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KARA R. RADABAUGH, CHRISTINA E. POWELL, AND RYAN P. MOYER, EDITORS

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Cover photograph: *Spartina alterniflora* and *Laguncularia racemosa* in St. Petersburg, Florida.
Photograph by Ryan P. Moyer

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Contents

Scores of fiddler crabs (*Uca* spp.) in a *Spartina alterniflora* salt marsh in New Smyrna Beach, Florida. Photograph by Ryan P. Moyer.

Acknowledgments

This report was funded by a grant from Florida's State Wildlife Grants Program in order to support the study of high-priority coastal habitats in accordance with the State Wildlife Action Plan. The Coastal Habitat Integrated Mapping and Monitoring Program (CHIMMP) was based on the framework established by the Seagrass Integrated Mapping and Monitoring (SIMM) program and reports generated by Laura Yarbro, Paul Carlson Jr., and numerous other contributors from across Florida. The CHIMMP editors wish to thank Amber Whittle, Kathleen OKeife, Andrea Alden, and Caroline Gorga for their support and guidance throughout the course of CHIMMP. We also wish to thank the dozens of scientists and managers from across Florida who contributed directly to the writing of this report and to the many others who provided comments and contributions during the CHIMMP workshops. Christi Santi, a GIS specialist with the Florida Fish and Wildlife Conservation Commission (FWC), created regional maps and calculated wetland acreages for this report. Amber Whittle and Shannon Whaley completed the technical review of the document. Bland Crowder completed scientific review, copy review, and layout. Several FWC coastal wetlands interns and technicians assisted with CHIMMP vegetation monitoring or editing (Amanda Chappel, Ioana Bociu, Allie Wilcox, Barbara Clark, Danielle Pavlik, Joshua Michael, Dana Parkinson, Stuart Penoff, Victoria Manzella, Joshua Breithaupt, Emma Dontis, Taylor Nielsen, and Reba Campbell).

This report is a collaboration among many authors from governmental and independent agencies. The views, statements, findings, conclusions, and recommendations expressed herein are those of the authors and do not necessarily reflect the views of the State of Florida, the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, the U.S. Fish and Wildlife Service, or any of their subagencies.

Coastal Habitat Integrated Mapping and Monitoring Program (CHIMMP)

The Coastal Habitat Integrated Mapping and Monitoring Program, or CHIMMP, was initiated by the Coastal Wetlands Group at the Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute (FWRI) in St. Petersburg, Florida. CHIMMP was based on the framework established by the Seagrass Integrated Mapping and Monitoring (SIMM) program (myfwc.com/research/habitat/seagrasses/projects/active/simm/). The main objectives of CHIMMP were to build a network of collaboration among salt marsh and mangrove mapping and monitoring programs in Florida to identify the status and needs of coastal wetlands and to make recommendations for their management. An additional component of CHIMMP, still under way at the time of the writing of this report, is the side-by-side assessment of a variety of coastal wetland mapping and monitoring techniques.

Three CHIMMP workshops were held at the FWRI in April 2014, September 2015, and January 2017 to bring together coastal wetland scientists and managers from across Florida. Attendees presented their work on current mangrove and salt marsh mapping and monitoring efforts and compiled recommendations for CHIMMP and future coastal wetland endeavors in Florida. The regional boundaries and content for chapters in this report were established based upon recommendations of attendees at the 2014 workshop. See ocean.floridamarine.org/CHIMMP/ for further details concerning the CHIMMP workshops.

Many attendees of the 2014 workshop volunteered to contribute to the regional chapters of this report. Additional report coauthors were added based on regional need and personal recommendations. As a result of the collaborative nature of the report, the style and level of detail vary among chapters based upon contributing authors and regional data availability. Unless otherwise noted, all photographs in this document were taken by the CHIMMP editors for this report.

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See Appendix A for affiliation acronyms

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A mixed forest of mature *Rhizophora mangle, Avicennia germinans,* and *Laguncularia racemosa* (red, black, and white mangroves) in Weedon Island Preserve on Tampa Bay, Florida. Photograph by Ryan P. Moyer.

Executive Summary

Mangrove swamps and salt marshes provide valuable ecological services to coastal ecosystems in Florida. Coastal wetlands are an important nursery for many ecologically and commercially important fish and invertebrates. The vegetation stabilizes shorelines, protecting the coast from wave energy, storm surge, and erosion. Coastal wetlands are also able to filter surface water runoff, removing excess nutrients and many pollutants. Peat deposits sequester large amounts of carbon, making coastal wetlands a key sink in global carbon cycles.

Mangroves and salt marshes, however, are vulnerable to both direct and indirect threats from human development. Current threats include continued habitat loss, hydrologic alteration of surface and groundwater, sea-level rise, and invasive vegetation. Florida has extensive flood control and drainage structures that concentrate freshwater flow, resulting in widely variable salinity in coastal wetlands. From the early to mid-1900s, many coastal wetlands were ditched or impounded in attempts to control the mosquito population, drastically altering local hydrology and increasing the range of tidal influence. Urban and agricultural water demand has also reduced flow of both surface and groundwater, further exacerbating saltwater intrusion in conjunction with sea-level rise. While salt marshes and mangroves can accumulate substrate by trapping sediment and organic deposits, they may be forced to migrate inland if accretion rates cannot keep pace with rising waters. This process may result in reduced habitat extent if coastal wetlands are pinched out by nearby coastal development or sloped topography. Native vegetation must also compete for space against invasive species such as *Schinus terebinthifolius* (Brazilian pepper) and *Casuarina* spp. (Australian pines), which have encroached upon the edges of coastal wetland habitat.

Mangrove and salt marsh ecosystems are often in flux. Marsh vegetation can rapidly overtake regions of

cold-induced mangrove die-offs. As mangroves recover, they slowly shade out the marsh vegetation. In the past few decades, mangrove acreage has increased in many regions of Florida. A recent decreased frequency in cold events has facilitated the northern expansion of mangroves. In southern Florida, mangroves are also encroaching into adjacent inland habitats, particularly salt marshes. The effects of mangrove expansion on coastal wetland ecosystem services are the subject of multiple ongoing research projects throughout Florida. Such projects rely on quality spatial and temporal data of wetland habitat coverage.

According to the 2016 Cooperative Land Cover Map (version 3.2), Florida contains approximately 378,690 acres (153,250 ha) of salt marshes and 571,750 acres (231,380 ha) of mangrove swamp. The Cooperative Land Cover maps are one example of the numerous land cover data sets that include mapping of coastal wetland extent in Florida. These national, state, or local mapping programs use an array of land cover classification techniques. While nomenclature may vary, most of these classification schemes include categories for salt marsh and mangrove habitats. Land cover maps are created by classifying land cover in satellite images or aerial photography. Randomized ground truthing is critical for determining classification accuracy. Areal land classifications may vary widely among mapping data sets, requiring careful awareness on the part of the user, and are often available for only one time period. The land use/land cover (LULC) maps from Florida's water management districts provide the foundation for the most recent mapping data. However, the years when LULC maps were created vary among the districts and refinement of methods can hinder direct comparison of land cover extent over time.

Coastal wetland monitoring programs are often short-lived and vary widely in methodology. Monitoring most commonly occurs on protected public lands or at wetland mitigation or restoration sites. These monitoring projects are rarely long-term due to a lack of funding; restoration sites are generally monitored for only a few years. Although long-term funding is difficult to secure, monitoring over long time scales is increasingly important due to regional uncertainties as to how coastal wetland vegetation and substrate accretion will respond to sea-level rise, altered freshwater hydrology, and other disturbances. While periodic land cover mapping programs can capture large-scale changes in habitat extent, smaller-scale species shifts among mangrove and salt marsh vegetation are best captured by on-the-ground monitoring.

The chapters in this report summarize recent mapping and monitoring programs in each region of Florida. Content of each chapter includes a general introduction to the region, location-specific threats to salt marshes and mangroves, a summary of selected mapping and monitoring programs, and recommendations for protection, management, and monitoring. Land cover maps in this report generally use data from the most recent water management district LULC maps.

Through feedback compiled at the CHIMMP workshops and during the writing of this collaborative report, several needs and recommendations were identified for Florida coastal wetlands:

- Methodologically consistent, long-term statewide monitoring is needed to track coastal wetland responses to altered environmental conditions.
- Land classification schemes are not designed to categorize a mixture of salt marsh and mangrove vegetation. This deficiency hinders tracking mangrove expansion, as mangroves often occur as individuals or clusters in salt marsh vegetation.
- Management of freshwater inflow is key to maintaining appropriate salinity levels for coastal ecosystems.
- Through the early identification of stressed mangroves, managers can address hydrologic issues to prevent or lessen mangrove die-offs induced by poor hydrologic flushing.
- Cooperation is necessary among federal, state, and local governmental agencies and nonprofit groups to coordinate connectivity among preserved lands and to establish buffer zones for landward coastal wetland migration.
- Invasive vegetation encroaches on the boundaries of coastal wetlands. Preventing the further spread of these exotics requires constant effort and vigilance.

Chapter 1
Introduction

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Coastal wetland ecosystems of Florida

Mangrove and salt marsh ecosystems occupy the intertidal zones along the coast of Florida. Salt marshes dominate the coast in northern Florida where temperatures occasionally dip below freezing, while mangroves are predominant in the warmer, southern regions. In much of Florida, the ranges of mangroves and salt marshes overlap, and salt marshes often occur landward of a mangrove fringe (Figure 1.1).

Salt marsh vegetation

Salt marshes, also known as tidal or saltwater marshes, occur along the coastal areas of Florida in regions that are protected from large waves by barrier islands, river mouths, or sloping topography and shallow coastal waters (Wiegert and Freeman 1990). The emergent vegetation in salt marshes is predominantly composed of salt-tolerant grasses, rushes, succulents, and shrubs. Marsh profiles and dominant vegetation vary with climate, wave energy, tidal amplitude, geology, and coastal elevation. A marsh is generally separated into two distinct regions, low marsh and high marsh, based upon frequency of tidal flooding and dominant vegetation. The low marsh is flooded during the daily tidal cycle, while the high marsh is flooded only occasionally, during extremely high tides (Wiegert and Freeman 1990).

Juncus roemerianus (black needlerush) and *Spartina alterniflora* (smooth cordgrass) are the most common plants in Florida salt marshes. *J. roemerianus* and *S. alterniflora* typically grow in monotypic bands with abrupt transitions; *S. alterniflora* is more tolerant of flooding and dominates the low marsh, while *J. roemerianus* tolerates a wider range in soil salinity and dominates the high marsh (Stout 1984, Montague and Wiegert 1990). *S. alterniflora* stands range widely in both height and primary productivity. Shoots are frequently less than 1.6 ft (0.5 m) tall, although along banks of tidal creeks shoots may reach heights of 5–10 ft (1.5–3 m) (Weigart and Freeman 1990). *J. roemerianus* is generally found in the more landward high marsh, but may also be found in tidal creeks and in patches amid *S. alterniflora* on mounds with slightly higher elevation.

Other salt-tolerant plants in salt marshes include *Distichlis spicata* (saltgrass), *Monanthochloe littoralis* (key grass), *Spartina spartinae* (Gulf cordgrass), *Batis maritima* (saltwort), *Sesuvium portulacastrum* (sea purslane) and *Salicornia* spp. (glassworts). For detailed species lists, see Montague and Wiegert 1990 and USFWS 1999. Mangroves may also mix with *J. roemerianus* and *S. alterniflora* (Figures 1.2 and 1.3), especially at the salt marsh–mangrove transition. The high marsh is occupied by a more diverse array of plant species, and inland species of plants may be found intruding onto its landward edge and in regions of slightly higher elevation. The oligohaline marsh, with its low salinity of 0.5–5, is also habitat for vegetation with a lower salinity tolerance.

Figure 1.1. Extent of salt marsh and mangrove habitat within Florida.

Salt barrens (also known as salt pans, salt flats, or salterns) are unvegetated, exposed flats with high soil salinity as a result of salt left behind by evaporated seawater. Similarly, salt marsh algae beds are salt barrens dominated by algae rather than vascular plants. Although they lack the emergent vegetation characteristic of coastal wetlands, salt barrens are often classified as a subcategory of salt marshes within land cover classification schemes or simply included as part of the salt marsh mosaic.

Mangrove vegetation

Florida mangrove communities are composed of three mangrove species, *Rhizophora mangle* (red mangrove), *Avicennia germinans* (black mangrove), and *Laguncularia racemosa* (white mangrove). The closely associated *Conocarpus erectus* (buttonwood tree) is also common in Florida mangrove forests. Mangroves are facultative halophytes, meaning they grow well in brackish and salt water but do not require it for survival (Krauss et

Figure 1.2. An abrupt transition from *Juncus roemerianus* salt marsh to mangroves.

Figure 1.3. Low tide in a low marsh dominated by *Spartina alterniflora* and juvenile mangroves.

Figure 1.4. The prop roots of *Rhizophora mangle* stabilize the tree and provide large surfaces for aeration.

Figure 1.5. The pneumatophore roots of *Avicennia germinans* facilitate oxygen uptake.

al. 2008). Rates of mangrove growth and propagule establishment are highest in low to moderate salinities (Ball et al. 1997, Krauss et al. 2008). The mangroves' adaptations that allow them to cope with frequently inundated soil that is both anaerobic and high in salinity enables them to outcompete other plant species in coastal regions. The shade cast by these tall trees also enables them to outcompete other salt-tolerant species.

Rhizophora mangle grows closest to the water's edge. The large prop roots that extend from its trunk and lower branches (Figure 1.4) stabilize the tree and allow the roots to take in oxygen directly from the air rather than from the coastal soil, which is frequently anaerobic (Scholander et al. 1955, Odum and McIvor 1990). *R. mangle* is a salt excluder; the trees avoid taking up salt via a reverse osmosis process (Scholander 1968, Scott 2004) or by taking up freshwater directly when it is available (Kathiresan and Bingham 2001). *C. erectus, L. racemosa,* and *A. germinans* are all salt excreters and expel salt through glands in their leaves and petioles.

Figure 1.6. Leaf examples of *Rhizophora mangle* (left), *Avicennia germinans* (center), and *Laguncularia racemosa* (right). Upper surfaces of leaves are shown in the top row; lower surfaces are in the bottom row.

Figure 1.7. Excreted salt accumulates on the surface of *Avicennia germinans* leaves.

Avicennia germinans generally grows intermixed with or landward of *R. mangle*. They have an extensive network of cable roots and vertical root projections known as pneumatophores (Figure 1.5) that provide stability and aeration for the trees (Scholander et al. 1955, Scott 2004). The leaves (Figures 1.6 and 1.7), often encrusted in salt, are a shiny green and have small hairs on the lighter-colored underside. *A. germinans* is the most cold tolerant of the Florida mangrove species and can sprout from its root system after cold-induced dieback (Odum and McIvor 1990).

Laguncularia racemosa is generally found intermixed with or at higher elevations than *A. germinans*. *L. racemosa* can occasionally develop vertical roots including pneumatophores or pneumathodes, a slender vertical root that lacks an epidermis (Geissler et al. 2002, Nelson 2011). Also a salt excreter, *L. racemosa* has more oval leaves than the other mangrove species, and extrafloral nectaries on the petiole are visible as small protuberances (Figure 1.6).

Mangrove development is a viviparous process because the embryo germinates and grows as a propagule while still attached to the parent tree. The propagules are dispersed by water currents and can establish quickly in new areas through rapid root growth.

Conocarpus erectus (buttonwood tree) grows on the landward edge of mangrove swamps. The buttonwood tree gets its name from its small green spherical flowers. While not a true mangrove, *C. erectus* is a member of the family Combretaceae along with *L. racemosa* (Nelson 2011). *C. erectus* is salt tolerant, but it does not have a specialized root system or propagules (Odum et al. 1982, Nelson 2011).

Salt marsh and mangrove communities are often in flux with one another (Montague and Odum 1997). Mangrove communities often overtake salt marsh habitat (Figure 1.3), as the herbaceous marsh vegetation cannot survive in the shade of the mangrove trees. Occasional cold events, however, can cause extensive mangrove die-offs, after which salt marsh plants rapidly replace the mangrove swamps. The marsh may once again return to a mangrove-dominated ecosystem after the trees grow back from root stock or the establishment and growth of new mangrove propagules.

Ecological and economic value of salt marsh and mangrove ecosystems

Both mangrove swamps and salt marshes provide ecological and economic value through their ability to stabilize shorelines, support coastal fisheries, sequester carbon, and filter nutrients and other pollutants from runoff (Thayer et al. 1987, Kathiresan and Bingham 2001). The value of the ecosystem services provided by coastal wetlands has been placed at $10,000 per hectare (Barbier et al. 2011, Kirwan and Megonical 2013). Economic value varies widely by location and study, as storm surge protection and surface water treatment may be assessed at a higher value when adjacent to coastal development.

Salt marshes have one of the highest rates of primary production among the world's ecosystems (Montague and Wiegert 1990). Atmospheric carbon is sequestered in plant biomass and buried as peat in both salt marsh and mangrove ecosystems (Table 1.1) (Kathiresan and Bingham 2001, Russell and Greening 2015). Carbon that

Table 1.1. Estimated rates of carbon sequestration and denitrification (mean ± standard error) in selected ecosystems (table adapted from Bowden 1986, Mcleod et al. 2011, and Russel and Greening 2015).

Habitat	Carbon sequestration rate ($gC/m^2/yr$)	Denitrification rate ($gN/m^2/yr$)
Mangrove	226 ± 39	4 ± 2.0
Salt marsh	218 ± 24	1 ± 0.1
Seagrass	138 ± 38	9 ± 2.2
Temperate forest	5.1 ± 1.0	0.1–1
Tropical forest	4.0 ± 0.5	0.3
Boreal forest	4.6 ± 2.1	trace

is captured and sequestered by coastal wetlands and seagrass beds, known as blue carbon, acts as a sink in the global carbon cycle (Cebrian 2002, Kathiresan 2012). Loss of coastal wetlands across the planet may therefore have a significant impact on the global carbon budget. Likewise, the carbon sequestration that takes place as a result of coastal wetland restoration projects can now earn carbon credits for greenhouse gas reductions (VCS 2015).

Coastal wetlands play an important ecological role in the breakdown and biogeochemical cycling of organic matter, nutrients, and even some pollutants. The grasses in salt marshes slow the passage of water, enabling sediment deposition and facilitating nutrient uptake (Hammer 1989, Kathiresan and Bingham 2001, Barbier et al. 2011). Nutrients are not only taken up by plants and algae, but nitrate and nitrite are also converted to atmospheric nitrogen by denitrifying bacteria (Table 1.1). Water that has run through coastal wetlands has a lower nutrient concentration, reducing the need for artificial stormwater treatment (Russel and Greening 2015). Wetlands can also remove low amounts of water pollutants and metals such as iron, copper, and manganese through adsorption to fine-grained sediments and subsequent deposition (Lee et al. 2006). If the sediment is later disturbed, however, these pollutants are again released to the water column (Dyer 1995). While sediments in mangrove swamps can have high concentrations of heavy metals, the mangrove trees themselves maintain a low heavy metal concentration (Kathiresan and Bingham 2001).

Because they are situated on coastal boundaries, mangroves and salt marshes provide essential ecological services to both terrestrial and marine species. The dense vegetation provides a complex habitat that is used as a nursery shelter by many ecologically and commercially important fish and invertebrate species, such as *Centropomus undecimalis* (common snook), *Megalops atlanticus* (tarpon), *Crassostrea virginica* (eastern oyster), *Callinectes sapidus* (blue crab), and coastal shrimp (Lewis et al. 1985, Wiegert and Freeman 1990, Barbier et al. 2011). Both local and migratory birds use salt marshes as feeding and nesting grounds. *Mycteria americana* (Wood Stork), *Platalea ajaja* (Roseate Spoonbill), *Pandion haliaetus* (Osprey), *Tringa semipalmata* (Eastern Willet), and multiple species of herons and egrets use coastal wetlands for foraging or roosting. Salt-tolerant reptiles also use the lush habitat; *Malaclemys terrapin* (diamondback terrapin) and some subspecies of *Nerodia fasciata* (salt marsh snake) reside exclusively in salt marshes and mangroves (Montague and Wiegert 1990).

Salt marshes and mangroves stabilize shorelines, protecting inland ecosystems and human developments from wave energy, storm surge, and erosion (Barbier et al. 2011). While the shorelines of salt marshes are often eroded during large storms, the eroded sediment may be returned to the marshes during calmer intervals (Pethick 1992, Boorman 1999). The dynamic capacity to erode and redeposit sediment can make salt marshes more valuable than sea walls for protecting inland property, but marshes must be sufficiently broad in order to be a resilient storm buffer (King and Lester 1995, Boorman 1999). Mangroves also stabilize shorelines and reduce the wave and wind energy from tropical storms, providing some protection to inland developments (Kathiresan 2012, McIvor et al. 2012).

Common threats to Florida's coastal wetlands

Habitat loss

In the early 1800s Florida had an estimated 20.3 million acres (8.2 million ha) of freshwater and coastal wetlands (Dahl 2005). In the past one hundred years, high rates of coastal development in Florida have been detrimental to both habitat extent and health of coastal ecosystems. Coastal wetlands have been destroyed directly due to residential and commercial development and indirectly by pollution and changes in hydrology. Hefner (1986) estimated that from the mid-1950s to the mid-1970s, before wetlands were protected, 72,000 acres (29,137 ha) of wetlands were lost each year. By the 1980s, an estimated 23% (150,000 acres/60,702 ha) of historical mangrove coverage had been lost to development (Lewis et al. 1985). Governmental regulations such as the Clean Water Act in 1972 helped slow the filling of coastal wetlands (Dahl 2011). From 1985 to 1996, this annual rate of loss decreased to 5,000 acres (2,023 ha) due to the protection efforts of federal, state, and local governments and nongovernmental organizations (Dahl 2005).

Figure 1.8. Dead mangroves at the proposed Fruit Farm Creek mangrove restoration area within the Rookery Bay National Estuarine Research Reserve, Naples, Florida. Photograph by Cynthia Sapp.

Altered hydrology

Hydrology has been drastically altered across Florida by road construction, flood control structures, urban and agricultural water usage, mosquito ditching, and shoreline hardening. Impermeable surfaces and drainage systems concentrate terrestrial runoff, decreasing salinity in many coastal wetlands while concentrating freshwater outflow near culverts and streams (Lee et al. 2006). Seawalls, breakwaters, impoundments and other constructed features also alter hydrologic flow and can cause coastlines to be starved of or inundated by sediment (Bulleri and Chapman 2010). In some regions, blocked tidal flows and resulting stagnant water can slowly kill mangroves, resulting in localized die-offs (Figure 1.8). A lack of flushing can cause stress in the form of stagnation, anoxia, or hypersalinity. Stressed vegetation is more vulnerable to secondary stressors such as fungal infections and excessive herbivory (Silliman et al. 2005, Elmer et al. 2012).

From the 1930s to the 1960s, an extensive array of mosquito ditches was dug to drain marshes in an effort to reduce the *Aedes* spp. (marsh mosquito) population (Montague and Wiegert 1990). In the 1940s, salt marshes were also sprayed with DDT, which decreased the mosquito population until DDT-resistant strains of mosquitoes developed. Salt marshes were also impounded and flooded for mosquito control, as *Aedes* spp. will not lay eggs on standing water. These marsh impoundments altered natural water levels and restricted tidal flow, resulting in the decline of native flora and fauna and the incursion of freshwater species such as *Typha* spp. (cattails) and various species of invasive submerged aquatic vegetation. Impounded marshlands did, however, prove beneficial for some Florida species, particularly wading birds.

Climate change and sea-level rise

Dahl (2011) estimated that 99% of coastal wetland losses from 2004 through 2009 in the contiguous United States were due to saltwater intrusion, storms, land subsidence, sea-level rise, and associated erosion and marine processes. Sea level has crept up at a rate of 2–3 mm/yr over the past 50 years for most locations in Florida (NOAA 2014). Sea-level rise has large implications for salt marshes and mangrove communities as the vegetative community is affected primarily by frequency of tide inundation and salinity (Stout 1984).

Coastal wetlands can accommodate a certain extent of sea-level rise as they accumulate peat and trap sediment washed in by tides or storms. If these feedback mechanisms of vertical substrate accretion, subsurface expansion, and plant growth rate manage to keep up with sea-level rise, they may allow coastal wetlands to maintain their current position (Kirwan and Megonigal 2013). But sea-level rise and the concurrent increase in the salinity of pore water will likely accelerate the decomposition of soil organic matter in regions previously exposed to low salinity. Seawater provides sulfate, which microbes can use as a terminal electron acceptor for the remineralization of organic matter, enabling decomposition in anaerobic environments (Snedaker 1993). Landward salt marsh migration is possible where natural buffer zones of appropriate elevation are present, yet this may be hindered by local topography, urban development, or hardened shorelines such as seawalls or riprap (Montague and Wiegert 1990).

Inland migration of mangrove communities often results in mangroves encroaching on and overtaking salt marsh habitat (Saintilan et al. 2009, Krauss et al. 2011). The extent of mangrove communities increased 35% from 1927 to 2005 in the Ten Thousand Islands National Wildlife Refuge as mangroves overtook adjacent inland habitats (Krauss et al. 2011). This mangrove expansion is attributed to a combination of sea-level rise, altered hydrology, and other interacting factors (Krauss et al. 2011).

Mangroves have expanded their range both landward and northward in Florida (Williams et al. 2014). *A. germinans* expansion northward has been linked to a recent decrease in the frequency of cold events in central to northern Florida (Stevens et al. 2006). Cavanaugh et al. (2014) found a strong correlation between the increase in mangrove cover and the decrease in the number of days on which the temperature fell below −4°C. Mangrove extent north of 27°N latitude has increased in recent decades on the eastern coast of Florida; in some areas the extent of mangroves doubled from 1985 to 2011 (Cavanaugh et al. 2014). Portions of this recent mangrove expansion can be attributed to recovery from cold-event mortalities from the 1960s through the 1980s (Giri and Long 2014). In their northward migration, mangroves encroach on and replace salt marsh habitat. Given continued warming trends, mangroves may overtake salt marsh ecosystems for significant portions of the coast along northeastern Florida and the Gulf of Mexico (Osland et al. 2013). While mangroves support an important and productive ecosystem, local and migratory birds that use salt marshes as foraging and breeding grounds may be disadvantaged by this loss of habitat (Krauss et al. 2011).

Poor water quality

Runoff from urban and agricultural areas brings nutrients, pesticides, herbicides, hydrocarbons, and heavy metals into coastal wetlands (Kathiresan and Bingham 2001, Lee et al. 2006). Salt marshes have also been used directly as dumps for industrial and household pollutants and sewage (Montague and Wiegert 1990, Lee et al. 2006). While wetlands can absorb and utilize nutrients in runoff to a certain extent, high nutrient concentrations can cause eutrophication, hypoxia from the resulting algal blooms, and declines in species diversity (Lee et al. 2006).

Invasive species

Invasive species such as *Schinus terebinthifolius* (Brazilian pepper), *Melaleuca quinquenevria* (melaleuca), and *Casuarina* spp. (Australian pines) are maintaining a persistent presence on the borders of coastal wetland habitat in Florida. Rapid growth of these invasive species often outpaces growth by native marsh plants, particularly after a disturbance such as a hurricane or construction (USFWS 1999). *S. terebinthifolius* can easily take over a region after disturbances and produces chemicals that impede the growth of other plants. *M. quinquenevria* can invade pristine ecosystems; its roots then alter hydrologic patterns by absorbing large amounts of water, effectively excluding other plants. As a tall, salt-tolerant tree, *Casuarina* spp. easily shades out and displaces other species and a dense layer of its needlelike leaves accumulates under the trees, hindering the growth of native seedlings (Batish and Singh 1998).

Illegal trimming of mangroves

While a more minor concern than the previously mentioned threats to coastal wetlands, mangrove trimming practices for waterfront views often do not adhere to the 1996 Mangrove Trimming and Preservation Act. Common improper trimming includes severe hedging, in which the canopy of the mangroves is cut back to form a low hedge with unobstructed waterfront view. Hedging can meet trimming guidelines so long as the upper canopy is preserved, generally leaving at least 6 feet of height (1.83 m). Detailed mangrove trimming guidelines for homeowners are available from the Florida Department of Environmental Protection at www.dep.state.fl.us/water/wetlands/mangroves/docs/Mangrove-Homeowner-Guide.pdf.

Classification of coastal wetlands by remote-sensing techniques

Several techniques are used to categorize land cover and determine the spatial extent of coastal wetlands. Data sources include aerial photography and videography, high- and medium-resolution satellite images, hyperspectral sensors, radar, and LiDAR (Light Detection And Ranging), all of which provide data of variable utility, detail, and cost (Kuenzer et al. 2011). Visual elements of remote sensing images, such as color, gray tones, shadows, texture, and proximal associations, can be used to determine land use and wetland extent (Lyon 2001). Remote sensing of near-infrared light can be used to determine the health of plants. Live plants reflect infrared light; this reflected light is frequently visualized using a red color on aerial images. Healthy plants therefore appear bright pink or magenta, while unhealthy or dead plants appear darker (Lyon 2001, Kuenzer et al. 2011). The normalized difference vegetation index (NDVI) is calculated using visible and near-infrared light to assess vegetative ground cover or biomass. Near-infrared wavelengths are also useful for locating the waterline, as even a small amount of water will absorb infrared light (Lyon 2001).

Remote sensing of coastal wetlands is complicated by the variety of substrates and vegetation that make up these habitats. Leaves, branches, soil, and water are all parts of mangrove ecosystems, yet each has a unique spectral signature. Each mangrove species has unique spectral characteristics; even within a single species the spectral signature can vary with physiology, vitality, age, and season (Blasco et al. 1998, Wang et al. 2008, Kuenzer et al. 2011). Categorization is further complicated by the patchiness of mangrove ecosystems and intermingling with other types of vegetation. Intermittent patches of mangroves can be misclassified as mud flats or residential areas. Widely variable water levels in coastal wetlands due to tidal fluctuation, drought, or floods also make it difficult to discern if differing appearances are due to a change in land use or water level (Gao 1998). Precipitation also affects the appearance of waterways; clear, shallow water may appear dark or reflective, yet after rain the same waterway may be opaque due to suspended sediments (Lyon 2001).

Aerial photography and videography

Aerial photographs provide excellent spatial resolution at relatively low cost. They are extremely useful for local projects or for the creation of highly detailed maps, particularly where wetland extent is narrow or patchy. The availability of historical photographs makes aerial photography a useful tool for the study of changes in land use. Care must be taken, however, because image appearance can vary daily with cloud cover and shadow extent. Seasonal changes and precipitation alter foliage density and color, so it is optimal to compare land-use changes using photos taken at the same time of day and in the same season (Lyon 2001).

Satellite imagery

The use of aerial photography for land use mapping has somewhat declined with the advent of satellite imagery (Kuenzer et al. 2011). Costs increase with spatial coverage, so satellite data are more cost-effective for large-scale projects. Temporal variability in images due to calibration drift or variable sun angle and weather can be smoothed by image preprocessing and compiling images from multiple dates (Lyon 2001). Medium-resolution imagery is useful for general land use mapping and change detection on a large scale, but the spatial and temporal resolution may be too coarse to reveal details such as mangrove species or damage immediately following a hurricane or other extreme event. The medium-resolution images used for mangrove mapping commonly come from the Landsat (land remote-sensing satellite) series (Kuenzer et al. 2011). High-resolution imagery provides greater detail (resolution of 1.6–13 ft/0.5–4 m) than medium-resolution imagery but is more expensive.

Active remote sensing

In active remote sensing, terrestrial features are mapped by measuring the time it takes a pulse of a given wavelength to bounce off of a target and return to the sensor. LiDAR uses visible wavelengths, whereas radar uses microwaves. Unlike passive sensors that depend upon visible light, active radar sensors can be used in cloudy weather and at night (Kuenzer et al. 2011). Because the rapid laser pulses can penetrate gaps in tree canopy and reach the ground, LiDAR is useful for determining tree height and topography beneath mangroves. This technique is less useful in salt marshes as the dense cover of vegetation prevents the laser pulses from reaching the ground (Medeiros et al. 2015).

Image categorization of land use

Land cover categorization is initialized with either unsupervised or supervised classification of a training data set. In supervised classification, a researcher uses a data set of locations with known land cover to determine the spectral signatures of each land cover type. In unsupervised training, a computer algorithm clusters data based upon similar spectral characteristics (Lyon 2001, McCarthy et al. 2015). The accuracy of these preliminary clusters to classify land cover types is then assessed with ground truthing or aerial photographs. Clusters of similar land cover may be merged and the classification system is edited as needed (Gao 1998, Lyon 2001, Kuenzer et al. 2011).

Several methods can be used to analyze change in land use (Lyon 2001). Before categorization, aerial photographs may be transformed into single or multiband images through image enhancement in order to facilitate change detection. Alternatively, a principal components analysis may be used to compress variability from multiple spectral bands into a few principal components (Lyon 2001). In postcategorization methods, two images are categorized into their respective land cover types independently. The resulting land cover maps are then compared to each other to discern changes in land use.

Land cover classification schemes

A variety of land cover classification schemes exists both nationally and within Florida. Some of these classification schemes place greater emphasis on human development, while others focus on vegetation and ecosystem characteristics. Many of these schemes are hierarchical and become more specific at each higher level of classification. Selected statewide and national classification schemes are summarized in Table 1.2 and described in further detail below. In general *C. erectus* is either included as part of a mangrove swamp classification or, in some cases, as a subcategory of mangrove swamps (FNAI 2010). Similarly, salt barrens are included as part of salt marshes, while the Florida Natural Areas Inventory (FNAI) organizes salt barrens as a subcategory of salt marshes (FNAI 2010). Classification schemes may further subdivide mangrove and salt marsh habitats based on plant species composition (FDOT 1999, Kawula 2009, FNAI 2010), mangrove height (Cowardin et al. 1979), and general ecotype regions in Florida (NatureServe 2007). Some classification schemes also include a separate category for scrub mangrove ecosystems in the Florida Keys (Gilbert and Stys 2004, Kawula 2009, FNAI 2010).

Florida land cover classification schemes

The Florida Land Use and Cover Classification System (FLUCCS) was created by the surveying and mapping office of the Florida Department of Transportation (FDOT). The original classifications were published in 1985 (FDOT 1985) and the current wetland categories added in the 1999 revision (FDOT 1999). Florida water management districts (WMDs) use FLUCCS for land classifications and may modify them for their district (SFWMD 2009, SJRWMD 2009). Relevant FLUCCS classifications and their corresponding numbers include the following.

6000 Wetlands: water table meets or exceeds land height for a significant portion of the year
- **6100 Wetland hardwood forests:** 66% or more dominated by wetland hardwood species; freshwater or saltwater
  - **6120 Mangrove swamps:** dominated by mangrove trees, also may include buttonwood, cabbage palm, and sea grape
- **6400 Vegetated nonforested wetlands:** includes freshwater and saltwater marshes
  - **6420 Saltwater marshes:** dominated by specific salt-tolerant vegetation
    - **6421 Cordgrass:** 66% or more of vegetative cover is *Spartina* spp.
    - **6422 Needlerush:** 66% or more of vegetative cover is *J. roemerianus*

The Guide to the Natural Communities of Florida was first published in 1990 by the Florida Natural Areas Inventory (FNAI 1990). In 2010, the guide was updated to provide additional classifications and further information, such as species data, to aid in distinguishing among similar communities. Relevant FNAI 2010 classifications include the following.

Marine and estuarine vegetated wetlands: intertidal or supratidal wetlands with herbaceous or woody plants and salinity >0.5
- **Salt marsh:** herbaceous plants; few shrubs, no trees
  - **Salt flat:** dry, exposed salt marsh with bare soil and high salinity; sparse vegetation
- **Mangrove swamp:** wetland dominated by mangroves and buttonwood
  - **Buttonwood forest:** dominated by buttonwood trees
- **Keys tidal rock barren:** herbaceous vegetation and stunted trees, located on regions with exposed limestone in the Florida Keys

The Florida Fish and Wildlife Conservation Commission (FWC) created Florida land cover maps using 2003 data from Landsat TM (thematic mapper) satellite imagery (Gilbert and Stys 2004, Stys et al. 2004), updating the FWC land cover maps created using 1985–1989 data (Kautz et al. 1993). The 2003 land cover project used unsupervised classification schemes to categorize land cover. The final products included detailed descriptions of 43 land cover categories, published in Gilbert and Stys (2004). Relevant classifications include the following.

Table 1.2. Selected land cover and vegetation classification schemes.

Name	Affiliation	Region	Coastal Wetland Classification Scheme	Reference

Florida Land Use and Cover Classification System (FLUCCS)	Florida Department of Transportation (FDOT)	Florida	Wetlands
			  Wetland hardwood forests
			    Mangrove swamp
			  Vegetated nonforested wetlands
			    Saltwater marshes
			      Cordgrass
			      Needlerush
				FDOT 1999

Guide to the Natural Communities of Florida	Florida Natural Areas Inventory (FNAI)	Florida	Marine and estuarine vegetated wetlands
			  Salt marsh
			    Salt flat
			  Mangrove swamp
			    Buttonwood forest
			  Keys tidal rock barren
				FNAI 2010

Descriptions of Vegetation and Land Cover Types Mapped Using Landsat Imagery	Florida Fish and Wildlife Conservation Commission (FWC)	Florida	Marine and estuarine
			  Salt marsh
			  Mangrove swamp
			  Scrub mangrove (Keys only)
				Gilbert and Stys 2004

Florida Land Cover Classification System	FWC	Florida	Estuarine, intertidal
			  Exposed limestone
			    Vegetated
			      Keys tidal rock barren
			  Tidal marsh
			    Tidal marsh barren
			    Saltwater marshes
			      Cordgrass
			      Needlerush
			  Tidal swamp
			    Mangrove
				Kawula 2009

Vegetation Classification for South Florida Natural Areas	University of Georgia, U.S. National Park Service, South Florida Water Management District	Everglades	Forest
			  Mangrove forest
			Woodland
			  Mangrove woodland
			Shrubland
			  Mangrove shrubland
			Scrub
			  Mangrove scrub
			Marsh
			  Salt marsh
			(partial list; further subdivisions available)
				Rutchey et al. 2006

NatureServe Terrestrial Ecological Classifications	NatureServe, Landfire, The Nature Conservancy	Southeastern United States	Woody wetlands and riparian
			  Caribbean coastal wetland systems
			    South Florida mangrove swamp
			    Southwest Florida perched barriers tidal swamp and lagoon
			Herbaceous wetlands
			  Gulf and Atlantic coastal plain tidal marsh systems
			    Atlantic coastal plain Indian River Lagoon tidal marsh
			    Central Atlantic coastal plain salt and brackish tidal marsh
			    Florida Big Bend salt and brackish tidal marsh
				NatureServe 2007

Table 1.2 (continued). Selected land cover and vegetation classification schemes.

Name	Affiliation	Region	Coastal Wetland Classification Scheme	Reference
Classification of Wetlands and Deepwater Habitat of the United States	U.S. Fish and Wildlife Service	National	Estuarine, intertidal Emergent wetland Persistent Scrub-shrub wetland Broad-leaved evergreen Forested wetland Broad-leaved evergreen	Cowardin et al. 1979
National Vegetation Classification Standard, v. 2	Federal Geographic Data Committee	National	Forest and woodland Tropical moist forest Mangrove Shrubland and grassland Temperate and boreal shrubland and grassland Temperate and boreal salt marsh (partial list, further subdivisions available)	FGDC 2008
National Land Cover Data (NLCD)	U.S. Geological Survey (USGS)	National	Wetlands Woody wetlands Emergent herbaceous wetlands	www.mrlc.gov Vogelmann et al. 1998
Coastal Change Analysis Program (C-CAP) Classification System	National Oceanic and Atmospheric Administration (NOAA)	National	Wetland Marine/estuarine emergent wetland Haline (salt marsh) Mixohaline (brackish marsh) Estuarine woody wetland Evergreen Forest Scrub–shrub Dead	Klemas et al. 1993, Dobson et al. 1995

Marine and estuarine

23. Salt marsh: herbaceous and shrubby wetland in brackish waters

24. Mangrove swamp: dominated by mangroves and buttonwood trees; transitional regions may include salt marsh species

25. Scrub mangrove: few small mangroves (Florida Keys only)

The Florida Land Cover Classification System (Kawula 2009) was developed to create a single land cover classification scheme for Florida by integrating established classification systems. The Florida Land Cover Classification System's hierarchical classification scheme is based on the FNAI's Guide to the Natural Communities of Florida (FNAI 1990), FWC land cover descriptions (Gilbert and Stys 2004, Stys et al. 2004), FLUCCS classifications (FDOT 1999), and modifications made by various WMDs (Kawula 2009, SFWMD 2009, SJRWMD 2009). Relevant classifications (nonvegetated classifications omitted) include the following.

5000 Estuarine

5200 Intertidal

5210 Exposed limestone

5211Vegetated

52111 Keys tidal rock barren: herbaceous vegetation and stunted trees, located on regions with exposed limestone in the Florida Keys

5240 Tidal marsh: wetland inundated by tides daily, dominated by herbaceous plants with few shrub

5241 Tidal marsh barren: exposed, mostly bare dry soil with high salinity

5242 Saltwater marshes: estuarine wetland dominated by specific salt-tolerant plants

52421 Cordgrass

52422 Needlerush

5250 Tidal swamp: wetland dominated by mangroves or buttonwood

5251 Mangrove: coastal hardwood community with mangroves, buttonwood, and associated vegetation

The Vegetation Classification for South Florida Natural Areas is a specialized hierarchical classification system designed for the Everglades and surrounding areas (Rutchey et al. 2006). The system was developed to facilitate tracking vegetation changes as a component of the Comprehensive Everglades Restoration Plan (CERP). It was prepared by the U.S. Geological Survey (USGS) in cooperation with several other agencies (Rutchey et al. 2006). Each of the following categories contains numerous species-specific subgroups, including mixtures of multiple vegetation types. The classification system also includes species-specific categories for common invasive vegetation. Relevant classifications include the following.

Forest (F): high-density (>50% tree canopy cover) stands of trees >5 m (16.4 ft) high
- **Mangrove forest (FM):** regularly flooded forests with mangrove or buttonwood

Woodland (W): low-density stands of trees >5 m (16.4 ft) high
- **Mangrove woodland (WM):** regularly flooded woodland with mangroves and buttonwood

Shrubland (S): high-density stands of trees or shrubs <5 m (16.4 ft) high
- **Mangrove shrubland (SM):** regularly flooded shrubland with mangroves

Scrub (C): dwarf trees or low-density shrubs
- **Mangrove scrub (CM):** regularly flooded scrub with mangroves

Marsh (M): graminoid or herbaceous vegetation in shallow water
- **Salt marsh (MS):** salt-tolerant graminoid or herbaceous vegetation

The NatureServe terrestrial ecological classifications were developed specifically for the southeastern United States (NatureServe 2007). These ecological descriptions were prepared by the nonprofit conservation organizations NatureServe (www.natureserve.org) and The Nature Conservancy (www.nature.org) for LANDFIRE (landscape fire and resource management planning tools), a geospatial program that includes databases, ecological models, and land cover data for use in fire and resource management (www.landfire.gov). This classification system is specific not only to vegetation, but also to regional hydrology, geology, and energy input. Relevant NatureServe classifications include the following.

Woody wetlands and riparian
- **1470 Caribbean coastal wetland systems**
  - **South Florida mangrove swamp:** dominated by mangroves and buttonwood. Soils generally saturated at all times with brackish waters and flooded regularly by tides
  - **Southwest Florida perched barriers tidal swamp and lagoon:** includes mangrove forests with canopies up to 10 m (32 ft) tall and salt marshes. Extends from Tampa Bay to Charlotte Harbor. The term perched refers to elevated barrier islands

Herbaceous wetland
- **1490 Gulf and Atlantic coastal plain tidal marsh systems**
  - **Atlantic coastal plain Indian River Lagoon tidal marsh:** primarily high marshes that are protected by barrier islands along the Indian River lagoon
  - **Central Atlantic coastal plain salt and brackish tidal marsh:** dominated by *S. alterniflora* and *J. roemerianus*; occurs in northern Florida on the Atlantic coast. Has different tides and energy than Gulf coast salt marshes
  - **Florida Big Bend salt and brackish tidal marsh:** salt marshes along Big Bend; has low wave energy

National land cover classification schemes

The previously mentioned classification schemes were created specifically for Florida or the southeastern United States. National classification schemes often classify land cover based on vegetation type rather than by species. The Classification of Wetlands and Deepwater Habitats of the United States, developed by Cowardin et al. (1979) for the U.S. Fish and Wildlife Service, follows this type of general scheme. Relevant classifications include the following.

System: Estuarine (E): impacted by both seawater and freshwater runoff
- **Subsystem: Intertidal (2):** exposed substrate that is flooded by tides
  - **Class: Emergent wetland (EM):** dominated by herbaceous rooted plants, many of them perennial
    - **Subclass: Persistent (1):** plant species persist until the beginning of the next growing season (includes salt marshes)
  - **Class: Scrub-shrub wetland (SS):** dominated by woody vegetation <6 m (19.6 ft) high
    - **Subclass: Broad-leaved evergreen (3):** woody vegetation includes mangroves and other salt-tolerant trees, such as buttonwood

Class: Forested wetland (FO): dominated by woody vegetation >6 m (19.6 ft) high

Subclass: Broad-leaved evergreen (3): see above

The National Vegetation Classification Standard (NVCS, usnvc.org) is a hierarchical system designed by the Federal Geographic Data Committee (FGDC 2008). Relevant classifications include the following.

1. Forest and woodland
- **1.A Tropical moist forest**
  - **1.A.4 Mangrove** (further classifications available based on location and species)

2. Shrubland and grassland
- **2.C. Temperate and boreal shrubland and grassland**
  - **2.C.6 Salt marsh** (further classifications available based on location and species)

National Land Cover Data (NLCD) generated by the USGS uses its own classification system (Vogelmann et al. 1998, Fry et al. 2011). NLCD data sets are of limited utility to this study because the classifications do not differentiate between freshwater and coastal wetlands. Relevant classifications include the following.

4.3 Wetlands
- **4.31 Woody wetlands:** soil periodically saturated with water and vegetation cover is >20% forest or shrubs
- **4.32 Emergent herbaceous wetlands:** soil periodically saturated with water and vegetation cover is >80% perennial herbaceous

The National Oceanic and Atmospheric Administration's (NOAA's) Coastal Change Analysis Program (C-CAP) uses its own classification system. The original classification system was originally described by Klemas et al. (1993), and an updated summary is available in Dobson et al. (1995), which also explains how the land cover categories compare with those of Cowardin et al. (1997). Relevant classifications include the following

2.0 Wetland
- **2.3 Marine/estuarine emergent wetland**
  - **2.31 Haline:** salt marsh where salinity is ≥30
  - **2.32 Mixohaline:** brackish marsh where salinity is 5–30
- **2.4 Estuarine woody wetland**
  - **2.41 Deciduous**
    - **2.411 Forest**
    - **2.412 Scrub–shrub**
    - **2.413 Dead**
  - **2.42 Evergreen**
    - **2.421 Forest**
    - **2.422 Scrub–shrub**
    - **2.423 Dead**
  - **2.43 Mixed**
    - **2.431 Forest**
    - **2.432 Scrub–shrub**
    - **2.433 Dead**

Several of the classification schemes in Florida have crosswalk tables that show equivalent land cover categories among multiple schemes. Due to varying levels of specificity, categories may need to be combined or subdivided in order to translate between schemes. As part of the creation of the Florida Land Cover Classification System, crosswalk tables were made between this scheme and classification schemes from FWC, FLUCCS, and WMD modifications of FLUCCS (Kawula 2009).

Land cover mapping data in Florida

Land use data in Florida are available from a variety of regional, state, and national sources. A listing of data providers is compiled Table 1.3 and summarized in further detail below. This summary is also inclusive of some organizations that modify, enhance, and compile data generated by other providers. Land cover assessments generally relied on the use of satellite imagery or aerial photography. Land use classification schemes vary among agencies.

National land cover data sets

For more than 30 years, the National Wetlands Inventory (NWI) generated and updated highly detailed wetland maps following the Cowardin et al. (1979) classification scheme using a variety of methods and data sources, including aerial images (USFWS 2010). NWI maps are now made available online at www.fws.gov/wetlands/index.html.

The National Gap Analysis Program (GAP), run by the USGS, links together geographic layers of land cover, vertebrate species distribution data, and land conservation status (gapanalysis.usgs.gov). Data sets were created using multiseason Landsat ETM+ (Enhanced Thematic Mapper Plus) imagery from 1999 through 2001 with digital elevation model (DEM) derived datasets to model vegetation. General land cover classes from the

Table 1.3. Selected large-scale providers of coastal wetland land cover data in Florida

Program	Affiliation, region of map extent	Data origin, most recent data	Classification scheme	Reference
National Wetlands Inventory (NWI)	USFWS, national	Composite of multiple data and aerial image sources, 1970s to 2000s	Cowardin et al. 1979	USFWS 2010; www.fws.gov/wetlands
National Gap Analysis Program (GAP)	USGS, national	Southeast Gap Analysis Project, 1999–2001	NatureServe 2007, FGDC 2008	gapanalysis.usgs.gov/
Southeast Gap Analysis Project	USGS and North Carolina State University, southeastern U.S.	Landsat ETM+ and DEM models used to model vegetation classes, 1999–2001	NatureServe 2007, FGDC 2008	www.basic.ncsu.edu/segap/index.html
Wetland Status and Trends	USFWS, national	Remote imagery and randomized sample plots, 2009	Cowardin et al. 1979	Dahl 2005, 2011; www.fws.gov/wetlands/Status-and-Trends/index.html
Coastal Change Analysis Program (C-CAP)	NOAA, national coastline	Landsat 5 TM satellite imagery, 2010	Dobson et al. 1995	coast.noaa.gov/ccapftp/#/
2003 Florida Vegetation and Land Cover	FWC, Florida	Landsat ETM+ satellite imagery, 2003	Gilbert and Stys 2004	Stys et al. 2004, Kautz et al. 2007; ocean.floridamarine.org/mrgis/
Florida Water Management Districts (WMD) Land Use Land Cover (LULC) maps	NWFWMD	Color infrared or true color aerial photography, 2012–2013	FDOT 1999	www.fgdl.org/metadataexplorer/explorer.jsp
	SRWMD	Color infrared or true color aerial photography, 2010–2011	FDOT 1999	www.srwmd.state.fl.us/index.aspx?NID=319
	SWFWMD	Color infrared aerial photography, 2011	FDOT 1999	www.swfwmd.state.fl.us/data/gis/
	SFWMD	Composite of multiple data sources (see SFWMD 2005 for full listing), 2008–2009 (limited extent available for 2011–2013)	FDOT 1999, SFWMD 2009	my.sfwmd.gov/gisapps/sfwmdxwebdc/
	SJRWMD	Color infrared aerial photography, 2009	FDOT 1999, SJRWMD 2009	www.sjrwmd.com/gisdevelopment/docs/themes.html
FWC compilation of WMD mangroves and salt marshes	FWC, Florida	Compilation of WMD data, 1999–2011	FDOT 1999	geodata.myfwc.com/
Gulf of Mexico Data Atlas	NOAA, Gulf of Mexico coast and all of Florida	Mangrove data from FWC compilation of WMD data, wetlands data from NWI, 2000–2005	Mangrove data: FDOT 1999, NWI data: Cowardin et al. 1979	gulfatlas.noaa.gov/
Cooperative Land Cover (CLC) map	FNAI and FWC, Florida	Compiled from FWC 2003 land cover (Stys et al. 2004), WMD, aerial photography, and local data collections, 2003–2011	FNAI 1990, FDOT 1999, Gilbert and Stys 2004, Kawula 2009	Knight et al. 2010; www.fnai.org/LandCover.cfm

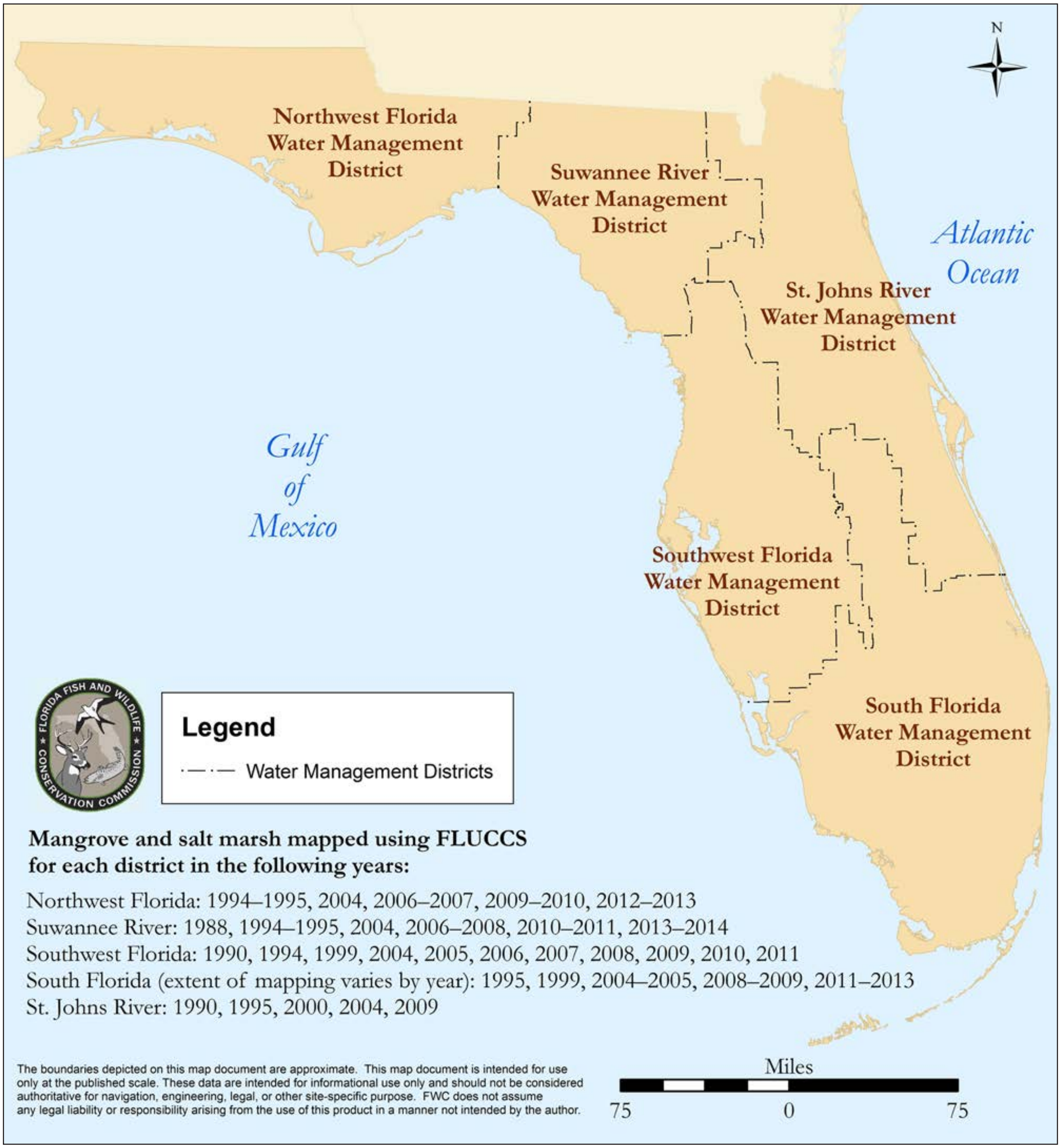

Figure 1.9. Water management districts in Florida.

National Land Cover Data were used (Vogelmann et al. 1998) as well as NatureServe's more specific terrestrial ecological classifications (NatureServe 2007). National GAP data sets are a compilation of data from regional GAP projects; Florida was a component of the Southeast Gap Analysis Project, which was a collaboration between North Carolina State University and the USGS (www.basic.ncsu.edu/segap).

