduct a risk assessment using the non-permanence tool provided by the VCS to determine the appropriate amount of buffer credits that will be subtracted from the net issuance of credits to the project. Buffer credits are then pooled together at the VCS program level to serve as insurance against reversals in individual projects. When there is a reversal event resulting in a loss of credits, an equivalent amount of buffer credits are cancelled to account for this loss. A non-permanence risk analysis will be assessed for each project geographic area identified in the PD, regardless of whether a grouped approach is taken or not.

Additional risks that may need to be assessed include those that deal with possible externalities caused by the project, such as activity-shifting, market, and ecological leakage. Activity-shifting leakage refers to activities causing GHG emissions being relocated to another location outside of the project boundary (e.g. displacement of land clearing to adjacent habitat). Similarly, market and ecological leakage refer to changes in GHG sources outside of the project area caused by activities inside the project area. The VCS VM0033 Methodology does not allow for projects that could lead to leakage.

Validation and Verification

Once a PD meeting all standard and methodology requirements is developed, it must be validated by a standard-approved validation/verification body[vi] (VVB) at the onset of the project. It is at this time that the general criteria, baseline, geographic area, and monitoring plan are approved. VCS requires new project activity instances to be documented in the monitoring report and audited in the verification report. As new project instances are added (in accordance with the pre-established eligibility criteria), credit can only be claimed from the start of the next verification period.

Summary of Grouped Project Requirements

The project description for a grouped project must include:

1. Defined geographic boundaries for all project instances (initial and future);
2. Baseline scenario and demonstration of additionality for all project instances/geographic areas;
3. Set of eligibility criteria for all future project instances; and
4. Description of the GHG accounting and monitoring procedures for all project instances.

And new project instances must:

1. Occur within one of the geographic areas defined in the PD;
2. Comply with the eligibility criteria in the PD;
3. Be included in the monitoring report;
4. Have clear right of use; and
5. Be validated at time of verification.

VII. Insight from an Afforestation Grouped Project

As there are currently no examples of grouped blue carbon projects, other land use grouped projects can provide insight into project development. The Lower Mississippi Valley Grouped Afforestation project description was prepared for The Nature Conservancy (TNC) by TerraCarbon in August 2012. The project aimed to convert degraded land, including cropland, pasture, and abandoned agricultural land, to bottomland forest. All lands involved in the project enrolled in a USDA conservation program, were planted with native bottomland species, and adopted a conservation easement held by TNC. The initial project instance consisted of 89.4 ha. This grouped project had a start date of October 5, 2011 and an expected crediting period of 32 years (Eaton et al. 2012).

The Nature Conservancy served as the project proponent/aggregator for the *Lower Mississippi Valley Grouped Afforestation Project* registered with the VCS. Non-profits or local community/governmental organizations representing both the community members and the environment make an ideal project proponent as they generally have more flexibility and can address issues more quickly than larger, federal government entities. The project included several offices within TNC, with the help of an independent consultant. A detailed list of proponents (and any other entities involved) was outlined with the respective roles and responsibilities clearly laid out (e.g. overall project management, contracting,

[vi] Validation/verification bodies (VVBs) approved by the Verified Carbon Standard are listed online at: http://www.v-c-s.org/verification-validation/find-vvb

landowner/agency liaison, investor relations, project validation, land purchase negotiations, easement compliance, reporting, etc.).

The Nature Conservancy identified the project area to be located "in the Lower Mississippi Valley within the states of Louisiana, Arkansas, and Mississippi." An overview including description of the project activities and monitoring plan was provided for the entire geographic boundary along with detailed boundary information (including GPS location) for the initial instance and areas for future instances. A baseline scenario was determined for the geographic area, and process for evaluating additionality was established.

Wherever possible, being consistent with technical and monitoring characteristics, as well as rights of use for all project instances in a grouped project, will help streamline documentation. The TNC PD included a list of permitted and prohibited uses for property included in the project area, as well as rights of entry for the project proponents. The PD also included a streamlined monitoring plan with which all project instances must comply. As new project instances are implemented, they are included in monitoring reports with relevant geographic and other information to demonstrate meeting eligibility criteria.

As blue carbon habitats can vary greatly in habitat type and characteristics, determining a baseline may be the most challenging aspect. When determining the baseline scenario for the project geographic area(s), including factors relevant for all project instances (not just the initial instance) will be helpful when adding new instances later. The TNC grouped project provided a baseline scenario for the entire geographic range of the Lower Mississippi Valley, including factors relevant to the initial instance as well as future instances (e.g. use of fire management).

For the TNC project, most of the afforestation activities occurred on privately-owned land, so TNC used carbon finance as an incentive to encourage land owners to adopt conservation easements in exchange for a percentage of carbon benefits, promoting land stewardship and addressing permanence with regard to land-use change. Using this strategy, TNC was able to encourage forestry conservation and restoration on privately-owned land and add in land parcels as additional easements were acquired.

Their monitoring strategy included procedures for measuring GHG removals across all project instances as well as evaluating compliance with conservation easement restrictions, proper protocol followed, and success/failure rate of restoration instances. The monitoring plan also outlined any remediation if deficiencies were discovered, e.g. re-vegetation where survival is below a certain threshold. Once finalized, copies of the monitoring plan were made available at all project areas. In their project documentation, TNC anticipated potential variances for new project instances. For example, new project instances could be added that use fire management, so the project documentation stipulated that any emissions incurred will be accounted for appropriately. Finally, each new project instance was given a unique identifier and incorporated into an overall project tracking system.

Key lessons learned from this project:

- Local non-profit/organization made an ideal project proponent;
- The original project documentation included anticipated variances for new project instances;
- Issues of permanence were addressed for project instances by requiring land owners to adopt conservation easements;
- Copies of monitoring plans were made accessible and applicable at all project locations; and
- Project tracking system kept record of all project instances added over time.

VIII. Remaining Challenges to Grouping Blue Carbon Projects

Though a grouped project approach allows for multiple project instances across a geographic area, there are limitations. Coastal wetlands are dynamic systems that can vary in habitat type, salinity, vegetation, soil type, etc., even across relatively small geographic areas. This can present a challenge to project developers when attempting to group project sites to ease the burden of monitoring. Another challenge is data collection. The VCS VM0033 Methodology allows for the use of published and default data – however default values will likely be too conservative to capture an accurate GHG reduction (potentially limiting the amount of credits that could be generated), and the availability of published data is currently quite limited. In most cases it will be necessary to collect field data to determine baseline and with-project scenarios. Field data collection, though more accurate, is more cost and labor intensive, and the development of validated models and proxies for quantifying emissions reduction remains a high priority research need. Blue carbon projects may take several years to generate significant offset amounts, which may affect investor/landowners' expectations on their return on investment. Finally, while monitoring for a group project can be combined, a system for allocating grouped results to individual project instances (including any reversals) in a fair and equitable way will need to be established and agreed upon during PD development.

IX. Grouping Projects in Tampa Bay

Planning a grouped blue carbon project in Tampa Bay will take forethought and planning, but could result in a higher return on investment for individual coastal restoration carbon finance projects. Although grouped projects allow the addition of instances over time, future instances will need to be fairly well identified when developing the PD (rather than adding in un-planned instances). The project proponent will want to have a good understanding of what, where, and when future project instances may be added to ensure they will be eligible for inclusion in the project.

The 2010 Tampa Bay Estuary Program Habitat Master Plan (and subsequent updates) is a valuable resource that may serve as a useful starting place for identifying restoration sites and activities that could be aggregated for a grouped carbon project. The VCS VM0033 Methodology allows for a variety of restoration activities to be used. Recall that depending on the variety of habitat types and restoration activities, grouped project descriptions may require multiple baseline scenarios with accompanying eligibility criteria.

When considering a grouped carbon project for Tampa Bay, referencing the Habitat Master Plan to identify restoration priority areas that are of similar habitat type is recommended. Listing these priority sites along with the recommended restoration activity can be a useful first step in identifying the size and number of projects that will likely have climate benefits, including those that restore/enhance sequestration, avoid conversion/habitat loss, and reduce emissions. While the project areas are being identified, project proponent(s) can also be working to attract additional project partners and stakeholders by promoting the ecosystem services provided by coastal wetlands, including the blue carbon potential. Then a timeframe for implementation can be developed (i.e. when particular project activities would begin).

The Tampa Bay Estuary Program Habitat Master Plan (2010) identifies the following priorities for restoration efforts:

- Restore low salinity tidal marshes which have been disproportionately impacted from development and other causes of habitat loss;
- Restore and preserve high marsh and coastal upland areas in anticipation of sea-level rise; and
- Increase land acquisitions and/or adoption of easements on privately-owned land where appropriate, targeting identified priority lands for conservation and restoration.

The Habitat Master Plan identifies priority sites for acquisition/restoration, including more than 40,000 acres for restoration on land either publicly owned or held in a public-private partnership. These 40,000+ acres are divided across 59 sites, of which 84% are less than 1000 acres and 52% are less than 100 acres, highlighting a benefit to using a grouped project approach for Tampa Bay restoration and land acquisition projects.

One of the identified challenges to developing a blue carbon offset project is the often limited availability of local habitat carbon storage and GHG emission data. This challenge is partly addressed for Tampa Bay by the recently completed Tampa Bay Blue Carbon Assessment (Sheehan et al. 2016), which provides Tampa-specific carbon sequestration and storage rates. In addition to providing local data values, the report notes that as sea-levels continue to rise, upland habitat will likely be converted to salt marsh; in areas where this increases vegetation, there potentially will be an increase in carbon sequestration. Carbon market incentives may support the conservation of upland areas for salt marsh migration in future habitat adaptation planning. The report also offers suggested management plans that can yield higher carbon sequestration rates, including management actions that focus on: restoring habitats bordering upland areas in order to maintain wetland habitat and associated sequestration into the future; targeting upland areas for acquisition and restoration; and improving water quality to help drive seagrass expansion. These recommended management plans may be considered when identifying potential blue carbon offset projects.

Though stakeholder involvement is strong in Tampa Bay and annual funds are made available for restoration, there is no dedicated source of public funding for habitat restoration. The Habitat Master Plan notes "as public funds become increasingly scarce, the need for a coordinated watershed approach that optimizes available funds – both private and public – for… habitat restoration activities" is evident. In addition to providing additional resources and funding streams to support restoration efforts, market mechanisms like the VCS VM0033 Methodology can support preservation of upland areas for habitat migration by providing an economic incentive for private land owners to adopt easements. With much of the restoration potential in Tampa Bay represented by small, fragmented parcels of available land, the option to group offset projects can enable stakeholders to take advantage of market incentives to further support restoration efforts.

Coastal wetlands provide many benefits to the Tampa area, including resilience to storms and coastal flooding, improved water quality, and habitat for many species including recreational and commercial fish species and endangered and threatened species, such as manatees and sea turtles. Due to the generally high costs of coastal restoration, projects are often conducted piecemeal as funding and other resources become available. The recognition of blue carbon as an important ecosystem service presents an opportunity to engage additional stakeholders within the Tampa Bay area, as well as the wider Florida and Gulf region. Options to group potential blue carbon restoration projects could be pursued at a variety of local, regional, state and Gulf-wide scales. New partners and investors interested in the global climate benefits of blue carbon projects can provide additional resources for restoration projects, helping to support long term management and monitoring at a variety of important ecosystem scales.

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