The U.S. Fish and Wildlife Service (USFWS) Wetlands Status and Trends program quantifies the extent of wetlands in the conterminous United States through remote sensing, randomized ground sampling, and statistical estimates (Dahl 2006, 2011). The most recent analysis compares changes in wetland extent from 2004 through 2009 (Dahl 2011) and an older examination of wetlands from 1985 to 1996 is specific to Florida (Dahl 2005).

The Coastal Change Analysis Program (C-CAP), run by the National Oceanic and Atmospheric Administration's Office for Coastal Management, provides regional land cover change information for the coastal United States. Data are acquired via Landsat 5 TM satellite images and classified according to a C-CAP classification scheme (Dobson et al. 1995). For Florida, land cover and trend analysis data are available for 1996, 2001, 2006, and 2010. C-CAP offers downloadable data sets (coast.noaa.gov/ccapftp/#/) and an online mapper (www.coast.noaa.gov/ccapatlas/) that provides county-specific maps and analysis of changes in the extent of freshwater and saltwater marshes.

Statewide and regional land cover data sets

FWC created land cover maps based upon Landsat TM 1985–1989 imagery (Kautz et al. 1993) and completed an updated version based on Landsat ETM+ 2003 imagery (Gilbert and Stys 2004, Stys et al. 2004). The similar methodology used to create the two maps enabled the comparison and analysis of land use change between the two time periods (Kautz et al. 2007).

The Florida water management districts periodically complete their own assessments of land use and land cover (LULC) in their jurisdictions (Figure 1.9). Land cover analysis is based on remote imagery, and classifications are based on FLUCCS (FDOT 1999) categories, sometimes with slight modifications (SFWMD 2009, SJRWMD 2009). Land cover mapping years vary among districts (Figure 1.9). District LULC data are available on the district websites (Table 1.3). Compiled WMD maps of mangrove and salt marsh extent from 1999 through 2011 are available at the FWC Marine Resources Geographic Information System (MRGIS) (ocean.floridamarine.org/mrgis). The WMD land cover maps are often used as the basis for land cover maps generated by other governmental agencies.

NOAA's Gulf of Mexico Data Atlas website (gulfatlas.noaa.gov/) compiles data from other sources. The data atlas includes an online mapping program that enables the viewing of compiled WMD coastal wetland data and NWI wetland land cover data.

The Cooperative Land Cover Map (CLC) was developed as a collaboration between FNAI and FWC to support the goals of the Florida Comprehensive Wildlife Conservation Strategy (FWC 2005, Knight et al. 2010). The CLC project compiled data from various sources and integrated them using aerial photography and local data collections. Data were obtained from the 2003 FWC land cover data set, Florida WMD LULC data, aerial photographs, and interviews with local experts (Knight et al. 2010). Each data set was assigned a confidence category to determine its ranking over other data sets. Due to the diverse array of data sources, multiple land classification systems were used (FNAI 1990, FDOT 1999, Gilbert and Stys 2004). All classifications were crosswalked into the Florida Land Cover Classification System (Kawula 2009).

Table 1.4. Total acres (and hectares) of salt marsh and mangrove swamp in Florida. See Table 1.3 for details on data sources.

Habitat	Florida Water Management Districts LULC maps	FWC 2003 Florida Vegetation and Land Cover	Cooperative Land Cover version 3.2
Salt marsh	385,000 (155,800 ha)	447,400 (181,060 ha)	378,690 (153,250 ha)
Mangrove	606,040 (245,260 ha)	588,320 (225,940 ha)	571,750 (231,380 ha)
Scrub mangrove	-	6,520 (2,640 ha)	-
Keys tidal rock barren	-	-	8,520 (3,450 ha)

Comparison of selected land cover data

Statewide assessments of total salt marsh and mangrove acreage vary among sources. Image types, resolution, classification schemes, minimum mapping units, and interpretation methods vary among agencies, leading to differences in overall acreage assessments. An example of variability in statewide assessments of total acreage of salt marshes and mangroves is shown in Table 1.4. Note some of this variability likely reflects different years of mapping efforts.

Figures 1.10 and 1.11 demonstrate differences between selected land cover data sets. A small section of coastal wetlands in northeast Tampa Bay (Figure 1.10) shows a high degree of similarity between polygon land cover maps developed by the SWFWMD, the Cooperative Land Cover program, and the National Wetlands Inventory. In this region, the NWI category of *persistent estuarine intertidal emergent wetland* directly corresponds to salt marsh and *estuarine intertidal wetlands with scrub–shrub broad-leaved evergreens* directly corresponds to mangroves. More patchy classifications are evident in the raster classification schemes, particularly in the maps created by the National Gap Analysis Program (GAP). Although GAP does have a salt marsh classification category, most of this area was classified as other types of vegetation (Figure 1.10).

Variability between these land cover classification maps becomes more evident in a section of the Ten

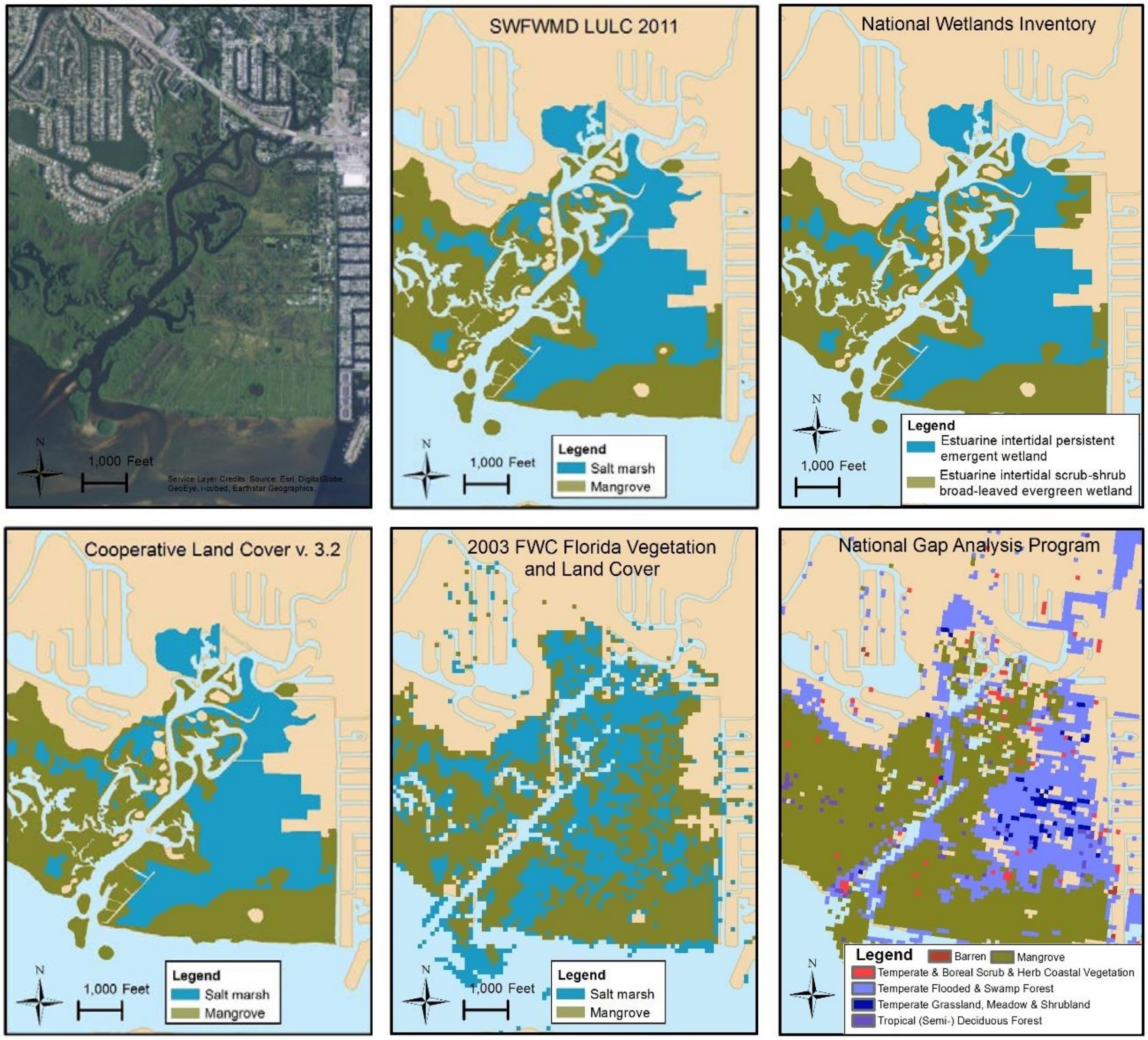

Figure 1.10. Northeast Tampa Bay example of raster and polygon coastal wetland mapping data from various sources. See Table 1.3 for details on data sources.

Thousand Island region in Southwest Florida (Figure 1.11). Maps generated by SFWMD and the Cooperative Land Cover Program are highly similar, since CLC maps utilize data generated by the water management districts as one of their data sources (Knight et al. 2010). The National Wetlands Inventory differentiates between scrub-shrub and forests of mangroves. Even when this differentiation is taken into account, however, the extent of persistent estuarine intertidal emergent wetland is less than that of salt marsh classified in the other maps. The raster 2003 FWC Florida Vegetation and Land Cover is again more fragmented yet presents similar distributions of salt marshes and mangroves, while the National Gap Analysis Program classifies much of the region as freshwater marshes.

Monitoring in coastal wetlands

Wetland monitoring is conducted intermittently throughout Florida through various in situ or remote sensing methods. Coastal wetland monitoring is typically completed in areas that are protected, such as state or national parks, or at sites of wetland mitigation or restoration projects (Figure 1.12). Rarely are these monitoring programs long-term, generally due to insufficient funding or resources (Fancy and Bennetts 2012). The minimum allotted time of monitoring for restoration or mitigation sites is typically 3–5 years, after which monitoring is discontinued because regulatory criteria have been met or funding is no longer available (Thayer et al. 2003, Lewis 2004, Lewis 2005, Lewis and Brown 2014). Although long-term funding is difficult to secure for prolonged monitoring projects, monitoring

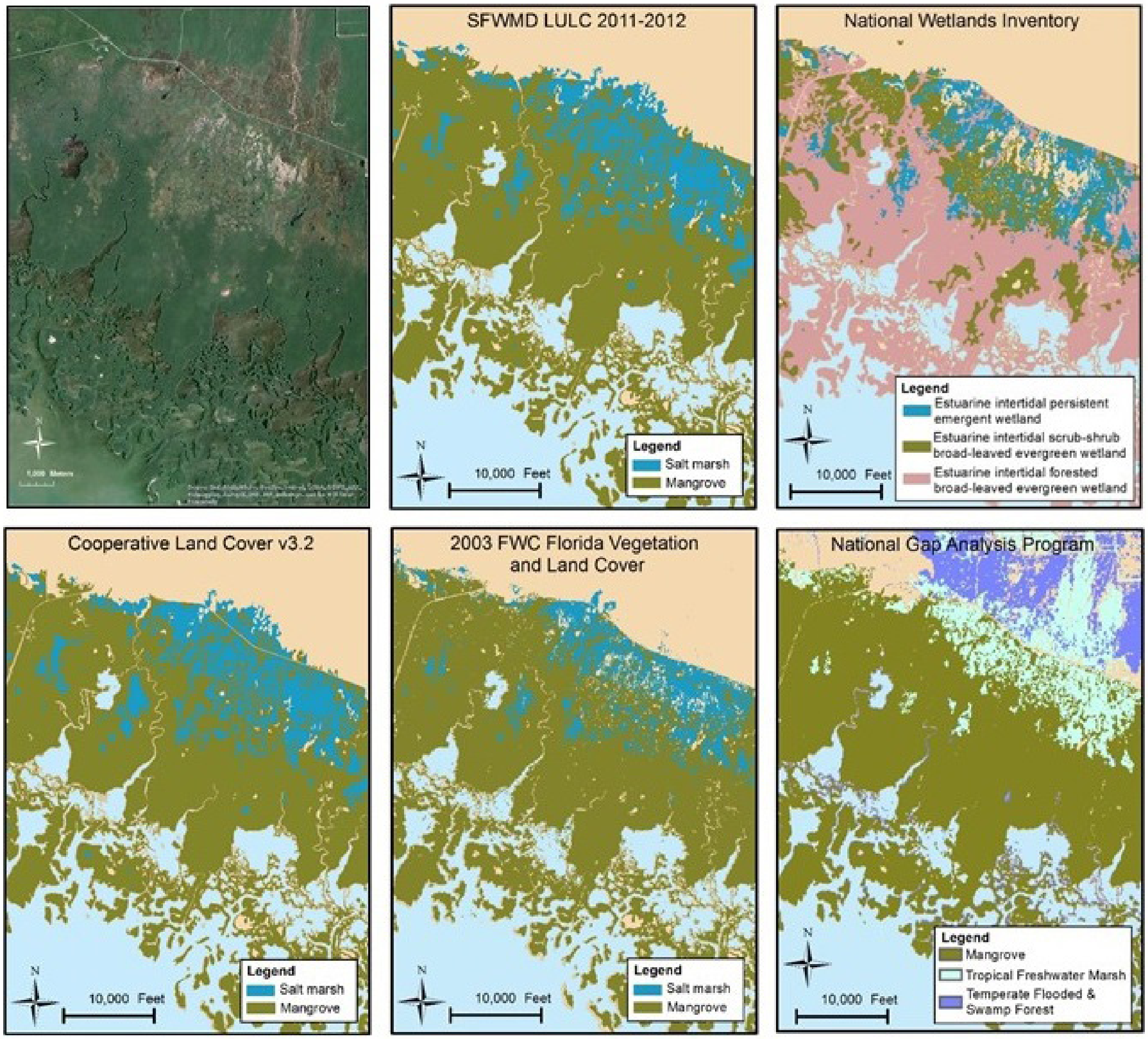

Figure 1.11. Ten Thousand Islands example of raster and polygon coastal wetland mapping data from various sources. See Table 1.3 for details on data sources.

Figure 1.12. A new salt marsh restoration project in Tampa Bay.

over long time scales is increasingly important due to regional uncertainties of how substrate accretion and vegetative growth will respond to sea-level rise, altered freshwater hydrology, and other disturbances. While periodic land cover mapping programs can document changes in habitat and land cover, more subtle, species-specific changes in vegetation coverage within each habitat are best captured by on-the-ground monitoring. Ecological monitoring is also critical in identifying impacts of disturbances, climate change, and altered hydrologic patterns on ecosystem services provided by coastal wetlands.

The protocols used to monitor wetlands differ depending on specific project goals, management questions, and type of wetland. Likewise, methods for monitoring restored or created wetlands can differ between local, state, and federal agencies and nongovernmental organizations. These methodologies also differ greatly from

Table 1.5. Examples of monitoring procedures used for coastal wetlands in Florida.

Name	Association, Region	Focus	Reference
Wetland Assessment Procedure (WAP)	SFWMD and Tampa Bay Water (TBW), Florida	Monitoring isolated wetlands for management considerations	SFWMD and TBW 2005
Wetland Rapid Assessment Procedure (WRAP)	SFWMD, Florida	Rating index for monitoring temporal changes in altered wetlands	Miller and Gunsalus 1997
Monitoring and Assessment Plan (MAP)	Comprehensive Everglades Restoration Plan (CERP), South Florida	MAP is used as a tool to assess CERP	CERP 2004
Uniform Mitigation Assessment Method (UMAM)	Florida Department of Environmental Protection (FDEP), Florida	Methods to assess mitigated habitats in Florida	FDEP 2012
South Florida/Caribbean Network (SFCN) Vital Signs Monitoring Plan	National Park Service (NPS) SFCN, South Florida	Monitor vital signs of national park ecosystems in SFCN, including coastal wetlands	Patterson et al. 2008
Vital Signs Monitoring in the Southeast Coast Inventory & Monitoring Network (SECN I&M)	NPS SECN I&M, Northeast Florida	Monitor vital signs of national park ecosystems in SECN, including coastal wetlands	DeVivo et al. 2008
Nutrient Criteria Technical Guidance Manual: Wetlands	U.S. Environmental Protection Agency (EPA), national	Assessing nutrient status and developing nutrient criteria for wetlands	USEPA 2008
Hydrogeomorphic Methodology (HGM)	U.S. Army Corps of Engineers, EPA, Federal Highway Administration, Natural Resources Conservation Service, and U.S. Fish and Wildlife Service, national	Evaluates wetland functionality and predicts impacts of future changes	USACE 2010
NERRS System-Wide Monitoring Program (SWMP) Vegetation Monitoring Protocol	National Estuarine Research Reserve System (NERRS), national, with 3 reserves in Florida	Long-term estuarine and coastal wetland vegetation monitoring	Moore 2013
Coastal Blue Carbon	The Blue Carbon Initiative, international	Methods to assess carbon stocks and emissions of coastal wetlands and seagrass	Howard et al. 2014
Ecological Mangrove Rehabilitation: A field manual for practitioners	Mangrove Restoration, international	Practical international guide for mangrove rehabilitation and monitoring	Lewis and Brown 2014
Methods for Studying Mangrove Structure	UNESCO Scientific Committee on Ocean Research, international	Field methods to quantify mangrove structure	Cintron and Novelli 1984
Remote sensing procedures (general)	Varied	Use of satellite data, aerial photographs, and LiDAR to monitor wetlands	Kasischke and Bourgeau-Chavez 1997, Ozesmi and Bauer 2002, Dahl 2006, Klemas 2011

those used in long-term monitoring, which seeks to determine long-term trends and responses to natural and anthropogenic changes to the environment. A list of selected monitoring protocols used in Florida is provided in Table 1.5. For a more thorough review of wetland monitoring and sampling methods, see Fennessy et al. (2004), Thayer et al. (2005), or Haering and Galbraith (2010).

Remote sensing can also be used to inventory and monitor wetlands and provides the advantage of wide coverage at lower cost than in situ sampling. Digital satellite data are easily integrated into GIS software, are available for large areas, and supply coverage for annual monitoring for a relatively low cost (Ozesmi and Bauer 2002). For detailed analysis of wetlands, however, aerial photography is preferred because it is easier to differentiate the spectral signatures of various habitats (Ozesmi and Bauer 2002). Remote sensing techniques and methodology vary widely depending on the technology used, research questions, and habitat variability (Kasischke and Bourgeau-Chavez 1997, Ozesmi and Bauer 2002, Dahl 2006, Klemas 2011).

Long-term monitoring of Florida coastal wetlands: examples of two methodologies

1. THE GUANA TOLOMATO MATANZAS NATIONAL ESTUARINE RESEARCH RESERVE

NIKKI DIX, Guana Tolomato Matanzas National Estuarine Research Reserve

The monitoring methods of the Guana Tolomato National Estuarine Research Reserve (GTMNERR) are provided here as an example of an extensive, long-term monitoring program for coastal wetlands. The GTMNERR's primary monitoring goal is to improve understanding of the ecological characteristics of the dynamic community and to discern the impacts of local and global changes on the estuarine ecosystem. Following the National Estuarine Research Reserve System (NERRS) protocols for biological monitoring (Moore 2013), specific objectives are to:

1. Establish permanent emergent intertidal vegetation monitoring sites throughout the estuary spanning the entire north–south gradient of the reserve.
2. Characterize patterns in vegetation species composition, abundance, and cover at multiple temporal and spatial scales.
3. Determine the influence of environmental characteristics on vegetation patterns.
4. Determine the impact of large-scale environmental changes (e.g., climate change, sea-level rise) on the emergent intertidal vegetation community.

Emergent marsh vegetation monitoring

The GTMNERR's emergent intertidal vegetation monitoring protocol is a combination of the NERRS Biological Monitoring protocols (Moore 2013), the National Park Service Southeast Coastal Network (SECN) protocols (Asper and Curtis 2013a, Curtis et al. 2013), and the Louisiana Department of Natural Resources Coastal Resource Division protocol (Folse and West 2004). The SECN protocol was developed in collaboration with NERRS scientists to ensure monitoring compatibility in salt marsh communities throughout the southeastern U.S. Atlantic coast. Sites were selected using a spatially balanced random-sample design developed by the SECN (Byrne 2012).

After examination of potential sampling sites, six permanent emergent transition zone sampling sites were chosen that met the selection criteria (Figure 1.13). Within each of the six sites, three replicate stations were established within a 70-m buffer. Because southeastern U.S. low marshes are easily disturbed by trampling (Turner 1987), permanent platforms were constructed to minimize foot traffic (Figure 1.14). Within each site, three replicate boardwalk systems were constructed, each consisting of two boardwalks, one approximately 9 m long and one approximately 3 m long (both oriented perpendicular to the marsh edge), which are connected during sampling with a removable cross-piece. Each station consists of five permanent 1-m^2 vegetation plots marked with PVC at opposite corners.

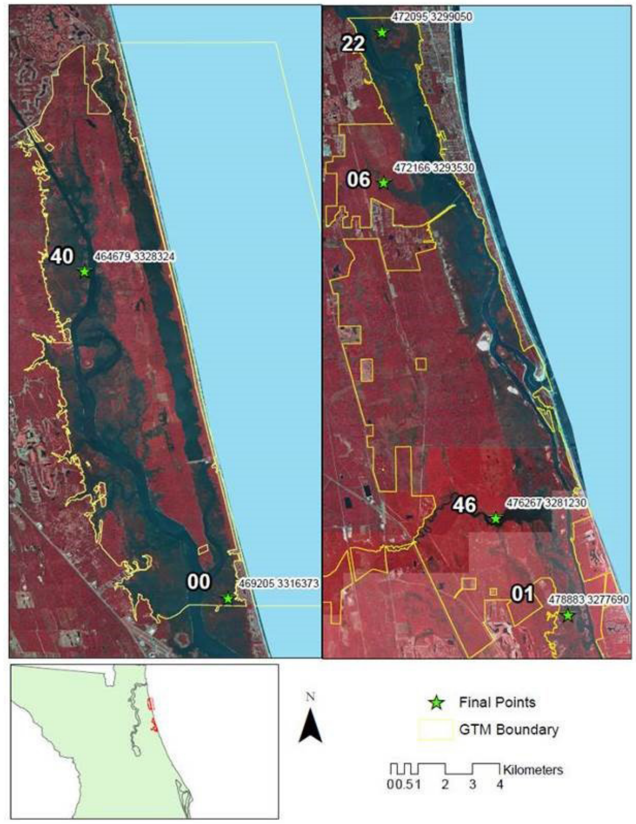

Figure 1.13. Locations of the six emergent-vegetation monitoring sites. At Moses Creek (06) and Pellicer Creek (46) transects extend to the terrestrial transition zone.

At two of the sites (Moses Creek [06] and Pellicer Creek [46]), three replicate transects were extended from the boardwalks to the terrestrial transition zone. Ten permanent 1-m^2 vegetation plots were marked with PVC on each replicate transect. Plots were evenly distributed beginning at 10 m from the shoreline at 10-m (Moses Creek) or 30-m (Pellicer Creek) intervals.

In each vegetation plot, maximum canopy height is determined by averaging the height of the five tallest individuals of the dominant species. Percent cover is de-

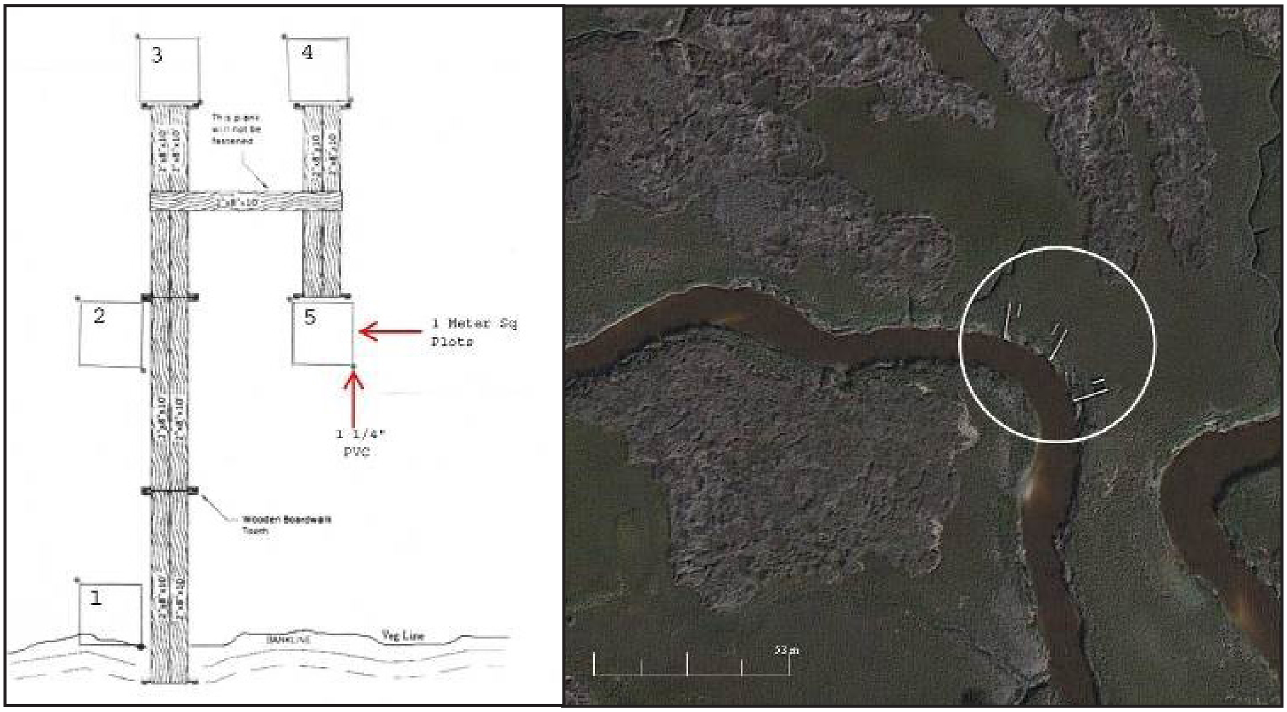

Figure 1.14. Schematic, left, of emergent vegetation platform and emergent platforms, right, located at Moses Creek (06) as seen from aerial imagery. Figure credit: GTMNERR

termined by visual estimates (in 5% increments) in the field as well as by the acquisition of close-to-earth nadir (downward facing) images processed in SamplePoint software (Booth et al. 2006). A lightweight collapsible camera stand (2 m high with a 1- × 1-m base) fabricated to the specifications outlined by Booth et al. (2004) and Curtis (2013) is used to acquire images in the field using a digital SLR camera with a remote trigger (Figure 1.15). The nadir images are cropped with Adobe Photoshop Elements 9 to the inside corners of the camera stand base for a 1-m^2 photo plot (Figure 1.16).

Images are imported into SamplePoint, in which 100 randomly generated pixels are classified to the species level by a biologist. More information on SamplePoint and the image classification process can be found at www.samplepoint.org/SamplePointTutorial.pdf. For species with cover less than 5%, a cover of 1% is assigned in the field. If a species is missed in the field but identified by SamplePoint, or vice versa, a cover of 1% is assigned in the laboratory.

Salt marsh platforms were installed in 2011, and initial measurements were conducted in 2012. Due to a lack of detailed phenological information of salt marsh vegetation in the GTMNERR, sampling was done monthly throughout 2014 to determine peak growing season. Sampling has continued annually, during peak growing season. The intention is to sample salt marsh sites for at least 50 years. Unfortunately, shore-to-upland transect monitoring behind the boardwalks resulted in degradation to the marsh from trampling. Therefore, ground-based shore-to-upland transect monitoring will be postponed until a solution (and necessary funds) for sampling without damaging the marsh can be found.

Figure 1.15. Assembled lightweight camera stand for close-to-earth remote sensing (left) and acquisition of nadir images (right). Photo credit: GTMNERR

Figure 1.16. Vegetation plot images dominated by, from left, *Spartina alterniflora*, *Batis maritima,* and *Juncus roemerianus*, cropped and prepared for processing in SamplePoint. Photo credit: GTMNERR

Figure 1.17. Biologist Jason Lynn lowers the pins of a surface elevation table, or SET. Photo credit: GTMNERR

GTMNERR emergent marsh sediment elevation monitoring

At each of the 18 emergent marsh vegetation monitoring stations, a deep-rod surface elevation table (SET) was installed roughly 6 m from the subtidal creek between the two platforms (Figure 1.17; Cahoon et al. 2002a, 2002b). SETs were installed in 2011, but initial measurements were delayed until 2013. Beginning in January 2014, SET monitoring was conducted monthly for one year, concurrently with salt marsh vegetation monitoring.

Sediment elevation is measured along the arm of the SET by lowering nine pins (Figure 1.17) to the marsh surface and measuring the distance from the arm to the top of the pin. Pin measurements are taken in all four cardinal directions from rod for a total of 36 pin measurements at each SET station.

Beginning in June 2013, concurrently with initial SET measurements, nine accretion/erosion plots per site were established using feldspar horizons (Asper and Curtis 2013b). Feldspar horizons were established by sprinkling white feldspar clay on the wetland surface, where it serves as a visible white marker horizon for cryogenic cores that are taken annually from the date of installation to assess sediment accretion (Cahoon et al. 1996).

GTMNERR mangrove monitoring

Following Moore (2013), the GTMNERR has identified two sites for mangrove monitoring, one on the Guana Peninsula at the northernmost extent of the range of *A. germinans* and one near Matanzas Inlet, where *A. germinans* is prevalent. Protocols are still under development, but initial monitoring efforts have been structured as follows. Each site has two replicate transects consisting of 5 10- × 10-m whole plots (100 m^2) distributed evenly along the transect with five 1-m^2 subplots in each whole plot (total of 25 1-m^2 subplots on each transect) (Figure 1.18).

Mangrove community dynamics are examined at three scales (whole plot, subplot, and individual tree), with specific metrics identified for each level. Together, these multiscale metrics provide comprehensive information on the scrub or shrub mangrove community while minimizing plot disturbance. Specific metrics are described for each level in Moore (2013) as follows:

- **Whole plot:** General characteristics of each of five whole plots along the transect are measured including percent cover (mangrove spp. vs. other) and soil pore-water salinity and temperature (both measured at the time of collection in the field).

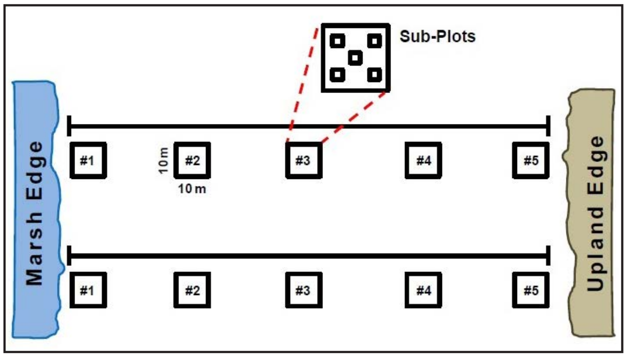

Figure 1.18. Layout of whole plots and subplots along a transect. Figure credit: Moore 2013

- **Subplot:** For each subplot, percent cover (mangrove spp. vs. other) is measured. Mangroves are identified by species and stage (shoot = no branches; tree = has branches). Trunk diameter (mm; ~2 cm above the sediment) and canopy height (cm) are measured for each individual tree. Note: this is different from the standard measure of trunk diameter used for larger mangrove trees, which is diameter at breast height (DBH), measured 1.4 m above the ground surface (Cintron and Novelli 1984).
- **Individual trees:** A subsample of up to 10 of the largest trees for each mangrove species in each whole plot are tagged and the following measurements taken to examine tree architecture (see Moore 2013 for further explanation):
  1. Canopy height (cm): distance from ground surface to top of canopy
  2. Trunk formation: single or multiple trunk
  3. Trunk diameter (mm): diameter just above sediment (~2 cm); if multiple trunks, the largest trunk is measured
  4. Clear height (cm): height from sediment to first branch
  5. Canopy, wide axis (cm): canopy width at the widest point
  6. Canopy, narrow axis (cm): perpendicular to the wide axis, canopy width at the widest point
  7. Canopy offset (cm): the horizontal distance between the trunk and the intersection of the wide and narrow canopy axes
  8. Ground cover: Species present in the area under the tree canopy

The methods described above will enable study of spatial patterns in vegetation at a variety of spatial and temporal scales within Florida NERR habitats. Long-term monitoring of these sites will facilitate determination of the impact of climate change and sea-level rise on abiotic parameters and emergent intertidal vegetation.

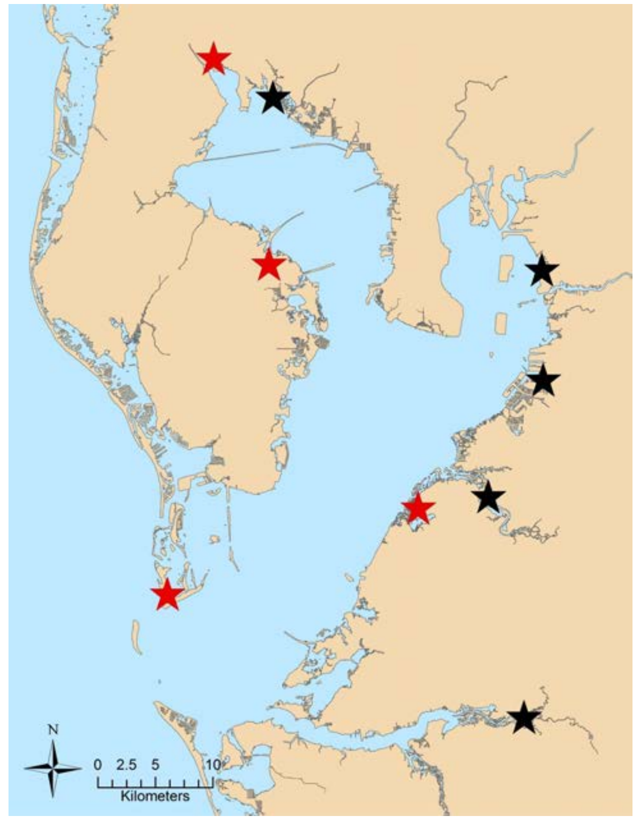

Figure 1.19. Tampa Bay CCHA monitoring sites, shown as black stars (established in 2015) and red stars (established in 2016).

2. CRITICAL COASTAL HABITAT ASSESSMENT MONITORING IN TAMPA BAY

LINDSAY CROSS, Tampa Bay Estuary Program

Methods developed by Doug Robison (Environmental Science Associates), Pamela Latham (Research Planning Inc.), Lindsay Cross, and David Loy (Atkins North America)

The Tampa Bay Estuary Program initiated a long-term monitoring program in 2015 for coastal habitats as part of a larger effort to manage, restore, and protect habitats critical to the ecological function of the Tampa Bay estuary (Sherwood and Greening 2012). The objective of the Critical Coastal Habitat Assessment (CCHA) is to “develop a long-term monitoring program to assess the status, trends, and ecological function of the mosaic

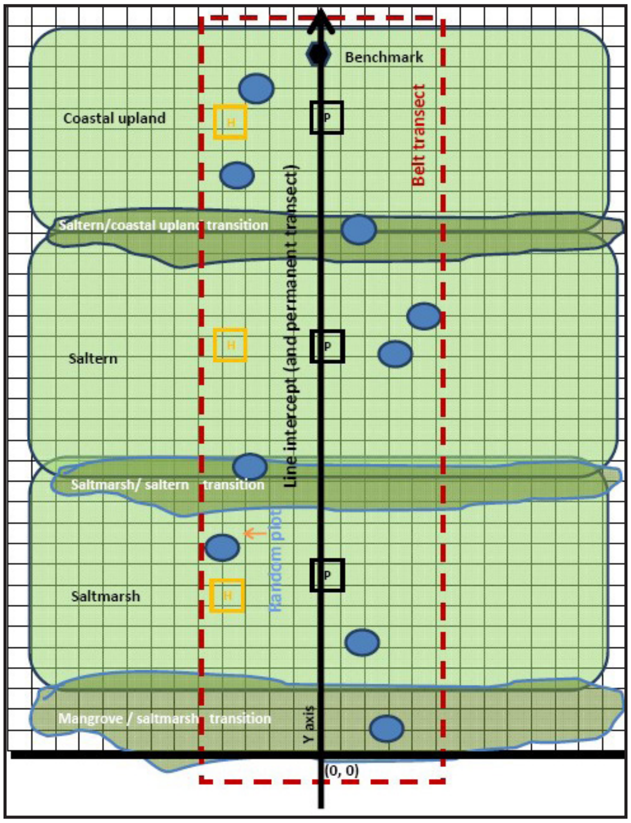

Figure 1.20. Stratified random sampling design with random plots (blue circles) in each vegetation strata (not to scale). Sampling design includes belt transect, line intercept, and individual sample plots. Yellow and black squares indicate soil core and Feldspar horizon (H) and piezometer (P) locations, respectively.

of critical coastal habitats to detect changes due to natural and indirect anthropogenic impacts including sea-level rise and climate change, and improve future management of habitats." This effort will be accomplished through development of a long-term fixed transect program that will characterize baseline (2015–2016) status and detect changes in habitat and ecosystem function over time. Monitoring locations were initially established in 2015 at five sites around the Tampa Bay watershed (Figure 1.19) in protected areas with minimal disturbance that have a full complement of emergent tidal wetland communities including mangrove, salt marsh, salt barrens, and coastal uplands. The CCHA is designed to be a long-term assessment with monitoring occurring every 3–5 years in perpetuity. Transects include randomized quadrats for detailed species analysis as well as a belt transect that that enables verification with aerial photointerpretation and vegetation mapping. The sampling approach is outlined in Figure 1.20.

Figure 1.21. Location of transect at Upper Tampa Bay Park, including mangrove, salt marsh, salt barren, pond, and upland habitats.

Elevation and abiotic parameters

- **Elevation:** Permanent benchmarks were established at the landward and seaward extent of the transect. Elevations were then surveyed along the entire transect at 5-ft (1.5-m) intervals following the FDEP standards for elevation surveys of beach profiles (FDEP 2014). Real-time kinematic (RTK) GPS technology was also evaluated as a survey technique.
- **Interstitial salinity:** Pore water was collected with a one-way hand pump from a freshly augured pit and measured using a conductivity meter, specific gravity meter, or handheld refractometer. Care was taken to ensure that pore water was collected at similar tidal stages across all monitoring sites.
- **Soils:** Soil samples were collected at the same locations as the vegetation samples and feldspar horizons and analyzed for total percent organic content and sediment grain size.
- **Feldspar horizons:** Feldspar marker horizons were placed within each vegetation zone within a 50- × 50-cm plot and at a thickness of approximately 0.25 inch (0.6 cm). Steel rebar was driven into the soil to mark the corners of the feldspar plot. Accretion will be monitored by coring within the feldspar plot every 6–12 months. It is anticipated that four sampling events can be conducted within each marker before replacement will be necessary due to washout in higher-energy areas and bioturbation by fiddler crabs.
- **Location markers:** GPS coordinates were recorded in each vegetation zone and at transitions. Available aerial photography (Figure 1.21), combined with photointerpretation and ground truthing, was used to develop detailed GIS habitat maps of each transect site.

Vegetation monitoring

- **Belt transect:** A belt transect (red dashed outline, Figure 1.20) was established along the entire transect. Percent cover by community type (e.g., mangroves, salt marsh, salt barren, coastal upland) was recorded for each zone.
- **Quadrat sampling along belt transects:** Basal percent cover of vegetation (the area occupied by the base of the plant) was recorded within 0.5- × 0.5-m quadrats along the entire permanent transect (solid black line, Figure 1.20).
- **Randomized quadrats:** Plots 1-m^2 (blue shaded circles, Figure 1.20) were randomly assigned in each habitat and transition zone based on XY coordinates derived from a random-point generator. Species and basal percent cover were recorded for all vegetation to provide measurements of density, frequency, and relative species dominance for each stratum (Figure 1.22).
- **Forest sampling:** Within the mangrove zone, tree sampling data were collected using the Point-Centered Quarter method (PCQ, Cottam and Curtis 1956). In the PCQ method, the distance to the closest tree, species of that tree, and the DBH of that tree are determined within each of four directional quarters. Tree height for the closest tree in each quarter was also collected using either a clinometer (in areas of sparse tree coverage) or an extendable survey rod (in areas of dense tree coverage). Finally, an estimate of percent canopy coverage was obtained using a densitometer.

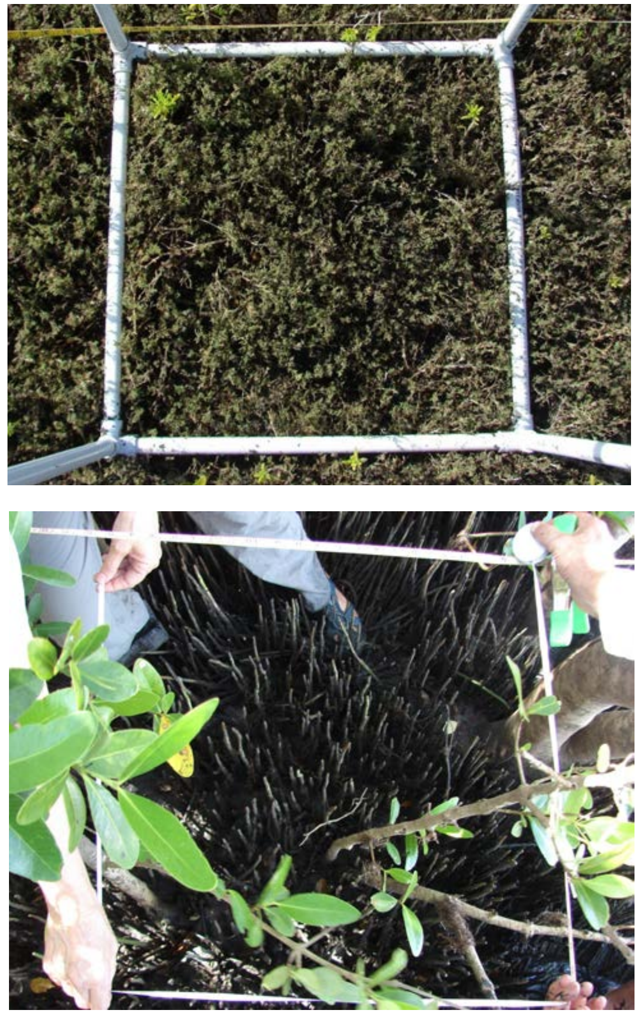

Figure 1.22. Assessing percent cover of vegetation in salt marsh and mangrove portions of the transect.
Photo: Tampa Bay Estuary Program.

Faunal monitoring

Faunal monitoring was conducted in each of the 1-m^2 randomly selected plots. The number of periwinkle snails (*Littorina* spp.) as well as fiddler crabs (*Uca* spp.) and their burrows were counted (Figure 1.23). In the forested zones, observed species of arboreal crabs were also recorded.

Phase 2 expansion of monitoring

A second phase of the project was initiated in 2016 in partnership with TBEP and the Florida Fish and Wildlife Conservation Commission Fish and Wildlife Research Institute. This phase implemented the same methods but incorporated four additional sites around the watershed, including some that have had hydrologic or other anthropogenic impacts, including restoration. This expanded the breadth of data acquired and may address whether habitats in disturbed sites react differently to sea-level rise than areas with less impacts. These additional four study sites are

Figure 1.23. Atlantic sand fiddler crab (*Uca pugilator*).
Photo: Tampa Bay Estuary Program.

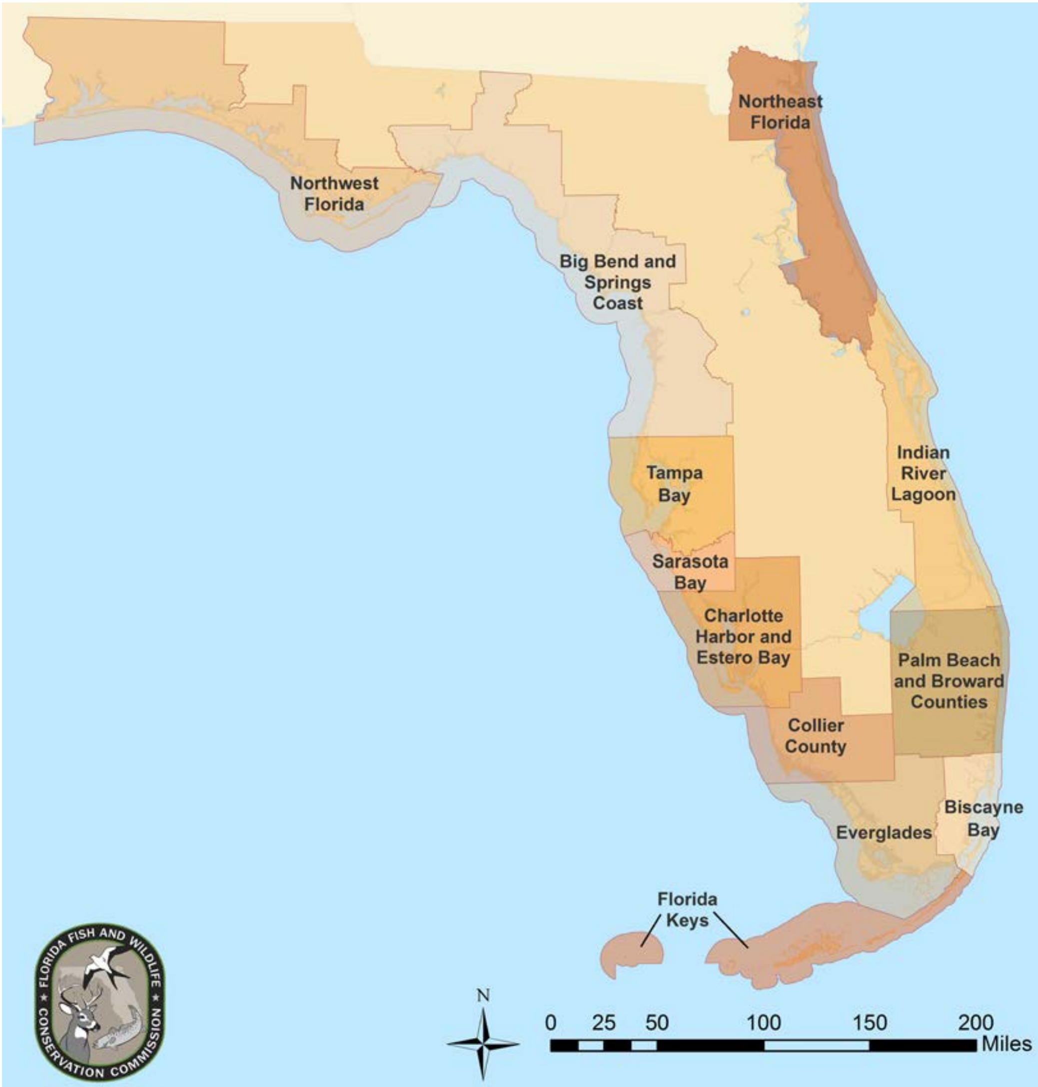

Figure 1.24. Regions of focus for the CHIMMP report chapters.

distributed across western Tampa Bay (see Figure 1.19). In addition, a multimedia training manual will be created that outlines, step-by-step, the methods and field and laboratory protocols used in the Tampa Bay project. This manual, and the other project deliverables, can be used by other agencies in Florida and elsewhere in the Gulf of Mexico to implement similar long-term monitoring programs. Results of the CCHA will be used to inform future management and restoration of habitats in the Tampa Bay watershed, with the goal of improving long-term success of habitat acquisition, restoration, and management.

Monitoring resources

While the majority of coastal wetland monitoring methodologies focus on monitoring restoration or mitigation sites (Table 1.5), long-term studies provide valuable information on vegetative and substrate responses to climate change and sea-level rise. Habitat mapping information provides documentation of large-scale changes in land cover, while complementary in situ monitoring enables study of the fine-scale changes in species composition and sediment characteristics of salt marshes, mangroves, and associated coastal habitats.

Numerous online monitoring resources are available, including portals of compiled monitoring data, statewide and nationwide programs, and general monitoring resources. These resources include:

- Southeast Global Change Monitoring Portal
  my.usgs.gov/gcmp/
- Southeast Coastal Water Quality Monitoring Metadata Project Web Portal
  www.gcrc.uga.edu/wqmeta/
- Governors' South Atlantic Alliance Coastal Wetlands Monitoring Report and Database

southatlanticalliance.org/coastal-wetlands-monitoring-report-and-database/

- Gulf Coast Prairie Landscape Conservation Collective Gulf Coast Vulnerability Assessment: gulfcoastprairielcc.org/science/science-projects/gulf-coast-vulnerability-assessment/
- Mangrove, Tidal Emergent Marsh, Barrier Islands, and Oyster Reef section: gulfcoastprairielcc.org/media/28948/gcva_11162015_final-2.pdf
- Gulf Coastal Plains and Ozarks Landscape Conservation Collective Surface Elevation Table Inventory for the Northern Gulf of Mexico: gcpolcc.databasin.org/datasets/6a71b8fb60224720b903c770b8a93929
- EPA National Wetland Condition Assessment: www.epa.gov/national-aquatic-resource-surveys/national-wetland-condition-assessment
- EPA Wetlands Monitoring and Assessment: www.epa.gov/wetlands/wetlands-monitoring-and-assessment
- National Estuarine Research Reserve System vegetation monitoring overview and data: cdmo.baruch.sc.edu/get/vegetation_index.html
- Restore America's Estuaries Blue Carbon Resources: www.estuaries.org/bluecarbon-resources
- FDEP overview of the wetland and other surface water regulatory and proprietary programs in Florida: www.dep.state.fl.us/water/wetlands/docs/erp/overview.pdf
- FDEP State of Florida Wetland Program Plan (program under way since 2013): www.epa.gov/sites/production/files/2015-10/documents/fl-wpp-2013.pdf. Projects in this plan include the Florida Wetlands Integrity Dataset: www.aswm.org/pdf_lib/mapping_webinar/fl_wetland_integrity_dataset_humphreys_mahjoor_091615.pdf
- Mangrove Restoration and Monitoring Resources: www.mangroverestoration.com/html/downloads.html

Region-specific chapters

The remainder of this report documents region-specific ecosystems, monitoring, and mapping programs across Florida. The 12 CHIMMP regions are separated as shown in Figure 1.24. Each chapter includes a general introduction to the region, location-specific threats to salt marshes and mangroves, a summary of selected mapping and monitoring programs, and recommendations for future protection, management, and monitoring.

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Chapter 2
Northwest Florida

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Description of the region

The numerous bays, peninsulas, barrier islands, and tidal creeks along the coast of northwest Florida create a circuitous coastline that provides extensive habitat for coastal wetlands (Figures 2.1 and 2.2). The region is characterized by low elevation and gentle topography. Variable past sea levels have left behind relict bars and dunes, and the predominantly sandy soils are moderately to poorly drained (FDEP 2008). The shoreline is dynamic; wave action, particularly that from tropical storms and hurricanes, continually reshapes the coastline and barrier islands. Salt marshes line the edges of bays and the shoreward side of barrier islands, where they are protected from Gulf of Mexico wave energy. In addition to providing habitat to a large array of animals, salt marshes also help stabilize the barrier islands and bay shorelines. The extensive seagrass beds found in many of the bays are made possible, in part, by the filtration of terrestrial runoff by salt marshes.

Marshes found in northwest Florida include freshwater, brackish, and salt marshes. Salt marsh vegetation is dominated by *Juncus roemerianus* (black needlerush), *Spartina alterniflora* (saltmarsh cordgrass), *Spartina patens* (saltmeadow hay or cordgrass), and *Distichlis spicata* (salt grass) (Livingston 1984, Handley et al. 2013, ANERR 2014). The transitional zone includes *S. patens*, *Sarcocornia ambigua* (perennial glasswort), *Scirpus pungens* (three-square bulrush), and *Baccharis* spp. (sea myrtle/groundsel shrubs) (Edmiston 2008, ANERR 2014). Inland oligohaline and freshwater marshes are dominated by *Scirpus* spp. (bulrushes), *Cladium jamaicense* (sawgrass), *Phragmites australis* (common reed), and *Typha* spp. (cattails) (FDEP 2012a, Handley et al. 2013, ANERR 2014).

Freezing temperatures in the winter limit the extensive proliferation of mangrove forests along the coast of northwest Florida. Mangrove trees, particularly the more cold-tolerant *Avicennia germinans* (black mangrove), do occur individually and in small clusters, but heavy freezes periodically cause massive diebacks. Cold winters in the 1980s led to 95–98% mortality of the mangroves in the northern Gulf, but more recently cold events have been less frequent, which has led to an expansion of mangroves in the area (Saintilan et al. 2014).

Northwest Florida has less urban development than southern Florida, but certain regions are growing rapidly in popularity as tourist destinations and retirement communities. Important economic components include fishing, shellfish harvesting, tourism, the military, agriculture, and forestry (Handley et al. 2013, ANERR 2014).

Subterranean water sources include the Floridan aquifer, the sand-and-gravel aquifer, and the surficial aquifer system. The watersheds of northwest Florida contain a high density of streams and extend north into portions of Georgia and Alabama. While the rivers have comparatively few flow-altering structures, the bays have been altered by shipping channels and by the opening and stabilization of tidal inlets to the Gulf. The U.S. Army Corps

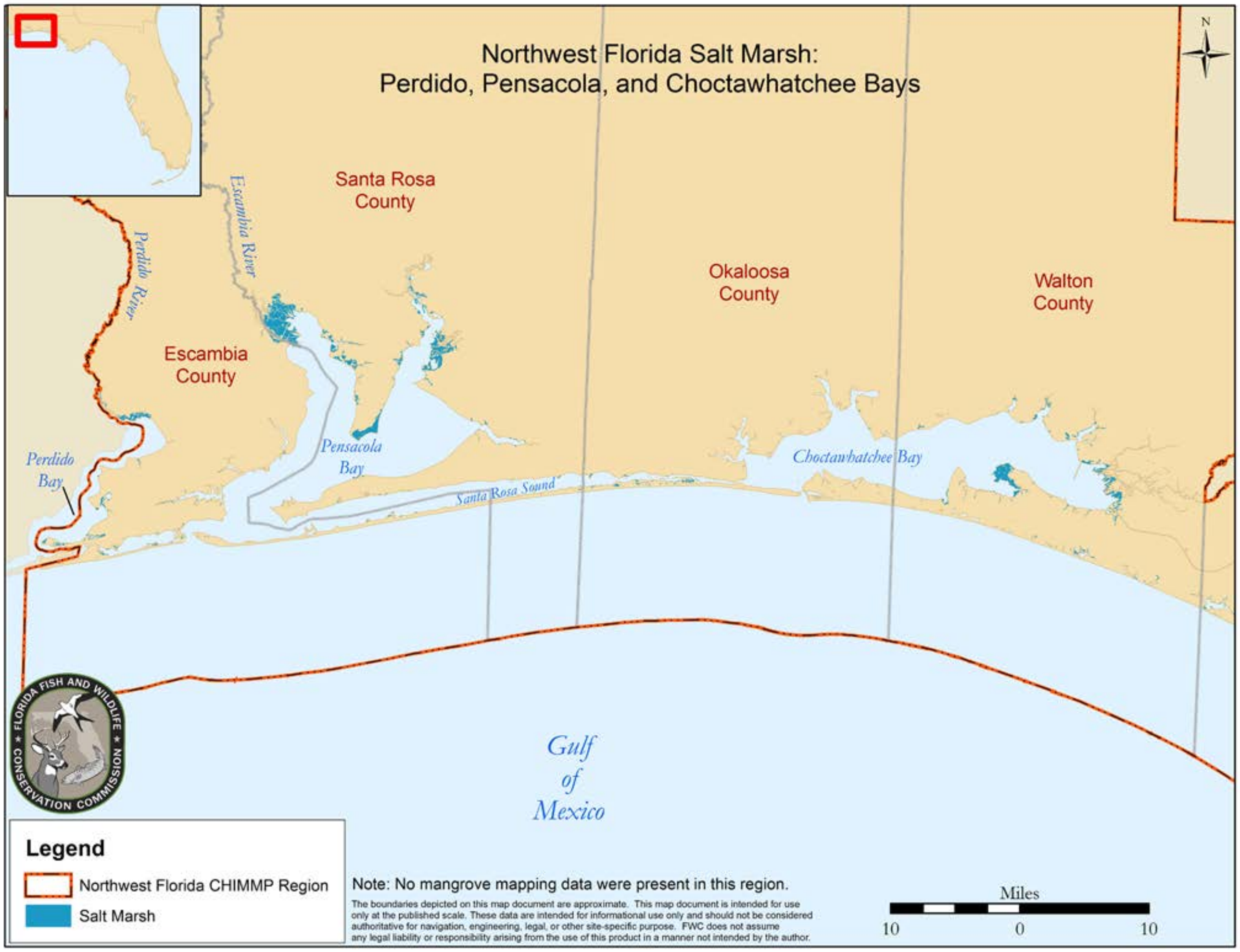

Figure 2.1. Salt marsh extent in northwest Florida. Data source: NWFWMD 2009–2010 land use/land cover data, based on FLUCCS classifications (FDOT 1999, NWFWMD 2010).

of Engineers constructed the Gulf Intracoastal Waterway around 1950, creating inland connections between Choctawhatchee Bay, St. Andrew Bay, Lake Wimico, and Apalachicola Bay (Brin and Handley 2007).

Perdido Bay

Perdido Bay lies on the border between Florida and Alabama and receives freshwater flow from the Perdido River (Figures 2.1 and 2.3). Extensive development lines the barrier islands and shorelines near the mouth of Perdido Bay. *J. roemerianus* salt marshes are found lining the shoreline of Tarkiln Bayou and along the mouth of the Perdido River. According to historical photos, Perdido Key once had a large area of salt marsh, much of which has been lost to erosion, leaving only an intermittent stretch of salt marsh just 1–4 ft (0.3–1.2 m) wide (FDEP 2006).

Overall, the watershed has fairly good water quality, with the exception of some point-source discharges into Elevenmile Creek and nonpoint-source discharges along development on the southern end (NWFWMD 2006a). High nutrient levels, biological oxygen demand, and coliform bacteria stemming from both point- and nonpoint-source pollution are the region's most common water quality problems (FDEP 2006).

Pensacola Bay System

The Pensacola Bay System includes Santa Rosa Sound, Pensacola, Blackwater, East, and Escambia Bays and several bayous (Figures 2.1 and 2.3). The bay receives freshwater flow from the Escambia, Conecuh, Blackwater, and Yellow rivers. More than 70% of the watershed is forested; the remainder contains agriculture and urban development (FDEP 2012a). The northern and eastern regions of Pensacola Bay are shallow (average depth 10 ft/3 m) and are often stratified (FDEP 2012a). *J. roemerianus* and *S. alterniflora* salt marshes proliferate in the lower reaches of the river flood plains. The bay opens to the Gulf of Mexico at the half-mile-wide Pensacola Pass.

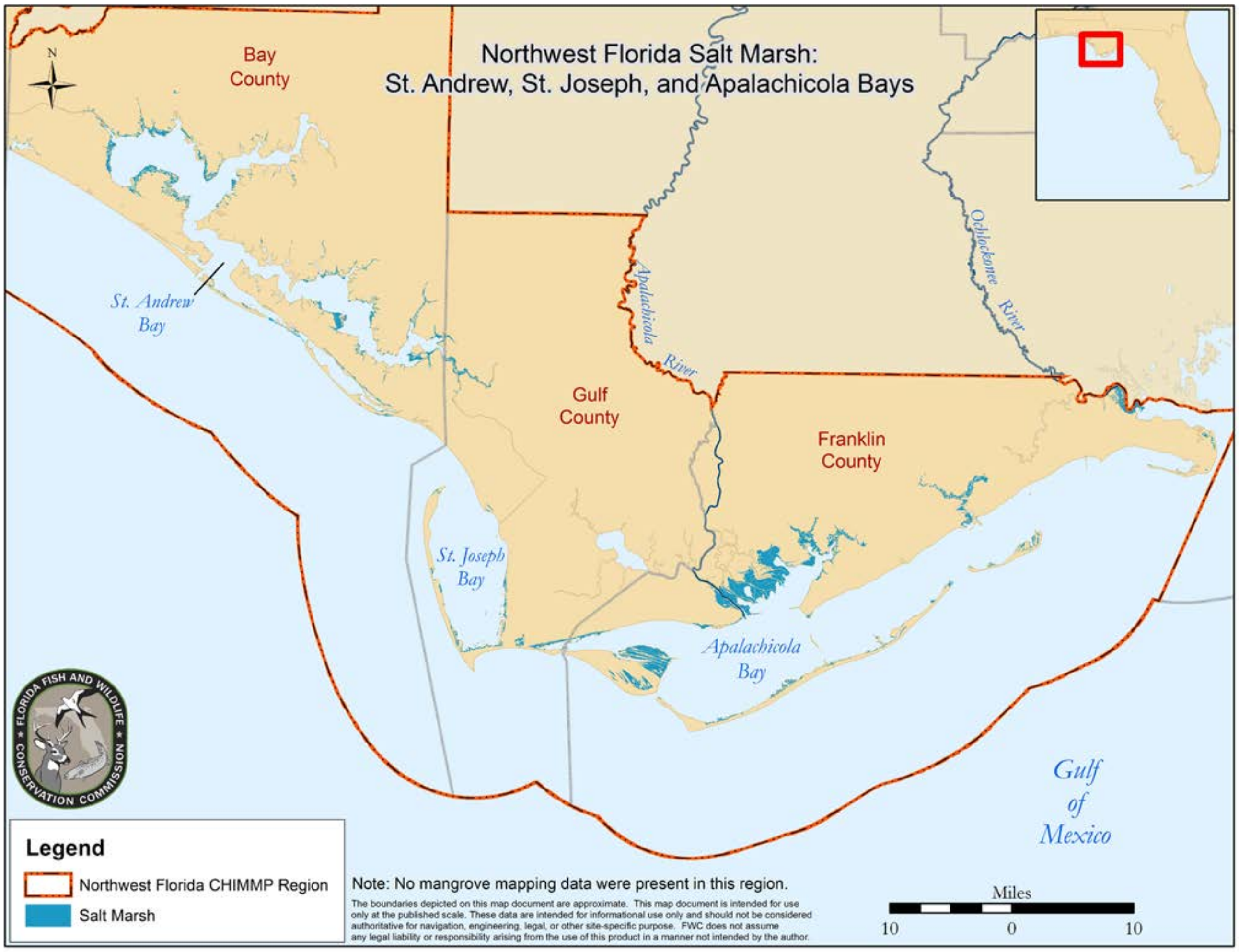

Figure 2.2. Salt marsh extent in northwest Florida. Data source: NWFWMD 2009-2010 land use/land cover data, based on FLUCCS classifications (FDOT 1999, NWFWMD 2010).

Discharge of wastewater into Pensacola Bay was a large problem from the 1950s through the 1970s, but water quality has improved significantly since passage of the Clean Water Act and implementation of best land-use practices (USEPA 2004, FDEP 2012a). Water quality concerns continue regarding nutrients, chlorophyll, and clarity near Pensacola and other urban areas (USEPA 2004). Wetlands have been subject to fragmentation and conversion to other land-use types along with secondary impacts of neighboring development (NWFWMD 2006a). From 1979 through 1996, the Pensacola Bay System lost 7% (2000 acres/809 ha) of surrounding wetland habitat to coastal development, sea-level rise, coastal subsidence, and erosion (USEPA 2004).

Choctawhatchee Bay

The primary source of freshwater to Choctawhatchee Bay is the Choctawhatchee River, the watershed of which extends north into Alabama (Figures 2.1 and 2.4). Salinity fluctuates with input from the river, and the bay is generally stratified with a halocline (Ruth and Handley 2007). Choctawhatchee Bay connects to Santa Rosa Sound, the Gulf Intracoastal Waterway, and to the Gulf at the relatively small East Pass. Historically the pass only opened intermittently, but it was dredged in 1929 to provide relief from flooding and the Corps of Engineers has maintained the pass since then to keep it open (Ruth and Handley 2007). After the East Pass was opened, higher salinities, stratification, and altered erosion patterns resulted in the loss of salt marsh and seagrasses in the bay (Livingston 2014). These changes may help explain why the salt marsh fringe of Choctawhatchee Bay is less extensive than that in other bays in northwest Florida (Reyer et al. 1988, Livingston 2014).

The human population is growing rapidly around Choctawhatchee Bay, frequently outpacing statewide growth rates (Ruth and Handley 2007, U.S. Census 2015). Development is increasing in association with businesses supporting Eglin Air Force Base and with an increasingly

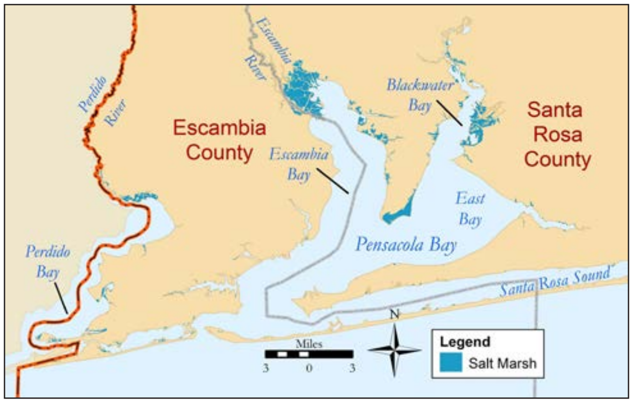

Figure 2.3. Salt marsh extent in Perdido and Pensacola Bays. Data source: NWFWMD 2009–2010 land use/land cover data (NWFWMD 2010).

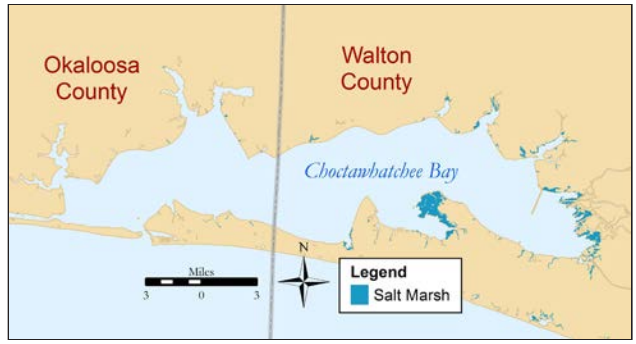

Figure 2.4. Salt marsh extent in Choctawhatchee Bay. Data source: NWFWMD 2009–2010 land use/land cover data (NWFWMD 2010).

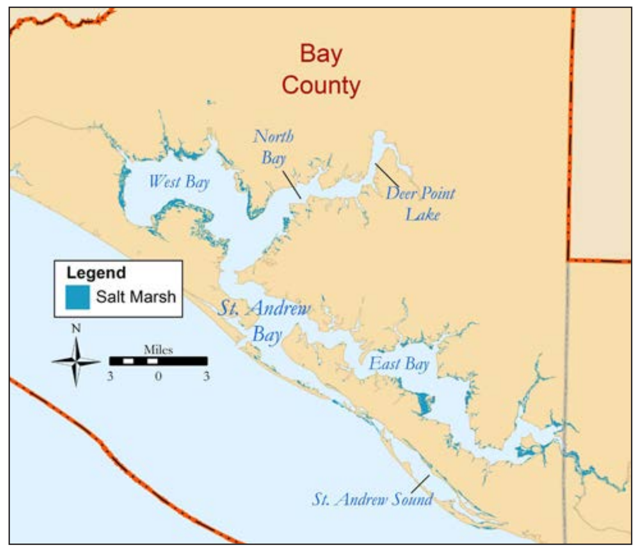

Figure 2.5. Salt marsh extent in St. Andrew Bay. Data source: NWFWMD 2009–2010 land use/land cover data (NWFWMD 2010).

popular retirement community (Ruth and Handley 2007). Development has caused habitat loss and has physically altered the bay through the construction of seawalls, jetties, bridges, and docks. Water quality is detrimentally impacted by increased pollutants and sedimentation in stormwater runoff and wastewater discharge (NWFWMD 2002, Ruth and Handley 2007). The low tidal energy and frequent stratification in the bay result in longer residence times for pollutants (NWFWMD 2002).

St. Andrew Bay

St. Andrew Bay (Figures 2.2 and 2.5) has three lobes (the West, North, and East Bays) that collect outflows from 10 major creeks (FDEP 2004). Narrow peninsulas protect the bay from Gulf waves and currents, resulting in little tidal flushing. Salt marshes dominated by *J. roemerianus* and *S. alterniflora* border the coastline of West Bay and East Bay (NWFWMD 2000). The natural filtration provided by the surrounding salt marshes contributes to the bay's characteristically clear water.

Historically, St. Andrew Bay was connected to the Gulf at the eastern end of Shell Island. After construction of a shipping channel through the center of the barrier peninsula in 1934, however, sediment slowly accreted in the East Pass until it closed in 1998. The East Pass was dredged in 2002 but closed again the following year due to sediment accretion (FDEP 2004). The coastline remains dynamic, and the shipping channel and surrounding beaches are dredged and renourished by the Corps of Engineers. Panama City and Tyndall Air Force Base are located on the eastern side of the bay. Tourism and the military are the dominant forces in the local economy, and much of the surrounding area is rural and under silviculture (Brin and Handley 2007).

St. Joseph Bay

St. Joseph Bay (Figures 2.2 and 2.6), located just west of Apalachicola Bay, is bordered by a spit extending out from St. Joseph Peninsula. Freshwater input into St. Joseph Bay is low; as a result, the average salinity in the bay reflects the salinity of the Gulf of Mexico. Small amounts of freshwater flow into St. Joseph Bay from the Gulf County Canal (which connects the bay to the Gulf Intracoastal Waterway), rainfall, small creeks, and groundwater seepage (SJBAP 2008). St. Joseph Bay is clear with a predominantly sandy bottom and supports extensive seagrass habitat.

Salt marshes dominated by *J. roemerianus* and *S. alterniflora* are found in fringes along the shoreline of the bay (SJBAP 2008). In the 1990s St. Joseph Bay salt marshes showed signs of stress (brown vegetation with

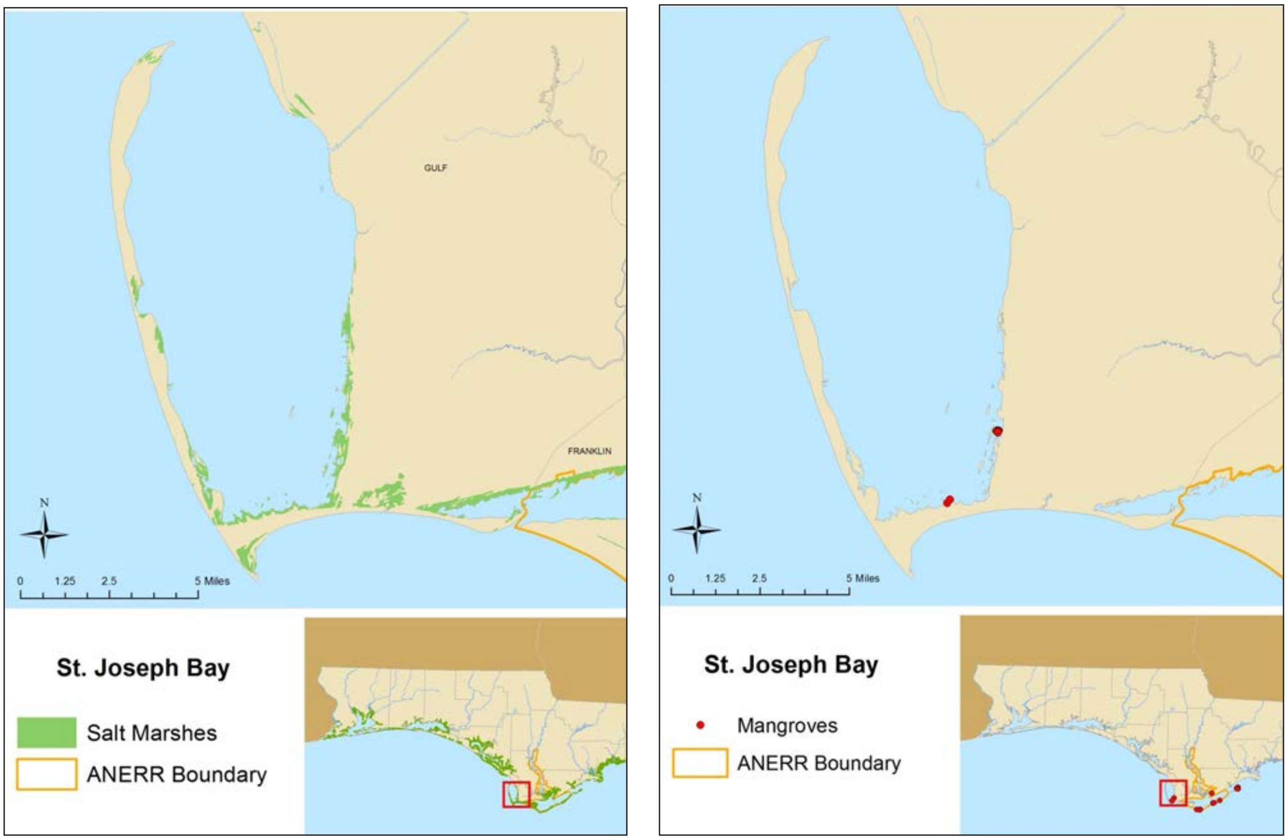

Figure 2.6. St. Joseph Bay salt marsh habitat and known mangrove locations. Data source: Apalachicola National Estuarine Research Reserve mapping (see text for details).

low above-ground biomass) and mortality (SJBAP 2008). Possible causes of this die-off include pathogens, pollution, drought-related factors, and lack of sediment (Flory and Alber 2002). Approximately 50% of the marsh grasses recovered naturally in the years after the die-off, and *S. alterniflora* was planted to aid repopulation of the remaining areas.

In 2009, Apalachicola National Estuarine Research Reserve (ANERR) staff began to map and document individual mangrove trees along the southeastern shoreline of St. Joseph Bay (Figure 2.6). Staff documented very few, small *Rhizophora mangle* (red mangrove) individuals that did not appear to survive the winter in 2010. *A. germinans* was far more abundant than *R. mangle* and better able to withstand the colder temperatures. Mapping efforts were discontinued in 2011 due to budget cuts, but reestablished in 2014.

Apalachicola Bay

The Chattahoochee and Flint rivers merge upstream of the Jim Woodruff Dam, forming the Apalachicola River, which then flows 106 mi (170 km) south to Apalachicola Bay (Figures 2.2 and 2.7). The large Apalachicola River watershed includes portions of Florida, Alabama, and Georgia, including Atlanta. Apalachicola Bay is therefore vulnerable to an array of upstream water quality and water quantity factors, and management of the watershed is complex due to different land- and water-use policies across three states (Edmiston 2008).

Apalachicola Bay is a broad, shallow estuary lined by barrier islands covering 220 mi^2 (570 km^2) (Edmiston 2008). The barrier islands provide protection from the waves of the Gulf, creating a low-energy environment in the bay. Oyster reefs are found throughout Apalachicola Bay, and shellfish harvesting is an important component of the local economy. The bay encompasses the ANERR, which also includes the lower 52 mi (84 km) of the Apalachicola River and several of its distributaries (ANERR 2014). A large amount of the land outside of ANERR is also publicly owned, including the Apalachicola National Forest and Tate's Hell State Forest, which limits human development and population growth. The region is one of the least populated coastal areas in the State, and current development is concentrated along the coast.

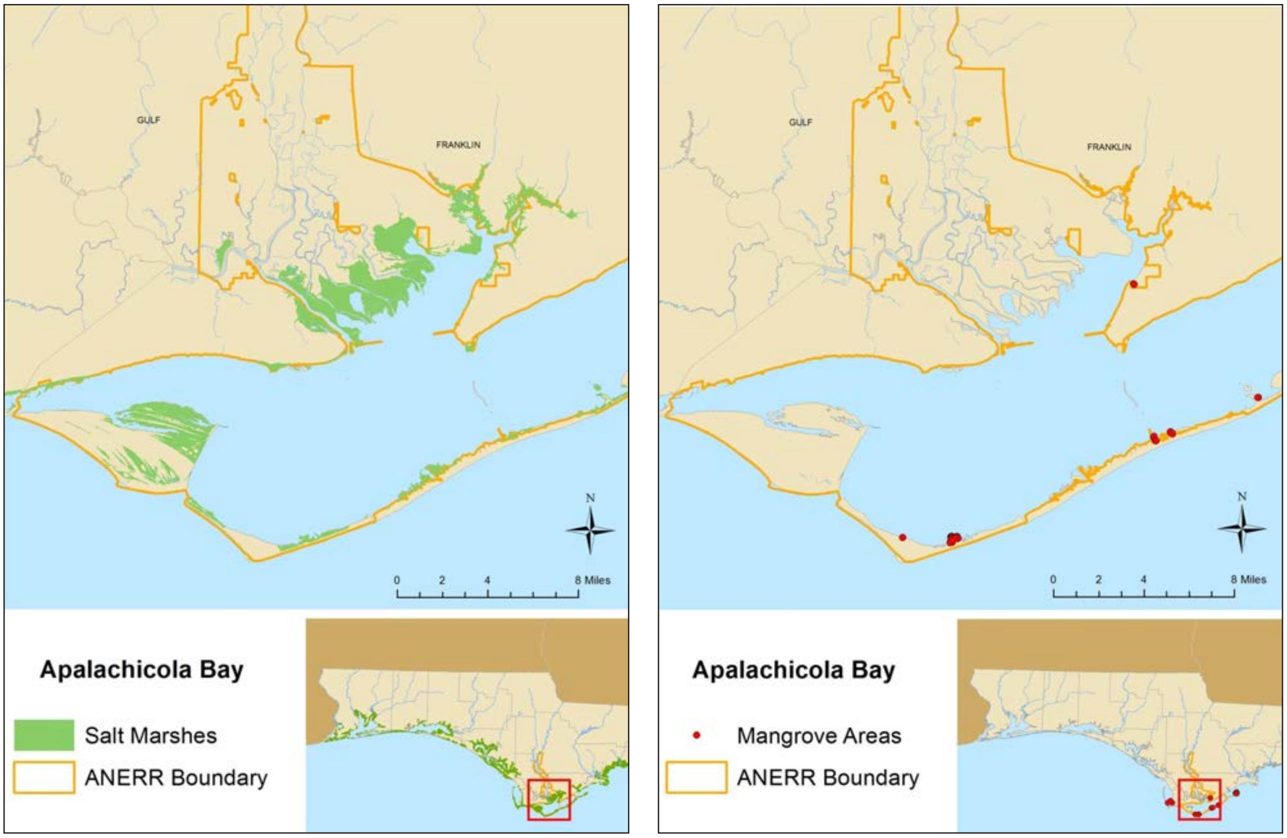

Figure 2.7. Apalachicola Bay salt marsh habitat and known mangrove locations. Data source: Apalachicola National Estuarine Research Reserve mapping.

Eastern Franklin County: Dog Island/St. George Sound

Dog Island is located 3.5 mi (5.6 km) offshore of Franklin County, providing a barrier-island border to St. George Sound (Figures 2.2 and 2.8). Salt marshes are found on the island and at the mouths of the Carrabelle, Ochlockonee, and Sopchoppy rivers. Dog Island contains dune ridges along with a mixture of salt and freshwater wetlands (Anderson and Alexander 1985). The bay side of the island contains salt marshes dominated by *J. roemerianus* and *S. alterniflora*, while freshwater marshes are found toward the interior. *A. germinans* dieback due to cold winter temperatures has often been extreme (70% of mangroves died in the winter of 1983–84), but the community subsequently recovered (Anderson and Alexander 1985).

Threats to coastal wetlands

- **Human development:** While northwest Florida is relatively undeveloped compared with south Florida, the population in Santa Rosa, Okaloosa, and Walton counties is growing faster than statewide averages (U.S. Census 2015). Urban development is generally concentrated near the coastline, which has both direct effects (habitat loss and fragmentation) and indirect effects (poor water quality and altered hydrology) on surrounding wetlands (NWFWMD 2000, Ruth and Handley 2007, ANERR 2014). Increasing tourism and recreational use of the coast also impact wetlands through improper vehicle use, trampling, pesticide use, erosion from boat wakes, and dredging for boat access (Handley et al. 2013). While numerous public lands afford protection from development, much of the rural, undeveloped coastline remains in private ownership and is susceptible to future development.
- **Water quality and quantity:** Population growth and urban development have altered the quantity and quality of freshwater entering estuaries. Population growth in the upstream reaches of the Apalachicola watershed has led to increasing demand for freshwater, resulting in decreased flows to the Apalachicola River (ANERR 2014). Improperly treated wastewater and urban runoff are issues in several of the bays (NWFWMD 2006a, SJBAP 2008). Poorly functioning septic systems are of particular concern, especially for their possible impact on the quality of shellfish in oyster-harvesting regions

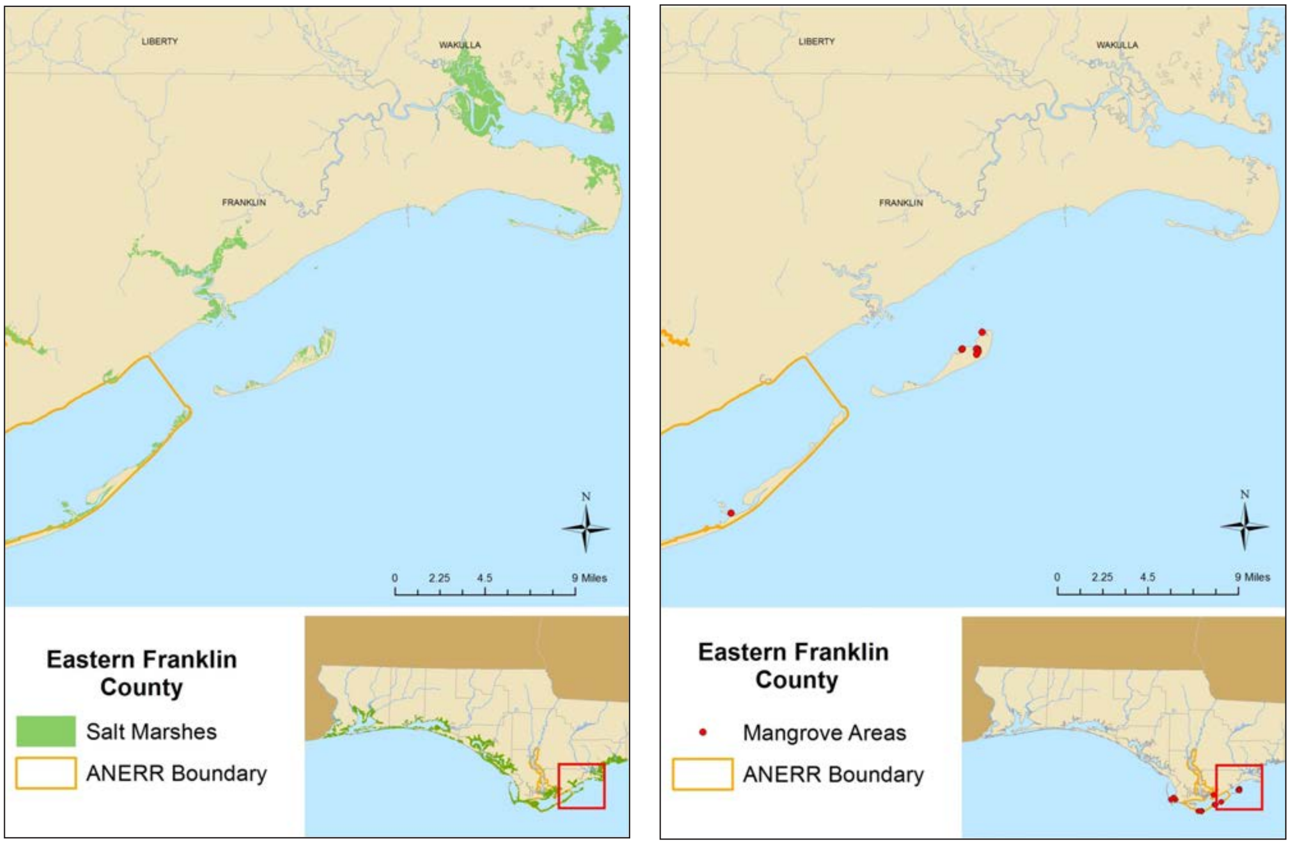

Figure 2.8. Eastern Franklin County (including Dog Island) salt marsh habitat and known mangrove locations. Data source: Apalachicola National Estuarine Research Reserve mapping.

(ANERR 2014). The impacts of chemical contamination and nutrient enrichment are worsened because many of these bays have small outlets into the Gulf; this causes stratification, limited tidal flushing, and a long residence time for contaminants (NWFWMD 2000, Brin and Handley 2007, FDEP 2012b).

- **Altered hydrology:** The hydrology of bays along the coast of northwest Florida have been altered by the construction of channels, the Intracoastal Waterway, and the opening or stabilization of tidal inlets to the Gulf. These alterations not only modify salinity and tidal flow in the bays, but they also alter patterns of accretion and erosion. Hydrology is also altered locally by hardened shorelines, bridges, and other coastal development. Stormwater runoff is diverted and concentrated by drainage systems collecting runoff from impervious surfaces. Even trenches designed to prevent the spread of forest fires alter surface water flow, compartmentalizing and channelizing runoff (FDEP 2008).

  Upstream alterations to rivers also change the delivery of freshwater to the estuaries. A dam was built in 1961 in the North Bay of St. Andrew Bay to create Deer Point Lake. The hydrology of the Apalachicola River has also been significantly modified by the Jim Woodruff Dam, channelization, and dredging. The straightening of the Apalachicola River has also resulted in increased flow rates and decreased river depth (ANERR 2014).

- **Erosion and accretion:** Patterns of erosion and accretion are altered by the construction and stabilization of shipping channels, sea-level rise, hardened shorelines, and subsidence (Handley et al. 2013). Erosion is particularly forceful during tropical storms and hurricanes. Cape San Blas on St. Joseph Bay is one of the most severely eroding locations in Florida and has eroded up to 40 ft (12 m) in one year (SJBAP 2008). Similarly, much of the salt marsh on Perdido Key has been lost to erosion (FDEP 2006).

- **Climate change and sea-level rise:** This area is susceptible to saltwater intrusion and the growing impact of tidal forces due to the low elevation and gentle topography. With higher sea level, tidal forces will reach farther upstream and storm surges will extend farther inland. Increasing salinity and inundation will likely result in salt marshes' displacing freshwater wetlands. Additionally, the proliferation of nonnative species may be aided by changes in abiotic factors, including temperature and salinity.

Even though cold events have historically restricted the proliferation of mangroves in northern Florida, *A. germinans* has been able to expand northward due to the reduced frequency of such events (Stevens et al. 2006). Mangroves in northwest Florida are still patchy and usually occur as solitary trees or in small clusters, but as their canopy coverage increases they can shade out and replace marsh vegetation (Stevens et al. 2006).

- **Natural events:** Naturally occurring events such as tropical storms, hurricanes, and droughts also threaten salt marsh habitat. For instance, when Hurricane Dennis made landfall on northwest Florida in 2005, an 8- to 10-ft (2.4–3 m) storm surge crossed the barrier islands in ANERR, depositing sediment and smothering aquatic vegetation. Many of the low-salinity marsh species were killed by inundation by sea water (ANERR 2014). Vegetation that survives the initial inundation from storm events may be ultimately displaced by invasive vegetation that thrives after a disturbance (Handley et al. 2013). Natural droughts, such as that in 1999–2001, also affect freshwater input, salinity regimes, nutrient delivery, and sedimentation (Ruth and Handley 2007).
- **Invasive species:** Invasive vegetation in and around wetlands in northwest Florida include *Triadica sebifera* (Chinese tallow), *Cinnamomum camphora* (camphor tree), *Arundo donax* (giant cane), *Lygodium japonicum* (Japanese climbing fern), *Schinus terebenthifolius* (Brazilian pepper), and an invasive strain of *Phragmites australis* (common reed) (NWFWMD 2006a, ANERR 2014). Otherwise, federally listed invasive species are currently not considered a serious threat to coastal wetlands in this region.

Mapping and monitoring efforts

Water management district mapping

The Northwest Florida Water Management District (NWFWMD) conducts periodic land use/land cover (LULC) mapping at regular intervals in its jurisdiction (Figure 2.9, Table 2.1). The features delineated in LULC maps are categorized according to the Florida Land Use and Cover Classification System (FLUCCS; FDOT 1999). NWFWMD LULC data sets are based on aerial orthoimagery and published at the 1:24,000 (1 in. = 2,000 ft) scale. The data files were created by Florida Department of Environmental Protection's Bureau of Watershed Restoration (NWFWMD 2010).

According to NWFWMD LULC data, salt marsh extent in northwest Florida has increased by more than 2,000 acres (809 ha) from 1994 to 2010 (Figure 2.9, Table 2.1).

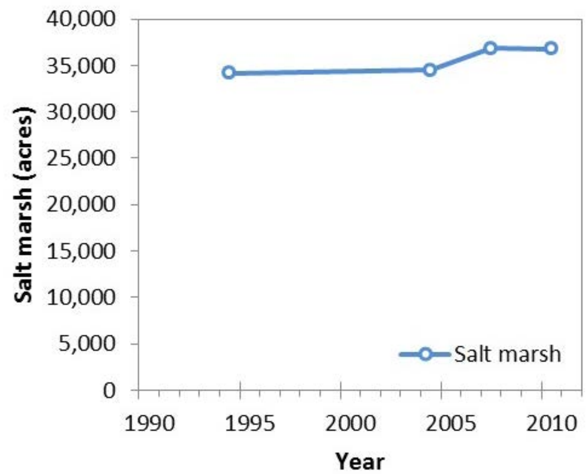

Figure 2.9. Recent acreages of salt marshes in northwest Florida, as derived from NWFWMD land use/land cover data (NWFWMD 2010).

Table 2.1. Recent acreages of salt marshes (FLUCCS 6420) in northwest Florida. Data sources: FDOT 1999, NWFWMD 2010.

Year	Salt marsh
1994–95	34,152
2004	34,483
2006–07	36,843
2009–10	36,804

The largest gain occurred when several wet prairies, nonvegetated wetlands, tidal flats, and mixed scrub–shrub wetlands from the 2004 LULC data set were reclassified as salt marsh in 2006–2007. Some of this variability may be due to refinement of mapping methods and classification rather than change in land cover. For example, one 75-acre (30 ha) region was recorded as a mangrove swamp (FLUCCS 6120) in NWFWMD's 1994–95 land use/land cover (LULC) data. This location, along western St. Andrew Bay, is classified as mixed scrub–shrub wetland (FLUCCS 6460) in later LULC data sets. The mixed scrub–shrub wetland classification (FLUCCS 6460) was not used in the 1994–95 LULC data yet proliferated in LULC data thereafter.

USGS and EPA emergent wetlands status and trend

Scientists with the U.S. Geological Survey (USGS) and the U.S. Environmental Protection Agency (EPA) partnered to map and analyze the status of coastal wetlands along the Gulf of Mexico. As part of that study, wetland extent in

Pensacola Bay and Choctawhatchee Bay was mapped from 1979 and 1996 data using stereoscopic photointerpretation and ground truthing (Handley et al. 2013). Vegetation was classified using Cowardin et al.'s (1979) classification system. Palustrine wetlands were found to have had a much greater decline from 1979 to 1996 (18,267 acre/7,390 ha lost, or 55.89%) than estuarine wetlands (436 acres/176 ha lost, or 4%). While several other estimates of marsh extent were also made in northwest Florida in the 1970s and 1980s, the methods used were so different that the data were difficult to compare (Reyer et al. 1988, FDEP 2012b, Handley et al. 2013).

Mapping of the Apalachicola National Estuarine Research Reserve

Using ArcGIS, ANERR staff isolated salt marsh layers from each of the following five regional land-cover data sets and merged them into one layer to provide a rough estimate of salt marsh habitat in this area overall (Figures 2.6–2.8):

- U.S. Fish and Wildlife Service National Wetlands Inventory (years of available data vary)
- Northwest Florida Water Management District (2009–11)
- Florida Fish and Wildlife Conservation Commission (FWC) compilation of Florida Water Management District data (1999–2011)
- Florida Natural Areas Inventory/FWC Cooperative Land Cover (2003–10)
- ANERR Habitat Mapping and Change Plan (NOAA/FDEP) (2012)

Mangrove habitat is not documented in any of the large regional data sets for northwest Florida, but ANERR staff have been monitoring individual mangrove trees in salt marsh habitats in the Apalachicola Bay area since 2009. Staff will continue to document this habitat annually, because observations indicate that these species are increasing in abundance, a trend that is expected to continue as a result of changing climate.

Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative mapping assessment

The Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative (GCPO LCC) is conducting a rapid ecological assessment of nine priority habitat systems defined in its draft Integrated Science Agenda, available at lccnetwork.org/resource/gcpo-lcc-draft-integrated-science-agenda. Estuarine tidal marsh along the Gulf Coast portion of the GCPO LCC region has been identified as one of the LCC's priority systems. As part of the assessment, the LCC is using land cover overlays from the National Wetlands Inventory, Cooperative Land Cover 3.0 and the Coastal Change Analysis Program in Florida to assess the extent of estuarine tidal marsh in the Gulf Coast portion of the western Florida panhandle. Overlays of multiple data sets are available at gcpolcc.databasin.org/.

National Estuarine Research Reserve monitoring

As part of the National Estuarine Research Reserve System's System Wide Monitoring Program (SWMP) bio-monitoring protocol, in 2014 ANERR staff began long-term monitoring of the freshwater and brackish emergent vegetation in the marshes of the lower Apalachicola River and the salt marshes of Little St. George Island. Monitoring locations are intended to represent natural estuarine communities that have not been significantly altered by natural causes or human activity (Moore 2009). Three transects at each location are monitored annually at the peak of biomass following Moore (2009). Two wells for monitoring pore water were installed adjacent to each transect.

Elevation and sediment accretion has also been studied in the Apalachicola region. In 1996 two sediment elevation tables (SETs) were installed by the Florida Geological Survey in a distributary of the Apalachicola River that drains into East Bay. Data from these SETs showed that the marshes did have high rates of accretion (as much as 0.5–0.75 in./14–19 mm per year). Nevertheless, overall elevation changes were negative due to compaction and subsidence in the river delta (Hendrickson 1997, Edmiston 2008).

Additionally, 20 SETs were installed in 2011–12 to monitor erosion and accretion rates in the lower-river marshes of the Apalachicola floodplain and in the salt marshes of the barrier islands. These monitoring efforts are part of the National Oceanic and Atmospheric Administration's Sentinel Site Program designed to track ecosystem integrity and socioeconomic health indicators for specific management initiatives. The data will be provided to researchers for modeling biological feedback to sea-level rise. These models will allow stakeholders and decision makers to understand how sea-level rise will affect freshwater and saltwater marsh habitats in the Apalachicola area.

Sea Level Affecting Marshes Model

As revealed by the Sea Level Affecting Marshes Model (SLAMM) developed in 2012 by The Nature Conservancy, the lands surrounding Apalachicola Bay are highly vulnerable to sea-level rise even under modest scenarios (Freeman et al. 2012). Forested wetlands would be replaced by salt-tolerant vegetation, reducing habitat extend for organisms that depend on forested wetland habitats. These changes would be exacerbated if freshwater inflow was reduced by drought or upstream demand.

Choctawhatchee Bay Live Oak Point shoreline erosion

Live Oak Point contains approximately 1,000 acres (404 ha) of salt marsh, the largest extent on Choctawhatchee Bay. The NWFWMD commissioned a study on shoreline changes in the salt marsh from 1941 to 2004 (NWFWMD 2006b). The study found that the salt marsh was eroding at a pace of 0.6 acre (0.24 ha) per year, which was likely to increase to 0.7 acre (0.28 ha) per year by 2020. It was noted that waves were carving into the marsh platform, undercutting the exposed peat and creating small ledges that ultimately broke off and were carried away by higher tides. Recommendations include the installation of permanent breakwaters to divert wave energy and the planting of salt marsh species in regions of accretion to compensate for erosional salt marsh loss (NWFWMD 2006b).

Independent research

Randall Hughes with the Florida State University Coastal and Marine Laboratory and Northeastern University began taking a closer look at *A. germinans* in the salt marshes of St. Joseph Bay in 2011. The less cold-tolerant *R. mangle* was found in the marshes as well. Over a five-year period she did not see any significant dieback, even during hard freezes. These trends are expected to continue, and it is anticipated that these species will become more abundant as the climate continues to change. Brief descriptions of the ongoing mangrove monitoring project and other salt marsh studies can be found at blog.wfsu.org/blog-coastal-health/.

Recommendations for protection, management, and monitoring

- Monitoring changes in habitat, water quality, and ecosystem health is a key component of management. Monitoring data should be used in conjunction with results of other scientific studies to aid in implementing best management practices for ecosystem management. The die-offs and stress signs demonstrated by St. Joseph Bay salt marshes point to the need for further study to identify specific stressors, restore affected areas, and implement long-term monitoring for areas of concern (SJBAP 2008). Studies of shoreline accretion and erosion would also help in prioritizing restoration and protection efforts for salt marshes (Handley et al. 2013).
- Mangrove range expands northward in Florida in the form of single trees or clusters of trees surrounded by salt marsh. Current land classification techniques are generally based on predominant vegetation types rather than on individual plants and so overlook individual trees. Presence/absence techniques, such as those shown in Figures 2.6–2.8, provide a better method of tracking mangrove proliferation.
- Engage communities and citizens in improving the stewardship of coastal resources. Encourage the planting of living shorelines along residential property and public parks. Shoreline vegetation provides stabilization, valuable ecosystem services, and is useful in educating the public.
- Identify and prioritize acquisition of lands and restoration of habitats that act as buffers and that will allow coastal wetlands to move inland as habitat is lost due to sea-level rise and erosion. Buffer zones of undisturbed native vegetation around wetlands and other sensitive habitats also help trap sediment and nutrients, stabilize the shoreline, lessen flooding, and provide habitat for other native species (SRC 2002).
- Thoughtful urban planning can decrease the impacts of development on surrounding natural areas. The use of porous pavement decreases concentration of stormwater runoff, and open, vegetated, curved stormwater paths mimic more natural drainage patterns (SRC 2002). When possible, construction of septic tank systems near wetlands and shorelines should be discouraged. The cumulative impact of urban development on coastal habitats should be considered, even though development permits are issued for individual projects (NWFWMD 2000). When combined together, multiple developments can fragment habitat and alter the hydrology of wetlands.

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Chapter 3
Big Bend and Springs Coast

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Description of the region

The region between Tampa Bay and the Panhandle barrier island system is a marsh-dominated coast commonly referred to as the Big Bend of Florida. At the State level and in this chapter, the region is split in two; the northern counties from Wakulla to Levy County are called the Big Bend, and the southern counties from Citrus County to Pasco County are called the Springs Coast (Figure 3.1). This extensive region is divided between three water management districts (Figure 3.2): Northwest Florida, Suwannee River, and Southwest Florida (NWFWMD, SRWMD, and SWFWMD, respectively). The gentle topography, low wave energy, and broad, shallow Florida Shelf provide ideal conditions for the extensive salt marshes along the Big Bend and Springs Coast (Rupert and Arthur 1997, FDEP 2014).

Temperature, elevation, salinity, and tidal inundation influence coastal wetland vegetation (Coultas and Hsieh 1997). Broad swaths of *Juncus roemerianus* (black needlerush) marsh dominate in this region, which is characterized by low wave energy, a semi-diurnal 3.2-ft (1 m) tidal range, and freshwater input from the Floridan aquifer (Stout 1984, Wolfe 1990, Clewell et al. 2002). *J. roemerianus* does not tolerate inundation as well as *Spartina alterniflora* (smooth cordgrass), which occurs in the low marsh and is present mainly in borders along the coastline and tidal creeks (Coultas and Hsieh 1997). Marsh zones in this region may be very broad due to the gentle slope of the land. Where salinity is lower, near rivers or spring-fed creeks, salt marsh grades into oligohaline and freshwater marshes, dominated by *Cladium jamaicense* (saw-grass), *Typha* spp. (cattails), and forested wetlands (Clewell et al. 2002, Light et al. 2002).

As elevation increases on the landward edge of the marsh or in isolated pockets, the vegetation transitions through halophytic marsh and scrub into hammock communities dominated by *Sabal palmetto* (cabbage palm), *Juniperus silicicola* (southern red cedar), and *Quercus virginiana* (live oak) (Williams et al. 1999). Elevated islands of coastal hammock communities are interspersed in both salt and brackish marshes (Leonard et al. 1995, Williams et al. 1999).

Salt marshes in the Big Bend and Springs Coast include tidal creeks and some natural levees created by sand and sediments deposited during high tides and storms (Leonard et al. 1995, Wright et al. 2005). Salt barrens are common in the marsh interior, particularly in counties north of the Suwannee River (Raabe et al. 1996, Hoffman and Dawes 1997). These sparsely vegetated salt barrens occur between the marsh and coastal forest at elevations only centimeters above mean high water (Raabe et al. 1996). Extensive seagrass beds are found seaward of the salt marshes, interspersed with unvegetated intertidal flats (Mattson et al. 2007). Oyster reefs are found near river mouths, tidal creeks, and offshore, depending on freshwater inputs and tidal fluctuations (Seavey et al. 2011).

Mangroves can be found as a fringe along the coastal mainland and barrier islands, particularly at Cedar Key (Figure 3.3), in the Ozello archipelago, and in Pasco County. Freezing temperatures limit the northern range of mangroves, although *Avicennia germinans* (black

Figure 3.1. Salt marsh and mangrove extent in the Big Bend and Springs Coast region. Data source: NWFWMD 2009–2010, SRWMD 2010–2011, and SWFWMD 2011 land use/land cover data, based on FLUCCS classifications (FDOT 1999, NWFWMD 2010, SRWMD 2011, SWFWMD 2011).

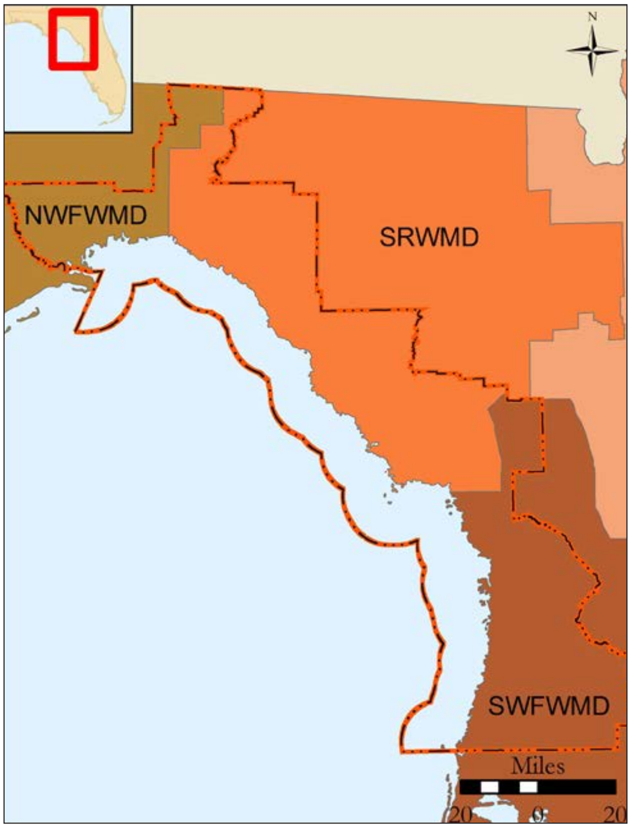

Figure 3.2. Water management districts within the Big Bend and Springs Coast Region (outlined in red) include parts of the Northwest Florida, Suwannee River, and Southwest Florida water management districts (NWFWMD, SRWMD, and SWFWMD).

mangrove) has been able to expand northward due to reduced frequency of extreme cold events (Lugo and Patterson-Zucca 1977, Kangas and Lugo 1990, Stevens et al. 2006, Cavanaugh et al. 2014). This expansion in mangrove swamps, often at the expense of salt marsh habitat, is clearly visible in land classification data from SRWMD and SWFWMD (Figure 3.4).

Local geology and hydrology

The underlying limestone shelf is found close to the land surface along the Big Bend and Springs Coast (Rupert and Arthur 1997), resulting in a relatively stable shoreline compared to other regions in Florida (Raabe et al. 2004). The karst limestone is occasionally exposed on land and along stream beds (Wolfe 1990, FDEP 2014). The coastline in this region has limited free sediment, but this sediment is maintained within the system due to the low-energy environment (Rupert and Arthur 1997) and redistribution during wind and storm events (Leonard et al. 1995, Wright et al. 2005). A few natural sandy beaches occur on Seahorse and Cedar keys, remnants of ancient sand dunes (Wright et al. 2005).

The area is not a traditional estuary, since it is not partly enclosed by land (Wolfe 1990). However, it is bounded by a broad, shallow limestone shelf that sufficiently dampens wave energy, resulting in a low-energy estuarine environment (Rupert and Arthur 1997). Year-round the coastal waters are typically less saline than seawater due to freshwater inputs (Orlando et al. 1993). The Floridan aquifer lies close to the surface here, and freshwater springs contribute to several spring-fed rivers and directly to the marsh and coastal waters (Coultas and Hsieh 1997, Raabe et al. 2011). Flow from the springs is fairly consistent compared with that of surface streams, since groundwater responds more slowly to changes in rainfall (Wolfe 1990). The spring water is very clear, and the temperature is consistent year-round. The mean water temperature is approximately 22.2 °C (72 °F), roughly the same as the mean air temperature (Hornsby and Ceryak 2000), making the region a natural haven for manatees in colder weather and a popular tourist destination.

Human impacts

In part due to the lack of extensive beaches, the Big Bend and Springs Coast has remained less developed than the rest of Florida. Often referred to as the nature coast of Florida, it has been classified as one of the least polluted coastlines in the continental United States (Livingston 1990). The Suwannee River lacks the impoundments and diversions commonly found in developed regions, making it one of the least impacted river systems in the United States (Katz and Raabe 2005, Thom et al. 2015).

Population in the Springs Coast, however, is increasing (U.S. Census 2015). In places like Hernando Beach, coastal wetland habitat has been dredged and filled in the construction of subdivisions (Wolfe 1990). Although the Big Bend is predominantly undeveloped and much of the population is rural, human impact is growing as the region becomes increasingly popular for ecotourism and marine activities (FDEP 2014). Other economically important industries in the region include pit mining for limerock, cattle ranging, hog ranging, fishing, and shellfish harvesting (Wolfe 1990, FWC 2004, FDEP 2014).

A large array of protected lands and coastal waters are found along the Springs Coast and Big Bend. Aquatic preserves include the extensive Big Bend Seagrasses Aquatic Preserve, which covers nearly 1 million acres (404,700 ha), along with the smaller Alligator Harbor and St. Martins Marsh Aquatic Preserves (FDEP 2014). The region includes five national wildlife refuges (NWRs): St. Marks, Lower

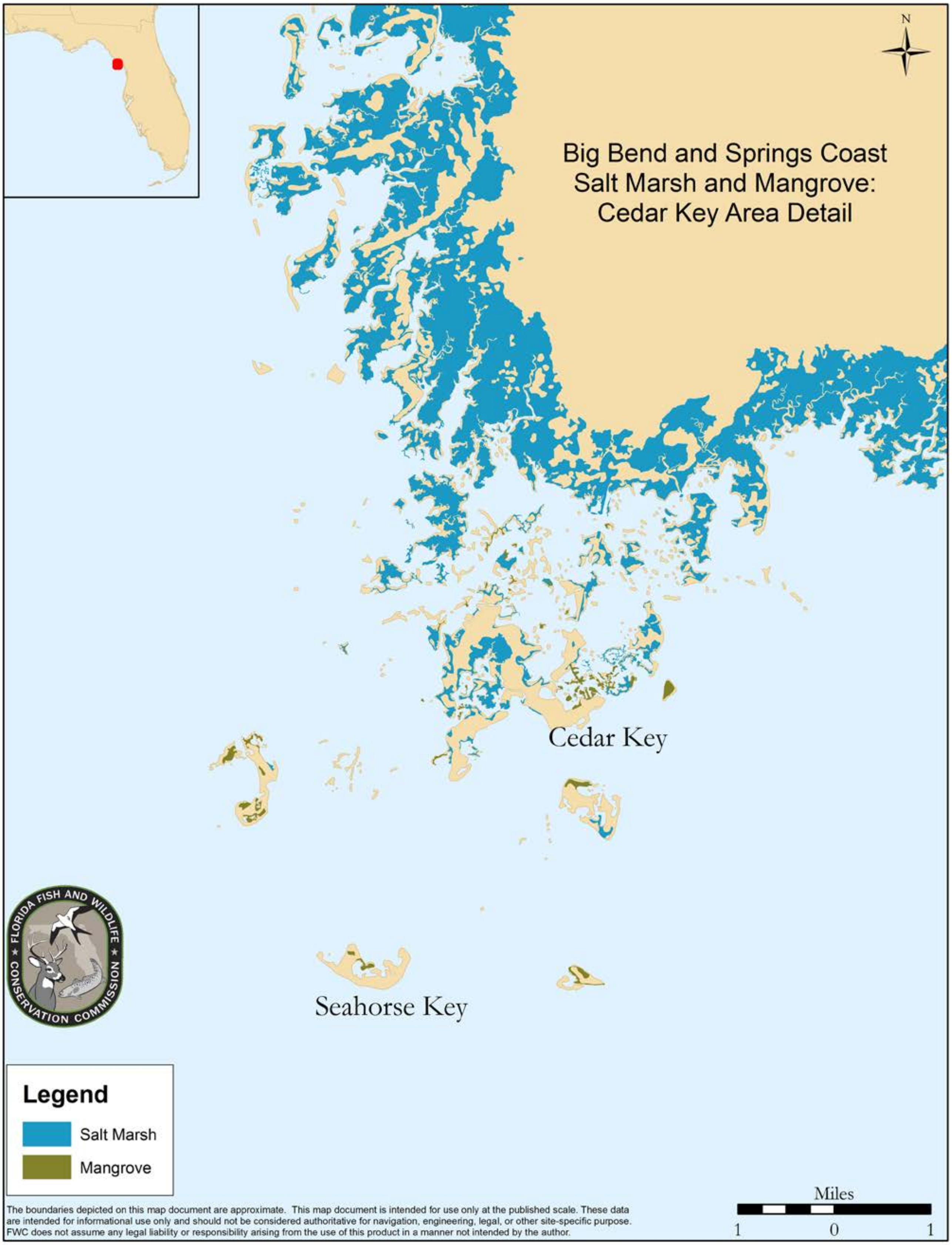

Figure 3.3. Extent of salt marshes and mangroves around Cedar Key. Data source: SRWMD 2010–2011 land use/land cover data, based on FLUCCS classifications (FDOT 1999, SRWMD 2011).

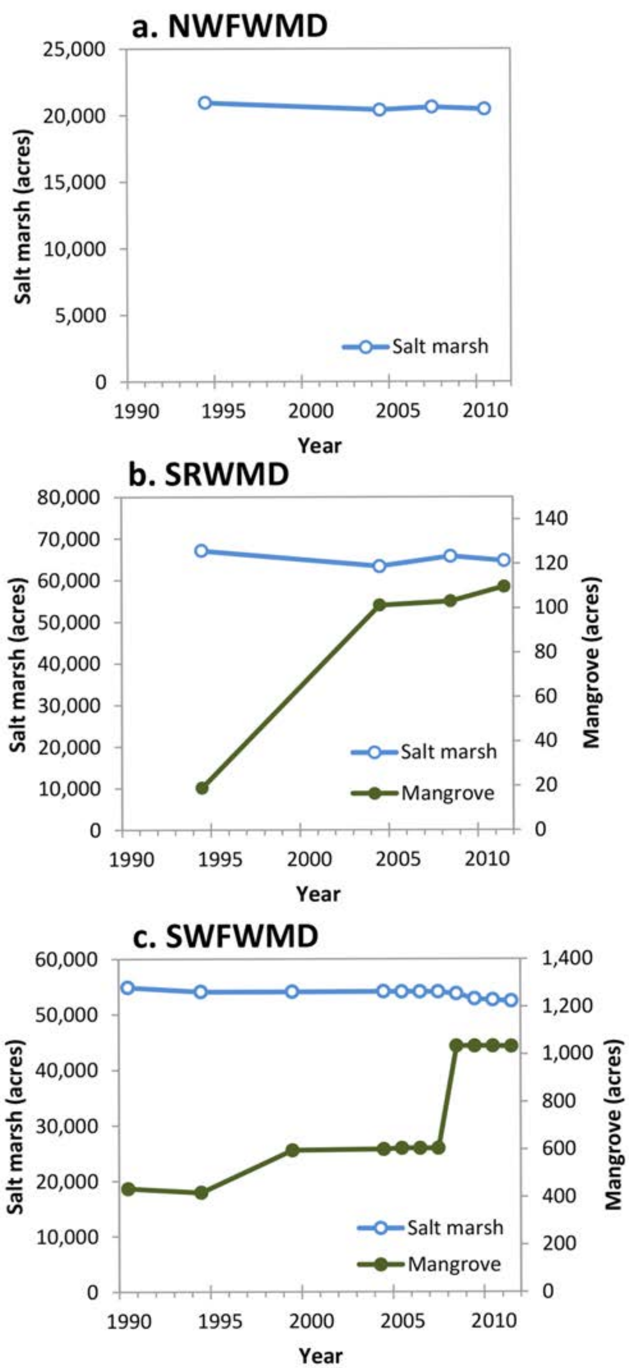

Figure 3.4. Recent acreages of salt marshes and mangrove swamps in the Big Bend and Springs Coast region, by water management district (FDOT 1999, NWFWMD 2010, SRWMD 2011, SWFWMD 2011).

Suwanee, Cedar Keys, Crystal River, and Chassahowitzka, totaling more than 155,000 acres (62,700 ha). In addition to public land owned by water management districts, State-managed lands along the coast include Econfina River State Park, Big Bend Wildlife Management Area, Waccasassa Bay Preserve State Park, Crystal River Preserve State Park, the Marjorie Harris Carr Cross Florida Greenway, Werner-Boyce Salt Springs State Park, Withlacoochee Gulf Preserve, and Cedar Key Scrub State Reserve.

Threats to coastal wetlands

- **Climate change and sea-level rise:** Sea-level rise will impact coastal wetlands in this region through greater inland inundation and heightened wave erosion. At Cedar Key, sea level rose an average of 0.077 in. (1.97 mm) per year from 1914–2015 (NOAA 2016). The Big Bend and Springs Coast is particularly susceptible to flooding by storm surge and sea-level rise due to the gentle slope of the topography. In regions with just 5 ft of elevation gain over 3 mi (~1.5 m over 5 km), 2 in. (5 cm) of increased sea level can affect land 500 ft (150 m) inland, with drastic impacts on coastal forests adjoining the tidal marsh system (Stumpf and Haines 1998).
- **Altered hydrology:** Although the population in this region is relatively small, humans have impacted both surface and groundwater hydrology. Ditches, dams, and flood-protection structures alter surface water flow, rates of drainage, and water retention times (Wolfe 1990). The Hickory Mound impoundment in Taylor County altered salinity regimes when it was built in 1968 to create a brackish marsh and augment waterfowl habitat (FDEP 2014). Roads through low-lying lands can function as levees, decreasing hydrologic connectivity of the wetlands, fragmenting habitats, and obstructing water flow (Warren Pinnacle 2011). Boating channels have also been dredged in parts of the region, the most prominent of which is the remnant western edge of the attempted Cross Florida Barge Canal, which ends in Withlacoochee Bay.

  Freshwater withdrawal and water extraction to support urban regions such as the growing Tampa Bay population results in lower groundwater levels and decreases spring discharge (SWFWMD 2001); Seven Springs in Pasco County has stopped flowing entirely (Harrington et al. 2010). Although less freshwater is withdrawn in the SRWMD than in the other water management districts, that rate increased rapidly from 1975 to 2000 (Marella 2014). Flow in the Suwannee River has also decreased due to withdrawal upstream; since monitoring began in 1931, the four lowest average annual flows in the Suwannee River have all occurred since 2000 (USGS 2013, Thom et al. 2015). Additionally, the drinking-water supply in Cedar Key was contaminated by saltwater intrusion during a drought in 2012 (Smith 2012). Alterations to surface hydrology and reduction in freshwater flow threaten oligohaline marshes and encourage the landward incursion of salt marsh species.

- **High nutrient concentrations:** Increased nutrient concentrations are an important water-quality concern in natural springs and the Suwannee River (Thom et al. 2015). Fertilizers, atmospheric deposition, septic tanks, and manure contribute nitrogen to surface water and seeps into groundwater, which later comes to the surface at springs (Katz et al. 1999, Harrington et al. 2010). Nitrate levels are particularly high during periods of low flow (Pittman et al. 1997, Katz et al. 1999, FDEP 2003). Nitrate levels in spring boils along the Springs Coast range from 0.185 to 0.575 mg/L, frequently exceeding the Florida Department of Environmental Protection's nitrate threshold of 0.35 mg/L for clear-water streams (Harrington et al. 2010). Isotope studies indicate that the primary contributors of nitrogen to these springs are inorganic fertilizer, most likely from lawn and golf course application, and septic tanks (Harrington et al. 2010). Wastewater discharged via land application and retained in percolation ponds may also contribute nutrients to groundwater (Harrington et al. 2010). Surface water naturally percolates down to the aquifer, but this process is accelerated by drainage wells and sink holes (Wolfe 1990).

  The response of coastal wetlands to eutrophication is variable and poorly understood (Kirwan and Megonigal 2013). Deegan et al. (2012) found that high nutrient levels increased above-ground *Spartina* spp. biomass at the expense of root systems and subsequently decreased marsh soil stability. Nitrogen concentrations from the Chassahowitzka River and other nearby springs are already 50 times that found in pristine conditions (Dixon and Estevez 1998). This region has also experienced marked salt marsh loss and shoreline erosion (Raabe et al. 2004). Interactions among the many related factors and the tendency of tidal marsh ecosystems to resist disturbances up to a threshold make it difficult to predict the impacts of increasing nutrients in coastal wetland environments (Kirwan and Megonigal 2013).

- **Mangrove encroachment:** Several hard freezes in the 1980s killed *A. germinans* along Cedar Key and the Springs Coast. Salt marshes, primarily *S. alterniflora* (Clewell et al. 2002), recolonized the area after the freezes, yet subsequent mild winters allowed *A. germinans* to reclaim the area and expand northward. Mangroves at the northern end of their range tend to establish on the Gulf edge of salt marshes, often on islands (Figure 3.3). As the mangroves increase in size and canopy coverage, they shade and eventually replace marsh vegetation (Stevens et al. 2006, Cavanaugh et al. 2014).

- **Erosion:** Despite the relative stability afforded by the shallow limestone shelf, the shoreline along the Big Bend has been eroding at 3.9 ft (1.2 m) per year over the past 120 years (Raabe et al. 2004, Raabe and Stumpf 2015). Mapping efforts comparing historical and modern shorelines show both the loss and gain of marsh habitat along the Big Bend. In several locations, including those just north of Weeki Wachee and just east of Cedar Key, salt marshes have been disproportionately replaced by unvegetated mud flats or open water (Raabe et al. 2004). Landward movement of salt marshes has compensated for this loss of salt marsh habitat, but at the expense of upland forest communities that cannot tolerate increased salinity (Kurz and Wagner 1957, Williams et al. 1999, Raabe et al. 2004, Raabe and Stumpf 2015). This inland migration of the marsh has been documented at 2–3 times the rate of loss to water (Raabe and Stumpf 2015).

- **Invasive vegetation:** As in much of the rest of Florida, invasive plant species threaten coastal wetlands in the Big Bend and Springs Coast region. More than 500 nonnative plant species have been documented in Florida (FWC 2014), and more than 60 nonnative invasive plant species have been identified in the Big Bend Aquatic Preserve alone, including *Eichornia crassipes* (water hyacinth), *Schinus terebinthifolius* (Brazilian pepper), and *Casuarina* spp. (Australian pine) (FDEP 2014). Increased nutrient levels may also make freshwater *Cladium jamaicense* (sawgrass) marshes vulnerable to invasion by native *Typha* spp. (cattails) in a manner similar to that in South Florida marshes (Newman et al. 1998).

- **Industrial pollutants:** Prior to 1998, the Fenholloway River was classified as a Class V body of water (designated for industrial use), as it received point-source pollutants from the Buckeye Foley pulp mill, mining companies, and the City of Perry's wastewater-treatment plant (FWC 2004). Fishing and shellfish harvest were banned there, and more than 5,700 acres (2,300 ha) of seagrass beds were lost off the coast of the Fenholloway River (Mattson et al. 2007). Water quality in the river has somewhat improved in recent decades. The river was upgraded to a Class III body of water in

1998 (FDEP 2012), indicating it is now a water body with limited recreation, fish consumption, and aquatic life due to human impacts.

Mapping and monitoring efforts

Coastal wetland elevation monitoring

The U.S. Fish and Wildlife Service Southeast Region Inventory and Monitoring Network is conducting coastal wetland elevation monitoring in 18 national wildlife refuges in the southeastern United States. This monitoring effort collects data on surface elevation, accretion, pore-water salinity, and vegetation at permanent monitoring sites in selected priority wetland habitats. The objectives of this monitoring program are to observe impacts of sea-level rise in priority habitats, monitor rates of change in wetland elevation, and forecast longevity of these habitats in refuges within the South Atlantic Landscape Conservation Cooperative (SALCC). Elevation is measured using the rod surface elevation table method, which uses a permanent subsurface benchmark to monitor sediment height and calculate vertical changes in wetland surface (Cahoon et al. 2002, Cahoon and Lynch 2003). Monitoring locations along the Big Bend include a *J. roemerianus* salt marsh north of the Suwannee River in Lower Suwannee National Wildlife Refuge, a *Cladium jamaicense* (sawgrass) oligohaline marsh south of the river in Lower Suwannee NWR, and a *J. roemerianus* salt marsh in St. Marks NWR. Baseline data from this vegetation monitoring are available (Boyle et al. 2015). The Southeast Region Inventory and Monitoring Network is partnering with the U.S. Geological Survey (USGS), The Nature Conservancy, the National Park Service (NPS), SALCC, the National Estuarine Research Reserve System (NERRS), and the National Geodetic Survey to accomplish many aspects of this project. The data are being used in conjunction with similar data collected at permanent monitoring sites maintained by the NPS, NERRS, and USGS to better examine landscape-scale changes resulting from sea-level rise.

Gulf of Mexico and Southeast Tidal Wetlands Project

The USGS partnered with the University of Florida and the Florida Geological Survey to conduct the Gulf of Mexico and Southeast Tidal Wetlands Project, which used satellite imagery to evaluate changes in Big Bend marshes (Raabe and Stumpf 1997). Temporal variation in water level, vegetation land cover, and the normalized difference vegetation index (NDVI) were assessed using a time series of satellite images and classified by observed types of disturbance (fire, drought, flooding, storm surge). Several surface elevation tables were used to monitor marsh height and rates of sedimentation (Ladner et al. 2001, Cahoon et al. 2002, Cahoon and Lynch 2003). Thermal infrared mapping enabled the identification of coastal seeps and springs (Raabe et al. 2011), and terrain was mapped using an airborne laser swath mapping system (Raabe et al. 2008). Nineteenth-century topographic sheets were used to compare historical and modern features along the coastline (Raabe et al. 2004). The study found that salt marsh has been migrating landward along much of the Big Bend, overtaking upland habitat. Meanwhile, the edge of the marsh has been lost to open water at a rate of 3.9 ft (1.2 m) per year, and even more rapidly at several locations (Raabe and Stumpf 2015).

Water Resource Inventory and Assessment for the Lower Suwannee National Wildlife Refuge

The Water Resource Inventory and Assessment for Lower Suwannee National Wildlife Refuge summarizes information on water resources, provides an assessment of water resource needs and issues of concern, and makes recommendations for addressing the identified needs and concerns (Thom et al. 2015). Major topics addressed include the natural setting of the refuge (topography, climate, geology, soils, hydrology), impacts of development and climate change, significant water resources and associated infrastructure within the refuge, past and current water monitoring activities on and near the refuge, water quality and quantity information, and the State's regulatory framework for water use. The greatest concerns identified by the Water Resource Inventory and Assessment are decreased flows and increased nutrient concentrations in both surface and groundwater.

SWFWMD Tidal Rivers monitoring

Coastal wetland characterizations of riverbanks were conducted from 1997 to 2002 to support SWFWMD development of guidelines for minimum flows and water levels. With coastal vegetation being limited by salinity, tidal amplitude, and soil moisture, studies such as that by Clewell et al. (2002) have sought to define relationships between salinity regimes and the distribution of wetlands in tidal rivers. Data collection methods used included identification of plant community distribution from aerial imagery, shoreline surveys, and vegetation quadrats for identification of species composition and abundance.

Table 3.1. Recent acreages of salt marshes and mangrove swamps in water management districts in the Big Bend and Springs Coast region (FDOT 1999, NWFWMD 2010, SRWMD 2011, SWFWMD 2011).

District/Year	Salt marsh	Mangrove
NWFWMD		
1994–1995	20,946	0
2004	20,410	0
2006–2007	20,619	0
2009–2010	20,455	0
SRWMD		
1994–1995	67,104	19
2004	63,357	101
2006–2008	65,772	103
2010–2011	64,672	110
SWFWMD		
1990	54,871	435
1994	54,090	418
1999	54,097	596
2004	54,135	600
2005	54,116	604
2006	54,109	604
2007	54,092	604
2008	53,749	1,035
2009	52,815	1,035
2010	52,620	1,034
2011	52,442	1,033

Water management district mapping

The three water management districts in this region (NWFWMD, SRWMD, and SWFWMD) conduct periodic land use/land cover (LULC) mapping at regular intervals in their jurisdictions (Figure 3.2). The features delineated in LULC maps are categorized into saltwater marsh or mangrove swamp classifications according to the Florida Land Use and Cover Classification System (FLUCCS) (FDOT 1999). Some of the variability between sampling years (Figure 3.4, Table 3.1) is likely due to refinement of sampling methods and variation in resolution of aerial photography.

- NWFWMD LULC data sets are based on aerial orthoimagery and published at 1:24,000 (1 in. = 2000 ft) scale. The data files were created by FDEP's Bureau of Watershed Restoration (NWFWMD 2010).
- SRWMD LULC data sets are also based on aerial orthoimagery. Data scales and agencies that conducted photointerpretation vary among years; the most recent LULC data were created by FDEP's Bureau of Watershed Restoration. Land cover data are also available from 1988 but different methods and classifications were used, therefore the 1988 data are not provided for comparison here (SRWMD 2011).
- Each iterative LULC map product created by SWFWMD is an update to the previous map. Features in 1-foot color infrared imagery are photo-interpreted at a scale of 1:8,000. After the review of newly acquired imagery source data, updates and changes to map line work are conducted using on-screen digitizing techniques, at a scale of 1:6,000. SWFWMD's LULC mapping standards require wetland features to be at least 0.5 acre (0.2 ha) in area to be classified in the map (SWFWMD 2011).

National Wetlands Inventory mapping

A note of caution should be made regarding the National Wetlands Inventory (NWI) mapping and all uses of NWI maps for mapping, analysis, and models in this region. The boundary between salt marshes and upland forest communities in the Big Bend and Springs Coast is frequently classified as the Cowardin et al.'s 1987 classifications of E2FO3 (estuarine intertidal forested broad-leaved evergreen wetland) or E2SS3 (estuarine intertidal scrub-shrub broad-leaved evergreen) (NWI 2014), categories often interpreted by users as mangrove. In much of Florida these categories are indeed used to identify mangrove swamps, but in the Big Bend mangrove swamps do not appear along the landward salt marsh boundary. The vegetation composition of this boundary, commonly referred to as a transition, includes salt-tolerant scrub and marsh, cabbage palms, pine, wetland forested mix, and mixed scrub/shrub wetland (Williams et al. 1999, Raabe et al. 2004, SRWMD 2011). The erroneous interpretation of a marsh-to-forest transition zone as mangrove produces misleading results in subsequent applications (e.g. SLAMM models), where expansion of intertidal habitat into coastal forest is interpreted as expansion of mangroves (Warren Pinnacle 2011). This type of error propagation must be searched for and remedied.

Recommendations for protection, management, and monitoring

- Mangroves continue to expand their range and encroach upon salt marsh habitat in the Big Bend and Springs Coast. This expansion and proliferation may start as individual trees surrounded by salt marsh, yet current land classification techniques are generally based on predominant vegetation types rather than individual plants. This gap necessitates monitoring with the use of presence/absence techniques or biomass change rather than traditional vegetation classification categories to accurately track mangroves in this region.

- The rate of landward migration compensates for the rate of loss and erosion along the shore (Raabe and Stumpf 2015). Land purchases for conservation should be aimed at linking habitats and providing room for landward migration, requiring coordination between state, federal, and local conservation managers.
- Protection and management of coastal wetlands must incorporate watershed and groundwater management, including the monitoring of water quantity and quality. Sufficient freshwater flow is necessary to maintain salinity gradients along the coast and moderate saltwater inundation. Although the ultimate impacts of eutrophication on coastal wetland vegetation are difficult to predict (Kirwan and Megonigal 2013), efforts to reduce nutrients are recommended to prevent ecosystem-level alterations to the stability and biomass allocation of emergent estuarine vegetation.
- Preventing the introduction and spread of invasive species requires active monitoring and the early detection and removal of present exotic vegetation.
- Due to the large area and relatively wild status of the region, monitoring based upon vegetation and wetness indices derived from Landsat Thematic Mapper data may be more efficient than traditional land cover classifications. This process eliminates errors associated with classification and enables rapid identification of regions with unusual changes that can then be further investigated with high-resolution data. The use of high-resolution Digital Elevation Model maps derived from LiDAR data may also be useful when assessing current impacts or predicting responses to vegetation changes associated with sea-level rise.

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U.S. Fish and Wildlife Service Southeast Region Inventory and Monitoring Network coastal wetland elevation monitoring: www.fws.gov/southeast/IMnetwork/abiotic.html

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Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative compilation of Gulf of Mexico surface elevation tables: gcpolcc.databasin.org/maps/new#datasets=6a71b8fb60224720b903c770b8a93929

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Chapter 4
Tampa Bay

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Description of the Region

The Tampa Bay region is located on the west-central coast of Florida. It includes Tampa Bay proper, Florida's largest open-water estuary, which has a surface area of approximately 400 mi^2 (1,036 km^2) at high tide (Figure 4.1). The bay is fed by a watershed of roughly 2,600 mi^2 (6,730 km^2) with four major rivers (Hillsborough, Alafia, Manatee, and Little Manatee) and more than 100 small tributaries. The watershed includes large portions of Hillsborough, Pinellas, and Manatee counties, as well as smaller portions of Pasco and Polk counties. The area is highly urbanized, and the population around Tampa Bay has quintupled since the 1950s. Hillsborough, Pinellas, and Manatee counties were estimated to be home to more than 2.6 million people in 2015, and the population continues to grow (U.S. Census 2015). Although the area is highly developed, it also includes many city, county, and state parks and preserves, aquatic preserves, and national wildlife refuges.

The demands of a growing population have altered local hydrology due to freshwater withdrawal from tributaries and the construction of water reservoirs (Yates and Greening 2011). The concomitant increase in the extent of impervious surfaces in the watershed has resulted in increased runoff, transporting more nutrients and other pollutants into the bay. After Tampa Bay's deteriorating health became evident in the 1970s, upgraded sewage-treatment requirements in St. Petersburg and Tampa reduced nutrient outflow into the bay and reversed trends in eutrophication (Greening and Janicki 2006, Holland et al. 2006). Improvements in water quality, coupled with habitat restoration and protection plans, have increased the overall health of Tampa Bay ecosystems, but the growing population requires that management plans be adaptive (Holland et al. 2006, Yates and Greening 2011).

Tampa Bay and its shoreline contain a diverse array of habitats, flora, and fauna due to the bay's large size and wide salinity gradient. Coastal or estuarine wetlands include mangroves, salt barrens, and polyhaline, mesohaline, and oligohaline salt marshes. The system is dominated by mangroves, which has made up 67–75% of its total estuarine wetland coverage since the 1950s (Figures 4.2 and 4.3). Salt marshes made up 22–28% of coastal wetlands, and salt barrens making up the remaining 2–6%. In recent decades the proportion of mangroves has steadily increased as the proportion of salt marsh and salt barren coverage have decreased (Robison 2010).

Coastal wetlands generally declined in coverage from the 1950s to the early 1990s (Table 4.1, Figure 4.2). Since then, land acquisition and habitat restoration, undertaken primarily by public agencies but also by nongovernmental entities, have led to modest gains in habitat acreage (Figure 4.2). The largest increases in terms of both acreage and proportion have been seen in mangrove coverage; increases in salt marsh acreage and proportion have been

Figure 4.1. Mangrove and salt marsh coverage in the Tampa Bay region. Data source: SWFWMD 2011 land use/land cover data, based on FLUCCS classifications (FDOT 1999, SWFWMD 2011).

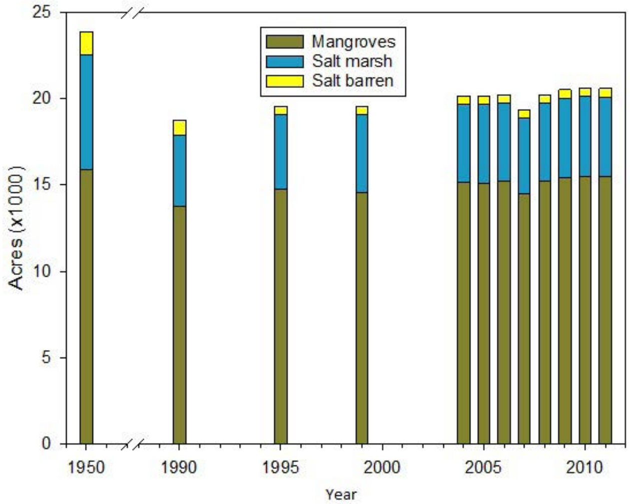

Figure 4.2. Baywide acreages of emergent saltwater vegetation, 1950–2011. See Table 4.1 for data sources.

moderate. Salt barren acreage remained relatively steady from 1995 to 2011, but it remains roughly one-third that estimated for the 1950s. Status and trends for coastal wetlands are explored by habitat type and bay segment in Tables 4.2–4.4 and Figure 4.3. Land cover classifications used for the 1950s data vary somewhat from Florida Land Use and Cover Classification System (FLUCCS) categories (FDOT 1999). See Lewis and Robison (1995) for a full explanation of land cover classifications and methods for estimating coastal wetland extent in 1950 and 1990.

Land use was first mapped by the Southwest Florida Water Management District (SWFWMD) in 1990, but mapping methodologies have varied over time (see Robison 2010). SWFWMD did not systematically map salt barren habitat types until 2004, but Robison (2010) estimated extent of salt barren habitat for 1995 and 1999 from color photography. Table 4.5 presents acreage and proportional changes in acreage of emergent saltwater vegetation over various time periods in each bay segment of Tampa Bay.

Clearwater Harbor and St. Joseph Sound

The northwestern portion of Pinellas County lies outside the Tampa Bay watershed (Figure 4.1). This region includes both salt marshes and mangroves in Clearwater Harbor to the south and St. Joseph Sound to the north (Table 4.6). Aerial photography from 1942 was used to establish land cover from that year; about 65% of the watershed had still not been developed (Janicki and Atkins 2011b). The largest loss of coastal wetlands in this area has been around the city of Clearwater, a result of extensive coastal development. In St. Joseph Sound, Clearwater Harbor North, and Clearwater Harbor South, 57, 67, and 98%, respectively, of mangrove habitats have now been lost (Janicki and Atkins 2011a, 2011b). Much of the remaining salt marsh and mangrove habitats in this area are found on several undeveloped barrier islands (Caladesi, Honeymoon, Three Rooker, and Anclote). Because the region is so highly developed, management efforts focus on preserving the wetland habitats that remain.

Ecosystem services provided by Tampa Bay wetlands

Coastal wetlands are extremely valuable to the Tampa Bay region. A project team from the U.S. Environmental Protection Agency Gulf Breeze Laboratory has performed extensive monitoring and modeling to determine the value of ecological services provided by the suite of habitats in Tampa Bay and its watershed (Russel et al. 2011, Russel and Greening 2015). Notable valuable services of wetlands include improvement of water quality, flood protection, and improvement of air quality and aesthetics. In addition to providing essential habitat and food sources for many estuarine species, wetlands also provide such ecosystem services as sequestering atmospheric carbon (Moyer et al. 2016) and reducing nitrogen in wastewater and stormwater discharges.

Table 4.1. Historical acreage estimates for Tampa Bay coastal wetlands.

Year	Data source	Mangroves	Salt marsh	Salt barren	Total
1900*	Lewis and Robison 1995	16,538	16,200	1,012	33,750
1950	Lewis and Robison 1995	15,894	6,621	1,371	23,886
1990	Lewis and Robison 1995	13,764	4,117	877	18,758
1995	Robison 2010	14,760	4,343	445	19,548
1999	Robison 2010	14,595	4,478	469	19,542
2004	SWFWMD	15,149	4,513	492	20,154
2005	SWFWMD	15,127	4,527	492	20,146
2006	SWFWMD	15,246	4,478	482	20,206
2007	SWFWMD	14,511	4,390	446	19,347
2008	SWFWMD	15,242	4,477	490	20,209
2009	SWFWMD	15,462	4,543	515	20,520
2010	SWFWMD	15,495	4,640	501	20,636
2011	SWFWMD	15,500	4,603	501	20,604

*1900 values based on estimated 1950s proportions, as described in Lewis and Robison (1995). Raabe et al. (2012) showed that proportions may have been quite different before 1900.

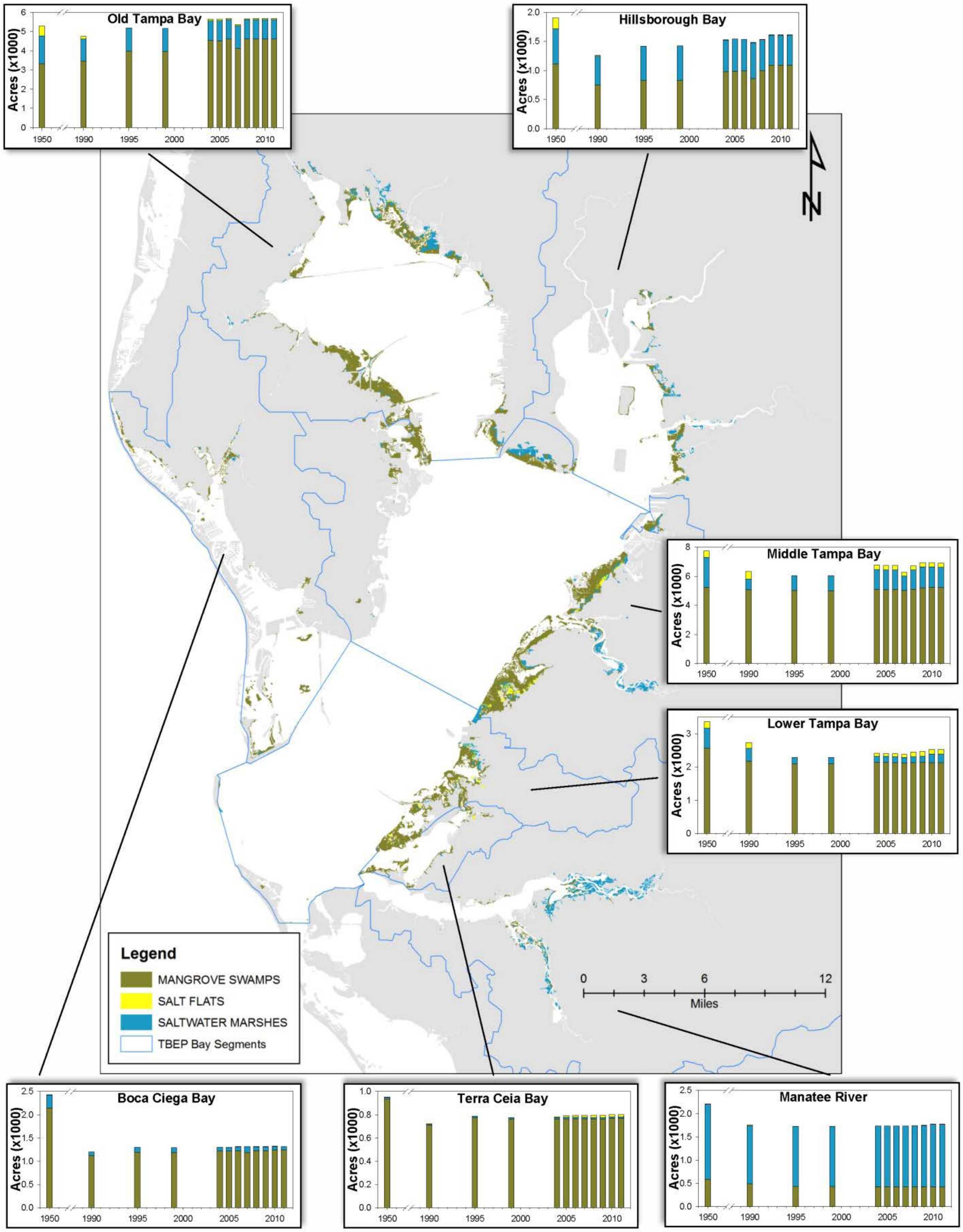

Figure 4.3. 2011 extent of coastal wetlands in the Tampa Bay region and acreage changes, 1950–2011, by bay segment. See Table 4.1 for data sources.

Table 4.2. Mangrove acreages in Tampa Bay from 1950–2011, by bay segment.

Year	Data source	Old Tampa Bay	Hillsborough Bay	Middle Tampa Bay	Lower Tampa Bay	Boca Ciega Bay	Terra Ceia Bay	Manatee River	Total
1950	Lewis and Robison 1995	3,321	1,112	5,225	2,563	2,143	937	592	15,893
1990	Lewis and Robison 1995	3,452	751	5,061	2,174	1,121	711	494	13,764
1995	SWFWMD	3,971	830	5,009	2,095	1,193	775	432	14,305
1999	SWFWMD	3,956	828	5,004	2,096	1,191	762	432	14,269
2004	SWFWMD	4,522	979	5,107	2,135	1,217	763	426	15,149
2005	SWFWMD	4,514	986	5,081	2,136	1,218	766	426	15,127
2006	SWFWMD	4,614	995	5,089	2,127	1,229	765	427	15,246
2007	SWFWMD	4,119	862	5,034	2,116	1,190	765	425	14,511
2008	SWFWMD	4,605	996	5,089	2,132	1,230	764	426	15,242
2009	SWFWMD	4,608	1088	5,210	2,139	1,231	762	424	15,462
2010	SWFWMD	4,610	1093	5,222	2,130	1,243	770	427	15,495
2011	SWFWMD	4,613	1093	5,224	2,131	1,242	770	427	15,500

Table 4.3. Salt marsh acreages in Tampa Bay, 1950–2011, by bay segment.

Year	Data source	Old Tampa Bay	Hillsborough Bay	Middle Tampa Bay	Lower Tampa Bay	Boca Ciega Bay	Terra Ceia Bay	Manatee River	Total
1950	Lewis and Robison 1995	1,446	603	2,075	606	274	13	1,604	6,621
1990	Lewis and Robison 1995	1,150	499	737	389	84	6	1,252	4,117
1995	SWFWMD	1,206	590	1,041	187	106	13	1,292	4,435
1999	SWFWMD	1,207	596	1,040	187	106	13	1,292	4,441
2004	SWFWMD	1,033	545	1,345	185	84	13	1,308	4,513
2005	SWFWMD	1,035	553	1,354	181	83	13	1,308	4,527
2006	SWFWMD	1,009	537	1,352	178	82	13	1,307	4,478
2007	SWFWMD	1,178	617	981	168	125	13	1,308	4,390
2008	SWFWMD	1,002	535	1,352	183	80	13	1,312	4,477
2009	SWFWMD	1,003	520	1,423	183	80	13	1,321	4,543
2010	SWFWMD	1,005	515	1,427	263	75	13	1,342	4,640
2011	SWFWMD	999	515	1,395	264	75	13	1,342	4,603

"Restore the Balance" Management Plan

Scientists and resource managers in the Tampa Bay region have developed and adopted habitat restoration targets and paradigms as part of the Tampa Bay Habitat Master Plan (Lewis and Robison 1995) and Tampa Bay Habitat Master Plan Update (Robison 2010). Production of these documents was coordinated by the Tampa Bay Estuary Program (TBEP). The documents were adopted by the TBEP's Policy Board, which includes elected officials and agency representatives at local, regional, state, and national levels. Because the master plans were vetted by technical and citizen advisory committees, they are often integrated into the habitat management plans for other local government partners, such as the SWFWMD, which has incorporated the restoration goals and projects into the Surface Water Improvement and Management (SWIM) Plan for Tampa Bay (SWFWMD 1999).

Table 4.4. Salt barren acreages in Tampa Bay, 1950–2011, by bay segment. Data not available for 1990–2004 because the SWFWMD did not systematically map salt barren habitat types before 2004.

Year	Data Source	Old Tampa Bay	Hillsborough Bay	Middle Tampa Bay	Lower Tampa Bay	Boca Ciega Bay	Terra Ceia Bay	Manatee River	Total
1950	Lewis and Robison 1995	516	195	436	194	14	1	15	1,371
1990	Lewis and Robison 1995	147	13	533	168	0	6	10	877
2004	SWFWMD	80	2	309	89	4	5	3	492
2005	SWFWMD	78	2	306	86	4	13	3	492
2006	SWFWMD	58	2	306	93	4	16	3	482
2007	SWFWMD	58	2	271	93	4	16	2	446
2008	SWFWMD	58	2	271	136	4	17	2	490
2009	SWFWMD	58	2	286	144	4	19	2	515
2010	SWFWMD	58	2	282	134	4	19	2	501
2011	SWFWMD	58	2	282	134	4	19	2	501

Quantitative protection and restoration targets have been established for coastal wetlands as part of the Tampa Bay management plan under an approach called Restore the Balance. Due to the extensive coastal development in the watershed, it is not realistic to expect to regain habitat acreage that was present in the 1950s. But because many fish and wildlife species rely on various estuarine habitats throughout their life cycles, Restore the Balance attempts to restore historical proportions of estuarine habitats in an attempt to ensure that there are no bottlenecks to the life history of any species that uses Tampa Bay (Morrison et al. 2011). This approach may prove challenging with current trends of mangrove expansion, as mangroves frequently overtake salt marsh habitat. The impacts of sea-level rise and climate change will also likely influence the relative proportions of habitats in the Tampa Bay area. These impacts, as well as Restore the Balance and other management strategies, will be evaluated in the 2017 Habitat Master Plan Update for Tampa Bay.

The Restore the Balance concept establishes targets using the 1950s ratio of estuarine habitats. The 1950s were selected as a starting point because they preceded much of the extensive development in the watershed (although Tampa and St. Petersburg were well established). Also, the first high-quality aerial photographs are available for the entire watershed in the 1950s, enabling photo-interpretation of land cover. Analyses of wetland extent for more recent periods (1990s, 2000s, 2010s) allowed determination of areal coverage and proportion by wetland type. Over the past 25 years, mangrove and salt marsh acreage have increased (Figure 4.2). The proportion of mangroves exceeds their 1950s proportion, while the proportions of both salt marsh and salt barrens are less than in the 1950s.

Quantitative Restore the Balance targets are established by basing desired habitat ratios on the wetland habitat that has been least impacted. In the Tampa Bay region, mangroves have actually increased in overall proportion and so are deemed the least impacted habitat. Restoration targets can be set for the remaining habitat types by utilizing the 1950s proportion in the equation $c/a = b/x$, where x = acreage restoration target for habitat of interest, a = current acreage of least-impacted habitat, b = 1950s proportion of target habitat, c = 1950s proportion of least-impacted habitat (Robison 2010). The acreage target becomes the change required to restore the historical proportion. The critical coastal habitat targets, as adopted in the Tampa Bay Habitat Master Plan Update, are shown in Table 4.7. Opportunistic restoration of mangrove habitat is still encouraged, but there is not a numeric restoration target for this habitat.

Mangrove dominance increasing

Mangrove coverage is increasing in Tampa Bay, likely as a result of climatic changes and hydrologic alterations. In previous decades, winter freezes led to mangrove die-offs. Freezes have been much rarer in recent decades and mangroves have encroached into areas previously inhabited by salt marshes. Tampa Bay coastal wetlands have shifted from a salt marsh-dominated system in the 1870s to a mangrove-dominated system (Raabe et al. 2012). By comparing present-day land cover to historical topographic maps and surveys from the 1870s, Raabe et al.

Table 4.5. Change in emergent saltwater vegetation in Tampa Bay during different periods, by bay segment. Data compiled from Lewis and Robison (1995) and Southwest Florida Water Management District land use/land cover data (SWFWMD 2011). Bay segments: OTB, Old Tampa Bay; HB, Hillsborough; MTB, Middle Tampa Bay; LTB, Little Tampa Bay; BCB, Boca Ciega Bay; TCB, Terra Ceia Bay; MR, Manatee River. SWFWMD did not systematically map salt barren habitat types until 2004.

MANGROVES												
Bay segment/ year	1950	1990	% Change 1950–1990	1995	% Change 1990–1995	1999	% Change 1995–1999	2005	% Change 1999–2005	2010	% Change 2005–2010	2011	% Change 2010–2011
OTB	3,321	3,452	3.94	3,971	15.03	3,956	−0.38	4,514	14.11	4,610	2.13	4,613	0.07
HB	1,112	751	−32.46	830	10.52	828	−0.24	986	19.08	1,093	10.85	1,093	0.00
MTB	5,225	5,061	−3.14	5,009	−1.03	5,004	−0.10	5,081	1.54	5,222	2.78	5,224	0.04
LTB	2,563	2,174	−15.18	2,095	−3.63	2,096	0.05	2,136	1.91	2,130	−0.28	2,131	0.05
BCB	2,143	1,121	−47.69	1,193	6.42	1,191	−0.17	1,218	2.27	1,243	2.05	1,242	−0.08
TCB	937	711	−24.12	775	9.00	762	−1.68	766	0.52	770	0.52	770	0.00
MR	592	494	−16.55	432	−12.55	432	0.00	426	−1.39	427	0.23	427	0.00
TOTAL	15,893	13,764	−13.40	14,305	3.93	1,4269	−0.25	15,127	6.01	15,495	2.43	15,500	0.03

SALT MARSH													
Bay segment/ year	1950	1990	% Change 1950–1990	1995	% Change 1990–1995	1999	% Change 1995–1999	2005	% Change 1999–2005	2010	% Change 2005–2010	2011	% Change 2010–2011
OTB	1,446	1,150	−20.47	1,206	4.87	1,207	0.08	1,035	−14.25	1,005	−2.90	999	−0.60
HB	603	499	−17.25	590	18.24	596	1.02	553	−7.21	515	−6.87	515	0.00
MTB	2,075	737	−64.48	1,041	41.25	1,040	−0.10	1,354	30.19	1,427	5.39	1,395	−2.24
LTB	606	389	−35.81	187	−51.93	187	0.00	181	−3.21	263	45.30	264	0.38
BCB	274	84	−69.34	106	26.19	106	0.00	83	−21.70	75	−9.64	75	0.00
TCB	13	6	−53.85	13	116.67	13	0.00	13	0.00	13	0.00	13	0.00
MR	1604	1252	−21.95	1,292	3.19	1292	0.00	1,308	1.24	1,342	2.60	1,342	0.00
TOTAL	6,621	4,117	−37.82	4,435	7.72	4,441	0.14	4,527	1.94	4640	2.50	4,603	−0.80

Table 4.5 (continued). Change in emergent saltwater vegetation in Tampa Bay during different periods, by bay segment. NA: data not available.

SALT BARREN

Bay segment/ year	1950	1990	% Change 1950–1990	1995	% Change 1990–1995	1999	% Change 1995–1999	2005	% Change 1990–2005	2010	% Change 2005–2010	2011	% Change 2010–2011
OTB	516	147	−71.51	NA	NA	NA	NA	78	−46.94	58	−25.64	58	0.00
HB	195	13	−93.33	NA	NA	NA	NA	2	−84.62	2	0.00	2	0.00
MTB	436	533	22.25	NA	NA	NA	NA	306	−42.59	282	−7.84	282	0.00
LTB	194	168	−13.40	NA	NA	NA	NA	86	−48.81	134	55.81	134	0.00
BCB	14	0	−100.00	NA	NA	NA	NA	4	400.00	4	0.00	4	0.00
TCB	1	6	500.00	NA	NA	NA	NA	13	116.67	19	46.15	19	0.00
MR	15	10	−33.33	NA	NA	NA	NA	3	−70.00	2	−33.33	2	0.00
TOTAL	1371	877	−36.03	NA	NA	NA	NA	492	−43.90	501	1.83	501	0.00

(2012) determined that the ratio of salt marshes to mangroves has shifted from 86:14 to 25:75. Other estimates place the ratio of marshes to mangroves in Tampa Bay closer to 50:50 around 1900 (Lewis and Robison 1995). In either case, the Tampa Bay area is increasingly dominated by mangroves, as has been seen in parts of south Florida (Morrison et al. 2011). This trend is expected to continue due to climate change and sea-level rise, which favor mangrove expansion at the expense of other estuarine habitats (Sherwood and Greening 2012, 2014).

Mangroves provide many of the same ecosystem services as salt marshes, so mangrove expansion is not necessarily detrimental except for its effects on obligate salt marsh species. However this trend does suggest that resource managers must carefully evaluate restoration goals and paradigms such as Restore the Balance to determine if they are still realistic, attainable, and ecologically appropriate (Raabe et al. 2012, Sherwood and Greening 2012, 2014). If marshes and salt barrens are increasingly squeezed out of existing habitat, managers must also determine at what cost their long-term survival should be protected and how to ensure that there is adequate coverage and diversity of coastal habitats to support myriad estuary-dependent species.

Threats to coastal wetlands

While coastal wetlands enjoy greater protection due to regulations and management priorities adopted in the late 20th century, threats to their short- and long-term survival remain. The dominant threats to coastal wetlands in Tampa Bay include:

- **Coastal development:** Human population growth and urban sprawl continue in the Tampa Bay area, resulting in direct and indirect impacts on natural shoreline. Local, state, and federal permitting agencies require mitigation for impacts to these wetlands, which may differ with project location or conditions.
- **Hydrologic modifications:** Development in the watershed may also indirectly impact coastal wetlands through changes to natural hydrologic regimes. Freshwater flow may be reduced by impoundments or increased due to concentrated runoff from impervious surfaces. Reduced freshwater retention in the watershed leads to lower freshwater flows during the dry season (Robison 2010). Additionally, in the 1950s and 1960s many coastal wetlands in the Tampa Bay region were ditched in an effort to reduce mosquitoes (Morrison et al. 2011). The mosquito ditches altered tidal flow and sediment elevation, increasing salinity and removing uninterrupted habitat gradients in much of the bay.

Table 4.6. 2010 coastal wetland acreages surrounding Clearwater Harbor and St. Joseph Sound. Data from Janicki and Atkins (2011b).

	St. Joseph Sound	Clearwater Harbor North	Clearwater Harbor South	Total
Mainland mangrove	209	3	24	236
Island mangrove	153	390	24	567
Mainland salt marsh	448	3	2	454
Island salt marsh	77	13	0	90

Table 4.7. Protection and restoration targets of coastal wetlands in Tampa Bay under the Restore the Balance initiative (Robison 2010).

	Protection target (2007/2008 acres)	Restoration target (additional acres required)	Total target acreage for protection and restoration
Mangroves	15,139	opportunistically restore	15,139 (aim to protect existing acreage)
Salt marsh	4,395	1,918	6,313
Salt barren	447	840	1,287

- **Invasive vegetation:** Exotic plants, particularly *Schinus terebinthifolius* (Brazilian pepper) and *Casuarina* spp. (Australian pines), crowd the upland edges of coastal wetland habitat. Despite attempts to remove them, it is unlikely that these abundant species will be eradicated from the Tampa Bay area (Holland et al. 2006). It is illegal to sell or plant *Casuarina* spp. and *S. terebinthifolius* without a permit, and property owners are encouraged to remove plants of either species when encountered.
- **Climate change and sea-level rise:** Climate change impacts, including sea-level rise and warmer temperatures, are expected to influence long-term wetland extent and condition. In Florida, long-term stations recording sea level have measured a rise of about 8 in. (20 cm) in the past 100 years (Mitchum 2011). Rates of sea-level rise are accelerating; South Florida is expected to see sea levels rise by 32–40 in. (81–102 cm) by 2100 (Mitchum 2011); some estimates of global sea-level rise exceed 6 ft (1.8 m) by 2100 (NOAA 2012).

  Coastal vegetation is expected to migrate landward in response to sea-level rise, but this is only possible if refugia, undeveloped conserved land, are present adjacent to coastal wetland habitats. But extensive urban development in much of the Tampa Bay area inhibits landward migration. The rate of sea-level rise, rate of sediment accretion, and availability of adjacent natural land will all determine whether coastal wetlands are able to successfully retain their current position, migrate, or be squeezed out of existing habitat zones.

Mapping and monitoring efforts

Water management district mapping

To assist in resource management decision-making, SWFWMD conducts regional land use and land cover (LULC) mapping at regular intervals within its jurisdiction (SWFWMD 2011). Features in 1-ft color infrared imagery are photointerpreted at a scale of 1:8,000. After the review of new imagery, updates and changes to map line work are digitized at a scale of 1:6,000. The features delineated in LULC maps are categorized according to FLUCCS categories (FDOT 1999). The coastal wetland features of interest here are mangrove swamp (FLUCCS 6120), saltwater marsh (FLUCCS 6420), and salt flat (FLUCCS 6600). SWFWMD's LULC mapping standards require that wetland features be at least 0.5 acre (0.2 ha) in area to be classified in maps.

Critical Coastal Habitat Assessment

The Critical Coastal Habitat Assessment is a new long-term monitoring program for Tampa Bay that will assess the status, trends, and ecological function of a mosaic of critical coastal habitats. Its purpose is to detect habitat changes due to natural and indirect anthropogenic impacts, including those resulting from sea-level rise and climate change, and to improve habitat management (Janicki 2013, Sherwood and Greening 2012, 2014). To accomplish this, long-term fixed-transects were established in 2015–2016 to characterize baseline habitat structure (see full description in Chapter 1). Monitoring will be completed every 3–5 years to detect trends and assess changes in extent and ecological function of those habitats over time. Transects were established at nine sites around the Tampa Bay watershed in areas that have a full complement of emergent tidal wetland communities including mangroves, salt marshes, salt barrens, and coastal uplands. A multimedia training video will also be produced to aid other programs and communities in implementing similar long-term monitoring programs. Updates and documents will be posted at www.tbeptech.org/committees/habitat-partnership.

Tidal tributaries project

The remaining natural shorelines of tidal tributaries in Tampa Bay generally include a mix of emergent saltwater vegetation. These systems have been identified as prime nursery habitat for a variety of estuarine-dependent fauna. The TBEP first initiated a comprehensive monitoring program in selected Tampa Bay tidal tributaries in 2006 (Sherwood 2008). A large-scale assessment of tidal creeks in Tampa Bay, Sarasota Bay, and Charlotte Harbor was completed in 2013–2014 (SBEP 2016). The monitoring program included a general characterization of shoreline vegetation and later expanded surveys and habitat assessments throughout the tidal extent of small tidal tributaries in the bay (e.g., www.sarasota.wateratlas.usf.edu/tidal-stream-assessments). This work will be extended to other tidal tributaries and major rivers entering the bay as funds become available.

MangroveWatch

MangroveWatch is a citizen-science initiative established in Australia by Norm Duke and Jock Mackenzie, of James Cook University (Mackenzie et al. 2016, www.mangrovewatch.org.au/). Its purpose is to foster citizen awareness and involvement in the management of mangroves by enabling nonscientists to easily gather important forest monitoring data. In 2012, students and faculty in the biology department at Saint Leo University began using MangroveWatch's monitoring and mapping techniques in parts of Tampa Bay. The monitoring is accomplished by recording a video of the mangroves from a small boat running parallel to the shoreline. Geotagged images are extracted from the video (1 image per second of video) and visually evaluated at Saint Leo for forest characteristics such as canopy completeness, relative density of seedlings, evidence of anthropogenic canopy alteration, and signs of stress (e.g., dead trees, bare branches, obvious discoloration of leaves). The data from the evaluation of the images are used to generate GIS maps of shoreline forest condition, represented as 33-ft (10-m) color-coded linear shoreline segments. The Pinellas County Tampa Bay shoreline from the Skyway Bridge approach to Safety Harbor was recorded and evaluated biannually in 2012 and 2013. In 2014 and beyond, an annual (March-May) recording schedule was adopted. Citizens' groups have contacted MangroveWatch with requests to expand monitoring and mapping in other parts of Tampa Bay including Upper Tampa Bay Park, Cockroach Bay, and Terra Ceia Bay.

Minimum flows and levels

The SWFWMD has been characterizing riverbank vegetation since 1990 to support development of minimum flows and levels for the tidal portions of the Alafia, Hillsborough, Little Manatee, and Manatee rivers. Data collection methods include shoreline surveys and vegetation quadrats for identification of species composition and abundance. A full list of the reports from this project may be found at www.swfwmd.state.fl.us/projects/mfl/mfl_reports.php.

Tampa Bay restoration projects

The TBEP tracks success in restoring critical habitats, including salt marshes and mangroves, in the Tampa Bay area and reports the data annually to the U.S. Environmental Protection Agency. These data are also available in a downloadable geospatial format on the Tampa Bay Estuary Atlas (www.tampabay.wateratlas.usf.edu/restoration/).

Recommendations for protection, management, and monitoring

- Future wetland mapping and monitoring efforts should continue current programs, ensuring methodologically consistent, long-term data sets, as well as new initiatives meant to supplement coverage data with more rigorous monitoring of wetland quality. SWFWMD-led LULC analyses are critical tools for identifying regional trends in wetlands coverage. It would be advantageous to develop a supplemental monitoring program using photointerpretation of the LULC or other aerial imagery to assess wetland health, stress, hydrology, and disturbances. Smaller-scale changes in health and the extent of mangroves should be assessed using rigorous ground-truthing and monitoring. The fixed-location monitoring carried out in the Critical Coastal Habitat

Assessment is a powerful tool for detecting even subtle changes in habitat condition, but it is limited to selected sites. This program should be expanded to additional locations, and stable, long-term funding is needed. Citizen-science projects, such as MangroveWatch, should also be considered as possible sources of long-term, on-the-ground data on habitat quality.

- The previously mentioned Tampa Bay Habitat Master Plans have established several habitat restoration and management priorities for Tampa Bay (Lewis and Robison 1995, Robison 2010):
    - The concept of developing habitat mosaics that incorporate numerous habitat types, salinities and elevations has been embraced by the management and restoration community and has resulted in 1) more sophisticated restoration projects that are more similar to natural landscapes, 2) additional habitat for numerous wildlife species, and 3) habitats that are more resilient to disturbances and climate change.
    - The Restore the Balance approach to habitat protection and restoration seeks to restore and create habitats that have been disproportionately lost, such as salt marsh and salt barren habitats. The 2010 master plan update (Robison 2010) also advocates for larger restoration projects that incorporate major hydrological modifications such as re-establishing historical hydrological conditions or using treated wastewater to hydrate wetlands for the creation or restoration of salinity gradients and enhancing nutrient removal. Future master plans should focus on the validity of the Restore the Balance approach and existing habitat restoration paradigms.
    - Efforts to systematically map and monitor wetlands, establish measurable restoration targets, develop management recommendations, identify appropriate locations for habitat restoration, and track progress toward goals have been key components of regional planning. An evaluation of watershed-wide land use/land cover changes should be made every 3 years and an evaluation of habitat restoration and protection targets made every 10 years.
    - Tampa Bay scientific and resource management agencies have demonstrated that setting habitat priorities and targets can lead to measurable gains in habitat coverage, despite extensive and continuing development within the watershed. But ensuring the existence of abundant, high-quality emergent saltwater vegetation in Tampa Bay will require efforts by the Tampa Bay community at large including public entities, nongovernmental organizations, companies, academic institutions, citizens, and visitors.
- Public-private partnerships should be formed to protect or establish habitat on privately owned parcels of land. Such partnerships are especially important, because public entities' ability to acquire new lands is limited. Wetland restoration should continue to represent a mix of habitats, elevations, and salinities to ensure better long-term viability in the face of sea-level rise. When possible, upland areas adjacent to natural or created wetlands should also be protected, enabling landward migration of coastal wetlands. Restoration persistence in the face of sea-level rise should be tracked using long-term, on-the-ground monitoring as well as remote sensing to better inform future restoration projects. A comprehensive monitoring program that takes into account wetland ecosystem function would better position resource managers to modify management regimes when impacts to coverage or condition are detected. Finally, results, successes and challenges should be periodically shared within and beyond the Tampa Bay region via workshops, conferences, peer-reviewed literature, and site visits.

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Chapter 5
Sarasota Bay

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Description of the region

The Sarasota Bay region extends from Anna Maria Sound in the north to Venice Inlet in the south (Figure 5.1). It includes Sarasota Bay proper, Palma Sola Bay in Manatee County, and a series of smaller, contiguous bays to the south (Roberts, Little Sarasota, and Blackburn Bays; Figure 5.2). The bay connects with Tampa Bay to the north through Anna Maria Sound and the Gulf of Mexico through three passes: Longboat, New, and Big Sarasota passes. Sarasota Bay is not a classic estuary under the influence of a major river, but rather a coastal lagoon bounded by barrier islands. Phillippi Creek, which drains into Roberts Bay, is the largest of 16 tidal tributaries that drain into the bay. Sarasota Bay has 52 mi^2 (135 km^2) of open water and a watershed comprising 150 mi^2 (390 km^2) (SBEP 2007).

Sarasota Bay first acquired its present shape 5,000 years ago, when offshore sand bars became barrier islands (SBEP 1992). Wetlands appeared on these barrier islands and the mainland shoreline 3,500 years ago. While salt marshes are present in the greater Sarasota Bay area, mangrove swamps make up more than 90% of coastal wetlands and often overtake herbaceous coastal habitats. *Rhizophora mangle* (red mangrove) and *Avicennia germinans* (black mangrove) are the most abundant mangrove species and dominate 50% of the tidal wetland vegetation (SBEP 1992).

In 1950, the Sarasota Bay watershed comprised about 4,104 acres (1,660 ha) of tidal wetlands; the average area of each wetland was about 22 acres. Wetland acreage decreased 38% (1,609 acres/651 ha) from 1950 to 1990 (SBEP 1992). Much of this loss was due to dredge-and-fill operations in the 1950s and 1960s. The rate of loss was greatest from 1950 through 1975 at an average of 40 acres (16 ha) per year; rates of wetland loss decreased to 20 acres (8 ha) per year from 1975 through 1990. Losses were greatest in the Anna Maria Island, Sister Keys, and Blackburn Bay regions. The average size of wetlands also drastically decreased to 5.6 acres (2.3 ha) during this time (SBEP 1992).

Urban development in the cities of Sarasota and Bradenton and on the barrier island communities has resulted in significant losses of coastal wetlands and an overwhelming hardening of shorelines in this region. Tourism drives the economy of Sarasota County and is the second-largest economic sector in Manatee County (SBEP 2007). Approximately 25% of the area's population is seasonal; this seasonal proportion reaches 70% on the barrier islands (SBEP 2007). Rapid population growth and coastal development have taken their toll on Sarasota Bay ecosystems. Coastal development replaced mangrove swamps and natural shorelines with buildings and seawalls; more than 100 mi (160 km) of seawalls are present today around Sarasota Bay (SBEP 2010). Increased coastal runoff and poor wastewater management resulted in poor water quality in the bay due to additional loading of sediment, nutrients, and pollutants. In the late 1980s, Sarasota Bay had reduced bivalve and fish harvests and diminished extent of seagrass beds (SBEP 2010).

The turning point for Sarasota Bay came in 1989, when the Sarasota Bay Estuary Program (SBEP) was formed and the community came together to improve water and habitat quality in the bay. Extensive studies were compiled in the 1992 Framework for Action, which also outlined goals and recommendations for improving the bay (SBEP 1992). Key focus areas in-

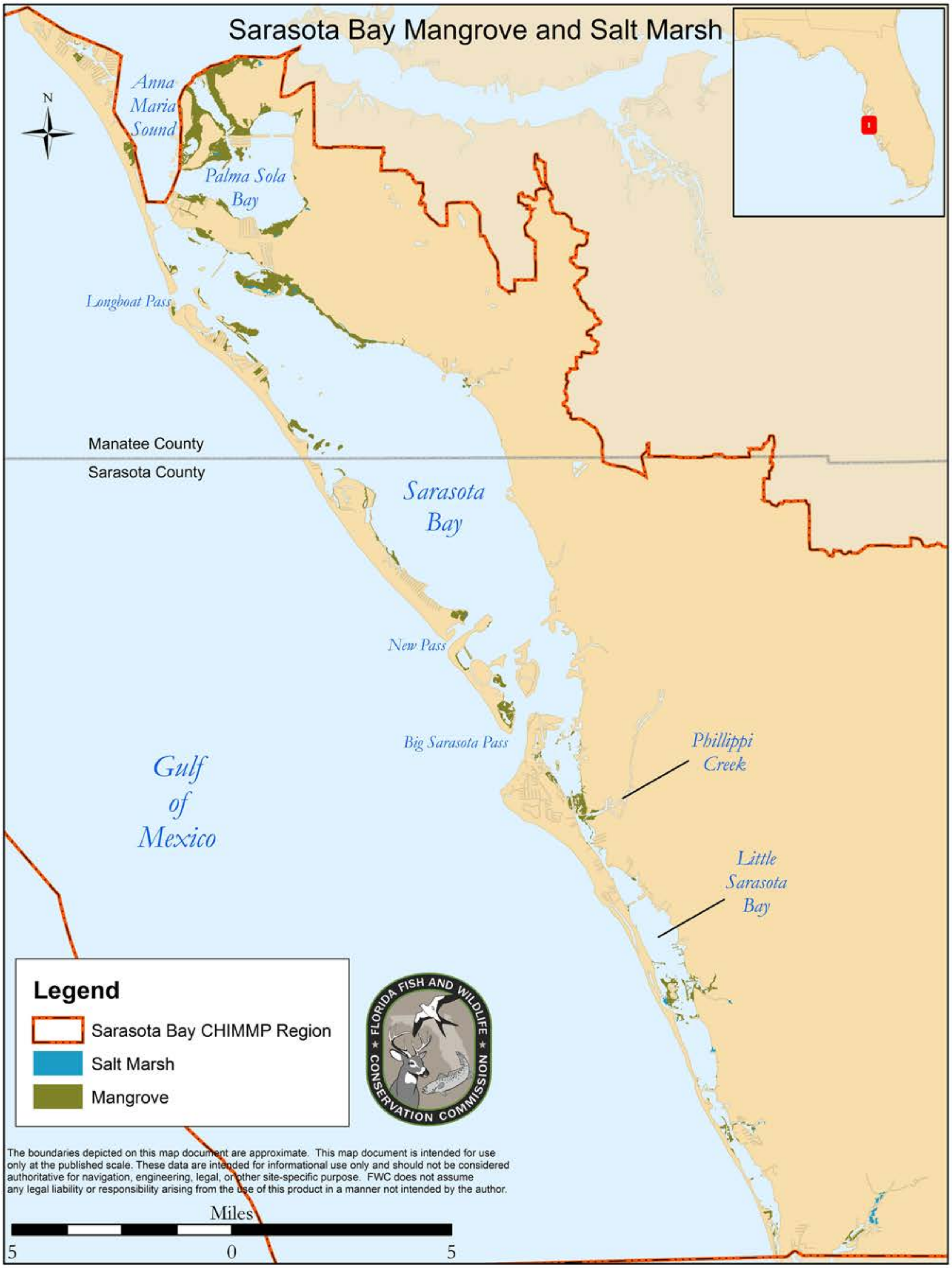

Figure 5.1. Mangrove and salt marsh coverage in the Sarasota Bay region. Data source: SWFWMD 2011 land use/land cover data, based on FLUCCS classifications (FDOT 1999, SWFWMD 2011).

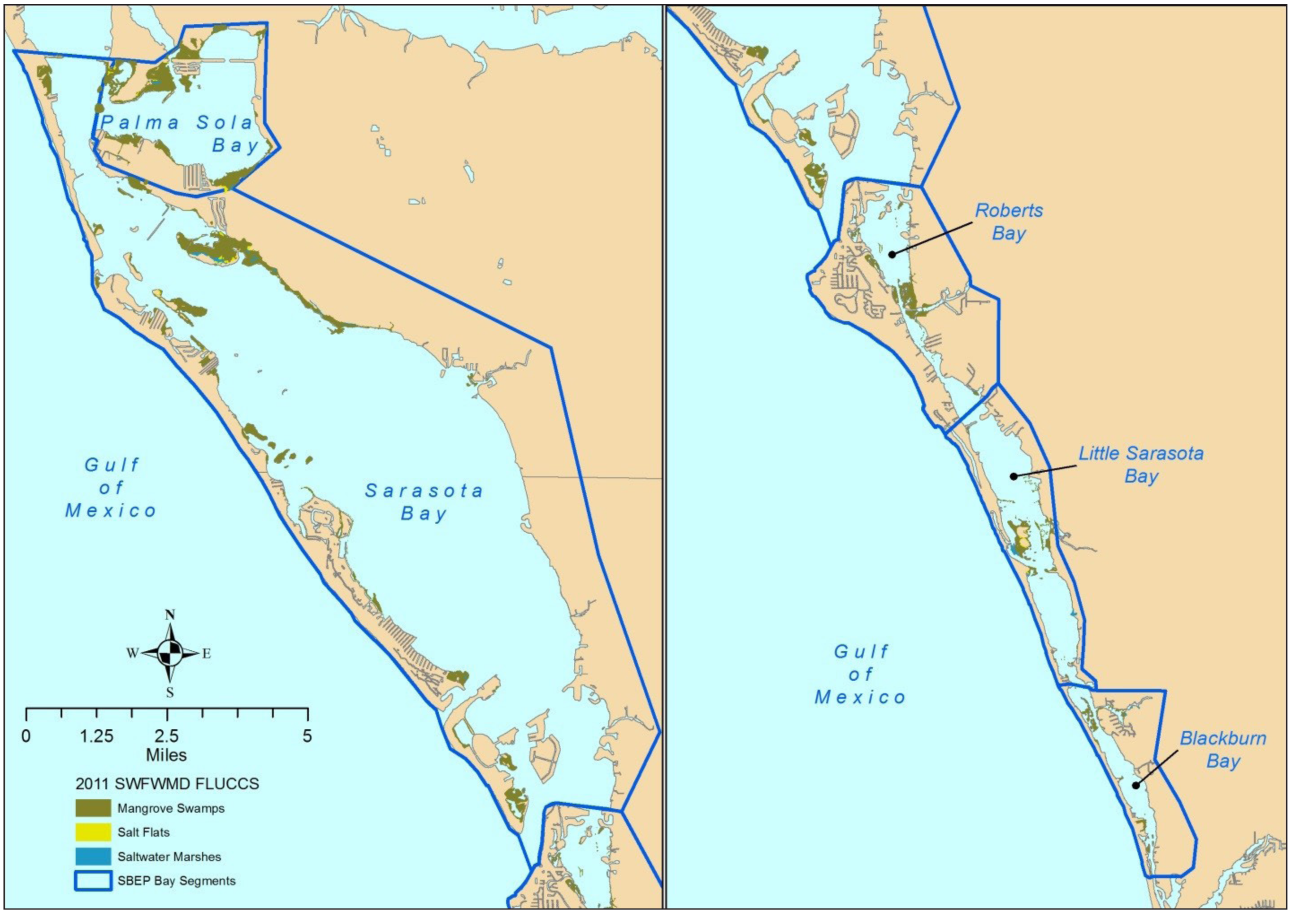

Figure 5.2. Sarasota Bay proper and surrounding bays with current (2011) extent of emergent saltwater vegetation and salt flats. Data source: SWFWMD 2011.

cluded improving water clarity, seagrass extent, shoreline habitats, fisheries, stormwater quality, and overall management and access to the bay. As a result of large-scale community efforts and regulations, nitrogen pollution entering the bay has decreased 64% since 1989 and nitrogen loading from wastewater has decreased 95% (SBEP 2010).

The status of Sarasota Bay wetlands was assessed as part of the 1992 Framework for Action (SBEP 1992). Although habitat was lost to development, the wetlands that remained were found to be in fairly good condition. Larger wetlands (those greater than 0.5 acre/0.2 ha) were found to be in better condition than smaller ones (less than 0.5 acre/0.2 ha), and wetlands were found to be in similar condition on the mainland and the barrier islands.

Mangrove acreage increased after the establishment of the SBEP and the Framework for Action (Table 5.1, Figure 5.3). An early policy of SBEP was to create a mechanism for the restoration and enhancement of wetlands. To facilitate this policy, SBEP developed a comprehensive approach to coastal wetland management that included monitoring, restoration, enhancement, and protection. The goal of the wetlands program was to restore at least 18 acres (7.3 ha) of intertidal wetlands and 11 acres (4.5 ha) of freshwater wetlands annually (SBEP 1995, SBEP 2010). Since 1995, 1,550 acres (627 ha) of intertidal wetlands in Sarasota Bay has been restored (SBEP 2014). The Five Year Habitat Restoration Plans (Scheda 2010, Scheda 2016) were also developed as a planning guide to be used by the SBEP and its partners to identify, prioritize, and implement restoration projects throughout the watershed.

Table 5.1 and Figure 5.3 show a slight increase in total acreage of mangroves mapped after 1990. This increase was due to natural causes, such as conversion of marsh to mangrove, and to mangrove restoration efforts. The increase in coastal wetland habitat from 1999 to 2004 (Figure 5.4) was due primarily to the inclusion of a salt flat category in Southwest Florida Water Management District (SWFWMD) mapping efforts. Salt flats were present before 2004 but had never been mapped. The breakdown of salt marsh, salt flat, and mangrove habitats across the regions of the greater Sarasota Bay area (Figure 5.2) is shown in Table 5.2.

Table 5.1. Recent acreages of mangrove swamps and salt marshes in the Sarasota Bay region. Data source: SWFWMD 2011.

Year	Mangrove	Salt marsh
1990	2,204	115
1994	2,309	104
1999	2,301	106
2004	2,355	106
2005	2,355	100
2006	2,345	100
2007	2,323	99
2008	2,330	97
2009	2,333	94
2010	2,337	92
2011	2,337	92

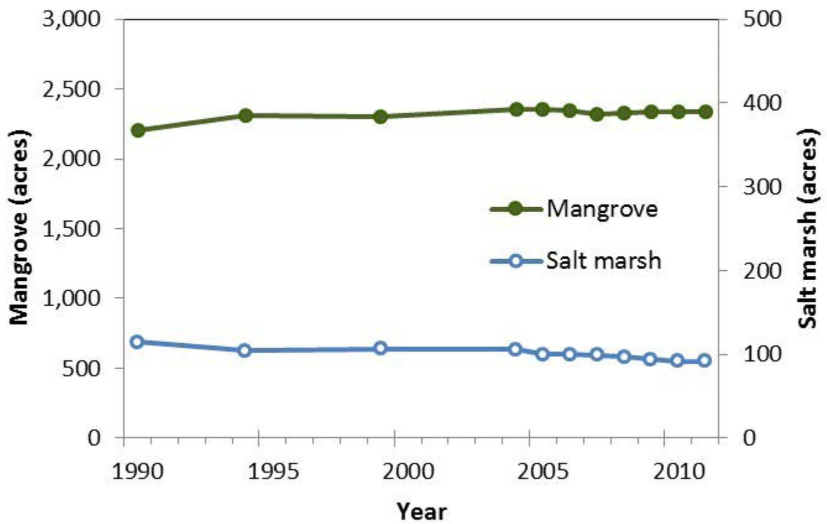

Figure 5.3. Changes in acreages of mangrove swamps and salt marshes in the Sarasota Bay region. Data source: SWFWMD 2011.

Threats to coastal wetlands

- **Climate change and sea-level rise:** Sea-level rise and coastal development are, perhaps, the most significant stresses to remaining coastal wetlands, although their impacts will be felt on differing time scales. The high degree of coastal development along Sarasota Bay restricts landward migration of coastal wetland habitats in response to sea-level rise, emphasizing the need to conserve remaining coastal upland habitat. The high proportion of seawalls and other hardened shorelines will prevent this landward migration, which will likely lead to the loss of mangrove fringes on seawalls.
- **Hydrologic alterations:** Historical practices that have affected the hydrology of the Sarasota Bay region include extensive coastal construction, dredge-and-fill operations, mosquito-ditching, creation of spoil piles, and the closure of Midnight Pass between Siesta Key and Casey Key. A 1990 assessment found that 15 tidal wetlands in the Sarasota area had extensive ditching, spoil piles, or both (SBEP 1992). Many of the hydrologic alterations occurred during dredge-and-fill operations in the 1950s and 1960s and during the construction of the Intracoastal Waterway. While many of these practices are no longer permitted, their influence on hydrologic patterns in the bay continues. Additionally, the increase in impervious surfaces that accompanies urban development results in the diversion and concentration of stormwater runoff (SBEP 2010).
- **Invasive vegetation:** Invasive plant species, such as *Schinus terebinthifolius* (Brazilian pepper) and *Casuarina* spp. (Australian pines), thrive on the additional elevation provided by spoil piles, enabling them to encroach into coastal wetland habitat (SBEP 1992). The altered hydrology and elevation from mosquito-ditching and spoil piles have facilitated the encroachment of invasive nonnative species into disturbed areas.
- **Mangrove trimming:** Landowners along Sarasota Bay frequently trim or prune mangroves to maintain a waterfront view. In 1992, top-down pruning, or hedging, was found to be the prevalent practice; the less detrimental practice of selective limb removal was used less than 5 percent of the time (SBEP 1992). Forty percent of property owners trimmed most or all of the mangroves on their property. In 1996, the Mangrove Trimming and Preservation Act provided statewide regulations on mangrove trimming, affording protection against extreme mangrove trimming or removal. Assurance of proper mangrove trimming, however, still requires homeowner education and enforcement in order to protect trees from excessive damage.
- **Additional threats:** In the 1990 assessment, approximately a quarter of Sarasota Bay wetlands were found to display some form of natural damage, including lightning strikes, freeze damage, herbivory, and erosion (SBEP 1992). While some erosion is natural, wave energy from boating wake contributes to erosion in several areas, particularly along the Intracoastal Waterway (SBEP 1992).

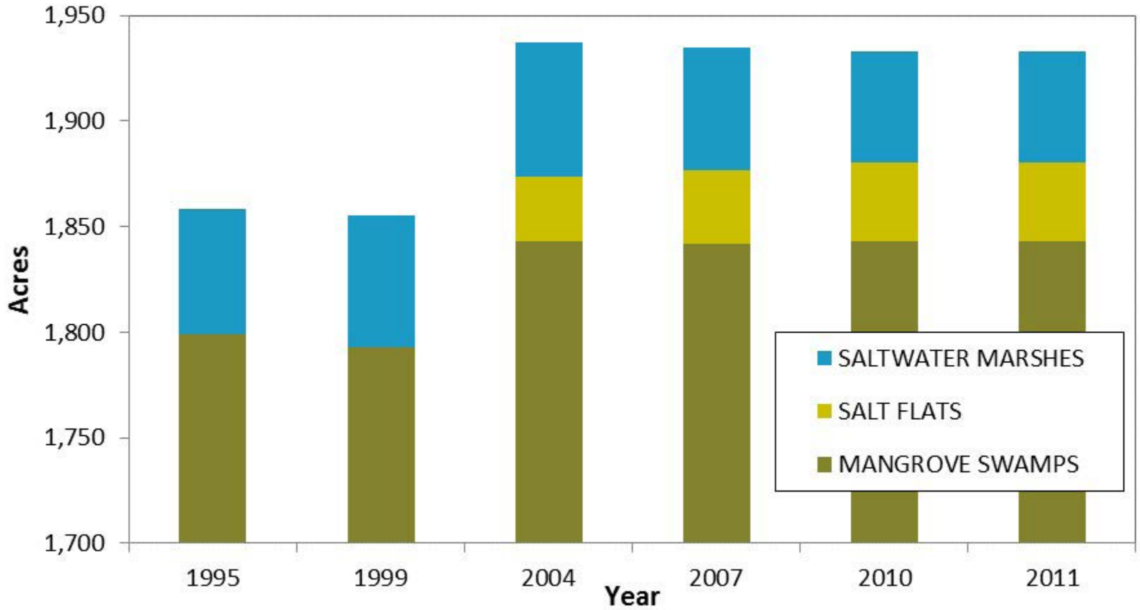

Figure 5.4. Historical acreages of emergent saltwater vegetation and salt flats in selected bay segments surrounding Sarasota Bay (Figure 5.2). SWFWMD did not map salt flats before 2004. Data Source: SWFWMD 2011.

Table 5.2. 2011 acreages for emergent wetlands and tidal flats in Sarasota Bay and selected bay segments. Data source: SWFWMD 2011.

	Mangroves	Salt flats	Salt marsh	Total
Blackburn Bay	54	0	2	56
Little Sarasota Bay	124	7	12	143
Palma Sola Bay	550	11	8	568
Roberts Bay	149	0	1	149
Sarasota Bay	966	20	29	1,016
TOTAL	1,843	38	52	1,933

Mapping and monitoring efforts

Water management district mapping

To assist in resource management decision-making, the SWFWMD conducts regional land use and land cover (LULC) mapping at regular intervals within its jurisdiction (SWFWMD 2011; Figure 5.3, Table 5.1). Features in 1-ft color infrared imagery are photointerpreted at a scale of 1:8,000. After the review of new imagery, updates and changes to map line work are digitized at a scale of 1:6,000. The features delineated in LULC maps are categorized according to FLUCCS categories (FDOT 1999). The coastal wetland features of interest here are mangrove swamp (FLUCCS 6120), saltwater marsh (FLUCCS 6420), and salt flat (FLUCCS 6600). SWFWMD's LULC mapping standards require that wetland features be at least 0.5 acre (0.2 ha) in area to be classified in a map.

Tidal Stream Assessment Project

The Tidal Stream Assessment Project is part of a multicounty effort from Pinellas to Lee County designed to collect data on vegetation, bathymetry, and habitat in 16 tidal creeks on the central west coast of Florida. In the summer of 2013, the University of South Florida's Florida Center for Community Design and Research undertook the assessment in collaboration with Mote Marine Laboratory, Janicki Environmental Inc., and the Estuary Programs of Tampa Bay, Sarasota, and Charlotte Harbor. The data from this project is available at www.sarasota.wateratlas.usf.edu/tidal-stream-assessments and is summarized in Eilers 2013, Eilers 2014, and SBEP 2016.

Shoreline vegetation mapping

In 2014, SBEP initiated a shoreline vegetative assessment of all of its tidal tributaries (Eilers 2014). Sixteen creeks were surveyed for all vegetation types, including mangroves and marshes, from the mouth of the creek to the nontidal freshwater reaches. This information increased the resolution of shoreline vegetation maps in the watershed. All tidal creek assessments (both SW Florida and Sarasota Bay) can be accessed at www.sarasota.wateratlas.usf.edu/tidal-stream-assessments/.

Recommendations for protection, management, and monitoring

- The Sarasota Bay Estuary Program has developed wetland policies that recommend restoration and enhancement, rather than just protection, for critical estuarine wetlands. A key goal outlined in the Comprehensive Conservation and Management Plan (CCMP) for Sarasota Bay (SBEP 1995, updated SBEP 2014) is to restore and protect coastal wetlands. The Five Year Habitat Restoration Plan (Scheda 2010) serves as the strategic document to support the SBEP's wetland policies and identify target restoration areas. The Restoration Plan includes a schedule of actions and priorities with the goal of restoring at least 18 acres (7.3 ha) of intertidal wetlands and 11 acres (4.5 ha) of freshwater wetlands annually. CCMP recommendations for the protection and restoration of coastal wetlands include the following:
    - Conservation and improvement projects need to be identified, coordinated, and monitored. Many restoration activities can be integrated with road or recreational improvements by state and local governments.
    - The importance of upland areas adjacent to wetlands should be recognized and incorporated into land purchases, conservation efforts, and restoration projects.
    - Citizen involvement through community education, clean-up efforts, and outreach to homeowners will facilitate endeavors to protect coastal wetlands in highly populated areas. Homeowners with waterfront properties should be encouraged to maintain natural shorelines, landscape with native plants, and practice responsible mangrove trimming.
    - Consistent policies regarding alteration of shorelines are needed. Fines for violation of environmental policies can discourage harmful activities and also fund environmental projects within the watershed.
- Replace seawalls and other hardened shorelines with living shorelines. Living shorelines reduce pollution from runoff, and the gradual topography facilitates inland migration of mangroves in response to sea-level rise.
- Other recommendations include the removal of old spoil piles, mosquito ditches, and other barriers to tidal flow. Help existing wetlands by reducing boat wakes that cause erosion and removing invasive vegetation (SBEP 1992).

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Tidal Stream Assessment Project: www.sarasota.wateratlas.usf.edu/tidal-stream-assessments

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Chapter 6
Charlotte Harbor and Estero Bay

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Description of the region

Charlotte Harbor is a large, complex estuary bordered by barrier islands that receives freshwater input from the Myakka, Peace, and Caloosahatchee rivers along with many other minor tributaries (Figure 6.1). Farther south, Estero Bay is also lined by barrier islands and receives freshwater flow from many small rivers and creeks. The substrate of the region is composed of deltaic accumulations deposited on the limestone bedrock 5,000 years ago when the rising sea flooded the Peace and Myakka rivers (FDEP 2007). The sediments in the region are predominantly poorly drained sandy and mucky soils. Coastal topography is low and gradually sloped, although numerous 15- to 20-foot (4.5–6 m) tall mounds and middens built by Native Americans contribute to local variability in elevation.

Mangrove forests dominate the remaining natural shorelines of Charlotte Harbor. These mangrove forests generally follow the classic species zonation, with *Rhizophora mangle* (red mangrove) present along the shoreline, followed by *Avicennia germinans* (black mangrove) and *Laguncularia racemosa* (white mangrove) farther inland. Salt marshes are not easily seen from the water as they are found on the landward side of the mangrove forests or on the interior of islands. Salt marshes in this region can be subdivided into 12 types based upon the predominant vegetation. *Juncus roemerianus (*black needlerush) and mixed-vegetation high marsh are the most common types (Beever et al. 2012). Additional common salt marsh vegetation includes *Spartina alterniflora* (smooth cordgrass), *Acrostichum* spp. (leather ferns), *Schoenoplectus robustus* (saltmarsh bulrush), *Distichlis spicata* (salt grass), and *Salicornia* spp. (glassworts). Salt marshes are diverse and may include intermittent algal mats, salt barrens, shrub mangroves, and *Conocarpus erectus* (buttonwood) trees (Beever et al. 2012).

Many of the region's original coastal wetlands were removed from the 1950s through the 1970s, a time in which the area was undergoing drastic population growth and was developed for agriculture, suburbs, and boat navigation. Large areas of salt marsh habitat were destroyed when 400 mi (640 km) of canals were constructed to provide entire subdivisions with waterfront property (SFWMD 2008). Twenty-five percent of the original mangrove swamps were lost to dredge-and-fill developments, and 41% of the natural shoreline has been significantly altered or lost (Beever et al. 2009, CHNEP 2013a). Changes to topography and hydrology included construction of navigation channels, mosquito ditches, spoil piles, seawalls, dams, and residential canals (FDEP 2007).

The population of the region has grown enormously in the past 50 years and continues to grow. From 2000 to 2007, the population of counties adjacent to Charlotte Harbor increased an average of 17% per county (Beever et al. 2009). According to projections from the U.S. Census, the estimated 2015 population was 701,982 for Lee County and 173,115 for Charlotte County (U.S. Census 2015). Human population is concentrated along the coastline, with the majority of residents living within 10 mi (16 km) of the Gulf of Mexico or an estuary's coastline (Beever et al. 2009). The estuarine and coastal waters are valuable to the local economy for tourism, sport and commercial fishing, and many forms of aquatic recreation (CHNEP 2008, CHNEP 2013a).

Management of the seasonally-alternating excess and shortage of freshwater has been an ongoing struggle for human development of South Florida at the expense of natural ecosystems. Flood-prevention structures alter natural hydrologic systems, concentrating freshwater run-

Figure 6.1. Mangrove and salt marsh coverage in the Charlotte Harbor region. Data source: SWFWMD 2011 and SFWMD 2009 land use/land cover data, based on FLUCCS classifications (FDOT 1999, SFWMD 2009a, SWFWMD 2011).

off in outflows and often deflecting flow away from salt marshes. This management has led to ecosystem shifts toward plant species that are more tolerant of high salinities (Beever et al. 2011). In the dry season, commercial, agricultural, and residential demand for water restricts freshwater input into natural ecosystems (Beever et al. 2012). Freshwater flow has decreased in the Peace River due to upstream urban, agricultural, and mining demands and depletion of the Floridan Aquifer (CHNEP 2013a). The upstream regions of the Caloosahatchee River have been channelized, and freshwater releases from Lake Okeechobee are regulated via the Franklin lock and dam. High-nutrient freshwater releases during the summer rainy season and limited freshwater flow during the dry season have led to widely variable estuarine conditions in the Caloosahatchee (CHNEP 2008, Beever et al. 2009).

The majority of the remaining natural shoreline is protected by state parks and other preserves. Charlotte Harbor includes five aquatic preserves: Pine Island Sound, Matlacha Pass, Cape Haze, Lemon Bay, and Gasparilla Sound Charlotte Harbor. State parks in the region include Charlotte Harbor Preserve, Cayo Costa, Myakka, Stump Pass Beach, Gasparilla Beach, and Don Pedro Island. While some barrier islands along Estero Bay are highly developed, the mainland shoreline of the bay remains natural, and much of it is preserved within Estero Bay Preserve State Park. Other state parks around Estero Bay include Lovers Key and Mound Key Archaeological State Park.

Threats to coastal wetlands

- **Altered hydrology and development:** The two greatest anthropogenic threats facing coastal wetlands in the Charlotte Harbor area are continued urban development and alteration of the natural hydrology (Beever et al. 2011). Unnatural hydrologic patterns due to flood-control structures and increasing demand for freshwater often starve or inundate coastal wetlands with freshwater. Continued population growth not only results in direct habitat loss in coastal regions and adjacent buffer zones, but also has indirect effects through pollution and continually growing demands for freshwater.
- **Climate change and sea-level rise:** Climate change is likely to increase seasonality and weather extremes in southwest Florida, causing more extreme temperatures and increasing precipitation during the wet season and less during the dry season (Peterson et al. 2008, Beever et al. 2012). Sea-level rise will result in increased inundation and coastal erosion. In 2009, Lee County had 22,241 acres (9,000 ha) of mangroves and 1,517 acres (613 ha) of salt marsh located at or below 1.5 ft (0.46 m) of elevation; these low elevations are vulnerable to seawater inundation at even modest estimates of future sea-level rise in the region (Beever et al. 2009). Mangrove habitat is projected to continue to expand inland in response to climate change, often at the expense of salt marsh habitats (NWF 2006). But if urban development is present landward of existing coastal wetland habitat, these coastal wetlands will be squeezed out by rising sea level (CHNEP 2009). Increases in hurricane severity, erosion, temperature extremes, anthropogenic disturbances, and invasive species will also likely lead to further ecological destabilization and shifts in species abundances (Beever et al. 2012, FDEP 2014a).
- **Invasive vegetation:** As of 2007, Charlotte Harbor Preserve State Park documented 38 invasive plants and 22 invasive animals (FDEP 2007). *Schinus terebinthifolius* (Brazilian pepper), *Melaleuca quinquenervia* (melaleuca), and *Casuarina* spp. (Australian pines) are very common in the region and encroach on the edges of mangrove and salt marsh habitat (CHNEP 2011).
- **Storm events:** Large numbers of mangroves were killed in 2004 when Hurricane Charlie made landfall in the Charlotte Harbor region as a Category 4 storm. The trees were killed and stripped of their leaves by the initial force of the storm, but they also suffered afterward from increased desiccation, disease, and insect herbivory (FDEP 2007). Coastal wetlands in the region can recover relatively quickly from natural disturbances such as hurricanes, fires, and drought, but they are more vulnerable to invasive vegetation afterward (Beever et al. 2009).
- **Mangrove trimming:** While much of Charlotte Harbor's coastlines are within preserves and state parks, urbanized development is present along a significant part of the estuarine shoreline, and mangroves are often trimmed along these waterfront properties (CHNEP 2011). Proper mangrove trimming, according to regulations established by the Florida Department of Environmental Protection (FDEP), has minimal impact on mangrove productivity, but improper hedging can result in the loss of more than 80% of productivity and kill the trees. Only 20% of mangroves are trimmed according to permitting regulations, and enforcement is difficult because FDEP field personnel are stretched extremely thin (Beever et al. 2011).
- **Erosion:** Coastal erosion has increased in recent decades, partly due to coastal development and boating inlets interrupting natural sediment flow (Beever et al. 2012). Several regions of critical erosion already occur on the outer edges of barrier islands in the region (Beever et al. 2009, FDEP 2014b).

Table 6.1. Historical acreages of mangrove swamps (FLUCCS 6120) and salt marshes (FLUCCS 6420) in Charlotte Harbor (Figure 6.1), by water management district. Data sources: SFWMD 2009a, SWFWMD 2011.

Year	SWFWMD Mangrove	SWFWMD Salt marsh
1990	18,810	8,171
1994	18,428	8,507
1999	18,403	8,533
2004	18,740	8,665
2005	18,737	8,679
2006	18,720	9,544
2007	18,719	9,543
2008	20,507	7,426
2009	20,490	7,732
2010	20,457	7,546
2011	20,461	7,571
Year	**SFWMD Mangrove**	**SFWMD Salt marsh**
1995	42,462	3,891
1999	41,093	3,732
2004–2005	41,057	4,160
2008–2009	41,482	4,612

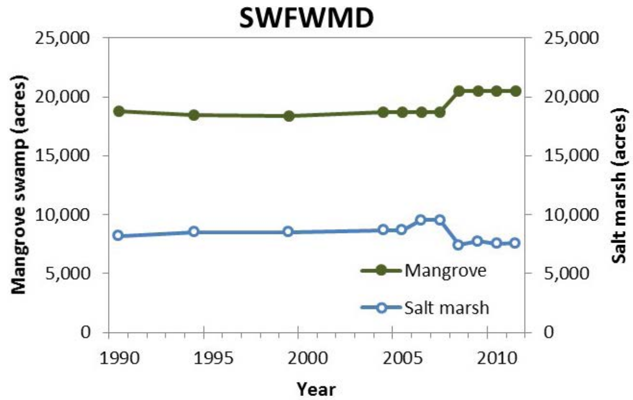

Figure 6.2. Acreages of mangrove swamps and salt marshes in the SWFWMD's portion of Charlotte Harbor (Figure 6.1 and Table 6.1). Data source: SWFWMD 2011.

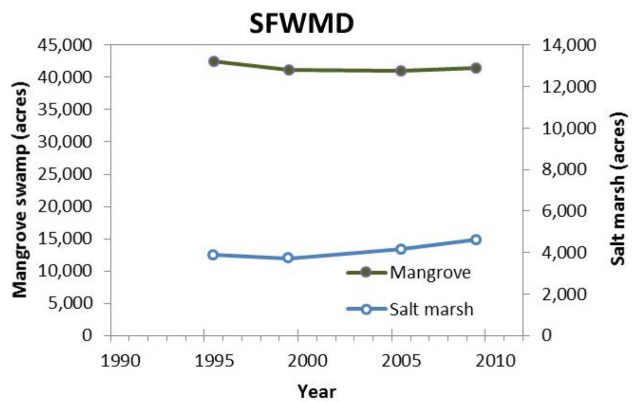

Figure 6.3. Acreages of mangrove swamps and salt marshes in the SFWMD's portion of the Charlotte Harbor region (Figure 6.1 and Table 6.1). Data source: SFWMD 2009a.

Mapping and monitoring efforts

Water management district mapping

The Charlotte Harbor and Estero Bay region is divided between the Southwest Florida Water Management District (SWFWMD) and the South Florida Water Management District (SFWMD) (Figure 6.1). SWFWMD conducted land use and land cover (LULC) surveys from 1990 through 2011 (Table 6.1, Figure 6.2). Features in 1-ft color infrared imagery were photointerpreted at a scale of 1:8,000. After the review of new imagery, updates and changes to map line work are digitized at a scale of 1:6,000. The features delineated in LULC maps are categorized according to Florida Land Use and Cover Classification System (FLUCCS) categories (FDOT 1999). SWFWMD's LULC mapping standards require that wetland features be at least 0.5 acre (0.2 ha) in area to be classified in maps.

SFWMD also conducts fairly regular LULC surveys within its boundaries (Table 6.1, Figure 6.3). The 2008–2009 land cover classifications were based on an SFWMD modified FLUCCS classification system (FDOT 1999, SFWMD 2009b). Minimum mapping units were 5 acres (2 ha) for uplands and 2 acres (0.8 ha) for wetlands. The 2008–2009 maps were made by interpreting aerial photography and updating 2004–2005 vector data (SFWMD 2009).

Some of the year-to-year variability seen in water management district salt marsh and mangrove acreage (Figures 6.2 and 6.3) is likely due to refinement of mapping methods and spatial resolution rather than actual annual variation (Beever et al. 2012, CHNEP 2014). Small annual changes in salt marsh and mangrove extent continue to occur as a result of restoration projects, mangrove encroachment into salt marshes, and small amounts of permitted development (CHNEP 2009, CHNEP 2011, CHNEP 2014). A salt marsh mapping study conducted during 2010–2012 (see below) offers a high-resolution map of salt marsh that identifies these small changes (Beever et al. 2012).

Charlotte Harbor National Estuary Program and Southwest Florida Regional Planning Council mapping

Beever et al. (2012) mapped 14,853 acres (6,010 ha) of salt marsh of all types in 2010–2012 within the Charlotte Harbor National Estuary Program (CHNEP) study area. Local acreages of salt marshes among the regional watersheds are shown in Table 6.2. Total salt marsh extent was greater in the 2010–2012 CHNEP study than in earlier mapping by the Florida Fish and Wildlife Conservation Commission, SFWMD, and SWFWMD (Beever et al. 2012). These differences are not thought to be the result of an actual increase in salt marsh extent, but rather the product of refined mapping methods in the CHNEP study. Significant areas of salt marsh were incorrectly mapped as mangrove forest in earlier mapping efforts and other areas of mangrove were designated as salt marsh. In some watersheds, some freshwater marsh and bare sand upland areas were previously mapped as salt marsh (Beever et al. 2012). An example of these adjustments (labelled as working base modifications) is shown in Figure 6.4, while Figure 6.5 shows the total extent of salt marshes and mangroves in the Charlotte Harbor region as determined by CHNEP and Southwest Florida Regional Planning Council (SWFRPC) mapping.

Predevelopment maps were created by SFWMD, CHNEP, and consultants using historical aerial photographs (Beever et al. 2012). Calculations based on these maps reveal that more than half of the salt marsh in the Charlotte Harbor area has been lost to development (salt marsh loss in each watershed is shown in Table 6.3). However, 74% of the remaining salt marsh extent is located on conserved land (Table 6.3).

In 2014, CHNEP initiated a new two-year mapping effort for mangroves in the Charlotte Harbor region. Mangroves were mapped by geomorphic type and species (example shown in Figure 6.6). Geomorphic types include overwash island, fringe, riverine, basin, hammock, scrub, and altered mangrove hedge. In addition, areas with die-offs, stress, and potential future loss were identified. Areas with blocked tidal flow can lead to stagnant water, which is a stressful condition for mangroves that may lead to die-offs, a phenomenon also referred to as a mangrove heart attack (Lewis et al. 2015). Further CHNEP efforts have focused on the identifying characteristics of stressed mangroves, including spectral signatures, which enable early identification and strategy development to prevent mangrove die-offs (Beever et al. 2016).

Table 6.2. Salt marsh acreage in Charlotte Harbor watersheds, as mapped by CHNEP in 2010–2012. Data source: Beever et al. 2012.

Watershed	Cord-grass	Black needlerush	Leather fern	Saltmarsh bulrush	Scrub mangrove	Algal	Saltern	Succulents	Mixed	Grasses	Shrub buttonwood	Total
Caloosahatchee	0.00	138.51	76.54	0.00	45.72	6.58	11.16	4.32	66.33	40.16	0.00	389.32
Charlotte Harbor	0.00	190.48	8.28	0.00	315.34	248.40	327.44	307.19	2,622.71	202.84	0.00	4,222.68
Dona and Roberts Bay	0.00	30.37	5.30	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	35.71
Estero Bay	0.00	726.26	38.58	0.00	246.95	532.74	198.45	167.15	779.50	65.57	18.71	2,773.91
Lemon Bay	0.04	10.62	37.82	0.00	1.37	12.28	11.01	21.59	25.10	42.35	0.00	162.18
Matlacha Pass	0.00	14.04	0.28	0.00	449.45	78.38	46.85	123.34	1,466.90	149.23	0.90	2,329.37
Myakka River	0.00	1,028.95	52.40	0.00	4.95	16.75	8.18	6.67	129.43	44.40	0.00	1,291.73
Peace River	0.04	1,446.11	238.27	337.37	51.35	7.90	1.42	32.97	180.98	5.25	0.00	2,301.66
Pine Island Sound	2.72	8.33	7.23	0.00	90.97	340.70	51.58	280.51	512.85	51.27	0.00	1,346.16
Total	2.81	3,455.16	388.15	337.37	1,160.39	1,237.14	644.97	939.42	5,717.47	560.92	19.62	14,463.42

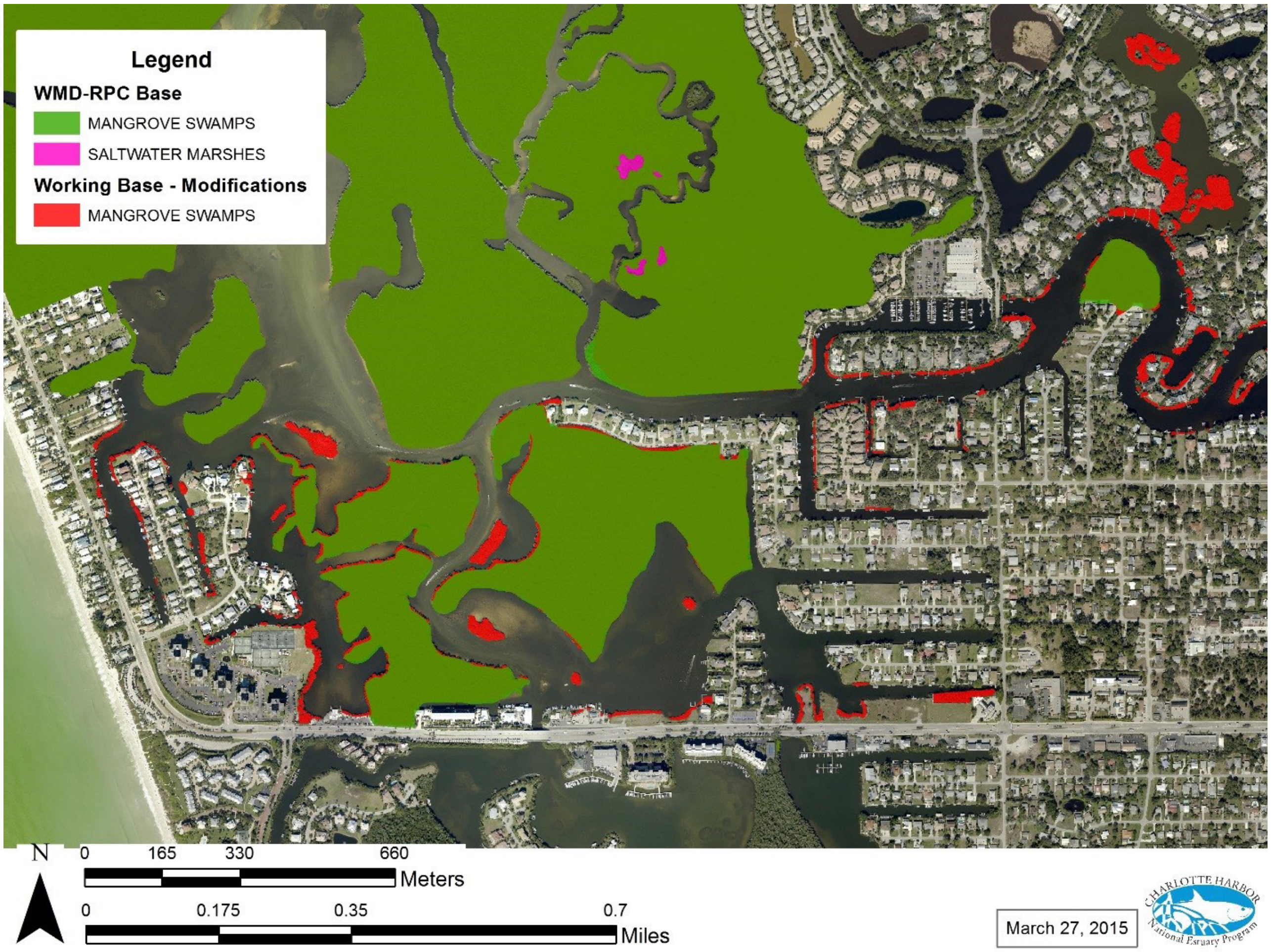

Figure 6.4. Example of mapping adjustments (working base modifications) made by CHNEP and SWFRPC to water management district and regional planning council base maps (WMD-RPC Base) near the Imperial River, south of Estero Bay.

Local assessments and reports

Many recent assessments of the Charlotte Harbor estuary and watershed are available from the Conservancy of Southwest Florida (CSF 2005, CSF 2011), CHNEP, and SWFRPC (Beever et al. 2009, 2011, and 2012, CHNEP 2008, 2009, 2011, 2013a, 2013b, and 2014). These documents include vulnerability assessments, estuary report cards, monitoring reports, and conservation and management plans for the region. The tidal stream assessment project mentioned in Chapters 4 and 5 also includes Charlotte Harbor and Estero Bay (SBEP 2016). The multicounty collaborative effort includes monitoring data on vegetation, bathymetry, and habitat in tidal creeks on the central west coast of Florida. The data from this project are publically available at www.sarasota.wateratlas.usf.edu/tidal-stream-assessments and are summarized in SBEP 2016.

Estuary report cards

The Conservancy for Southwest Florida used water quality and mapping data to create the 2005 and 2011 estuary report cards (CSF 2005, CSF 2011). The regional grades in these report cards were based on factors such as water nutrient concentrations, dissolved oxygen concentrations, presence of pathogens and heavy metals, hydrology, extent of all wetlands and mangroves compared with historical data, and area of conservation lands. Common problems identified included low concentrations of dissolved oxygen and high concentrations of nutrients, pathogens, or mercury. Some regions also received low scores due to altered hydrology, few remaining mangroves, and small amounts of conserved land. A summary of the scores given to the relevant regions is provided in Table 6.4; full evaluations and detailed maps of modern and historical mangrove extent may be found in the technical report (CSF 2011).

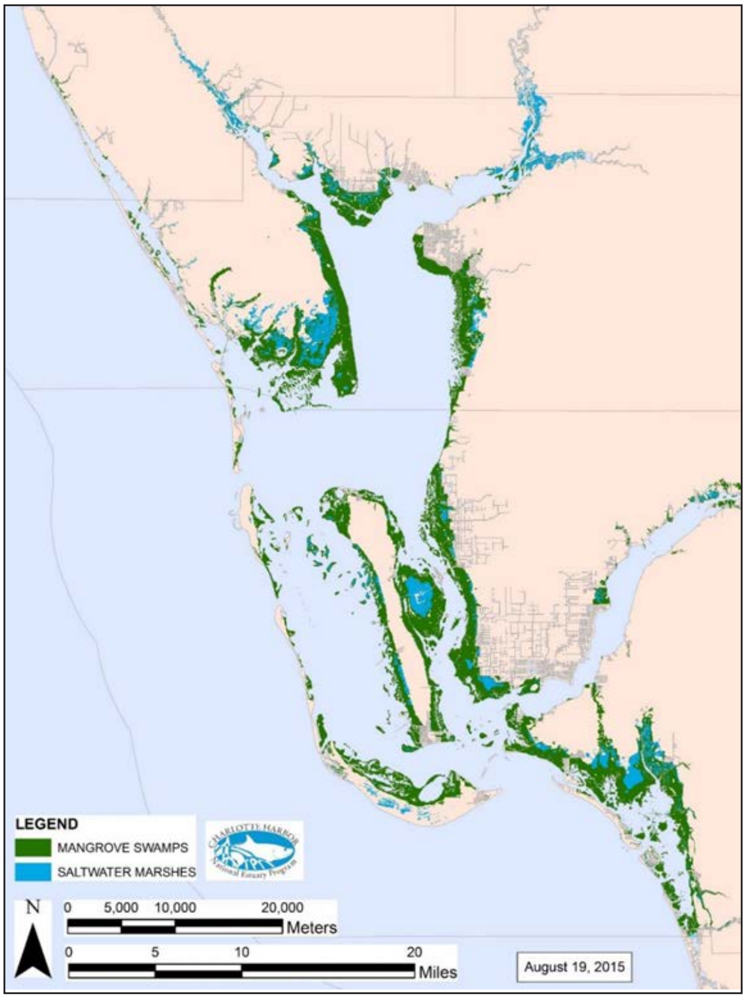

Figure 6.5. Mangrove swamp and salt marsh in Charlotte Harbor/Estero Bay, determined by the Charlotte Harbor National Estuary Program and the Southwest Florida Regional Planning Council.

Volunteer shoreline surveys

CHNEP used volunteers to conduct shoreline surveys in 2007, 2010, and 2013. The surveys identified the percentage of mangroves present on the shoreline, mangrove height and trimming style (if trimmed), the presence of nonnative vegetation, shoreline hardening, and type of construction. While the entire Charlotte Harbor estuary coastline was not surveyed, the same regions were covered in 2010 and 2013 (CHNEP 2013b). These surveys found an increased presence of mangroves and Brazilian pepper in several of the surveyed regions.

Sea Level Affecting Marshes Model

The Sea Level Affecting Marshes Model (SLAMM) Version 4.1 (NWF 2006) predicts coastal vegetation changes using the Intergovernmental Panel on Climate Change A1B climate scenario, which foresees a mean sea-level rise of 15.2 in. (38.6 cm) by 2100 (IPCC 2001). SLAMM predicts that 89% of salt marshes in the Charlotte Harbor area will disappear by 2100, but mangrove extent will increase by 75% (NWF 2006). Mangroves are expected to overtake large amounts of salt marsh habitat, but their success also depends upon their ability to accumulate sediment at a pace that keeps up with sea-level rise.

Table 6.3. A comparison of predevelopment and modern salt marsh extent in Charlotte Harbor watersheds, as mapped by CHNEP in 2010–2012. Conserved land was identified using SWFWMD and SFWMD 2009 LULC maps and 2011 Southwest Florida Regional Planning Council maps. Data sources: Beever et al. 2011, Beever et al. 2012, SFWMD 2009a, and SWFWMD 2011.

Watershed	Predevelopment acreage	2010–2012 acreage	Acreage change	% change	Current salt marsh acreage on conserved land	% of current salt marshes on conserved land
Caloosahatchee	2,659	389	−2,269	−85%	305	78%
Charlotte Harbor	11,548	4,223	−7,325	−63%	3,808	90%
Dona and Roberts Bay	6	36	30	488%	1	3%
Estero Bay	2,055	2,774	719	35%	2,508	90%
Lemon Bay	1,023	162	−861	−84%	111	69%
Myakka River	935	1,292	357	38%	511	40%
Peace River	5,540	2,302	−3,239	−58%	710	31%
Pine Island Sound and Matlacha Pass	10,577	3,679	−6,898	−65%	3,109	85%
Total	34,343	14,857	−19,486	−57%	11,063	74%

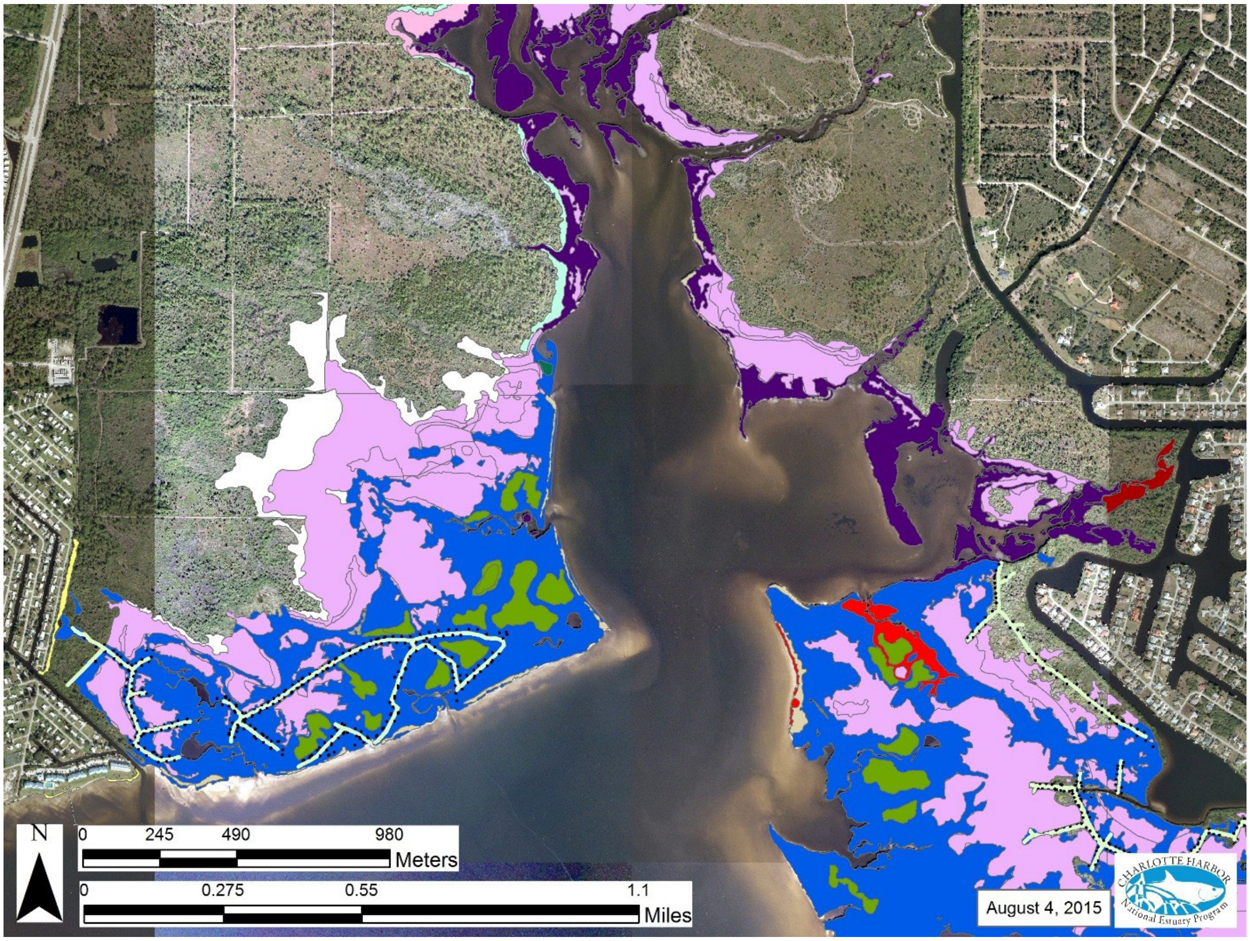

Figure 6.6. Example of detailed CHNEP mapping along Tippecanoe Bay in northern Charlotte Harbor. Pink = salt marsh, blue = mixed mangrove fringe, olive green = basin black mangrove, red = red mangrove fringe, white = white mangrove fringe, beige = tropical hardwood hammock (coastal berm), black dots = spoil along mosquito ditches.

Recommendations for protection, management, and monitoring

- Elevation-appropriate buffer zones that are protected from human development are needed on the landward edge of coastal wetlands. These will allow coastal wetlands to move inland as habitat is lost due to sea-level rise and erosion (CHNEP 2013a).
- Hydrologic flow following natural seasonal patterns needs to be re-established in the estuary. This includes minimizing large pulses of freshwater, establishing a reliable aquifer flow, restoring water conveyances, and planning for future water demands in the area (CHNEP 2013a).
- Additional public education and enforcement regarding appropriate mangrove trimming are needed. More FDEP personnel are needed to enforce mangrove trimming regulations, or mangrove trimming should be banned (Beever et al. 2011).
- Monitoring to document the effects of climate change and identify early signs of ecosystem-wide shifts is needed to best implement management and mitigation strategies (Beever et al. 2009). Invasive species and locally altered hydrology can also drive ecosystem shifts, but pre-emptive rehabilitation of stressed and degraded coastal wetland habitats could aid particularly vulnerable regions (Lewis et al. 2015, Beever et al. 2016). Recommendations regarding wetland mitigation practices in southwest Florida may be found in Beever et al. (2011).
- Management concerns in the Charlotte Harbor Preserve State Park management plan (FDEP 2007) include the need for mapping and inventory of plant and animal communities, increased effort to control the extent of invasive species, and hydrologic modeling. The plan also reinforced the need for consistent monitoring of natural resources and restoration projects. FDEP seeks to find a balance between land preservation efforts and making specific regions accessible for recreation. Continued population growth in the region necessitates conservation of freshwater resources and increases the importance of conserved land.

Table 6.4. Wildlife habitat grades of regions in and around the Charlotte Harbor Estuary. Data source: CSF 2011.

Estuary	Wetlands percent remaining	Mangroves percent remaining	Averaged percentage	Conservation lands percentage	Overall wildlife-habitat grade
Coastal Venice	48%	47%	48%	12%	C−
Lemon Bay	70%	55%	63%	25%	B
Greater Charlotte Harbor	64%	57%	61%	18%	B−
Pine Island Sound	70%	100%	85%	56%	A+
Caloosahatchee	39%	38%	39%	16%	D−
Estero Bay	62%	85%	74%	21%	B−

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Conservancy of Southwest Florida: www.conservancy.org/

Southwest Florida Regional Planning Council: www.swfrpc.org/

South Florida Water Management District: www.sfwmd.gov/

Southwest Florida Water Management District: www.swfwmd.state.fl.us/

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Chapter 7
Collier County

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Description of the region

Collier County includes the large coastal developments of Naples and Marco Island but also contains a network of protected lands with large uninterrupted areas of coastal habitat (Figure 7.1). These coastal public lands include Rookery Bay Aquatic Preserve, Rookery Bay National Estuarine Research Reserve (NERR), Cape Romano–Ten Thousand Islands Aquatic Preserve, Ten Thousand Islands National Wildlife Refuge, Collier-Seminole State Park, and Everglades National Park. Coastal estuarine waters are generally shallow; Ten Thousand Islands National Wildlife Refuge has a mean depth of 10 ft (3 m) (USFWS 2000). Salinity varies widely with freshwater inflow, generally staying above 34 in the dry season and fluctuating between 20 and 32 in the wet season (Soderqvist and Patino 2010). The substrate is Miami limestone from the Miocene, which is overlaid by a poorly drained assortment of late Pleistocene sands, organic material, and mangrove peat (USFWS 2000). The coastal islands also contain quartz sand and shell hash (FDEP 2012). Coastal elevation is very low, although shell mounds from Native American populations and some small sandy dunes provide some local variability (USFWS 2000).

The undeveloped coastline and many small islands in Collier County are vegetated by extensive mangrove forests (Figure 7.1). According to version 3.0 of Cooperative Land Cover data, there are approximately 86,300 acres (43,900 ha) of mangroves and 25,800 acres (10,400 ha) of salt marsh in the county (FWC and FNAI 2014).

The extensive network of small islands along the coastline results in a high edge-to-area ratio in these island mangrove habitats. *Rhizophora mangle* (red mangrove) is commonly found along the fringe of coastal islands and tidal creeks. *Avicennia germinans* (black mangrove) and *Laguncularia racemosa* (white mangrove) tend to prefer higher elevation or disturbed areas usually found on the interior and landward side, although mixed-species mangrove forests are also found in the area (USFWS 2000). *Conocarpus erectus* (buttonwood) is common in areas of slightly higher elevation, such as on ridges along levees or on beach strands. Powerful hurricanes in 1918 and Hurricane Donna in 1960 caused massive deforestation in the region; consequently, most of the mangroves are second-growth forests (USFWS 2000, FDEP 2012). Hurricane Andrew in 1992 and Hurricane Wilma in 2005 also caused extensive damage to the mangroves (Smith et al. 1994, FDEP 2012). Andrew caused slightly more tree loss in island mangroves, while Wilma caused significantly more damage in basin forests and set back recovery of the forests after Andrew (Smith et al. 2009).

Mangroves dominate the coast, while salt marshes dominated by *Spartina* spp. (cordgrasses), *Juncus roemerianus* (black needlerush), and *Distichlis spicata* (salt grass) occur further inland (Figure 7.1). Most of the salt marshes lack a direct tidal connection in most places but flood at high tides and during storms. Coastal ponds containing saline, brackish, or freshwater are also found in close association with the salt marshes. Upland habitat is not common along the coast due to the low elevation (USFWS 2000).

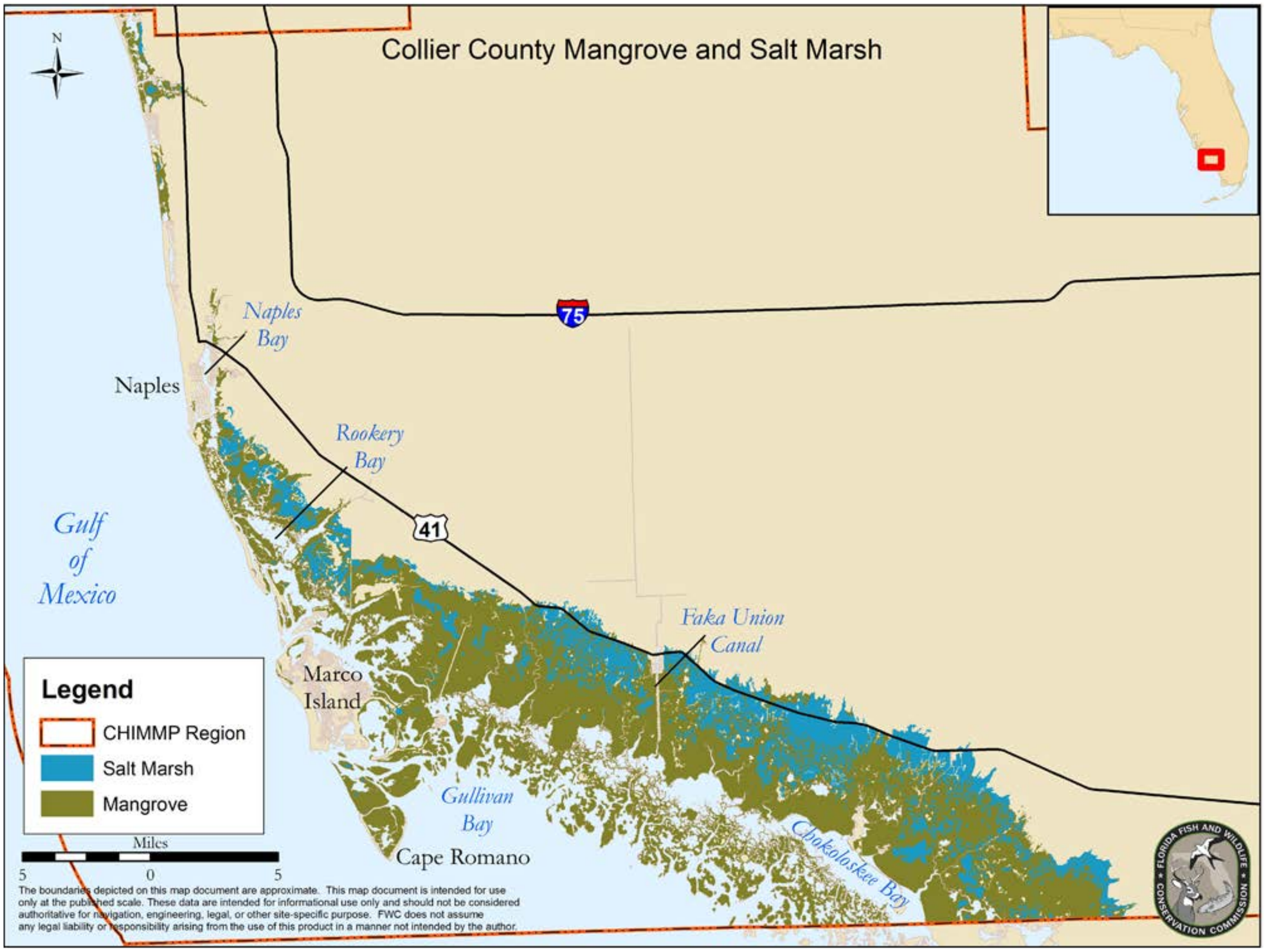

Figure 7.1. Mangrove and salt marsh habitats in Collier County, Florida according to SFWMD 2011–2013 land use/land cover data following FLUCCS classifications (FDOT 1999, SFWMD 2009a).

Mangroves have expanded inland as a result of altered hydrology due to drainage canals diverting freshwater flow, U.S. 41 impeding surface water flow to salt and brackish marshes, and sea-level rise. Mangrove extent in Ten Thousand Islands National Wildlife Refuge increased 35%, or 4,640 acres (1,878 ha), from 1927 to 2005 (Krauss et al. 2011). Constructed waterways, such as the Faka Union Canal (Figure 7.1), facilitate mangrove expansion by increasing the upstream reaches of tidal influence, enhancing the dispersal of mangrove propagules inland (Krauss et al. 2011).

Human development and hydrologic alterations

Rapid development and a lack of environmental regulation before 1970 resulted in extensive loss and alteration of wetlands in Collier County (USFWS 2000). This loss was followed by a period of rapid population growth; from 1980 to 1998, the population of the county increased by 144% (FDEP 2012). With an estimated population of 357,305 in 2015, the population of Collier County is lower than that of other urban centers in South Florida. However it grew at an estimated rate of 11.1% from 2010 to 2015, outpacing the state growth average of 7.8% (U.S. Census 2015). Tourism, commercial fishing, and sportfishing are central components of the economy.

The once extensive mangrove shoreline along Naples and Marco Island has been irreversibly transformed by development and hydrologic alterations (Turner and Lewis 1997). Mangrove fringe adjacent to urban areas was removed to pave the way for residential developments and commercial ventures. Naples Bay lost more than 70% of its fringing mangrove shoreline in the 1950s and 1960s, when extensive dredge-and-fill operations and shoreline modifications made way for residential communities including Port Royal, Royal Harbor, Aqualane Shores, Windstar, and Moorings Bay (FDEP 1981, Schmid et al. 2006). Mangroves were extensively removed on Marco Island in the 1960s and 1970s to make way for the current framework of dredged canal-front homes.

Although human development has been extensive in many parts of the county, large tracts of protected land and mangrove expansion have enabled mangroves to retain 70% of their original acreage in the Rookery Bay watershed and to exceed their historical acreage in the Ten Thousand Islands watershed (CSF 2011). In the northern part of the watershed, however, extensive human development has caused water quality problems along the coast, including low dissolved oxygen, high nutrients, and increased levels of other pollutants (CSF 2011). A series of canals were dug by the Gulf American Corporation during 1963–1971 to drain extensive areas for the planned South Golden Gate Estates development. These canals connect to the Faka Union Canal and discharge at Port of the Islands, resulting in increased freshwater flow and water turbidity, along with decreased fish populations and seagrass growth in Ten Thousand Islands National Wildlife Refuge (USFWS 2000, Shrestha et al. 2011). Much of the planned South Golden Gate Estates were not developed, and the State of Florida purchased most of the private lots between 1998 and 2001 to implement the hydrologic restoration plan of the region, now known as Picayune Strand State Forest (SFWMD and USDA 2003). The restoration plan aims to restore hydrology by blocking canals, pumping out water, and removing roads to restore more natural sheet flow (USFWS 2000, SFWMD and USDA 2003). The first of three pump stations for the restoration effort was opened in 2014 (Staats 2014). Additional efforts to improve sheet flow in the Ten Thousand Island region include the installation of 62 culverts along 48 miles (77 km) of Tamiami Trail (U.S. 41) in Collier County from 2004 to 2006 (Abtew and Ciuca 2011).

Threats to coastal wetlands

Coastal wetlands are threatened by anthropogenic and natural phenomena. Finn et al. (1997) classified 15 different causes of mangrove die-offs in the area including lightning strikes, hurricanes, frost, and human impacts. In southwest Florida, *A. germinans* die-offs often occur as a result of an extended period of surface-water retention due to impoundment, increased surface-water runoff, blocked tidal exchange, or stagnant tidal circulation leading to prolonged submersion and stress on pneumatophores. This can eventually kill the mangrove, and the subsequent decay of biomass belowground can cause peat subsidence, decreasing elevation and resulting in further inundation (Worley 2005).

- **Coastal development and altered hydrology:** Urban construction has been linked to many instances of mangrove die-off in Collier County. For instance, urban and road construction along Clam Bay led to altered hydrology and widespread death of *A. germinans* in the 1990s (Worley and Schmid 2010). While much of Collier County is now conservation land, population growth and development continue, particularly along State Road 951 and south of U.S. 41. This development continues to impact coastal wetlands via habitat destruction, impaired water quality, and altered hydrology, such as roads blocking tidal exchange (Zysko 2011).
- **Storm events:** Hurricanes and tropical storms shape the structure of mangrove forests by causing widespread defoliation and mortality and by altering tree sizes and species abundance (Smith et al. 2009). Powerful hurricanes between 1918 and 1960 killed many of the mangroves in the region (USFWS 2000, FDEP 2012) and coastal wetlands were heavily damaged by Hurricane Andrew in 1992 (Smith et al. 1994). Peat collapse is also suspected of causing mortality after storms and is thought to have been responsible for the *A. germinans* die-offs following the 1935 Labor Day hurricane and Hurricane Donna in 1960 (Wanless et al. 1995).
- **Climate change and sea-level rise:** *C. erectus* and *L. racemosa* have already overtaken significant expanses of salt marsh and brackish marsh as they expand inland, primarily as a response to rising sea levels (Krauss et al. 2011, Barry et al. 2013). Rising sea levels may also enable mangrove expansion into salt barrens. The tidal flushing provided by a small increase in sea level can decrease hypersaline conditions of the salt barren, creating favorable conditions for mangroves to colonize there. Despite current trends in mangrove expansion, mangroves are still at risk if the rate of sea-level rise exceeds the rate of substrate accumulation or inland migration. Development along some regions of coastal Collier County also block mangroves and salt marsh from migrating inland, pinching out coastal wetland habitat.
- **Disease and other biotic factors:** Disease is usually not the root cause of mortality in coastal wetland forests; rather, diseases tend to occur in areas that are stressed by other influences (Jimenez et al. 1985). *Cytospora rhizophorae,* a fungus found in mangrove forests in Collier County, is a classic example. This fungus tends to attack stressed *R. mangle* trees and has a mortality rate as high as 32% (Wier et al. 2000). Similarly, after the cold snap in the winter of 2008, some parts of mangrove forests became infested with wood-boring beetles. Under healthy conditions these boring beetles tend to attack living twigs or branches, but the tree usually recovers.

But in stressed conditions severe infestations are more likely to develop, possibly to the extent that the trees become girdled and die. Given that current and future stressors to coastal wetlands are likely to increase due to anthropogenic and natural causes, disease and infestations could have a greater influence on mortality rates.

- **Invasive vegetation:** Invasive vegetation, mainly *Schinus terebinthifolius* (Brazilian pepper) but also *Casuarina* spp. (Australian pines), *Melaleuca quinquenervia* (melaleuca), and *Colubrina asiatica* (latherleaf) tend to dominate along the fringe of marsh and mangrove habitats (USFWS 2000). Removal efforts are ongoing as funding is available, but maintaining control is a constant challenge.

Mapping and monitoring efforts

Institute for Regional Conservation mapping

The southwest coast of Collier County has been mapped according to the Comprehensive Everglades Restoration Plan (CERP) by the Institute for Regional Conservation (IRC). Due to funding constraints, efforts have been limited to Rookery Bay NERR (Barry et al. 2013, Barry and van der Heiden 2015), Ten Thousand Island National Wildlife Refuge (Barry 2009), and Picayune Strand State Forest. Results of this mapping are shown in Figure 7.2. Each agency with land-management responsibilities has been responsible for finding the funding to contract with IRC to conduct the mapping efforts. Having IRC conduct the mapping for all the agencies has provided a contiguous map with consistent methodology.

The vegetation maps were created based on extensive field work, multiple years of aerial photography interpretation, and LiDAR. The field data collection included photo points and GPS track logs with observed vegetation, including the presence of rare and nonnative vegetation. To produce a historical vegetation map, IRC integrated field observations, interviews with long-time residents, and 1940 aerial photography. The habitat mapping efforts in Rookery Bay NERR have documented widespread mangrove die-off areas within the reserve (Barry et al. 2013). The die-offs, many in areas dominated by *A. germinans*, are most likely due to a combination of anthropogenic causes (namely altered hydrology) and natural factors (hurricanes). Overall, vegetation analysis from 1940 through 2010 reveals that salt marshes have changed the most, overwhelmingly toward mangrove-dominated communities (Barry and van der Heiden 2015). These dramatic changes are probably caused by rising sea level and hydrologic alterations.

Vegetation classifications in the IRC maps follow the categories used by CERP (Rutchey et al. 2006), Florida Natural Areas Inventory communities (FNAI 2010), and Florida Land Use and Cover Classification System (FLUCCS; FDOT 1999). Figure 7.2 illustrates the level of detail inherent in the classification, which is necessary for detecting subtle changes in vegetation that might be associated with anthropogenic influences and effects of sea-level rise. These fine-scale maps are especially important as they have established baseline data on the extent and cover of specific vegetative communities and can be used in the future to document changes.

Mapping mangrove stress in Rookery Bay and Ten Thousand Islands

Neafsey (2014) mapped mangrove stress through a combination of imagery interpretation (Esri Basemap) and field surveys, using the South Florida Water Management District's (SFWMD) definition of mangrove forests. Preliminary results are shown in Figure 7.3. An index was created to map the status of mangrove forests on a scale of 1 to 5:

1. functional mangrove, no exotics, and no impoundments (66,370 acres/26,859 ha)
2. mosquito ditching (373 acres/151 ha)
3. impoundments (704 acres/285 ha)
4. impoundments and mosquito ditching (84 acres/34 ha)
5. circular zones of high mangrove mortality (232 acres/94 ha)

Ongoing data collection includes detailed vegetation mapping and inventory in stress zones, collecting mangrove tissue samples for assessing the possible influence of hydrologic changes on tree physiology (i.e., Na:K and other biochemical indicators of plant health), and monitoring key soil properties (salinity, pH, and total sulfides). These results indicated that 1,394 acres (564 ha) of the total 67,763 acres (27,423 ha) examined were stressed or dead, amounting to 2.06% of the surveyed mangroves.

Focusing on an area of high mangrove mortality, the Conservancy of Southwest Florida (CSF) and Coastal Resources Group Inc., found that more than half of the 1,000 acres (404 ha) of mangroves surveyed near Goodland were stressed or dead (see Fruit Farm Creek restoration explanation below). Further research and field verification are needed to complete accurate maps of the healthy, stressed, and dead mangroves in Rookery Bay NERR and to prepare restoration plans for future efforts.

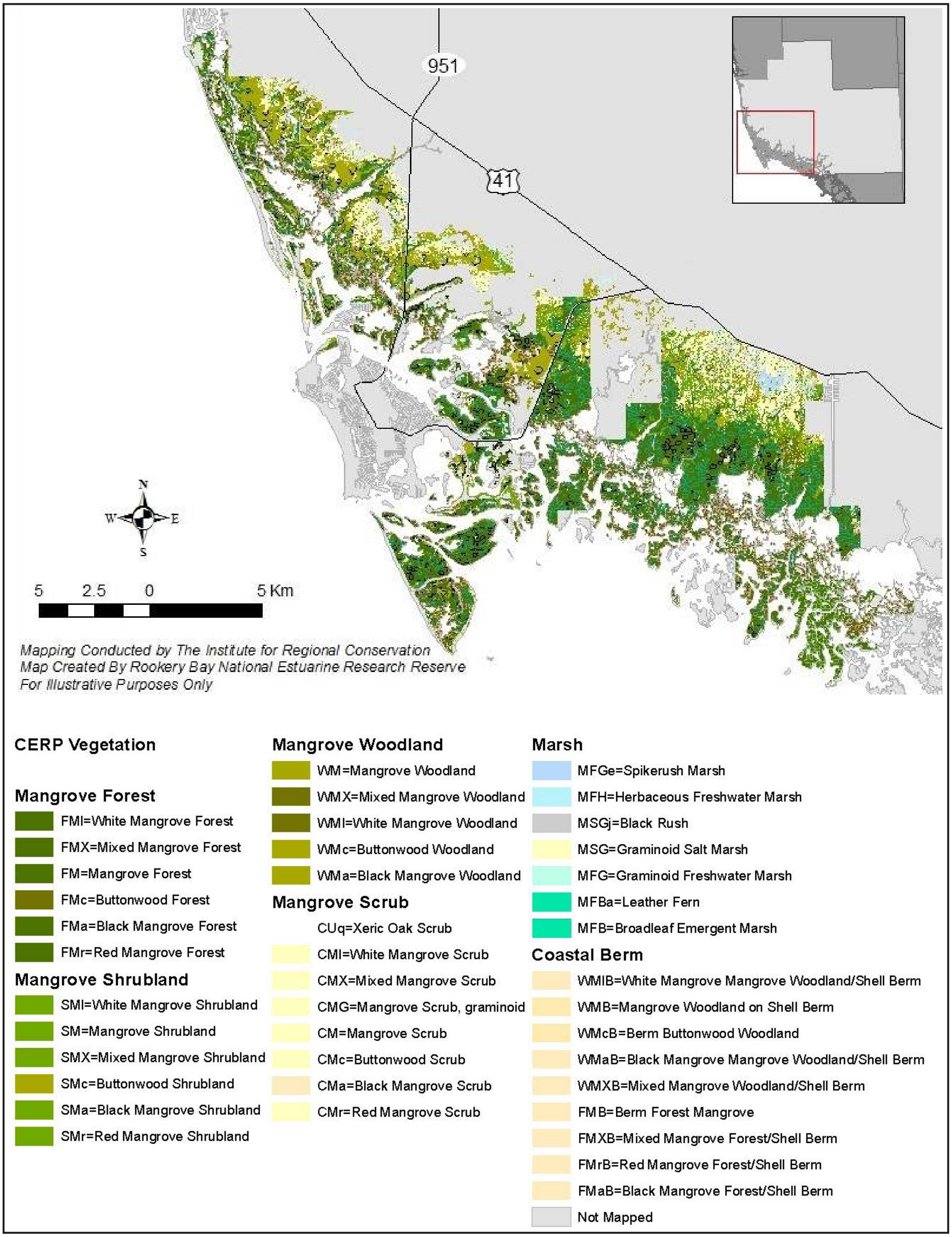

Figure 7.2. Salt marsh and mangrove habitats mapped in the Rookery Bay National Estuarine Research Reserve (Barry et al. 2013) and Ten Thousand Islands National Wildlife Refuge (Barry 2009) according to the CERP classifications (Rutchey et al. 2006).

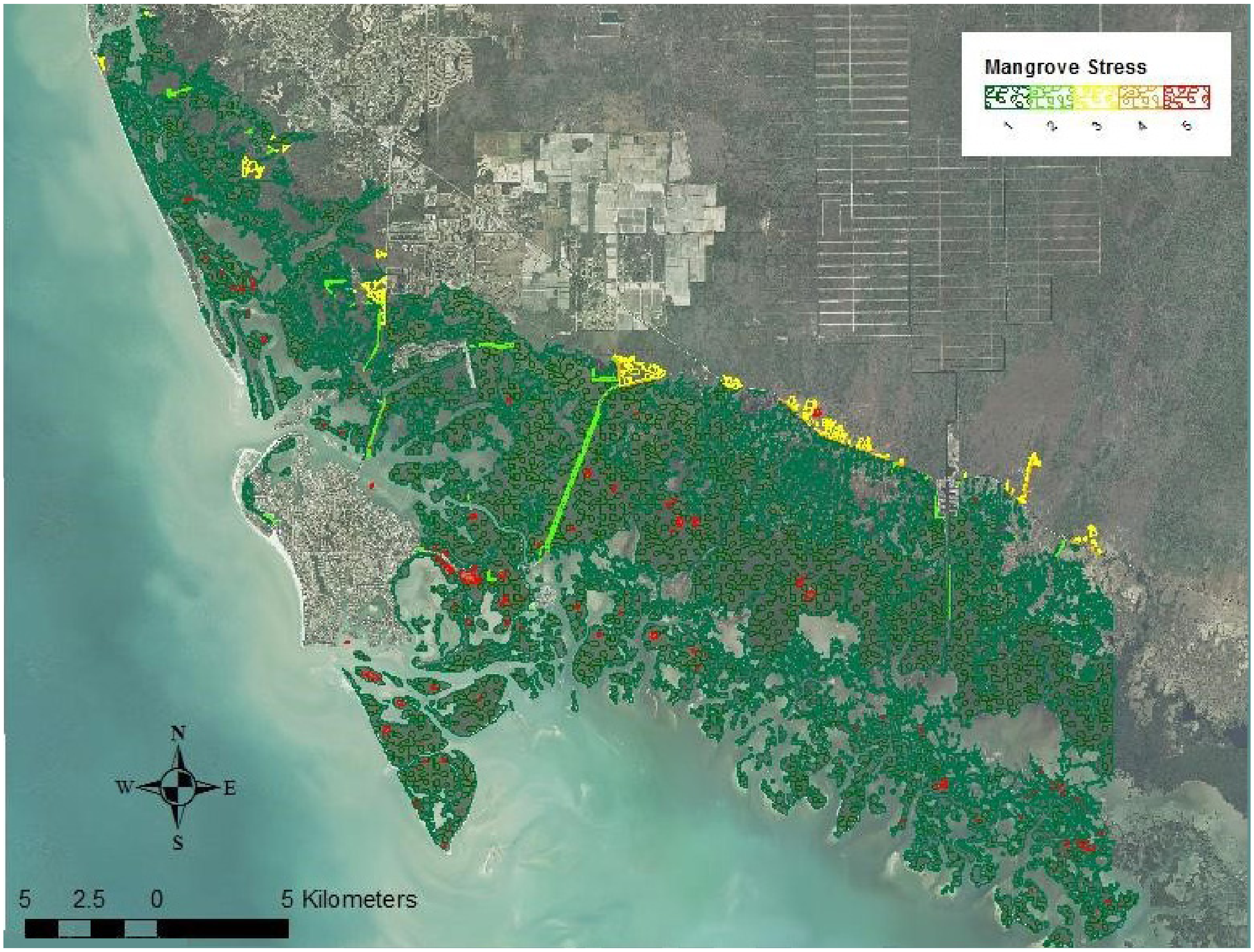

Figure 7.3. Mangrove stress mapped in Rookery Bay and Ten Thousand Islands on a scale of 1–5 (modified from Neafsey 2014). See text for description of classification system.

Water management district mapping

SFWMD conducts fairly regular land use/land cover (LULC) surveys within the district. Figure 7.1 shows the 2008–2009 LULC map; classifications are based upon a SFWMD modified FLUCCS classification system (FDOT 1999, SFWMD 2009b). Minimum mapping units were 5 acres (2 ha) for uplands and 2 acres (0.8 ha) for wetlands. The 2008–2009 maps were made by interpreting aerial photography and updating 2004–2005 vector data (SFWMD 2009a).

Marco Island mapping

Patterson (1986) mapped mangrove habitats in the Marco Island area using aerial photography from 1984, 1973, 1962, and 1952 and examined the change in area of mangrove communities among aerial photographs. He performed an accuracy assessment on the maps with ground truthing and helicopter surveys. Patterson (1986) calculated that the total mangrove acreage in the Marco Island area declined from 11,285 acres (4,566 ha) to 8,574 acres (3,470 ha) from 1952 to 1984. The decline was primarily due to the residential development of Marco Island, but hurricanes during the 1960s also contributed.

Monitoring restoration projects

There have been numerous mangrove and hydrologic restoration projects in Collier County during the past 20 years; selected examples are listed below. Monitoring efforts are still under way in a few of these projects and have provided valuable information to guide management and restoration decisions for stressed and dead mangroves.

- **Fruit Farm Creek:** This phased mangrove restoration effort was initiated in 2000. Preliminary studies by CSF investigated the factors that contributed to the nearly 600 acres (242 ha) of dead and stressed mangroves near Goodland. A multiagency organizational group led by the Coastal Resources Group was formed in 2005 and created restoration plans for a two-phase program totaling 225 acres (103 ha).

Tidal exchange to a 4-acre (1.6 ha) test site in the die-off area was restored in 2012 with funding from the U.S. Fish and Wildlife Service Coastal Program and was monitored by CSF and the Coastal Resources Group. This hydrologic restoration program (Turner and Lewis 1997) followed the basic principles of ecological mangrove restoration outlined by Lewis (2005) and Lewis and Brown (2014), under which no mangroves were planted. Volunteer mangroves are now colonizing the site. An additional 221 acres (89 ha) of stressed and dead mangroves are planned for restoration as part of Phase 2, pending funding (Zysko 2011). Monitoring reports and plan descriptions are available at www.marcomangroves.com.

- **Picayune Strand restoration project:** In 1996 SFWMD developed a conceptual plan for the hydrologic restoration of Picayune Strand State Forest. Additionally, the forest was identified as essential habitat and incorporated in the effort to restore the western Everglades as part of CERP in 1998. The restoration efforts included the installation of pump stations, spreader channels, 83 mi (133 km) of canal plugs, and 227 mi (365 km) of road removal (www.evergladesrestoration.gov/). The Picayune Strand restoration project will improve sheet flow, wetland habitats, and the ecological connectivity between adjacent state and federal conservation lands. The project should be completed by 2020. A number of monitoring projects have been associated with the restoration, including vegetative, hydrologic, and wildlife assessments conducted by a variety of agencies (SFWMD, U.S. Army Corp of Engineers, U.S. Fish and Wildlife Service, Rookery Bay NERR, CSF, Florida Gulf Coast University, and Audubon). See Chuirazzi and Duever (2008) for a summary and baseline data from the restoration project.
- **Clam Bay Natural Resource Protection Area:** In 1999, Collier County initiated a 10-year, multiagency restoration project in Clam Bay estuary. Tidal flow was improved by dredging the main tidal creeks, clearing small tributaries, and installing hand-dug channels to drain excess surface water. Restoration and monitoring of permanent plots and transects was initiated by Lewis Environmental Services Inc. and is continued by CSF and Turrell, Hall, and Associates.

  Monitoring data have indicated that restoration has successfully increased tidal flushing and removed a substantial amount of standing freshwater from the die-off areas, consequently leading to natural revegetation (Worley and Schmid 2010). Long-term viability remains uncertain, given the various stressors affecting this system and the need for annual maintenance of some of the tidal channels. Monitoring should be continued for evaluation of the long-term success of the restoration.
- **Windstar Country Club:** In 1982, restoration commenced on 15 acres (6 ha) of mangrove forest as mitigation for impacted wetlands (Lewis 1990, Peters 2001). Postmitigation monitoring was conducted from 1989 through 2000 to compare colonization, growth, and succession in the restored site with that in a natural mangrove forest (Proffitt and Devlin 2005). By 2000, species richness and vegetation cover in the created mangrove forest were similar to those of the natural forest, although the trees were smaller with higher stem density and differed in species composition.
- **Henderson Creek Mangrove Restoration:** Three hectares of mangrove forest, leveled and filled in 1973, were restored in 1991. One year of post-restoration monitoring found differing species composition of fish and macroinvertebrates in the restored site compared to those at an adjacent natural mangrove forest (Shirley 1992). In a longer-term monitoring study of Henderson Creek and the Windstar Country Club sites, McKee and Faulkner (2000) found that the ecosystem and biogeochemical functions of the restored sites varied widely depending on hydrology, salinity, and soil characteristics.

Recommendations for protection, management, and monitoring

- Prevent rapid stormwater runoff in the watershed. Extensive drainage canals and urban stormwater systems rapidly transport and concentrate stormwater rather than release it as a steady, continuous flow. While hydrology cannot be fully restored due to human development, unnecessary drainage canals can be filled to diffuse surface water, rehydrate dried wetlands, and reduce salinity in coastal wetlands (CSF 2011). Additionally, sustainable agricultural practices, enhanced wastewater treatment, and stormwater management are needed to reduce nutrient input and subsequent eutrophication of coastal estuaries.
- Cooperation between federal, state, and local governments and institutions is critical to prevent habitat fragmentation in regions vulnerable to development (FDEP 2012).
- A regional effort to map and characterize conditions, prioritize restoration areas, and define monitoring and

management objectives for restoration would improve understanding and enhance management of coastal wetlands. Because of the range of participating organizations, an interagency team could provide the best approach for developing and implementing a plan over the long term.

- Monitoring vegetation and water quality will help identify locations of stress and changes over time (FDEP 2012). Unfortunately, most monitoring has been limited to specific hurricanes or individual projects due to limited funding. Long-term monitoring is critical to evaluating the success of restoration projects and developing management models to identify areas of stress, and predicting recovery as a result of restoration actions. Interagency cooperation in the restoration of mangrove forests along Florida's southwest coast may also lead to valuable insights that can be shared with other regions and countries in the global effort to maintain and regain coastal mangrove forests.

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Chapter 8
Everglades

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Description of the region

The Everglades began to form 5,000 years ago when rising sea levels enabled the retention of freshwater in South Florida, allowing for peat deposition and the development of wetlands atop the Pleistocene marine limestone substrate (Hoffmeister 1974, Gleason and Stone 1994). The Everglades is bordered on the northwest by the Big Cypress Swamp and on the east by the Atlantic Coastal Ridge, which functions as a natural barrier to surface water flow. The ecology and health of the Everglades are maintained by the quantity and quality of freshwater delivered to the system. Historically, the Everglades was tightly linked to a large watershed that encompassed much of central and southern Florida (Figure 8.1). Water meandered down the circuitous Kissimmee River to Lake Okeechobee, where it spilled over the southern edge of the lake into an expansive sawgrass marsh. The sheet of surface water then slowly made its way south, supporting a variety of freshwater marshes in the interior and mangroves and salt marshes along the coast. The interior ridge and slough landscape consists of dense stands of *Cladium jamaicense* (sawgrass) growing on ridges with a slightly higher elevation than the adjacent parallel sloughs of water. The *C. jamaicense* marsh is interspersed with bayhead and tropical hardwood hammock forest communities, or "tree islands," that grow atop elevated limestone or woody peat outcrops (Armentano et al. 2002). Major hydrologic pathways through the Everglades include Shark River Slough which flows into Whitewater Bay, and Taylor Slough, which flows into Florida Bay (Figure 8.2).

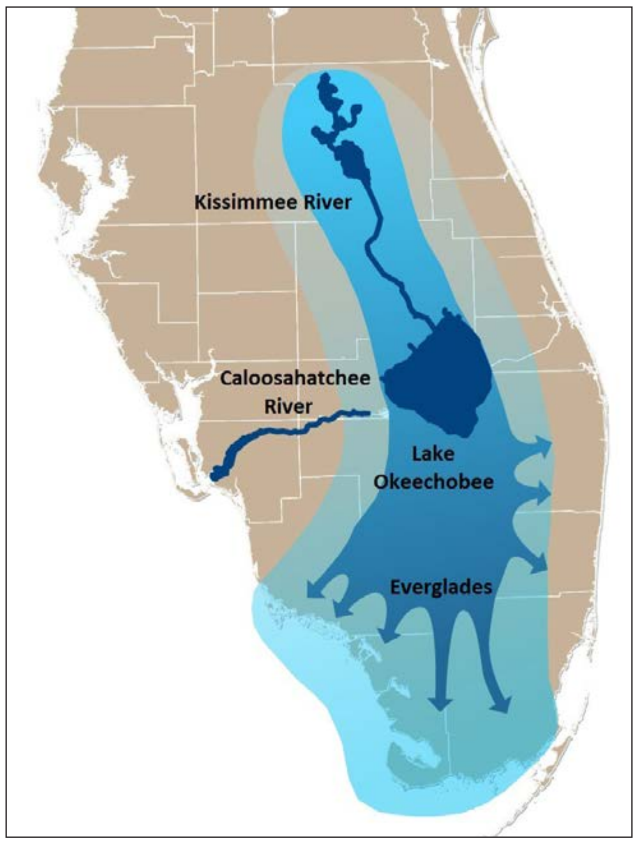

Figure 8.1. Historical flow of surface water in the South Florida watershed. Figure credit: Chris Anderson, based on CERP 2014.

The low elevation and gentle topography of South Florida supports broad swaths of coastal wetlands (Figure 8.3). Mangroves line almost the entire coast of the Everglades, although in some locations they are pushed farther inland by marl, shell, and sand berms. Salt marshes dominated by *Juncus roemerianus* (black needlerush) and *Spartina alterniflora* (smooth cordgrass) are found inland of these mangroves (Lodge 2010).

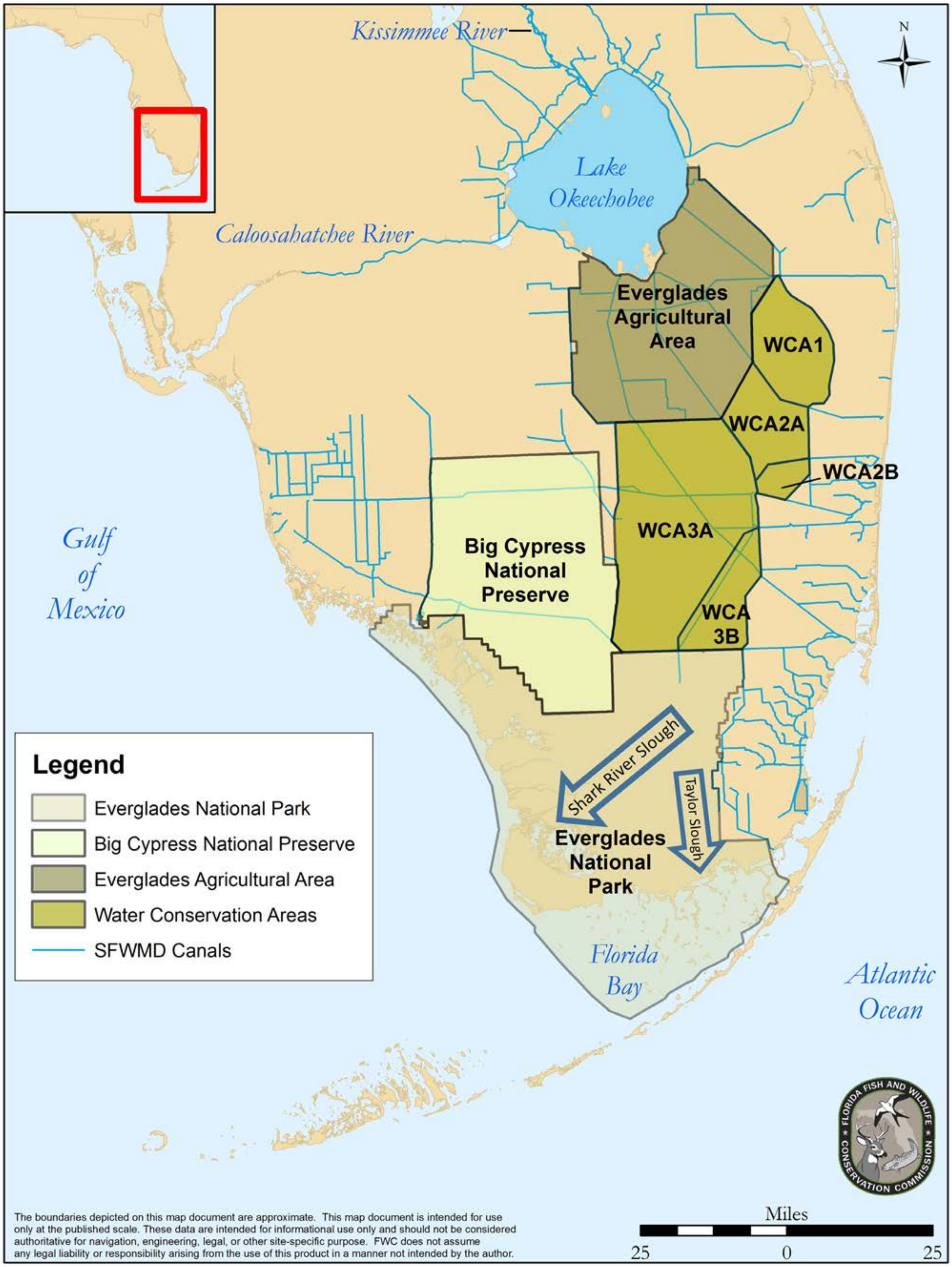

Figure 8.2. Major features of the current South Florida watershed.

Figure 8.3. Salt marsh and mangrove extent in the Everglades. Data source: SFWMD 2004–2005 and 2009 land use/land cover data, based upon FLUCCS classifications (FDOT 1999, SFWMD 2009a).

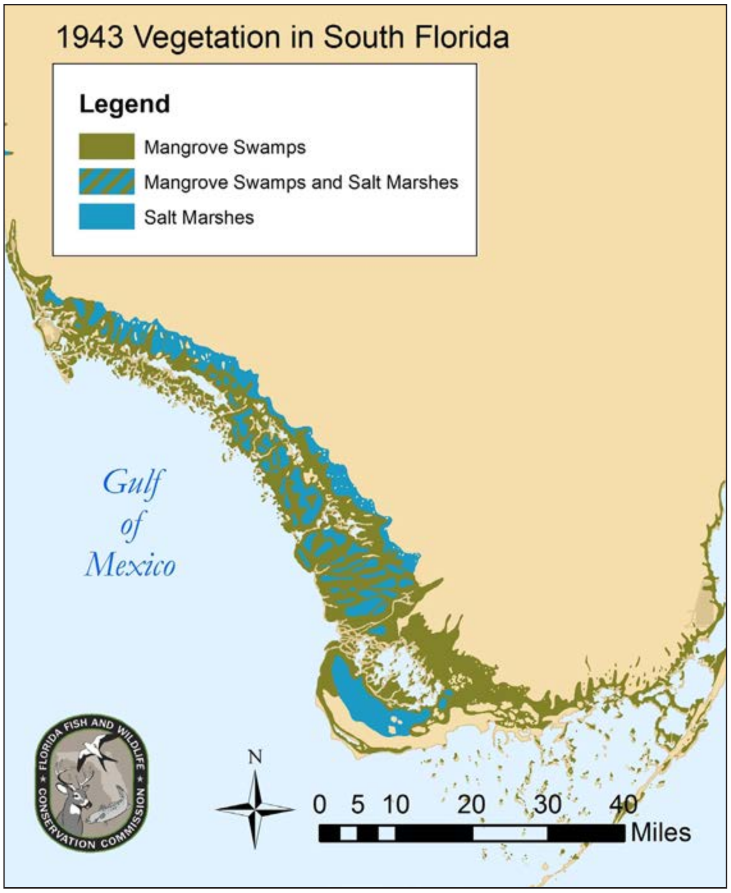

Figure 8.4. Extent of mangrove swamps and salt marshes in 1943, before the hydrologic changes of the Central and South Florida Project. Data source: Davis 1943.

Small changes in elevation determine the distribution of different vegetative communities. For instance, an additional 3.3–4.9 ft (1–1.5 m) of elevation on intermittent ridges enable the growth of tropical hardwood forest communities (Armentano et al. 2002). Florida Bay contains 237 islands made of marl, mangrove peat, and sand. Habitat varies depending on island elevation but can include tropical hardwood trees, mangroves, or algal flats (Armentano et al. 2002).

Because the Everglades are naturally limited in phosphorus, the ocean is the main source of nutrients for coastal plant growth there (Childers et al. 2005, Davis et al. 2005, Castañeda-Moya et al. 2013). Salinity incursions during the dry season provide phosphorus to plants in the oligohaline marsh. Mangrove productivity, basal area, and aboveground biomass increase toward the coast, likely due to increasing phosphorus availability near the ocean (Chen and Twilley 1999, Childers et al. 2005, Davis et al. 2005). In the Shark River estuary, the high-nutrient mangrove forests along the coast are typically dominated by *Laguncularia racemosa* (white mangrove), while *Rhizophora mangle* (red mangrove) is predominant in the lower nutrient forests 3–6 mi (5–10 km) upstream (Chen and Twilley 1999).

Hydrologic alterations

Massive hydrologic changes have drastically altered abiotic conditions in the Everglades ecosystem (Figure 8.2). Although hydrologic adjustments began in the late 1800s, the U.S. Army Corps of Engineers' Central and Southern Florida Project completed major changes to hydrology in the 1950s and 1960s. The goals of Central and Southern Florida Project were to prevent floods and to drain lands for agriculture and development through a series of levees, impoundments, pumps, and canals. Ultimately, these efforts resulted in the diversion of natural surface water into constructed channels that ushered freshwater out to sea (Huber et al. 2006). The Herbert Hoover Dike prevented water from seeping over the southern edge of Lake Okeechobee. Instead, freshwater was released through a network of canals to the east coast of Florida and to the Caloosahatchee River (Figure 8.2). The resulting drainage of land south of Lake Okeechobee enabled the development of the expansive Everglades Agricultural Area. Water continued to flow south from the Everglades Agricultural Area, and high-nutrient agricultural runoff resulted in the subsequent proliferation of *Typha* spp. (cattails) in the historically oligotrophic ecosystem (Chimney and Goforth 2001, Huber et al. 2006). The spread of agriculture and urbanization have reduced the area of the Everglades by 50%, and a large proportion of the remaining undeveloped areas is used as water conservation areas (Figure 8.2; Chimney and Goforth 2001). While the interior of the Everglades has been significantly altered by the Central and Southern Florida Project, Everglades Agricultural Area, water conservation areas, and human development, vegetation shifts are also apparent in coastal wetlands. The most noticeable difference in vegetation extent between 1943 (Figure 8.4) and today (Figure 8.3) is the expansion of mangrove swamps at the expense of salt marshes.

Disturbances due to human alterations in the natural hydrology were first reported in the Everglades as early as 1938 (Chimney and Goforth 2001). Extensive drying of the Everglades resulted in soil loss via oxidation, fires, loss of tree islands, invasion of nonnative species, and widespread changes in the Florida Bay ecosystem (McIvor et al. 1994, Chimney and Goforth 2001, Huber et al. 2006).

Awareness of the extensive environmental damage caused by human activity has led current and planned endeavors to be focused on conservation and restoration (Chimney and Goforth 2001, Huber et al. 2006). Major goals of the Comprehensive Everglades Restoration Plan (CERP) include ecological management of Lake Okeechobee and increasing freshwater sheet flow to the Everglades and adjacent estuaries.

A large portion of the Everglades is encompassed by Everglades National Park. Although authorized by Congress in 1934, Everglades National Park was not officially established until 1947 (USNPS 1979). In the 1970s and 1980s, Everglades National Park was recognized as a Biosphere Reserve, UNESCO World Heritage Site, and Wetland of International Importance; it is one of only three sites in the world to be placed on all three lists (USFWS 1999a).

Several regions in and around the Everglades have unique ecosystems as a result of their hydrology and location. These regions include Florida Bay, Cape Sable, and the Southeast Saline Everglades.

- **Florida Bay:** A broad, shallow bay south of the Everglades (Figure 8.3), Florida Bay was historically characterized by clear waters and extensive seagrass beds. In the late 1980s and early 1990s, large-scale ecological shifts resulted in widespread algal blooms and mortality of mangroves, seagrass beds, sponges, lobsters, and shrimp (McIvor et al. 1994). A myriad of problems were associated with these die-offs, including hypersaline waters, hypoxia, heat stress, and decreased water clarity due to phytoplankton blooms and turbidity (Fourqurean and Robblee 1999). While the ultimate causes of this complicated ecological shift remain unclear, it is thought to be linked to loss of freshwater flow, hypersaline conditions, abnormally warm temperatures, and increased amounts of sediment in the bay (Fourqurean and Robblee 1999). Extensive mangrove mortality events occurred in 1991 and 1992, particularly in the north-central part of the bay. The cause of these die-offs is thought to be linked to hypersalinity (McIvor et al. 1994, Fourqurean and Robblee 1999). The salinity in Florida Bay mangrove swamps depends upon tidal inundation and freshwater runoff from Taylor Slough and the C-111 canal (Figure 8.2 and 8.3). The amount of freshwater reaching Florida Bay is much less than historical levels; models reveal that salinities are higher in the euryhaline marshes bordering Florida Bay than they were prior to human development (Marshall et al. 2009). A similar Florida Bay seagrass die-off in 2015 has also been linked to hypersalinity, stratification, and anoxia (Hall et al. 2016).
- **Cape Sable:** Cape Sable (Figure 8.3) is the area of the Everglades least affected by urbanization and mainland hydrologic alterations because it is separated from the Florida mainland by Whitewater Bay (Wanless and Vlaswinkel 2005, Wingard and Lorenz 2013). Cape Sable includes extensive mangrove forests, many of which are dwarf mangroves (Zhang 2011, Wingard and Lorenz 2013). The region has not entirely escaped modification; in the 1920s ditches were dug through coastal berms to connect the interior lakes, which enabled saltwater intrusion (Wanless and Vlaswinkel 2005). Increased tidal and current strength due to sea-level rise have increased coastal erosion, redistributed sediment, created new tidal creeks, and increased tidal reach. As a result of saltwater inundation, the underlying peat in the formerly freshwater marshes is decaying, further decreasing substrate elevations on the interior of the cape (Wanless and Vlaswinkel 2005). Loss of freshwater wetlands, in Cape Sable and elsewhere in the Everglades, constitutes a threat to endangered species such as *Ammodramus maritimus mirabilis* (the Cape Sable Seaside Sparrow) (USFWS 1999b).
- **The Southeast Saline Everglades (the white zone):** The land northeast of Florida Bay has been named the Southeast Saline Everglades (Egler 1952, Ross et al. 2000). Prior to development and hydrologic alterations in South Florida, mangrove shrubs grew on the coast in a thin band that gradually transitioned to a sparse mangrove-graminoid marsh, and sawgrass-dominated freshwater marshes several kilometers inland (Ross et al. 2002). Restricted freshwater flows and highly variable soil salinities constrain plant growth in this region. From an aerial view, most of the Southeast Saline Everglades appears white due to the low vegetative cover and the highly reflective nature of the marl substrate and so has been named the white zone (Figure 8.3; Ross et al. 2000, Browder et al. 2005, Briceño et al. 2011). The vegetation in the white zone is generally not tall or dense enough to be categorized as mangrove forest under most land-cover classification systems. In most cases, the vegetation consists of short mangrove shrubland or scrub with few grasses.

Since the 1940s the white zone has expanded landward by approximately 0.9 mile (1.5 km) as a result of reduced surface freshwater flow to the Southeast Saline Everglades and sea-level rise (Ross et al. 2000). Between 1940 and 1994, the white zone shifted the least where surface freshwater was not restricted by roads or levees, demonstrating that freshwater flow can lessen the landward transgression of the white zone (Ross et al. 2000).

Figure 8.5. Presence of dead *Taxodium* spp. (cypress) in the southeast saline Everglades resulting from Hurricane Betsy. Note the presence of *Rhizophora mangle* (red mangrove) seedlings within the mixed marsh of *Cladium jamaicense* (sawgrass) and *Eleocharis cellulosa* (Gulf coast spikerush). Photo credit: Pablo L. Ruiz.

Impact of tropical storms and hurricanes

Tropical storms and hurricanes continually shape this unique ecosystem. The category 5 Labor Day hurricane that struck South Florida in 1935 caused extensive mortality to the coastal mangrove forest. The great girth and height of South Florida mangroves before the hurricane indicated that the region had likely not suffered such a severe storm for many decades (Craighead and Gilbert 1962, Armentano et al. 2002). Hurricanes Donna (1960) and Betsy (1965) also significantly affected many of the coastal communities of the Everglades (Figure 8.5). Hurricane Donna severely damaged the mangrove belt between Flamingo and Lostman's River; with few exceptions all mangrove trees greater than 5 cm (1.9 in.) in diameter were sheared off at 6.6 ft (2 m) above the ground (Craighead and Gilbert 1962). In 1965, Hurricane Betsy crossed the southern tip of Florida with winds of 109 mph (175 km/hr). A tidal surge increased soil chloride levels to as high as 19,000 ppm, and chloride levels remained elevated for several months (Alexander 1967). While many trees died as a direct result of wind damage, the elevated soil chloride levels had the greatest impact on the vegetation of the region, particularly in the marsh. Extensive areas of *C. jamaicense* were killed and were quickly replaced by *Eleocharis cellulosa* (Gulf coast spikerush) (Alexander 1967). The effects of Hurricane Betsy are still evident in the landscape, with dead *Taxodium* spp. (cypress) snags a common sight in the landscape (Figure 8.5).

In 1992, Hurricane Andrew crossed Florida, passing over the Everglades and destroying more than 70,000 acres (28,329 ha) of mangroves and causing extensive defoliation (Wanless et al. 1994, Armentano et al. 2002). Near the coastline, more than 90% of trees were uprooted or snapped (Smith et al. 1994, Wanless et al. 1994). Some storm-damaged forests recovered, but others transitioned into an intertidal environment. Many *Conocarpus erectus* (buttonwood) forests were converted to mangrove swamps or halophytic prairie due to the saltwater inundation and substrate changes (Armentano et al. 2002). The abundance of palms and hardwoods in the coastal Everglades has also declined due to transition into mangrove swamps and salt flats.

Threats to coastal wetlands

- **Hydrologic alteration:** Although the coastal wetlands in Everglades National Park are protected from direct impacts of urbanization, they are highly vulnerable to hydrologic changes and natural disturbances. According to hydrologic models, water levels in the major sloughs of the Everglades are a half foot (0.15 m) lower than historical levels; likewise freshwater delivery to coastal wetlands and estuaries is 2.5–4 times less than predrainage levels (Marshall et al. 2009). As a result of reduced freshwater input, the coastal wetlands bordering Florida Bay have experienced greater saltwater inundation and reduced hydroperiods. While historical average salinity in Florida Bay is estimated to have ranged from 3 to 30 (Marshall et al. 2009), average salinity ranged from 23 to 39 in a time series from 1998 through 2004 (Kelble et al. 2007).

  Additionally, many tidal creeks along the lower Everglades have been filled in by vegetation and sediment as a result of low freshwater flow and nutrients provided by rising sea levels (Davis et al. 2005). Choked waterways and reduced flushing are detrimental to wetlands as flushing by salt water or freshwater is important for the resiliency and long-term viability of wetlands (Davis et al. 2005, Wanless and Vlaswinkel 2005).
- **Climate change and sea-level rise:** The impact of reduced freshwater flow is exacerbated by saltwater intrusion due to storm surges and sea-level rise. Salt water has already extended into formerly oligohaline and freshwater marshes in the coastal Everglades, and mangrove habitat has expanded inland (Ross et al. 2000, Davis et al. 2005, Smith et al. 2013). Groundwater resources are also at risk of contamination by salt water (Wanless et al. 1994). Models indicate that inundation due to sea-level rise will be gradual at first but then will accelerate in some regions due to topography (Zhang 2011). Much of South Florida is a natural depression with moderate elevation, so inundation progresses rapidly once sea level reaches a threshold (4.1 ft/1.25 m is the threshold in Miami-Dade County). If natural barriers such as the Atlantic Coastal Ridge or the Big Cypress Swamp Ridge are breached, saltwater inundation would flood large portions of the Everglades (Wanless et al. 1994). Even a conservatively estimated sea-level rise of 1.6 ft (0.5 m) would inundate much of Everglades National Park.

  If peat accumulation cannot keep pace with sea-level rise, mangroves will move inland and the shoreline will erode (Davis et al. 2005). Increased wave activity would increase erosion and exposure of mangrove peat, making the organic matter vulnerable to oxidation. Oxidation may be avoided if organic carbon is transported inland and reburied as storm-surge deposits (Smoak et al. 2013).
- **Invasive vegetation:** As in much of Florida, invasive plants, such as *Schinus terebinthifolius* (Brazilian pepper), *Colubrina asiatica* (latherleaf), *Lygodium microphyllum* (Old World climbing fern), and *Melaleuca quinquenervia* (melaleuca) continue to expand their acreage and outcompete native plants on the edges of coastal wetlands in southern Florida (USFWS 1999a, Davis et al. 2005, Wingard and Lorenz 2013). Invasive vegetation is particularly threatening after a disturbance, as it can outpace the regrowth of native vegetation.

Mapping and monitoring efforts

Water management district mapping

The South Florida Water Management District (SFWMD) has conducted land use/land cover (LULC) surveys approximately every five years since 1995. The 2008–2009 land cover maps were created using SFWMD modifications to the Florida Land Use and Cover Classification System (FLUCCS) (FDOT 1999, SFWMD 2009b). Minimum mapping units were 5 acres (2 ha) for uplands and 2 acres (0.8 ha) for wetlands. The 2008–2009 LULC maps (shown in Figure 8.3) were made by interpreting aerial photography and updating 2004–2005 vector data (SFWMD 2009b).

Comprehensive Everglades Restoration Plan monitoring

Project reports, monitoring information, and feasibility studies produced under CERP are available at the CERP website www.evergladesrestoration.gov/, including the 2014 System Status Report (CERP 2014).

Long-term Ecological Research mapping and monitoring

The National Science Foundation's Long-term Ecological Research (LTER) network includes a section in the Florida Coastal Everglades. This program, based at Florida International University, was established in 2000 and involves the collaboration of many governmental, academic, and independent organizations. Interactive vegetation maps of the Everglades, created by the University of Georgia, the National Park Service, and SFWMD, are available at the Florida Coastal Everglades LTER website (fcelter.fiu.edu).

National Park Service's South Florida/ Caribbean Network mapping

The South Florida/Caribbean Network, the U.S. Army Corps of Engineers, and the South Florida Water Management District are collaborating to create vegetation maps of Everglades National Park and Big Cypress National Preserve. These maps will provide information on pre-CERP baseline reference conditions, documenting the spatial extent and pattern of vegetation communities before CERP was implemented. This mapping will characterize the ecosystem at the species-level at a spatial resolution of 0.6 acre (0.25 ha) (USNPS and USACE 2012, Giannini et al. 2015).

Everglades vegetation model

Everglades Landscape Vegetation Succession (ELVeS) is an open-source model written in Java that simulates changes in vegetation in response to varying abiotic conditions. Led by the South Florida Natural Resources Center of Everglades National Park, this Everglades model is based on vegetation niches, replacement probabilities, and time lags for transition periods. The model is available for download and use at www.cloudacus.com/simglades/ELVeS.php.

Mangrove height mapping

In 2006, mangrove height was mapped in Everglades National Park using data from the National Aeronautics and Space Administration's (NASA's) Shuttle Radar Topography Mission (Simard et al. 2006). These data were calibrated with airborne LiDAR (Light Detection and Ranging) and a U.S. Geological Survey (USGS) digital elevation model. Field data were then used to extrapolate mangrove biomass from tree height. Average tree height was found to be around 26 ft (8 m). This data set could provide a baseline against which to monitor ecological responses to restoration plans or ecological shifts.

Mangrove expansion mapping

Smith et al. (2013) created detailed maps documenting shifts in mangrove swamp and marsh habitat in three locations in the Everglades. In two of the three sites examined, the acreage of mangrove habitat expanded and marsh area declined from 1928 to 2004. This expansion in mangrove habitat has been attributed to sea-level rise. Marsh fires did not prevent landward mangrove expansion.

G-LiHT mapping

In May 2015, NASA used Goddard's LiDAR, Hyperspectral, and Thermal (G-LiHT) airborne imager to collect data in Everglades National Park (Cook et al. 2013, gliht.gsfc.nasa.gov). G-LiHT acquisitions along the Shark, Taylor, and Harney rivers targeted critical vegetation and hydrologic and salinity gradients that coincided with ground plots in marshes, mangroves, river mouths, and aquatic plant communities (David Lagomasino and Bruce Cook, personal communication). The complementary nature of LiDAR, optical data, and thermal data provides an analytical framework for the development of new algorithms that will enable researchers to map plant species composition, functional types, biodiversity, biomass, carbon stocks, and plant growth. G-LiHT data will also be used to support satellite missions (e.g., PACE, HyspIRI) and provide a link for upscaling field data to long-term satellite observations (e.g., Landsat) for studying multitemporal landscape dynamics.

Recommendations for protection, management, and monitoring

- While the ecosystem-scale shifts that occurred in Florida Bay in the early 1990s were linked to many factors, the mangrove die-offs were specifically attributed to hypersaline conditions (McIvor et al. 1994, Fourqurean and Robblee 1999). To prevent future die-offs, the frequency, severity, and geographic extent of hypersaline conditions must be reduced. The quantity, timing, and distribution of freshwater needs to be restored in order to maintain estuarine conditions in Florida Bay and the Everglades.
- Sea-level rise must be taken into account when assessing freshwater needs for Everglades restoration projects. The freshwater needs of coastal wetlands will increase as seawater inundation increases with sea-level rise.
- While sea-level rise and increased strength of coastal storms will result in greater coastal erosion and widening of tidal creeks, attempts to stop creek widening and close canals in locations such as Cape Sable are not recommended as these changes would likely have unintended consequences and result in erosion elsewhere (Wanless and Vlaswinkel 2005).
- Cape Sable, Florida Bay, and the Southeast Saline Everglades may serve as sentinel indicators of how rising sea level may impact the Everglades as a whole. Therefore,

focused research on these regions may aid in adaptive management and decision making (Wanless and Vlaswinkel 2005).

- The National Park Service has put together an extensive plan for combatting invasive species in the Everglades (USNPS 2006). But the current management scenario (www.evergladesrestoration.gov/content/ies/ies.html), based on opportunistic treatment and available funding, does not involve a standardized monitoring protocol. This plan should be augmented, however, to include a systematic approach for identifying, monitoring, and evaluating the effectiveness of the removal of nonnative species. Active restoration, including the planting of native species could further increase the success of combating invasive vegetation in high-priority areas.

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General references and additional regional information

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Everglades National Park: www.nps.gov/ever/index.htm

Florida Coastal Everglades Long Term Ecological Research Network: fcelter.fiu.edu/

National Parks Conservation Association, State of the Parks: www.npca.org/resources/1138-center-for-state-of-the-parks-florida-bay#sm.0000o5ohzabcwdf6zwl1hwpkh5khb

South Florida/Caribbean Network: science.nature.nps.gov/im/units/sfcn/index.cfm

Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative, Compilation of Gulf of Mexico Surface Elevation Tables (SETS): https://gcpolcc.databasin.org/datasets/6a71b8fb60224720b903c770b8a93929

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Chapter 9
Florida Keys

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Description of the region

The Florida Keys (Figure 9.1) are a 130-mi-long (210 km) archipelago on the southern edge of the Florida carbonate platform (Ross et al. 1992, FKNMS 2007). The islands are composed of Miami oolite and Key Largo limestone, which formed during the last interglacial period of the Pleistocene epoch (Hoffmeister and Multer 1968, Ross et al. 1992). Sediment types include rocky and organic soils, calcareous muds, and carbonate sands (Hurt et al. 1995). The highest elevation in the Keys is approximately 18 ft (5.5 m), but most of the islands do not extend higher than 6.6 ft (2 m) above sea level (Ross et al. 1992). Native American burial grounds and middens can be found in parts of the Keys and contribute to some local elevation (Goggin 1944).

Although a railroad to Key West was constructed in the early 1900s, the Keys had relatively low development until the completion of U.S. Highway 1 in the 1930s (Hurt et al. 1995). Today, tourism drives the economy, particularly for marine activities such as diving, snorkeling, and charter and recreational fishing (FKNMS 2007). The population of Monroe County, which includes the Keys and the western half of the Everglades is still relatively small, at 77,480 in 2015 (U.S. Census 2015).

The archipelago is encompassed by the Florida Keys National Marine Sanctuary. Within this extent, the many protected regions include Dry Tortugas National Park (not included in Figure 9.1 due to a lack of land use/land cover data), Key West National Wildlife Refuge (NWR), Great White Heron NWR, National Key Deer Refuge, and Crocodile Lake NWR. Additionally, approximately 13,000 acres (5,260 ha) of land acquired through various conservation efforts are managed by the Florida Fish and Wildlife Conservation Commission (FWC), Florida Department of Environmental Protection (FDEP), local governments, municipalities, and nongovernmental conservation organizations. The FWC Florida Keys Wildlife and Environmental Area, Dagny Johnson Key Largo Hammock Botanical State Park, John Pennekamp Coral Reef State Park, and several other Keys state parks contain large areas of protected habitat. The acreage of protected land is projected to increase as purchases are acquired through Florida Forever and the Monroe County Land Authority.

Rhizophora mangle (red mangrove) lines approximately 1,800 mi. (2,900 km) of shoreline in the Florida Keys National Marine Sanctuary (FKNMS 2007). *Avicennia germinans* (black mangrove) and *Laguncularia racemosa* (white mangrove) are also found throughout the Keys, often scattered among intertidal marshes (USFWS 1999a). The freshwater wetlands also include many mangrove and *Conocarpus erectus* (buttonwood) trees interspersed in the *Cladium jamaicense* (sawgrass) marshes (USFWS 1999a). Mangroves are an important stabilizer for the Florida Keys, which are exposed to tropical storms and hurricanes. Dwarf trees with heights of 3.3–10 ft (1–3 m) are common as a result of limited nutrients, rocky substrates, and soils with low organic matter (Hurt et al. 1995, USFWS 1999b). In organic soil in the Keys, *R. mangle* reaches heights of 10–20 ft (3–6 m) or more (Ross et al. 1994, Hurt et al. 1995). While most vegetation land cover data follow the standard mangrove and salt marsh classification schemes for the Florida Keys, the Florida Natural Areas Inventory adds a subdivision called “Keys tidal rock barren” (see Figure 9.2) to classify areas of dwarf mangroves and *C. erectus* on exposed limestone (FNAI 2010).

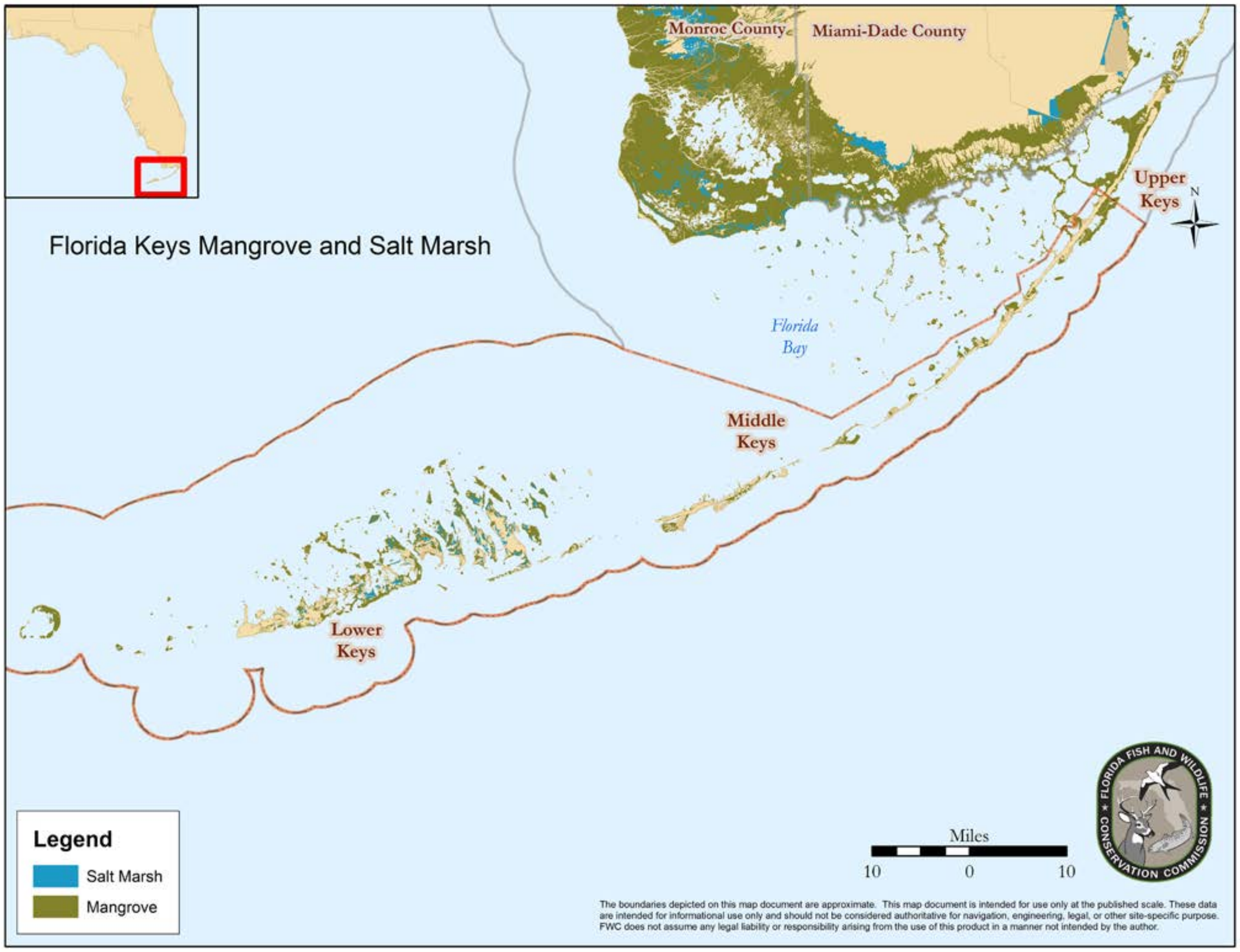

Figure 9.1. Mangrove and salt marsh coverage in the Florida Keys. Data source: SFWMD 2009 land use/land cover data, based upon FLUCCS classifications (FDOT 1999, SFWMD 2009a).

Many of the coastal wetlands in the Florida Keys were ditched, filled in, and fragmented for mosquito control or in dredge-and-fill operations to build neighborhood canals and fill wetlands for development (FKNMS 2007, TNC 2009). This wetland fragmentation decreased mangrove forest size and increased edge-to-area ratio (Strong and Bancroft 1994). As of 1994, 15% of mangrove forests in the Upper Keys (Figure 9.1) had been cleared for development; losses were particularly high for areas close to important roads (Strong and Bancroft 1994). Loss of coastal wetlands in the Keys has contributed to local problems with polluted surface runoff entering coastal waters (FKNMS 2002).

The low elevation of the Florida Keys makes them highly vulnerable to storm surge and sea-level rise. Upland forests of the Lower Keys have already lost many pine trees due to storms and saltwater intrusion (Ross et al. 2009). Even under an optimistic scenario of sea-level rise (1.15 ft/0.35 m by 2100), models by The Nature Conservancy (TNC) predict that 31% of Big Pine Key will be inundated. Under a high-end scenario (4.6 ft/1.4 m of sea-level rise by 2100), 96% of the island would be under water (TNC 2009).

In the short term, mangroves are one of the few ecosystems in the Keys that appear to be benefiting from sea-level rise (Glazer 2013). In many areas, mangroves have already encroached on salt marshes and uplands. Between 1935 and 1991 on Sugarloaf Key, mangrove habitat increased by 47%, while upland habitat decreased by 31% (Ross et al. 1992, Ross et al. 2009). Upland forest and freshwater ecosystems can transition rapidly to mangroves due to the effects of a single storm surge (Ross et al. 2009). Comparison of aerial photographs representing a span of about 60 years also shows the dramatic increase in *R. mangle* as it expands in many areas of the Keys (Kruer, unpubl. data). While landward expansion is common throughout Florida, mangroves in the Florida Keys have also been noted to expand seaward into shallow seagrass flats as mangrove islands or coastal mangrove fringe (Figure 9.3), in spite of the documented sea-level rise of about 3.5 cm/decade from 1971–

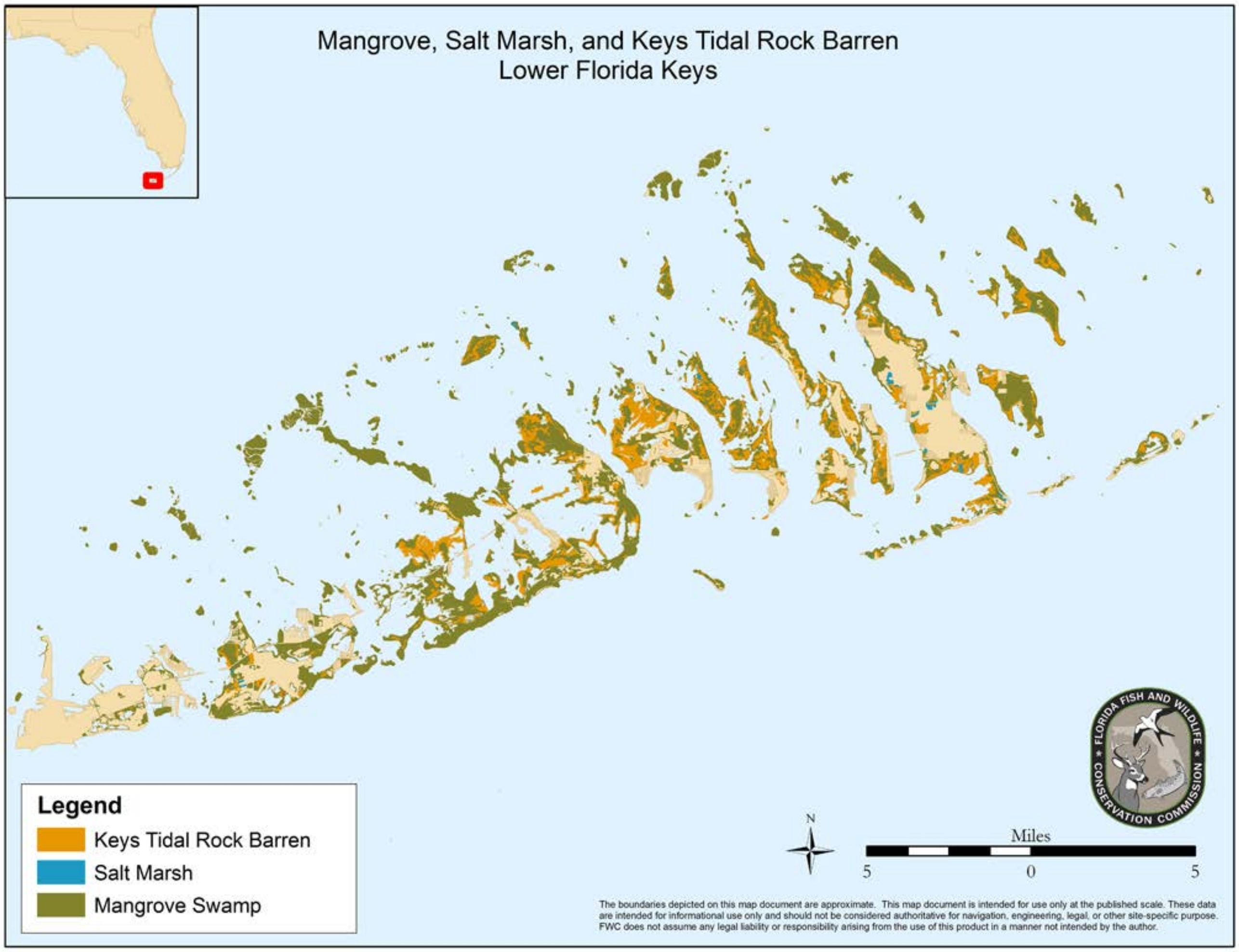

Figure 9.2. Mangrove, salt marsh, and Keys tidal rock barren extent in the Lower Florida Keys, as determined by the Cooperative Land Cover Map version 3.0 following the Florida Land Cover Classification System (Kawula 2009, FNAI 2010, FNAI and FWC 2014).

2015 in the Keys (NOAA 2013). This seaward mangrove expansion may be linked with local sediment accumulation and a recent lack of strong tropical storms. These trends in mangrove expansion have broad impacts throughout local ecosystems. Although the expansion in available habitat is beneficial for mangrove-dependent species, it results in the loss of seagrass, salt marsh, or upland habitat.

Mangroves also occur to a limited extent in Dry Tortugas National Park, although historical accounts note that mangroves are periodically killed by hurricanes (Doyle et al. 2002). Mangroves that survive today face challenging conditions, including erosion, an excess of pelican guano, a lack of freshwater, and low organic matter content in the sediment on the coral islands (Doyle et al. 2002). The presence of all three mangrove species indicate the successful colonization of drifting propagules from the Florida Keys.

Salt marshes are also found, to a lesser extent, in the Lower Keys (Figure 9.1). Herbaceous plants are often mixed in with scrub *R. mangle*, *L. racemosa*, *A. germinans,* and *C. erectus*. *Spartina spartinae* (Gulf cordgrass) dominates, but other *Spartina* species include *S. alterniflora* (smooth cordgrass), *S. bakeri* (sand cordgrass), and *S. patens* (saltmeadow cordgrass) (Ross et al 1992, Klett et al. 2006). Other salt-tolerant vegetation includes *Distichlis spicata* (saltgrass), *Sporobolus virginicus* (seashore dropseed), *Fimbristylis spadicea* (marsh fimbry), and *Batis maritima* (saltwort) (FNAI 2010). Wetland subtypes include open scrub salt marsh and buttonwood-dominated scrub salt marsh (USFWS 2009).

Threats to Coastal Wetlands

- **Climate change and sea-level rise:** The low elevation and small land area render habitats in the Florida Keys highly vulnerable to sea-level rise and storm surges. While upland habitats are the most vulnerable, salt

Figure 9.3. Mangrove expansion in Whale Harbor on Islamorada; aerial images from 1955 (left) and 2013. Mangrove expansion is evident landward on the islands and seaward in the flood tidal delta of the Whale Harbor inlet. Photo credits: Curtis Kruer (L) and Google Earth (R).

marshes also face steep declines in the face of rising sea levels as they are inundated or are overtaken by mangrove forests (Clough 2008). Mangrove area is expected to continue expanding in the short term at the expense of adjacent habitats. Some regions, such as Crocodile Lake NWR, lack room for landward expansion of mangroves and will likely experience declines in mangrove extent this century (Clough and Larson 2010). If sea-level rise progresses to 4.9 ft (1.5 m) or more by 2100, mangrove extent is predicted to eventually decline in other Florida Keys regions as well (Clough 2008).

- **Invasive species:** Several invasive species are already altering natural Florida Keys communities. They include *Causaurina* spp. (Australian pines), *Schinus terebinthifolius* (Brazilian pepper), and *Colubrina asiatica* (latherleaf) (Hadden et al. 2005, USFWS 2009). Removal of invasive species from publicly managed lands is made more difficult due to the proximity of privately owned lands that are often landscaped with nonnative plants.
- **Urban development:** Dredge-and-fill operations have already removed large extents of coastal wetlands in the Keys, and human development also impacts remaining mangroves and salt marshes through altered hydrology. Increased impervious surfaces and ditches alter the flow of freshwater, already in short supply due to the small land area available for collecting precipitation. A decline in coastal wetlands surrounding centers of urban development also has significant impacts for surrounding coastal water quality. Without coastal wetlands to act as a natural filter, pollution due to stormwater runoff enters directly into the ocean (FKNMS 2002).
- **Herbivory:** Federal protection and the establishment of the National Key Deer Refuge have allowed the population of the Key deer (*Odocoileus virginianus clavium*) on Big Pine and No Name keys to rebound from only 25–50 animals in the late 1940s to a population estimated to be around 1,000 today (Lopez et al. 2004, Barrett and Stiling 2006, Hoffman 2015). The deer are selective grazers; as a result the abundance of woody species preferred by the deer is lower on islands with high deer populations (Barrett and Stiling 2006). The density of small (<1.2 m) *R. mangle* trees was lower and foliage was stripped from *R. mangle* trees in areas with a high deer density (Barrett 2004). While the threats of herbivory may not be as great a threat to Florida Keys habitats as are sea-level rise and urbanization, the impacts of the Key deer highlight the need for ecosystem-level management in the Keys.

Mapping and monitoring efforts

Water management district mapping

The South Florida Water Management District (SFWMD) conducts fairly regular land use/land cover (LULC) surveys in the district. Land-cover classifications for 2008–2009 LULC maps were based on SFWMD modifications to the Florida Land Use and Cover Classification System (FLUCCS) (FDOT 1999, SFWMD 2009a). Minimum mapping units were 5 acres (2 ha) for uplands and 2 acres (0.8 ha) for wetlands. The most recent maps (Figure 9.1) were made by interpreting aerial photography and updating 2004–2005 vector data (SFWMD 2009b).

Local land cover mapping

In 2009, Photo Science Inc., of St. Petersburg, Florida, completed land use/land cover mapping of the Florida Keys for Monroe County (Photo Science 2009). The maps were created from high-resolution orthophotographs with a minimum mapping unit of 0.5 acre (0.2 ha) for all classifications with the exception of hammocks, which had a minimum mapping unit of 0.35 acre (0.14 ha). Classification categories included scrub mangrove (dwarf mangroves less than 5 ft/1.5 m tall), buttonwood, mangrove, and salt marsh.

Wetland habitats were also mapped as part of Key deer–management efforts (Folk et al. 1991) and for the Florida Keys Advance Identification Project (Kruer 1995). Mapped wetland communities included mangroves, salt marsh, and buttonwood wetlands (Kruer 1995). Nontidal wetlands (freshwater sloughs, freshwater basins, and impounded wetlands) also frequently included mangroves and other salt-tolerant vegetation.

Sea Level Affecting Marshes Model in the Florida Keys

The Sea Level Affecting Marshes Model (SLAMM) has been used to model the impact of various scenarios of sea-level rise on the Florida Keys (Clough 2008, Clough and Larson 2010, Glazer 2013). The study predicted that mangroves will continue to increase in acreage at the expense of higher-elevation habitats; therefore, mangrove-dependent species may initially benefit from sea-level rise (Glazer 2013). In the National Key Deer Refuge, mangrove extent is predicted to increase under all but the most extreme. The extent of salt marsh, transitional salt marsh, and brackish marsh are all expected to decline under all sea-level-rise scenarios (Clough 2008). Within Crocodile Lake NWR, mangroves and tidal swamps are predicted to decline under all scenarios (Clough and Larson 2010). This result is due to the fact that the narrow barrier island does not offer much area for retreat, and the extensive mangrove forests lining the bay are overtaken by open water.

Recommendations for protection, management, and monitoring

- Target specific areas for preservation that are representative of all local habitats, have the best chances of surviving sea-level rise, and have enough connectivity with other habitats for sufficient gene flow among organism populations (Ross et al. 2009). Given that sea-level rise is one of the primary threats to most habitats in the Florida Keys, the causes of climate change should be targeted, coupled with management and restoration of resilient natural areas (TNC 2009).
- Monitor, manage, and restore freshwater resources to a greater extent than at present due to their critical importance to wildlife including many listed species and migratory birds. Wetland restoration plans should take present and future freshwater resources into account, with regards to both saltwater intrusion and modification of surface hydrology by human development.
- Continue successful, ongoing programs that restore, protect, and enhance both tidal and nontidal wetlands throughout the Keys (FWC 2004, Hobbs et al. 2006). Continue to purchase strategic land to conserve Florida Keys habitats against human development (FWC 2004). Habitat connectivity, long-term resilience, and freshwater resources are key considerations for land purchases.
- Up-to-date mapping and monitoring of wetlands and adjacent upland vegetation would be useful in monitoring and quantifying habitat shifts. Data on mangrove cover and density would be beneficial because present mapping does not record density of mangroves, which lessens the ability to observe and quantify changes in forest structure.
- Florida Keys NWR management plans often note the need for some mosquito ditches and unnecessary canals to be filled because they alter hydrology and often result in stagnant water (Klett et al. 2006, USFWS 2009). Decisions regarding ditch restoration should be made case by case and should incorporate projections of sea-level rise and freshwater flow as well as mosquito control considerations. Ditch filling may be most beneficial for ditches that drained or allowed saltwater intrusion into historically nontidal wetlands (some of which are now dominated by *R. mangle* and *L. racemosa*). Some ditches are now important sources of freshwater to resident plants and animals. Thus, the preservation and enhancement of scarce freshwater resources should be considered before undertaking wetland restoration. Location-specific research is needed to determine whether ditch filling would in fact be beneficial for surrounding habitats.

- Management objectives of the Florida Keys National Marine Sanctuary, the NWRs in the Lower Florida Keys, state managed lands, Monroe County and municipalities frequently emphasize the importance of combating invasive vegetation to protect mangrove habitats (FKNMS 2002, FWC 2004, TNC 2009, USFWS 2009). Mapping and monitoring of the extent of invasive vegetation is critical to assessing effectiveness and optimizing efforts (FWC 2004, Hobbs et al. 2006).

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Chapter 10
Biscayne Bay

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Description of the region

Biscayne Bay was formed between 5,000 and 2,400 years ago when rising sea levels flooded a limestone depression on the Miami Ridge, creating a shallow estuarine lagoon (FDEP 2013). The bay is partly sheltered from the Atlantic Ocean by the Florida Keys and barrier islands off Miami (Figure 10.1). The Atlantic Coastal Ridge, an oolitic limestone feature that reaches a maximum elevation of 20 ft (6.1 m), runs along part of Biscayne Bay's western shore and separates the Everglades from the Atlantic Ocean. Biscayne Bay once had a strong hydrologic connection to the Everglades via rivers and creeks that ran through and around the Atlantic Coastal Ridge. Freshwater entered the bay as a diffuse sheet of surface water from the surrounding wetlands and through groundwater springs (Browder et al. 2005).

The hydrology of the region was drastically altered in the late 1800s and 1900s by the construction of dredged ditches, canals, and levees for the purpose of managing surface water and enabling urban development and agriculture. These water management structures cut off much of the surface freshwater flow, resulting in the loss of the many small creeks that used to permeate the mangrove forests (Browder et al. 2005). In contrast to historic sheetflow, the constructed canals localized and concentrated freshwater runoff to the bay, leading to drastic seasonal salinity fluctuations due to freshwater depletion or inundation.

Widespread mosquito ditching and reduced freshwater input led to extensive saltwater intrusion in the wetlands surrounding Biscayne Bay. By the 1940s and 1950s, mangroves and other salt-tolerant vegetation had expanded inland and colonized along the ditches (Ruiz and Ross 2004). Historically freshwater wetlands, such as Snake Creek, Oleta River, and Card Sound, now host salt-tolerant plants including mangroves (Ball 1980, Gaiser and Ross 2003, SFNRC 2006).

Freshwater also enters Biscayne Bay from upwelling of the Biscayne Aquifer. The aquifer is a subterranean wedge of water-bearing, highly-permeable limestone bedrock that extends across Miami-Dade County; it reaches its maximum thickness of 240 ft (73 m) at the eastern edge of the bay (CERP 2010). Since the aquifer is highly permeable, at shallow depths it is susceptible to groundwater contamination. The Biscayne Aquifer is one of the most important natural resources in the area, supplying public water for Miami-Dade, Broward, and southern Palm Beach counties. Flow from freshwater springs into Biscayne Bay declined in the early 1900s when altered Everglades hydrology lowered the water table (FDEP 2013). Groundwater levels continued to decline due to increasing urban and agricultural demand for freshwater.

Biscayne Bay is adjacent to the most heavily populated region in Florida. In 2015, the population of Miami-Dade County was estimated at 2.7 million and grew 7.8% between 2010 and 2015 (U.S. Census 2015). The Port of Miami River is Florida's fifth-largest port and receives both cruise and cargo ships (FDEP 2013). The northern portion of Biscayne Bay has been the most severely impacted, with six filled causeways, a major seaport facility, and highly urbanized development. South of greater Miami, urban development is replaced by agriculture. Water quality greatly improved in the bay in the 1970s with the development of more wastewater treatment plants and the elimination of direct sewage discharge into the bay, but it still receives significant amounts of nutrients and other pollutants in stormwater runoff (Browder et al. 2005, FDEP 2013).

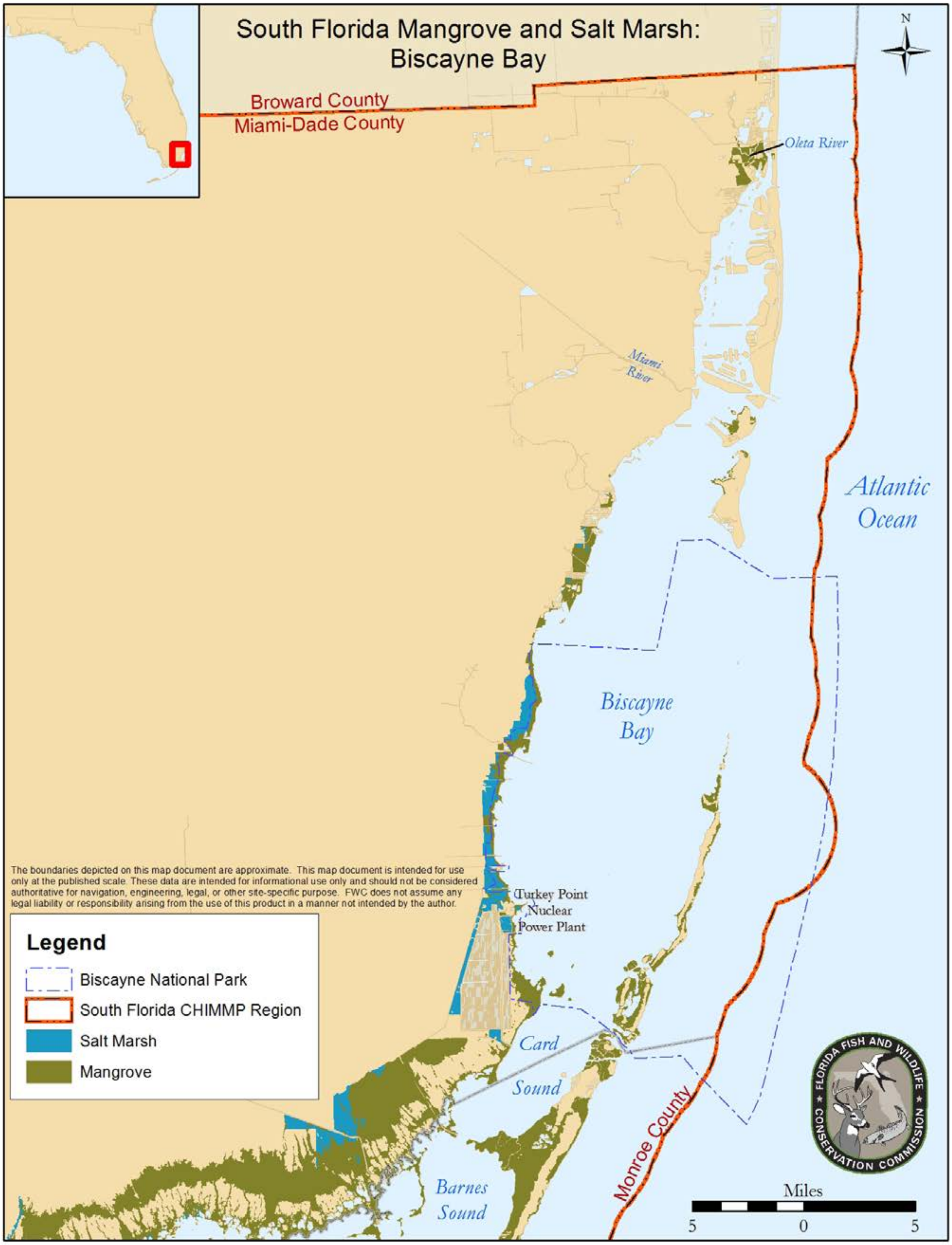

Figure 10.1. Mangrove and salt marsh coverage in the Biscayne Bay area. Data source: SFWMD 2004–2005 land use/land cover data, based upon FLUCCS classifications (FDOT 1999, SFWMD 2009a).

Figure 10.2. Aerial image of the white zone adjacent to Card Sound. The cooling canals of the Turkey Point Power Plant are visible in the upper portion of the image. Image credit: Google Earth.

The Turkey Point Power Plant in southern Biscayne Bay (Figure 10.1), which includes twin nuclear power stations and three fossil-fuel power stations, was constructed and began operation in the late 1960s and early 1970s. The warm-water effluent was found to have a detrimental impact on *Thalassia testudinum* (turtle grass) and on many of the fish and benthic organisms (Zieman and Wood 1975). Consequently, 168 miles (270 km) of cooling canals were built through 6,800 acres (2,750 ha) of mangroves adjacent to the power plant (FDEP 2013). These canals are now a productive nursery ground for *Crocodylus acutus* (the American crocodile), which is listed as threatened under the federal Endangered Species Act (FDEP 2013).

Mangroves dominate coastal wetland vegetation along Biscayne Bay. Mangrove canopy height is greatest along the bay's western shoreline and decreases further inland (Ruiz 2007). *Rhizophora mangle* (red mangrove) generally dominates along the coast and in many of the inland forests. *Avicennia germinans* (black mangrove), *Laguncularia racemosa* (white mangrove), and the closely associated *Conocarpus erectus* (buttonwood) become more prominent further inland (Smith et al. 1994, Ruiz 2007). Salt marshes, reduced in extent by the expansion of mangroves, tend to be dominated by *Juncus roemerianus* (black needlerush) or *Distichlis spicata* (salt grass) (Ruiz 2007).

Southeast Saline Everglades "white zone"

The region landward of Card Sound and Barnes Sound (Figure 10.1) is part of the area that has been named the Southeast Saline Everglades (Egler 1952, Ross et al. 2000). From an aerial view, this region of sparse vegetation appears white due to the highly reflective nature of the marl substrate (Figure 10.2) and so has been dubbed the white zone (Ross et al. 2000, Browder et al. 2005, Briceño et al. 2011). The vegetation in this region is composed of mangrove shrubs along the coastline, which transition to sparse mangrove–graminoid mixtures of predominantly *R. mangle* and *Eleocharis cellulosa* (Gulf Coast spikerush) (Ross et al. 2000). The vegetation transitions to *Cladium jamaicense* (sawgrass) freshwater wetlands further inland. Productivity in this coastal ecosystem is restricted by a combination of reduced seasonal freshwater flows, phosphorus limitation, and soil salinity. The vegetation in the white zone is generally not dense enough to be classified as mangrove forest under most land cover classification systems. The reduction in surface sheet water flow has led to the landward expansion of the white zone by about 0.9 mi (1.5 km) from the 1940s to the 1990s (Ross et al. 2000).

Biscayne Bay management

Managed regions in the bay include Biscayne Bay Aquatic Preserve (established in 1974), Biscayne Bay-Cape Florida to Monroe County Line Aquatic Preserve (established in 1975), and Biscayne National Park (established in 1980) (FDEP 2013). Biscayne Bay Aquatic Preserve boundaries are restricted to submerged lands in the bay itself; therefore most of the mapping and monitoring conducted by the preserve focuses on parameters such as seagrass extent and water quality (FDEP 2013). Several parks and preserves also line the shoreline of the bay, and all regions of the bay are used extensively for recreation. More than 500,000 people visit every year, and 54% of local residents report using the bay annually (CERP 2010, FDEP 2013).

In an effort to restore the wetlands in this region to a more natural state, the Comprehensive Everglades Restoration Plan (CERP) includes a Biscayne Bay coastal wetland project that aims to redirect freshwater from canals onto coastal wetlands adjacent to the bay (CERP 2010, CERP 2012). The three regions of focus for this restoration program are the Deering Estate, Cutler wetlands, and the L-31 East Flow-way wetlands near Military Canal. This surface flow of freshwater will help restore the coastal wetlands by re-establishing lower salinities, although invasive vegetation that has taken hold in some parts of this region may need to be addressed as well (Browder et al. 2005, Briceño et al. 2011, FDEP 2013). CERP efforts to increase surface freshwater flow may help reduce the extent of the white zone. Miami-Dade County restoration efforts in the area include habitat enhancement of spoil islands, shoreline stabilization, removal of invasive vegetation, native vegetation planting, and the creation of flushing channels (Milano 2000, FDEP 2013).

Threats to coastal wetlands

- **Climate change and sea-level rise:** Sea-level rise is a threat to coastal ecosystems and estuaries due to erosion, increased salinity, and increased landward extent of tidal range, which encourages coastal vegetation to migrate further inland (CERP 2010). Coastal wetland extent will be reduced in regions where extensive agriculture and urban development have replaced natural buffer zones. Additionally, saline intrusion into aquifers further diminishes freshwater availability from groundwater sources that are already under stress due to water demand and management (Browder et al. 2005).
- **Altered hydrology:** As previously mentioned, the canalization and reduction in sheet flow led to freshwater depletion in many wetlands along the bay. This alteration has resulted in shifts from freshwater vegetation to salt-tolerant vegetation. Increasing saltwater intrusion and the high salinity of water in the coastal wetlands decreases their productivity and ecosystem utility (Gaiser and Ross 2003, SFNRC 2006).
- **Urban development:** Biscayne Bay is located in heavily populated Miami-Dade County. With this large human population comes continued development, loss and fragmentation of natural habitats, and increased recreational use of the bay (Briceño et al. 2011). While sewage management has improved, pollution in stormwater runoff continues to contribute excess nutrients, herbicides, pesticides, fertilizers, heavy metals, and hydrocarbons to the bay (CERP 2010, Briceño et al. 2011, FDEP 2013).
- **Hurricanes and tropical storms:** The location of Biscayne Bay makes it highly vulnerable to the powerful winds and storm surge of hurricanes and tropical storms. Extensive damage occurred to mangrove forests after Hurricane Donna in 1960 and Hurricane Andrew in 1992. After Andrew passed over South Florida, there was catastrophic damage to the tall (10–15 m) *R. mangle* and *A. germinans* trees along the coast (Smith et al. 1994). By comparison, the smaller *R. mangle* trees located farther inland from the tall coastal trees suffered little damage. Mangroves on the barrier islands surrounding Biscayne Bay were also damaged by the intense storm surge from the hurricane (Smith et al. 1994).
- **Invasive species:** Like much of Florida, invasive vegetation such as *Schinus terebinthifolius* (Brazilian pepper) and *Casuarina spp.* (Australian pines) compete with native species along Biscayne Bay, particularly in regions recovering from disturbances (FDEP 2013).

Mapping and monitoring efforts

Water management district mapping

The South Florida Water Management District (SFWMD) conducts fairly regular land use/land cover (LULC) surveys. Land cover classifications are based upon SFWMD modifications to the Florida Land Use and Cover Classification System (FLUCCS) (FDOT 1999, SFWMD 2009b). Figure 10.1 presents data from 2004–2005 surveys. The most recent SFWMD LULC data available for the region were compiled in 2008–2009, but they are not shown here due to erroneously high acreages attributed to salt marshes in those years (see Ruiz et al. 2008 for a land use cover comparison). Minimum mapping units were 5 acres (2 ha) for uplands and 2 acres (0.8 ha) for wetlands. Maps were made by interpreting aerial photography and updating 1999 vector data (SFWMD 2009a).

Comprehensive Everglades Restoration Plan monitoring

Monitoring will be conducted as part of the CERP Biscayne Bay coastal wetland project once the construction phase is complete (CERP 2010, CERP 2012). Responsibility for monitoring of hydrology, ecology, water quality, and endangered species will be shared by the SFWMD and the U.S. Army Corps of Engineers.

Local vegetation mapping and monitoring

Several detailed mapping studies have been conducted in the coastal wetlands along Biscayne Bay. Ruiz and Ross (2004) did an inventory of mosquito and drainage ditches along the bay and compiled management and restoration recommendations. Ruiz et al. (2002), Ross and Ruiz (2003), and Ruiz (2007) used vegetation data from multiple transects to create species-specific vegetation maps of the western shore of Biscayne Bay between the Princeton and Mowry canals (see Figure 10.3). Ruiz et al. (2008) created a high-resolution vegetation map of Biscayne National Park that included portions of the western shore of the bay between the Deering Estate and Turkey Point.

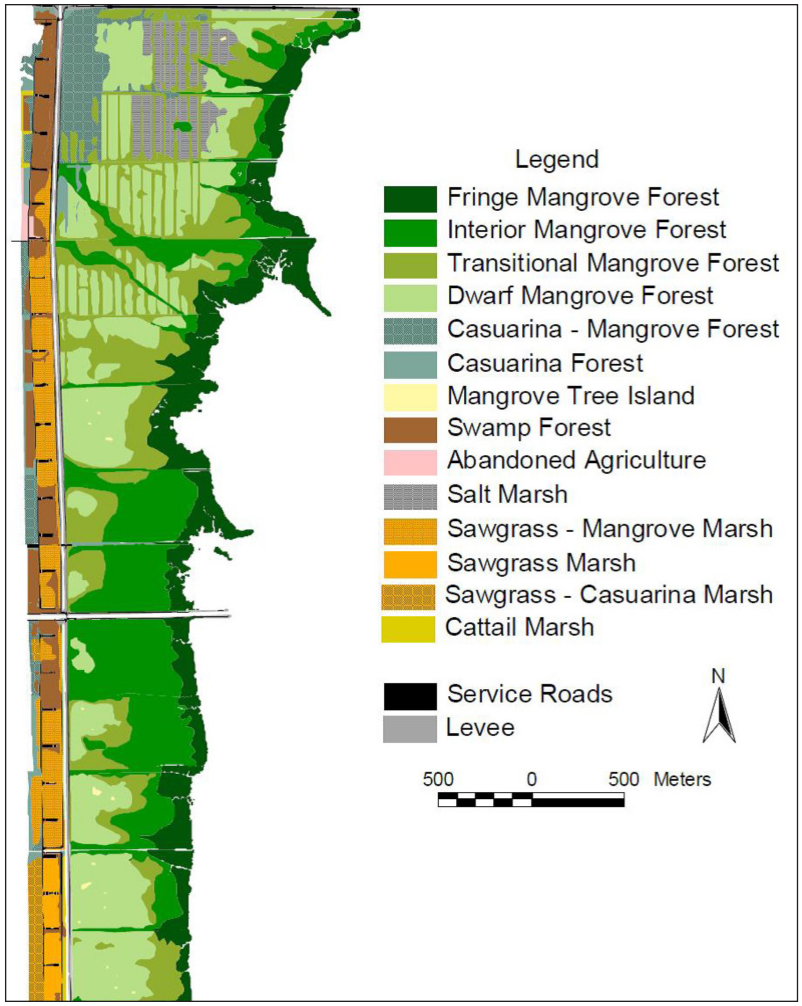

Figure 10.3. Vegetation between Princeton and Mowry canals, as mapped by Ross and Ruiz (2003).

Recommendations for protection, management, and monitoring

- Mosquito and drainage ditches need to be removed in order to improve hydrologic connectivity and freshwater retention, and simplify management of the wetlands. Ditch removal needs to be performed with caution, however, as it may cause mortality in the mangroves that have colonized the mosquito ditches and the disturbance may facilitate establishment of invasive vegetation (Ruiz and Ross 2004).
- Due to continued population growth and urban expansion, additional land acquisitions are necessary in order to make large-scale restoration and water redistribution plans feasible (Briceño et al. 2011). Undeveloped privately owned lands are rare in South Florida and are likely to be developed in the near future (CERP 2010).
- The South Florida Natural Resources Center outlined salinity targets optimal for the coastal mangrove zone along Biscayne Bay (SFNRC 2006). These targets include a maximum salinity of 30, which will require close monitoring during the dry season, and oligohaline conditions of 0–5 in the coastal mangrove zone during the summer rainy season.
- Sewage systems in the Miami area need to be upgraded, and stormwater treatment needs to address the issues of pollutants, nutrients, and sediment in runoff (FDEP 2013).

- An independent review of the CERP Biscayne Bay Coastal Wetlands Project by the Battelle Memorial Institute cited the need for more specific means of addressing sea-level rise and water availability in the region (BMI 2009). The review also questions whether the monitoring program is sufficient to detect ecosystem changes and stresses.
- Consistent regional mapping and monitoring of coastal land cover and vegetation are needed to monitor impacts of changing climate and hydrology (Briceño et al. 2011). For instance, SFWMD LULC data showed a 10-fold increase in the area of salt marsh around Biscayne Bay from 2004–2005 to 2008–2009. This difference reflects changes in mapping methodology rather than an actual increase in salt marsh extent.

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Chapter 11
Palm Beach and Broward Counties

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Description of the Region

Palm Beach and Broward counties (Figures 11.1 and 11.2) are Florida's second and third most populous counties, respectively, behind Miami-Dade County. The estimated 2015 population between the two counties exceeded 3.3 million (U.S. Census 2015). While dense urban development borders the limestone Atlantic Coastal Ridge and the sandy beaches along the coast, the western portions of the counties are dominated by wildlife management and water conservation areas. Palm Beach County also includes the Arthur R. Marshall Loxahatchee National Wildlife Refuge and a portion of the Everglades Agricultural Area. This region receives the highest amount of rainfall in Florida, averaging more than 4.9 ft (150 cm) per year (USFWS 1999a, FDEP 2012).

The underlying Biscayne Aquifer, which extends from Monroe County to southern Palm Beach County, supplies water for the Florida Keys and for Broward and Miami-Dade counties (Fish and Stewart 1991, USFWS 1999a). The aquifer reaches a thickness of over 200 ft (61 m) near the coast and progressively thins toward the center of the state (Fish and Stewart 1991, FDEP 2006). Saltwater intrusion into groundwater, particularly during periods of little rainfall, is increasingly problematic due to urban and agricultural demand for freshwater, drastically altered surface flow, and sea-level rise (FDEP 2006, SFWMD 2013).

Prior to human development much of the mainland coastal region was dominated by *Cladium jamaicense* (sawgrass) and other freshwater plants (USFWS 1999b, CERP 2005, FDEP 2006).The construction of the Intracoastal Waterway in 1912 and the dredging of inlets through the barrier islands altered hydrology and led to a brackish nearshore environment, killing freshwater species (FDEP 2006). The hydrology of the region was significantly altered when the U.S. Army Corps of Engineers constructed drainage canals connecting Lake Okeechobee to the Atlantic Ocean as part of the Central and Southern Florida Project in the 1950s and 1960s. Mosquito ditches and impoundments also altered local hydrology, although in many regions these ditches have since been filled and more natural topography and hydrology has been restored (FDEP 2012, LWLI 2013).

Palm Beach and Broward counties have lost the majority of their coastal wetlands to extensive urban development (Figures 11.1 and 11.2). Approximately 87% of mangroves were removed between 1940 and 1975 due to widespread construction during this period (Harris et al. 1983). South Florida Water Management District (SFWMD) mapping shows an increase in mangrove extent in recent decades (Figure 11.3, Table 11.1). The Palm Beach County Department of Environmental Resources Management (PBCERM) restoration efforts have expanded mangrove habitat in Palm Beach County by removing exotic vegetation and planting native species (Table 11.2). At the same time, the extent of remaining salt marsh has declined slightly (Figure 11.3). The decline in salt marsh extent is linked to loss of habitat and mangrove encroachment due to mild winters (Saintilan et al. 2014). When mangrove growth is not restricted by cold temperatures, mangroves can shade

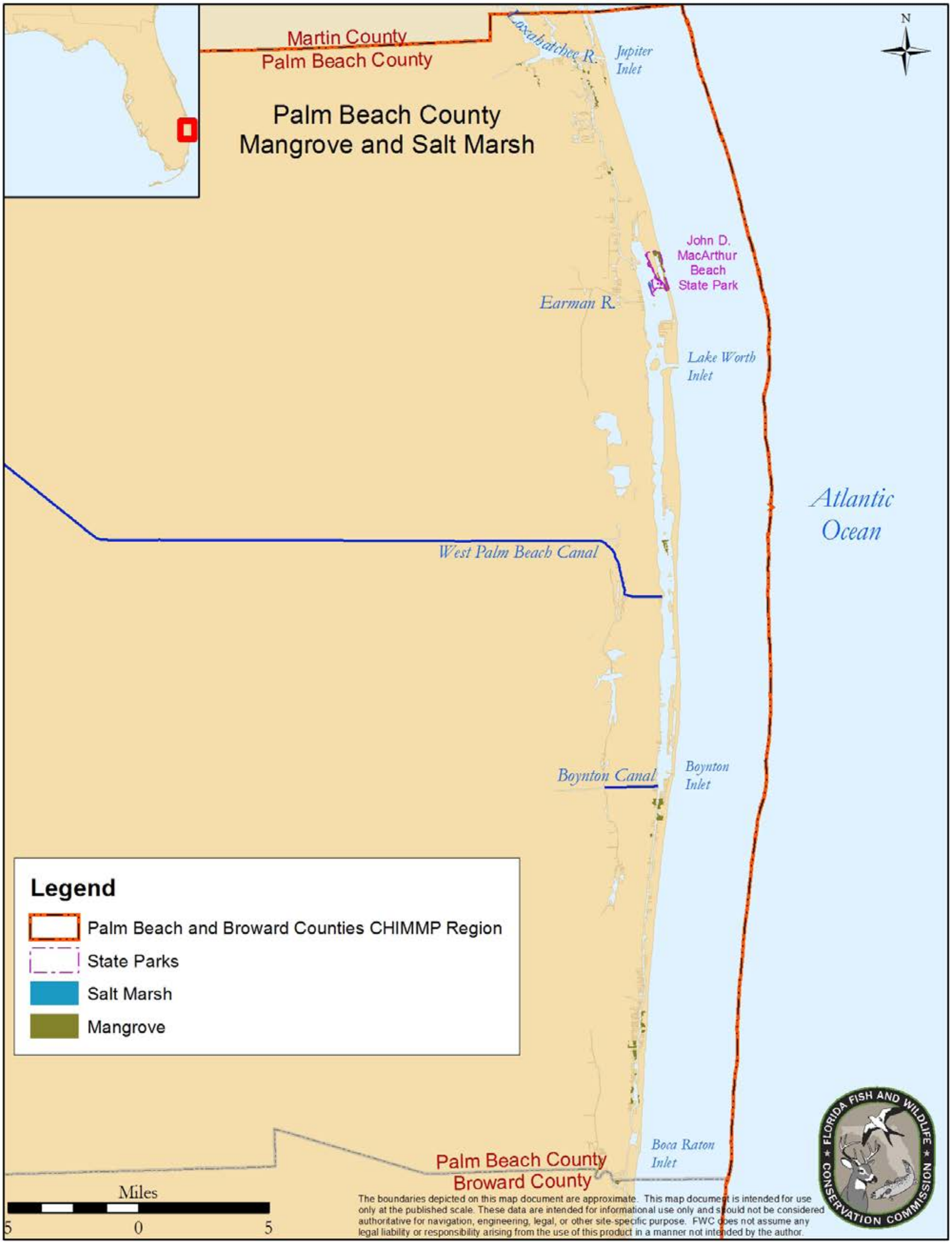

Figure 11.1. Salt marsh and mangrove extent in Palm Beach County. Data source: SFWMD 2008–2009 land use/ land cover data, based upon FLUCCS classifications (FDOT 1999, SFWMD 2009a).

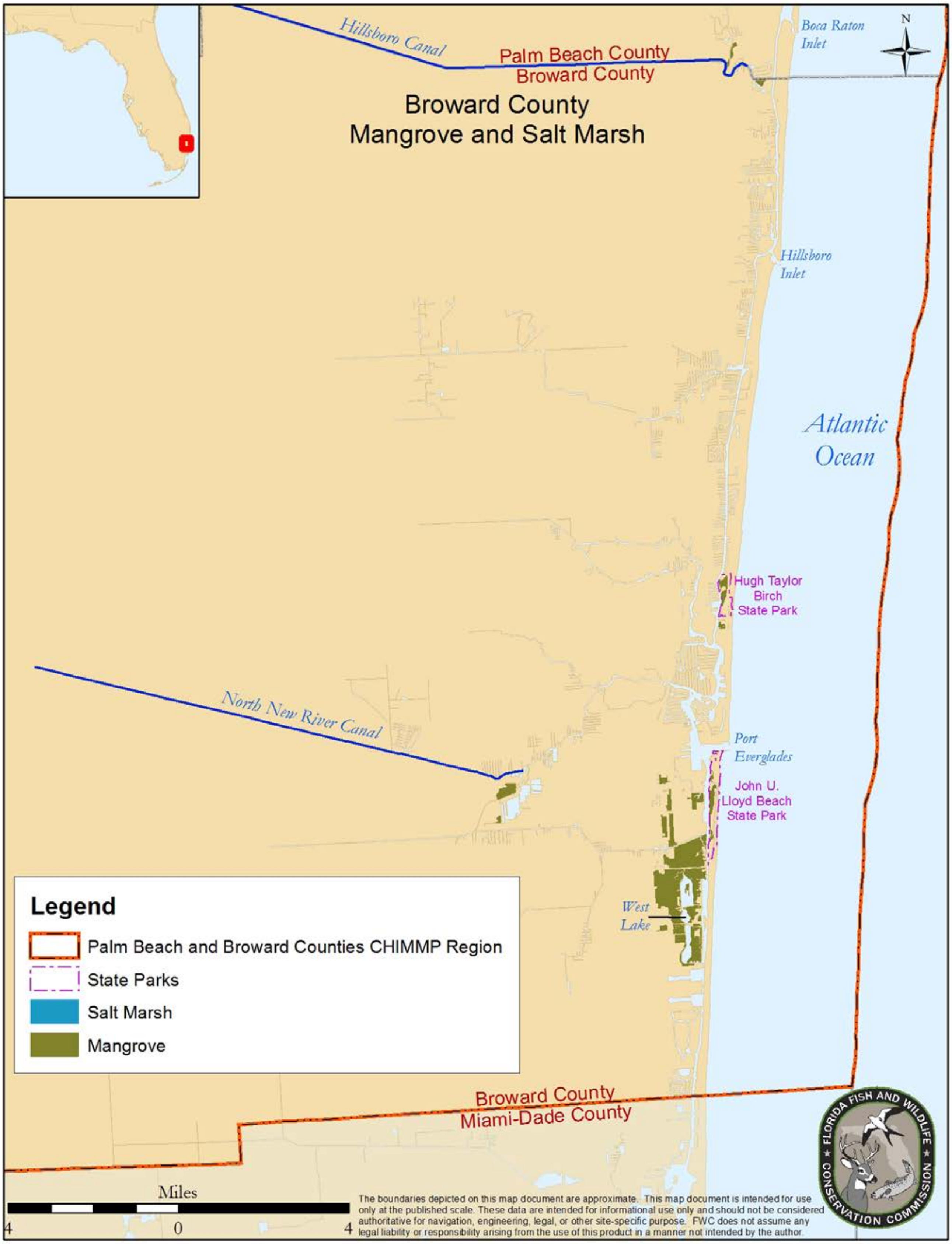

Figure 11.2. Salt marsh and mangrove extent in Broward County. Data source: SFWMD 2008–2009 land use/land cover data, based upon FLUCCS classifications (FDOT 1999, SFWMD 2009a).

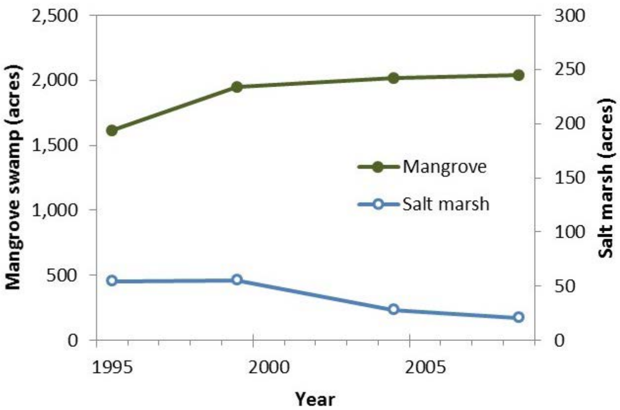

Figure 11.3. Acreages of mangrove swamp and salt marsh in Palm Beach and Broward counties Data source: SFWMD 2009a.

Table 11.1. Acreages of mangrove swamp (FLUCCS 6120) and salt marsh (FLUCCS 6420) in Palm Beach and Broward counties. Data source: SFWMD 2009a.

Year	Mangrove	Salt marsh
1995	1612	55
1999	1947	56
2004–2005	2015	28
2008–2009	2042	21

Table 11.2. Mangrove and cordgrass acreage in the Lake Worth Lagoon (LWL) and Intracoastal Waterway (ICW) of Palm Beach County (PBC). Data source: PBC 2008. No cordgrass data available in 1985 and 2001.

Habitat	Region	1985	2001	2007
Mangrove	North ICW	231	243	266
	North LWL	119	134	153
	Central LWL	52	56	58
	South LWL	76	73	73
	South ICW	152	147	162
	Total PBC	631	654	711
Cordgrass	North ICW			0.00
(*Spartina* spp.)	North LWL			0.00
	Central LWL			1.35
	South LWL			0.16
	South ICW			0.00
	Total PBC			1.51

and eventually replace salt marsh vegetation (Stevens et al. 2006). Studies of the salt marsh species *Spartina alterniflora* (smooth cordgrass) also suggest that nutrient enrichment in developed coastal systems may be a driver for salt marsh loss (Deegan et al. 2012), although coastal wetland responses to eutrophication are widely variable (Kirwan and Megonigal 2013).

Loxahatchee River

The Loxahatchee River crosses through Martin and Palm Beach counties before it reaches the Atlantic Ocean at the Jupiter Inlet (the downstream portion of the river is visible in Figure 11.1). The Northwest Fork of the Loxahatchee River (Figure 11.4) is composed of subtropical cypress swamp, mesic and hydric hammocks, and mixed hardwood forest. In 1985, it was designated Florida's first National Wild and Scenic River (SFWMD 2006). This swamp contains *Taxodium distichum* (bald cypress) trees that are at least 300 years old and is one of the last remaining bald cypress swamps in Southeast Florida. The Loxahatchee River is also Southeast Florida's last free-flowing river system (SFWMD 2006). Additionally, the tidal floodplains and estuary with its seagrasses, mangroves, and oyster beds are valuable ecological resources in the Loxahatchee River watershed. Mangroves are found fringing natural shorelines of the Loxahatchee River estuary, occasionally expanding landward as a full mangrove forest (SFWMD 2006). *Rhizophora mangle* (red mangrove) and *Laguncularia racemosa* (white mangrove) are dominant, while *Avicennia germinans* (black mangrove) is found along the Intracoastal Waterway.

Historically, the Jupiter Inlet opened and closed naturally due to storms and river flow. Altered hydrology as a result of the construction of the Intracoastal Waterway and the Lake Worth Inlet caused it to frequently remain closed. In 1947, Jupiter Inlet was permanently opened through dredging operations and the construction of jetties and sand traps (SFWMD 2006). The Loxahatchee River watershed has been permanently altered by the stabilization of the Jupiter Inlet, which heightens the effects of tidal amplitude and saltwater intrusion. The construction and operation of drainage canal systems also alters the natural pattern of freshwater flow and inundation of the floodplain. The increased surface water, soil salinity, and tidal inundation are major concerns for the survival of the remaining floodplain communities.

Lake Worth Lagoon

Lake Worth Lagoon (LWL) is a 22-mi-long (35 km), narrow estuary that extends along Palm Beach County

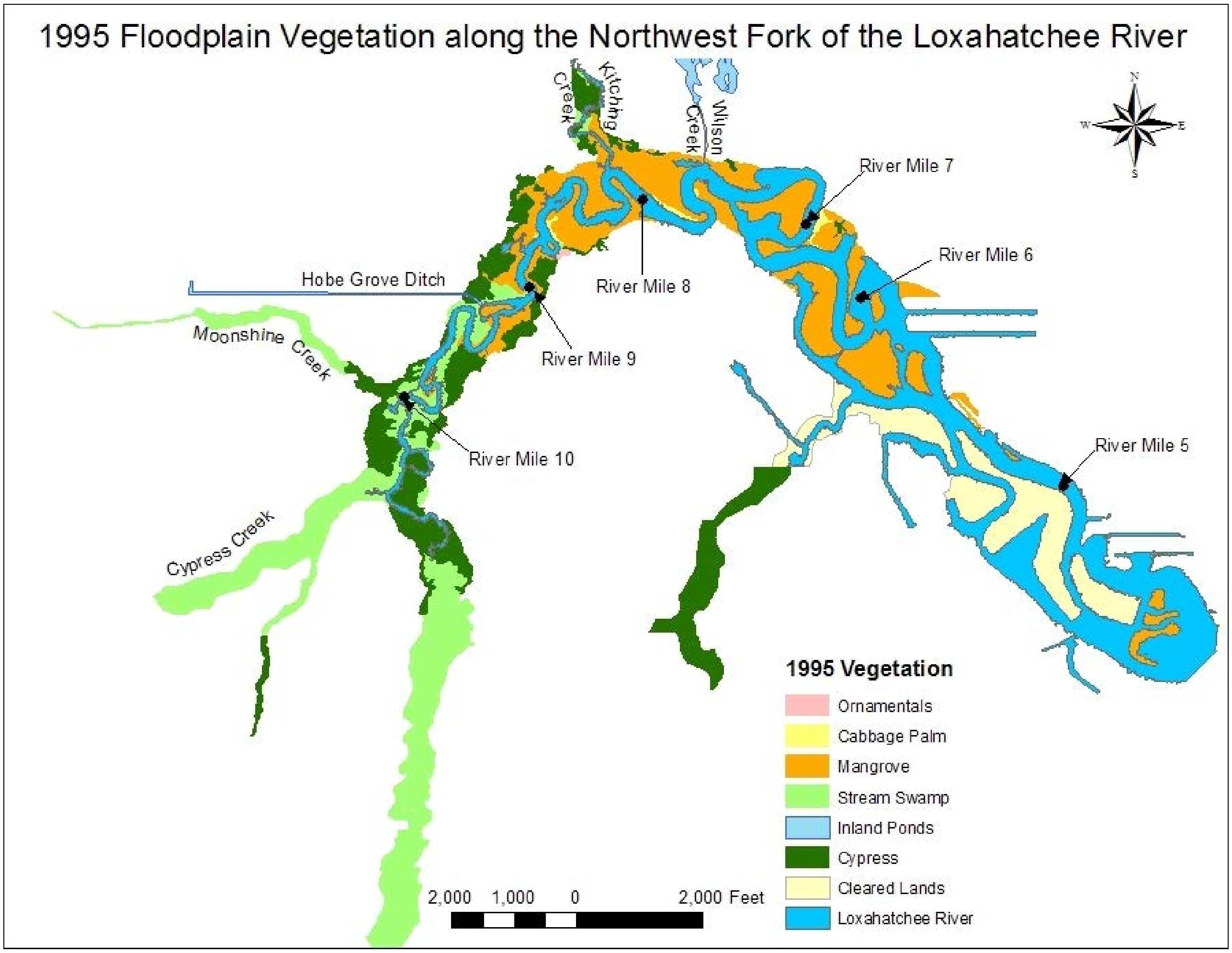

Figure 11.4. 1995 Floodplain vegetation along the upper Loxahatchee River (Martin County). Data source: Hedgepeth and Roberts 2009.

(Figure 11.1, detailed extent in Figure 11.5). Historically Lake Worth was a freshwater lake that received sheet flows of fresh surface water from the Everglades, but the construction of artificial inlets in the early 1900s caused the water to become brackish (USFWS 1999b, CERP 2005). More than 81% of the lagoon's shoreline is lined by urban development (PBCERM 2008), but mangroves do occupy some shorelines of the northern lagoon, islands, and a few patchy regions around the southern end of the lagoon (Figure 11.5, USFWS 1999b). LWL receives considerable freshwater input from the Earman River, West Palm Beach Canal, and Boynton Canal (C-17, C-51, and C-16 canals, respectively) (Figure 11.1, SFWMD 2013). This freshwater input decreases salinity in LWL and increases sedimentation. SFWMD regulates freshwater discharges in attempts to limit high-volume outflows and maintain estuarine salinities above 15 (SFWMD 2013).

Based upon 2007 habitat mapping (Table 11.2, PBC 2008) and additional mapping of PBCERM restoration projects between 2007 and 2012, the LWL has approximately 3.17 acres (1.28 ha) of salt marsh habitat (Figure 11.5). These patches of *S. alterniflora* salt marsh were created as part of PBCERM restoration projects and are often planted alongside or mixed with mangrove seedlings. Although *S. alterniflora* tends to be outcompeted by mangroves over time, it is an important pioneer species that will increase the chances for success of emergent vegetation (Lewis and Dunstan 1975, Crewz and Lewis 1991).

The North Palm Beach County portion of the Comprehensive Everglades Restoration Plan (CERP), now called the CERP Loxahatchee River Watershed Restoration Project, seeks to reduce freshwater flow to LWL by diverting it to the Loxahatchee Slough and Grassy Waters Preserve. The project aims to moderate freshwater flow and improve hydroperiods to the region. Other CERP projects in this region included the construction of sediment traps along the West Palm Beach Canal and the addition of sand near Ibis Isle in LWL to provide sufficient elevation for mangrove and salt marsh planting (SFWMD 2013).

Figure 11.5. Emergent saltwater vegetation surrounding Lake Worth Lagoon, 2013. Data source: LWLI 2013.

Broward County West Lake Park

Mangroves are present in a few parks and barrier islands along the coast of Broward County, such as John U. Lloyd Beach State Park and Hugh Taylor Birch State Park (Figure 11.2). The largest mangrove habitat in the county is found at Broward County West Lake Park in Hollywood (USFWS 1999b). In the 1920s, the region surrounding the park was dredged and filled to prepare for development (MacAdam et al. 1998). The land was never developed and was later purchased for conservation in 1980. From 1985 to 1996, a restoration effort removed exotic vegetation and decreased land elevation to encourage natural recruitment of mangroves (MacAdam et al. 1998). The region is now a 1,400-acre (566 ha) coastal wetland and mangrove preserve that includes two salt marshes dominated by *Borrichia arborescens* (seaside tansy) and *B. frutescens* (sea oxeye daisy) (USFWS 1999b).

Threats to coastal wetlands

- **Coastal development:** Palm Beach and Broward counties have lost the vast majority of their coastal wetlands to urban development, primarily from coastal construction between 1940 and 1970 (Harris et al. 1983). The coastal wetlands that remain are found primarily on protected public lands and so are less susceptible to the direct threat of development, though indirect impacts (discussed below) of a large human population impact these wetlands.
- **Hydrologic alterations:** The region has already undergone a major shift from freshwater to estuarine wetlands due to the dredging of inlets through the barrier islands and the rerouting of surface water. While extending the inland range of the tides did increase the extent of estuarine wetlands in the area, salinity is highly variable. Channelization led to the concentration of runoff while other regions were starved of freshwater, both of which hinder optimal salinity for estuarine wetlands (FDEP 2012, LWLI 2013). More localized hydrologic issues include stagnant water caused by remnant mosquito ditches, which are suboptimal for coastal wetlands because they lack complete tidal flushing (FDEP 2006, LWLI 2013).
- **Climate change and sea-level rise:** Extensive urban development along the shoreline restricts the extent of buf-

Figure 11.6. Detail of 2007 mangrove extent along the Intracoastal Waterway of the northern and southern portion of Palm Beach County. Data Source: PBC 2008.

fer zones and hinders landward migration. Sea-level rise threatens coastal habitats in this region as mangroves fringing seawalls or other hardened shorelines will likely be lost due to inundation. This region is also vulnerable to inundation due to storm surge from hurricanes, which are exacerbated by higher sea levels (LWLI 2013).

- **Water quality and pollution:** Runoff from the dense urban development in this region is detrimental to local water quality. Pollutants in freshwater runoff, including fertilizers and pesticides, often flow directly into coastal wetlands and lagoons. There is also the potential for hazardous spills due to high boat traffic and shipping (FDEP 2012).
- **Invasive vegetation:** Like much of coastal Florida, invasive vegetation such as *Melaleuca quinquenervia* (melaleuca), *Schinus terebinthifolius* (Brazilian pepper) and *Casuarina* spp. (Australian pines) compete with native vegetation for space and freshwater (FDEP 2012).
- **Erosion:** Much of the mangrove habitat lines the Intracoastal Waterway; bank erosion from prop wash and wake from heavy boat traffic threatens these mangroves (FDEP 2012).

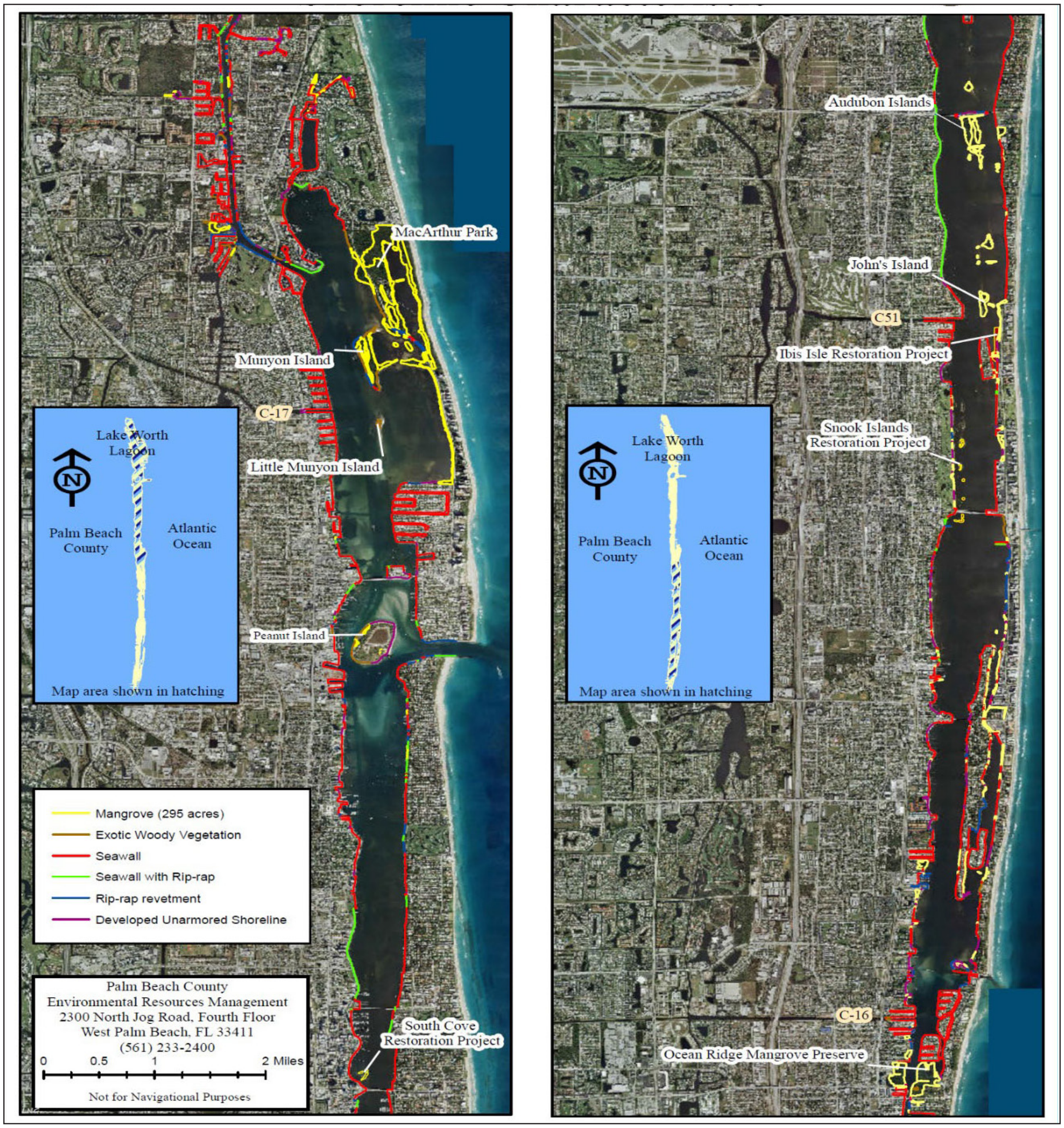

Figure 11.7. 2012 Shoreline characteristics along Lake Worth Lagoon. Data source: LWLI 2013.

Mapping and monitoring efforts

Water management district mapping

SFWMD conducts fairly regular surveys of land use and land cover (LULC). Salt marsh and mangrove extent is available for the LULC years 1995, 1999, 2004–2005, and 2008–2009 (see Table 11.1). Land cover classifications for 2008–2009 were based on a SFWMD-modified FLUCCS classification system (FDOT 1999, SFWMD 2009b). Minimum mapping units were 5 acres (2 ha) for uplands and 2 acres (0.8 ha) for wetlands. Maps were made by interpreting county-based aerial photography updating 2004–2005 vector data (SFWMD 2009a).

Palm Beach County Habitat Mapping

In 2007, the Palm Beach County Habitat Mapping Project used aerial photography to identify the extent of seagrass, mangrove, salt marsh, and oyster habitat in LWL and the Intracoastal Waterway in the northern and southern portions the county (PBC 2008). Aerotriangulation, digital orthophotography, field work, photointerpretation, and trend analyses were used to map these coastal resources. Mangrove extent from this project for the Intracoastal Waterway in the northern and southern portions of Palm Beach County is shown in Figure 11.6; shoreline characteristics of LWL are shown in Figure 11.7. This effort updated older maps from 1985 and 2001–2003 (PBC 2004). There has not been an update since 2007, although an extensive seagrass mapping effort was completed in 2013 for LWL, Lake Boca, and Jupiter Sound. A more recent mangrove assessment was completed as part of the Lake Worth Lagoon Management Plan in 2012 (Figure 11.5); the extent of mangroves along the LWL was found to have increased 8% from 1985 to 2012 (LWLI 2013). The increase in acreage of mangroves in LWL from 2007 to 2013 was determined by mapping mangroves at PBCERM restoration sites; this calculation was added to total acreage (LWLI 2013).

Loxahatchee River floodplain vegetation study

In 2003, SFWMD and the Florida Park Service established four new vegetative belt transects and studied six transects from previous studies for a total of 138 vegetative plots in the Loxahatchee River floodplain (Hedgepeth and Roberts 2009, Kaplan et al. 2010). These data were collected in preparation for establishing the minimum flow and levels requirements for the Northwest Fork of the Loxahatchee River. Since then, canopy has been examined every six years and shrub and groundcover every three years.

The study focused on the stability of floodplain plant communities. Due to inadequate hydroperiods, these floodplain plants were at risk of displacement by upland and transitional communities in the inland regions. In the tidal reaches, reduction in freshwater flow led to increased salinity, prompting the establishment of salt-tolerant species such as mangroves (Hedgepeth and Roberts 2009, Kaplan et al. 2010). The study concluded that *T. distichum* should be the primary species of concern for restoration and enhancement in this riverine swamp, while *Acer rubrum* (red maple) and *Carya aquatica* (water hickory) should be the primary species of concern for bottomland hardwood communities and *Sabal palmetto* (cabbage palm) for hydric hammock (SFWMD 2006, Hedgepeth and Roberts 2009). Restoration of the Loxahatchee River focuses on reducing salinities to less than 2 in the upper tidal reaches and improving hydroperiods on the riverine floodplain, which should in turn improve habitat quality for freshwater seed production, germination, and eventually reforestation throughout the river system. Continued vegetation, surface water, and soil monitoring of the floodplain will be necessary to ensure that the hydrologic conditions necessary for the long-term health of these vegetative communities are maintained. SFWMD has ongoing monitoring for freshwater flow, water quality, vegetation, seagrasses, and various animals in the North Fork of the St. Lucie River and the Loxahatchee River Floodplain and Watershed (SFWMD 2006). The Restoration Plan for the Northwest Fork of the Loxahatchee River (SFWMD 2006) chronicles these problems and provides ecological target species, performance measures, and monitoring requirements needed to track the success of restoration and guide future adaptive management and operational practices.

Recommendations for protection, management, and monitoring

- Because the construction of inlets and the resulting increase in tidal influence has caused expansion of mangroves into regions previously occupied by freshwater vegetation, management practices will vary depending on whether the overall objective is to protect existing coastal wetlands (LWLI 2013) or remaining freshwater vegetation (SFWMD 2006).
- Restore connectivity between isolated habitats and develop a monitoring program to assess impacts of sea-level rise on coastal ecosystems. Install living shorelines such as mangroves or other native vegetation in place of bulkheads or other artificial shorelines. Landward migration of mangroves and salt marshes should be facilitated with buffer zones adjacent to coastal wetlands habitats (SFRCC 2012). Further recommended responses to climate change are outlined in the Southeast Florida Regional Climate Change report (SFRCC 2012).
- Several regions, including parts of John U. Lloyd Beach State Park and Lantana Nature Preserve, were once ditched in an attempt to curb mosquito population growth (FDEP 2012, LWLI 2013). Although many ditches were filled in, water stagnates in remaining ditches and continued filling and restoration are recommended (FDEP 2012, LWLI 2013). Mangroves in Hugh Taylor Birch State Park would also benefit from increased circulation and tidal flushing, and spoil regions have been recommended for restoration to mangrove forest (FDEP 2006).
- Invasive vegetation continues to be a major threat to Florida wetlands. Efforts should be made to control the introduction of exotic species and to educate landowners about planting native species. Restoration efforts should continue to remove invasive vegetation that encroaches on salt marshes and mangroves.

- Goals in the Lake Worth Lagoon Management Plan include reducing sediment load, nutrient input, and contaminant input into the lagoon. The Action Plan also specifically aims to restore, create, and protect mangrove habitats (LWLI 2013). This result will be achieved through the education of landowners, installation of living shorelines, and collaboration with local partners and governmental agencies to complete habitat restoration projects.
- Goals in the John D. MacArthur Beach State Park Management Plan include the continued exotic vegetation removal, restoration of the beach dune community, updating plant and animal inventories, and improved mapping, monitoring, and management of designated species (FDEP 2005).

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Description of the region

The Indian River Lagoon (IRL) system extends 156 mi (250 km) along Florida's east coast from the Ponce de Leon Inlet in Volusia County to the Jupiter Inlet in Palm Beach County. The large latitudinal extent of the IRL contributes to its high level of biodiversity, as the estuary straddles temperate and tropical–subtropical climates (Swain et al. 1995, FDEP 2015). The IRL system consists of a series of coastal lagoons (Mosquito Lagoon, Banana River Lagoon, and Indian River Lagoon, Figure 12.1) bounded by barrier islands, and the St. Lucie River Estuary at the southern end (Figure 12.2). Watershed and resource management in the region is split between the jurisdictions of the St. Johns River Water Management District (SJRWMD) and the South Florida Water Management District (SFWMD) at the boundary of Indian River and St. Lucie counties. There are also five Florida Department of Environmental Protection (FDEP) Aquatic Preserves in the IRL system: Mosquito Lagoon, Banana River, Indian River–Malabar to Vero Beach, Indian River–Vero Beach to Fort Pierce, and Jensen Beach to Jupiter Inlet.

Sandy barrier islands, dunes, and paleoshorelines run parallel to the shoreline, and large shell middens from indigenous people provide some local elevation (FDEP 2015). Historically, the region was in a state of natural flux due to ephemeral inlets and seasonally variable freshwater runoff. Periodic tropical storms and hurricanes shifted barrier islands and caused inlets to open, close, or migrate (FDEP 2015). Humans have attempted to restrict and stabilize this variability with the construction of seawalls, dikes, canals, and fill. Constructed hydrologic alterations include 16 causeways, the Atlantic Intracoastal Waterway, many drainage canals, and five permanent inlets (Ponce, Sebastian, Fort Pierce, St. Lucie, and Jupiter inlets). Additionally, the Cape Canaveral Lock connects the Banana River Lagoon with the Atlantic Ocean, and the C-44 canal connects the St. Lucie River with Lake Okeechobee.

Human population in the region grew rapidly from the 1950s through the 1970s with the expansion of tourism, the space industry, and agriculture (FDEP 2015). From 2010 to 2015, the population of Volusia and Brevard counties was projected to grow at a rate of about 4.6%. Indian River, St. Lucie and Martin counties were projected to grow 6.4–7.7% during the same period, approaching the statewide average of 7.8% (U.S. Census 2015).

Coastal wetlands

Juncus roemerianus (black needlerush) and *Spartina alterniflora* (smooth cordgrass) dominate the salt marshes found in the northern IRL (Figure 12.1), while mangroves and marsh succulents (*Salicornia bigelovii*, *Sarcocornia ambigua*, and *Batis maritima*) are more abundant

Figure 12.1. Mangrove and salt marsh extent in the northern Indian River Lagoon. Data source: SJRWMD 2009 land use/land cover data, based upon FLUCCS classifications (FDOT 1999, SJRWMD 2009a).

in the central and southern IRL (Figure 12.2, Lewis et al. 1985). *Rhizophora mangle* (red mangrove), *Avicennia germinans* (black mangrove), and *Laguncularia racemosa* (white mangrove) intermix rather than forming species-specific elevation zones due to the microtidal nature of much of the estuary (FDEP 2015). *Conocarpus erectus* (buttonwood) is also found at higher elevations. *R. mangle* has become more abundant in the northern Mosquito Lagoon as a result of the lack of recent cold events, overtaking regions previously dominated by the more cold-tolerant *A. germinans* (FDEP 2009a). The overall area of mangrove forests in the region has also increased significantly since the extensive cold event mortalities in the 1960s–1980s (Cavanaugh et al. 2014, Giri and Long 2014). This increase in mangrove habitat correlates with the reduced frequency of cold events with air temperatures less than −4°C (Cavanaugh et al. 2014). Neighboring ecosystems include seagrass beds, blackwater streams, and freshwater tidal wetlands that are predominantly low salinity, yet are flooded at high tide.

In the 1950s through the 1970s, 75–90% of the salt marshes and mangroves along the IRL were lost to development (Figure 12.3), impounded, or ditched in attempts to control the salt marsh mosquito population (Taylor 2012). These impoundments were generally created using dragline excavators. During this process, sediment was removed from an adjacent parallel ditch and used to create an impoundment, effectively isolating coastal wetlands from neighboring marshes and tidal flow. Dragline ditches, networks of deep ditches and spoil piles, were also used to combat mosquitoes. These ditches were open to tidal flushing, but the higher elevation of the adjacent spoil piles facilitated the establishment of invasive vegetation such as *Schinus terebinthifolius* (Brazilian pepper) (Rey et al. 2012). This impoundment and ditching of salt marshes and the accompanying hydrologic alteration likely promoted mangroves at the expense of the historically abundant marsh succulents in many areas.

Recent efforts by SFWMD, SJRWMD, and county mosquito control districts to mitigate and restore impoundment hydrology include installing culverts through the impoundments or removing impounded sections. Rotational impoundment management is now used in much of the region, allowing seasonal connection to the estuary while continuing to control mosquito populations (Clements and Rogers 1964, Taylor 2012). In this process, the wetlands are isolated and flooded via pumps during the mosquito's summer breeding season (approximately May to October) and are left open to the estuary the remainder of the year. This management option has been found to improve water quality, plant diversity, and fish movement (Rey et al. 1990, Brockmeyer et al. 1997).

Approximately 80% of the impounded wetlands have been reconnected either seasonally or permanently (FDEP 2015). Wetland reconnection and restoration are a major part of the Surface Water Improvement and Management Plan (SWIM) for the IRL (SJRWMD and SFWMD 2002). Other efforts include the planting of native species, removal of invasive species, and the preservation of wetlands through land acquisition (SJRWMD and SFWMD 2002).

Hydrology and water quality

Historically, the IRL drainage basin was much smaller, and its boundary followed the Atlantic Coastal Ridge. Numerous canals were constructed from 1916 through the 1950s in order to drain much of the adjacent wetlands for agriculture (primarily for cattle ranging and citrus orchards). These canals greatly increased both the size of the IRL watershed and the rate at which water was delivered to the lagoon. The canals increased freshwater flow in the rainy season, concentrating stormwater runoff and dumping large quantities of freshwater and associated land pollutants into the lagoon (FDEP 2015). Overall flow in the dry season has decreased due to agricultural and urban consumption. The lagoons receive freshwater input from surface runoff and groundwater seepage, as well as minor inputs from precipitation, natural tributaries, and wastewater-treatment plants. In the 1960s and 1970s poorly treated wastewater was discharged into the IRL, resulting in poor water quality in the system, particularly near urban centers (FDEP 2015). Septic systems are still widely used in much of the area, and seepage of bacteria, phosphorus, and nitrogen from old systems that are not properly maintained are of particular concern (FDEP 2009a).

Groundwater sources in the region include the Floridan Aquifer, intermediate aquifer, and surficial aquifer. The Floridan Aquifer and the surficial aquifer are used for agricultural and public water supplies, although the Floridan aquifer becomes brackish in the southern IRL. The surficial aquifer contributes around 10% of all freshwater inputs into the IRL (Pandit and El-Khazen 1990). The SJRWMD and SFWMD have reduced permitted withdrawals from the surficial aquifer in attempts to protect wetlands and prevent saltwater intrusion (FDEP 2015).

The barrier islands that border the east side of Mosquito Lagoon, Banana River Lagoon, and Indian River Lagoon restrict tidal flushing and currents, resulting in high water-residence times and making the region sus-

Figure 12.2. Mangrove and salt marsh extent in the southern Indian River Lagoon. Data sources: SJRWMD 2009 and SFWMD 2008–2009 land use/land cover data, based on FLUCCS classifications (FDOT 1999, SFWMD 2009a, SJRWMD 2009a).

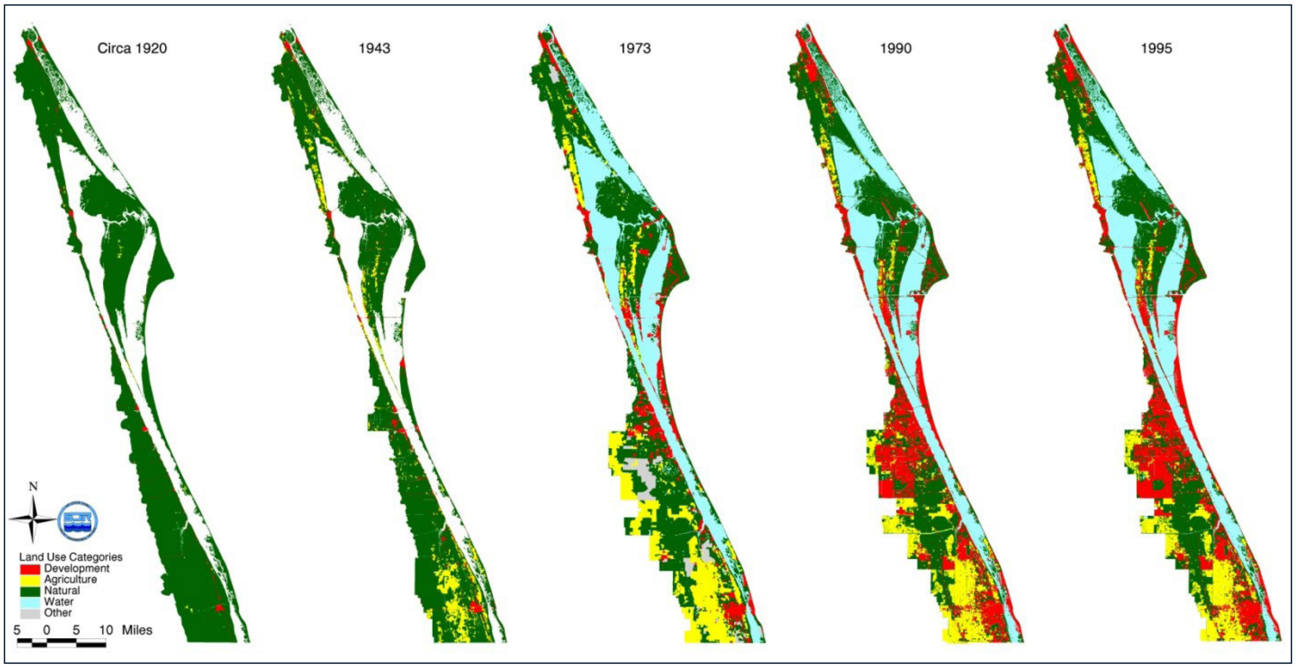

Figure 12.3. Changes in land use along the Indian River Lagoon from 1920 to 1995. Data source: SJRWMD

ceptible to impaired water quality (FDEP 2009a, FDEP 2009b, FDEP 2015). Water-level changes in the Mosquito Lagoon are generally driven by wind more than by tidal currents or rainfall (FDEP 2009a). Banana River Lagoon requires two years for complete flushing (FDEP 2013). In extreme summer drought conditions, evaporation, limited freshwater input, and limited flushing have caused salinity levels to reach 45 in Banana River Lagoon and parts of the northern IRL and southern Mosquito Lagoon (FDEP 2015). The average depth of the IRL is 4 ft (1.2 m); the water quickly warms in the summer, decreasing dissolved oxygen and facilitating the development of hypoxic or anoxic conditions (FDEP 2015). Flushing in the southern IRL is 10–15 times higher than in the northern lagoons (FDEP 2009b, FDEP 2015).

In 2010–2011, phytoplankton blooms, including a superbloom of algae in the class Pedinophyceae, resulted in extensive losses of seagrass in Brevard and Indian River counties with the largest percentage loss in Banana River Lagoon (SJRWMD et al. 2012). These blooms were followed by brown-tide blooms (caused by the alga *Aureoumbra lagunensis*), centered in the northern IRL and Mosquito Lagoon in 2012 and 2013, with numerous other local blooms throughout the system. The region also had unusual mortality events in July 2012 and April 2013 with extensive deaths of dolphins, manatees, and brown pelicans (FDEP 2015). Research into the ecosystem-wide relationships that led to these algal blooms and mortality events are forefront in scientific and management efforts in the region (SJRWMD et al. 2012).

St. Lucie Estuary

The St. Lucie Estuary (SLE), which connects to the southern IRL, was a freshwater river until the St. Lucie Inlet was dug in 1892, resulting in saltwater intrusion up to 16 mi (26 km) away at Midway Road in Fort Pierce (FDEP 2009c). Construction of the St. Lucie Canal (C-44 Canal) was completed in the 1920s, draining large areas west of the SLE and connecting water flow from Lake Okeechobee to the south fork of the SLE (FDEP 2015). These freshwater inputs drastically increased the sediment and nutrient load to the SLE. Depending on the duration and magnitude of freshwater releases from Lake Okeechobee, the estuarine salinity may become oligohaline, stressing or killing estuarine plants and animals (FDEP 2015). The Lake Okeechobee Watershed Project and IRL South Feasibility Plan components of the Comprehensive Everglades Restoration Plan (CERP) emphasize decreasing the amount of large freshwater discharges from Lake Okeechobee into the SLE (Bartell et al. 2004, CERP 2013). The SWIM plan for the IRL, including the SLE, is also focused on improving the quality of water entering the system (SJRWMD and SFWMD 2002).

The North Fork of the St. Lucie River was dredged and bermed for flood control and agriculture from the 1920s to the 1940s (FDEP 2009c). This straightening of the river isolated much of the flood plain and the oxbows from the main river channel, resulting in a faster-flowing river channel with regions of stagnation and sedimentation in the former oxbows (FDEP 2009c). The North Fork was connected to the C-23/C-24 canal system in the 1950s as a part of the Central and Southern Florida Project, further increasing the amount of freshwater diverted into the SLE (SFWMD 2009b). Tidal wetlands and mangrove forests along the St. Lucie estuary are dominated by *R. mangle*, with minor contributions from *Acrostichum danaeifolium* (giant leather fern) and *Salix caroliniana* (coastal plain willow) (FDEP 2009c). *S. terebinthifolius* has overtaken much of the mangrove habitat on the North Fork of the St. Lucie River, in part due to the straightening of the river channel (FDEP 2009c). A portion of the IRL South Feasibility Plan includes the reconnection of isolated oxbows along the North Fork in order to improve water filtration and habitat utilization in the remnant floodplain communities (Bartell et al. 2004).

Threats to coastal wetlands

- **Hydrologic alteration and water quality:** The hydrology of the IRL system has been significantly altered by the construction of drainage canals, increasing both the size of the watershed and the rate of surface water delivery. Impoundments and dragline ditching also decreased the functionality of coastal wetlands, hindering their ability to improve the quality of surface water. This combination of altered watershed hydrology, increased freshwater inflow, polluted runoff, loss of wetlands, and low flushing make the IRL highly susceptible to impaired water quality. The buildup of pollutants, strong temperature changes, hypoxic conditions, and superblooms have ecosystem-wide impacts on the estuary.
- **Urban development:** The rate of urban development and the draining of wetlands surrounding the IRL have slowed since their peak in the 1950s to 1970s, but the population continues to grow, and some of the remaining impounded coastal wetlands remain in private ownership. This limits restoration efforts, and these wetlands are still vulnerable to development (IRLNEP 2008).
- **Sea-level rise and climate change:** Sea-level rise will likely drive a landward migration of coastal wetland vegetation. Wetland extent will therefore decline in regions of urban development that lack appropriate buffer-zone habitat (IRLNEP 2008). The shallow extent of the lagoons makes them susceptible to warm temperatures and may drive the region toward dominance by tropical and subtropical species over more temperate species (IRLNEP 2008). In recent decades, since the last major freezes, the area occupied by mangroves has expanded at the expense of salt marsh and other adjacent habitats (Cavanaugh et al. 2014). If cold events continue to be infrequent, this pattern will likely result in continued encroachment of mangroves into salt marsh habitat.
- **Invasive vegetation:** Invasive vegetation, most notably the exotics *S. terebinthifolius* and *Casuarina* spp. (Australian pines), encroach on the edges of coastal wetland habitat, particularly on impoundments or on spoil islands (FDEP 2015). *S. terebinthifolius* is particularly prevalent along dragline ditches and on the bermed and straightened portion of the North Fork of the St. Lucie Estuary (FDEP 2009c). Also, native species such as *Juniperus virginiana* (red cedar) and *Baccharis angustifolia* (saltwater false willow) have colonized these areas of high ground, and thus woody species now inhabit regions of the marshes historically dominated by herbaceous vegetation.

Mapping and monitoring efforts

Water management district mapping

Since 1990 SJRWMD has conducted regular land use/land cover (LULC) sampling using aerial orthophotography. These mapping efforts also used wetland assessments from the late 1980s with the assumption that regions identified as wetlands were still wetlands if they had not been developed. Exceptions occurred in areas in which wetlands had been drained or experienced prolonged dry conditions (SJRWMD 2009a). In 2004, imagery had a ground sample distance resolution of 2 ft (0.62 m), captured from a height of 20,000 ft (6096 m). The minimum mapping unit for wetlands was 0.5 acre (0.2 ha). Land features were categorized according to the Florida Land Use and Cover Classification System (FLUCCS) (FDOT 1999) and outlined in the SJRWMD photointerpretation key (SJRWMD 2009b). Salt marsh acreage increased from 1990 to 2009 in the SJRWMD, largely due to impoundment removal and the reconnection of marshes to tides. These reconnections caused regions of predominantly freshwater vegetation to shift back to a tidal wetland ecosystem.

SFWMD also conducts regular LULC surveys within its boundaries. Land-cover classifications for 2008–2009 were based on SFWMD modifications to FLUCCS categories (FDOT 1999, SFWMD 2009c). Minimum mapping units were 5 acres (2 ha) for uplands and 2 acres (0.8 ha) for wetlands. The most recent maps were made by interpreting county-based aerial photography and updating 2004–2005 vector data (SFWMD 2009a).

North Fork St. Lucie River Floodplain vegetation study

In 2009, four transects were established through vegetation in the North Fork St. Lucie River Floodplain to study canopy, shrub, and groundcover communities in conjunction with soil conductivity and soil moisture in the floodplain (SFWMD 2015). This research was a cooperative effort between the Coastal Ecosystems Section of SFWMD, FDEP's Florida Park Service at the Savannas Preserve State Park, and the IRL Aquatic Preserve Office. The results of the survey indicated that most of the remaining floodplain consisted of hammock and bottomland hardwood communities (SFWMD 2015). Swamp communities had been limited by the placement of spoil material along much of the shoreline and at the openings of several oxbows. Most of what remains of the floodplain suffers from reduced hydroperiods. Saltwater intrusion was evidenced by the higher soil conductivity values downstream, in areas dominated by *L. racemosa*. Water managers are examining means of restoring upstream freshwater inflow and enhancing the floodplain habitat for fish and wildlife as CERP plans are implemented and adaptive management decisions are made.

North Fork St. Lucie River mangrove mapping

St. Lucie County mapped the extent of mangroves along the North Fork St. Lucie River from Port St. Lucie Boulevard northward to the fork of Ten Mile Creek and Five Mile Creek during January–February 2013 (Figure 12.4). Observations were made on intensive shoreline scouting trips, primarily by boat but also by land. Nearly all mangroves observed were *R. mangle*, with a few *A. germinans* at the southern end. Heights of some isolated trees were also recorded.

Salt marsh restoration at New Smyrna Beach

Using NOAA Habitat Restoration funding, FWC and SJRWMD restored 5 acres (2 ha) of salt marsh in 2014 in New Smyrna Beach by removing spoil from the site (Figure 12.5). The marsh is directly accessible by land and supports numerous programs for monitoring and research in conjunction with the nonprofit Marine Discovery Center located on the property. The site serves as a hub for regional restoration providing opportunities for developing monitoring techniques and harvesting plants for regional projects.

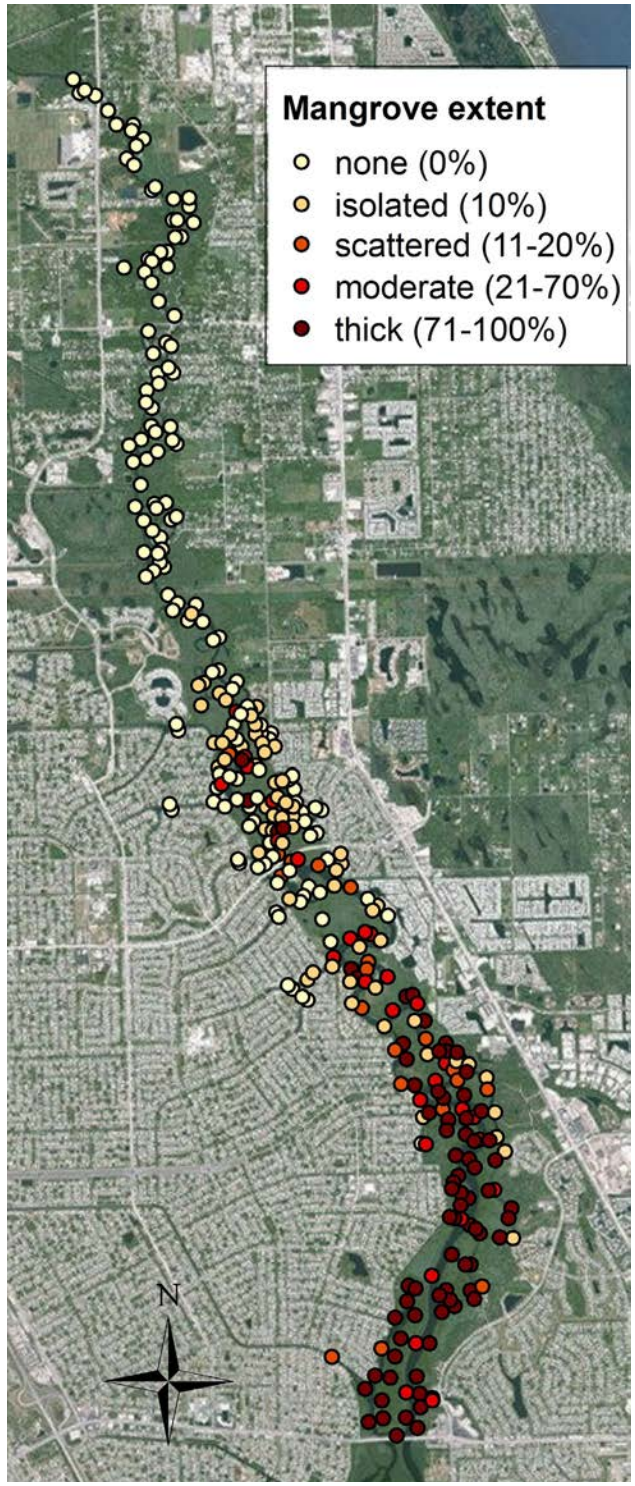

Figure 12.4. Density of mangroves along the North Fork of the St. Lucie River.

Recommendations for protection, management, and monitoring

- Continue efforts toward hydrologic reconnection by establishing breaches or culverts through impoundments,

Figure 12.5. Restored salt marsh at New Smyrna Beach, on property of the Florida Fish and Wildlife Conservation Commission.

enabling aquatic species to travel between lagoon and wetland habitats (IRLNEP 2008). Where practical, fully restore impoundments by returning dike material to the borrow ditch and grading to adjacent wetland elevation (Rey et al. 2012). Likewise, continue restoration of areas with dragline ditches and spoil piles to re-establish more natural wetland elevations. Encourage wetland protection, restoration, and management on private lands; pursue land purchases if necessary (IRLNEP 2008, Rey et al. 2012).

- Continue installation of living shorelines with native vegetation, which helps to prevent erosion, stabilize shores, and improve water quality (FDEP 2015). Nutrient reduction and improvement of water quality are focus areas in many IRL management plans; coastal wetlands act as vegetative buffers and assist in achieving these goals (SJRWMD and SFWMD 2002, BMAP 2013, FDEP 2015).
- The susceptibility of the IRL ecosystem to water quality issues, superblooms, and subsequent unusual mortality events highlights the need for further study to fully elucidate the cause-and-effect relationship in the overall ecosystem.
- The water quality of the St. Lucie Estuary is tightly linked to freshwater releases from Lake Okeechobee. Freshwater releases should be managed to reduce the frequency and duration of extreme salinities and high nutrient loads in the St. Lucie Estuary (SJRWMD and SFWMD 2002).
- As a part of urban planning, establish or enhance upland buffers along coastal wetlands to enable shoreward migration of coastal vegetation in the face of sea-level rise (IRLNEP 2008). Where needed, restore a natural gradient by removing dikes or berms between wetlands and adjacent uplands. Further research is also recommended to determine best ecosystem-level management practices in the face of changing coastal conditions (IRLNEP 2008).
- Continue efforts to remove invasive species, and encourage or plant native vegetation. Restoration efforts that re-establish proper wetland elevations facilitate the recolonization of native coastal wetland vegetation. Educate residents about invasive vegetation and continue efforts to rapidly recognize and address new invasive species.

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Description of the region

The coast of northeast Florida is a mosaic of interconnected estuarine habitats that include salt marshes, salt barrens, tidal creeks, and open water (Figure 13.1). Barrier islands, sand ridges, and dunes are found off the coast, protecting the extensive salt marshes by buffering energy from Atlantic waves, tides, and winds. Major river systems include the Nassau, St. Johns, Guana, Tolomato, and Matanzas rivers. The St. Johns River has the largest watershed in Florida and is often described as a series of interconnected lakes with a slow northern flow (NPS 1996). The eastern coast of Florida achieved its current shoreline 5,000 years ago after sea-level rise stabilized following the last ice age. The coast consists of multiple parallel terraces; these paleoshorelines were formed by variable sea levels during the Pleistocene (Frazel 2009). Sandy marine sediments are the largest component of the soils, although Native American populations that lived in the area left behind shell middens and burial mounds (Frazel 2009). Average annual rainfall is 55 in. (1.4 m); half of this precipitation falls between June and mid-October. Passing northeasters, tropical storms, and hurricanes bring strong waves to the region and cause extensive erosion along the coast.

The hydrology of the northeast coast of Florida has been altered by the Intracoastal Waterway, dikes, drainage ditches, and inland wells (Frazel 2009). The hydrology of the St. Johns River has been changed by dredging and deepening at its mouth in Jacksonville and by the construction of the Fulton Cut, which reduced tidal flow in the area. The Guana Dam was constructed in 1957 across the Guana River to improve hunting and fishing grounds. Originally located 394 ft (120 m) south of its current position, the St. Augustine inlet was modified in 1940 to improve navigation. Jetties were constructed on either side to stabilize the inlet. The Matanzas inlet has not been improved, although the construction of the Intracoastal Waterway has reduced current velocity and increased sediment deposition, such that the channel must be dredged (Frazel 2009). The Nassau River lacks channels or stabilization structures, although the location of tidal channels and the shape of Nassau Sound have changed significantly in the past century in response to a decrease in sediment supply and the shoreline stabilization of the St. Marys and St. Johns rivers (NPS 1996, Browder and Hobensack 2003).

Ground water is extracted from multiple depths including the Floridan Aquifer, deep artesian wells, and a shallow layer of freshwater (Frazel 2009, GTMNERR 2009). The Floridan Aquifer is about 2,000 ft (610 m) thick and is located approximately 100 ft (30 m) below the soil surface in Volusia County and is more than 500 ft (152 m) deep near the Georgia border (Scott and Hajishafie 1980). Average water levels of the Floridan Aquifer have dropped due to increasing urban and agricultural use (NPS 1996). Saltwater intrusion is a concern for freshwater supplies, particularly on the barrier islands (NPS 1996, Frazel 2009).

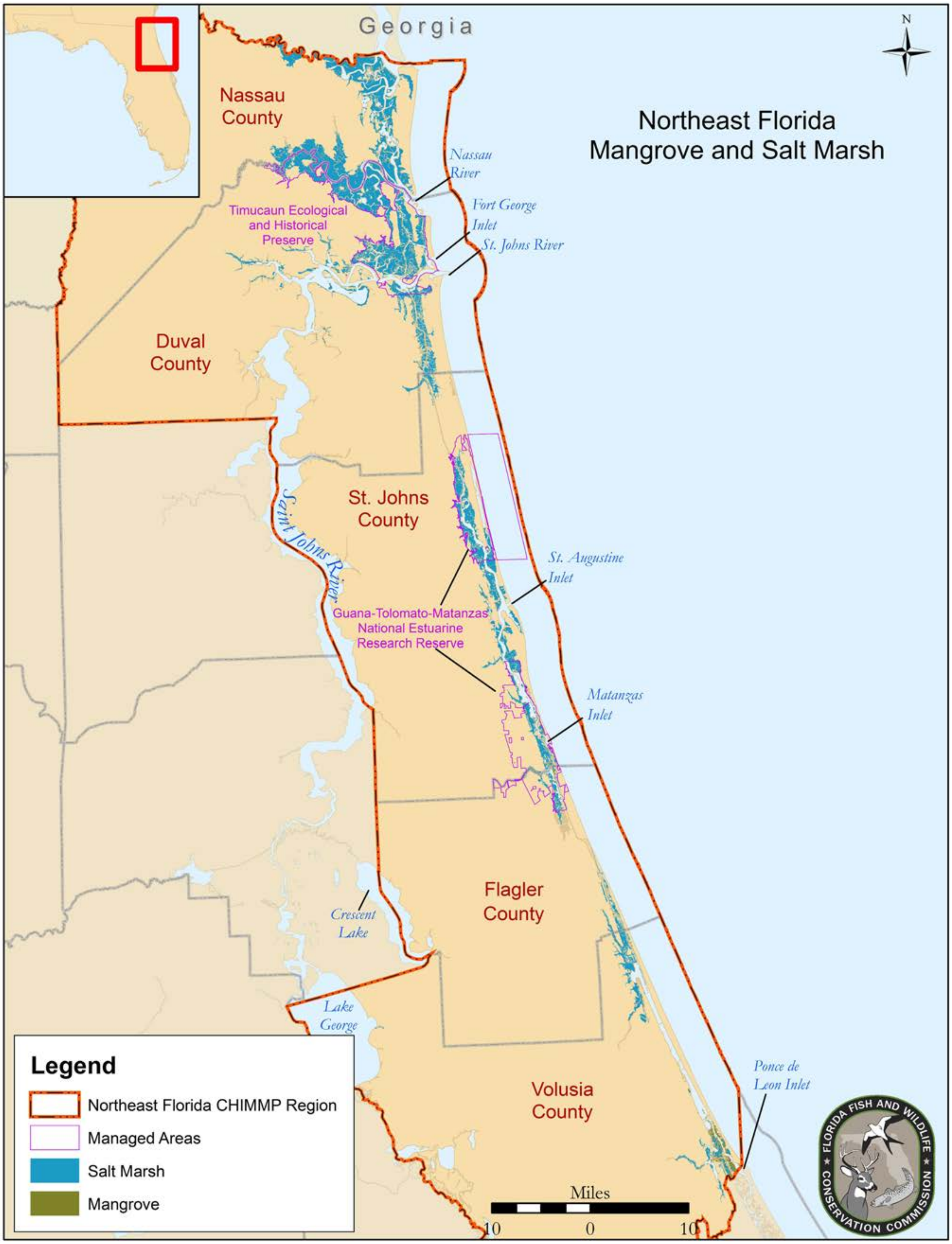

Figure 13.1. Salt marsh and mangrove extent in Northeast Florida. Data source: SJRWMD 2009a land use/land cover data, based on FLUCCS classifications (FDOT 1999, SJRWMD 2009a).

St. Johns, Flagler, and Volusia counties

Several reserves, state parks, and preserves are found along the northeast coast, including the Guana Tolomato Matanzas National Estuarine Research Reserve (GTMNERR). The reserve comprises approximately 75,000 acres (30,350 ha) of relatively undeveloped coastal and estuarine habitat and encloses a narrow (east–west) bar-bounded estuarine ecosystem that spans approximately 35 mi (56 km) north to south (Figure 13.2). The city of St. Augustine separates GTMNERR into northern and southern components; the northern component is associated with the Tolomato and Guana river estuaries, while the southern component incorporates the Matanzas River estuary. The GTMNERR is biogeographically positioned at the ecotone of two emergent vegetation habitats: salt marsh in the north (dominated by *Spartina alterniflora,* smooth cordgrass) and mangroves in the south (dominated by *Avicennia germinans,* black mangroves) (Zomlefer et al. 2006, Leitholf 2008, Frazel 2009). The *Spartina*-dominated low marsh is intermixed with and followed by the high-marsh species *Juncus roemerianus* (black needlerush), *Salicornia* spp. (glassworts), and *Batis maritima* (saltwort). About 20% of the land in the GTMNERR watershed is salt marsh; the remainder is pinelands, shrub and brushlands, hardwood hammocks, and barren lands. Oyster beds are common in the intertidal zones, while muddy and sandy tidal flats, barren of vegetation, can be found along channels and creeks (Frazel 2009).

St. Johns County contains the northernmost mangrove swamps and recorded examples of *A. germinans, Rhizophora mangle* (red mangrove), and *Laguncularia racemosa* (white mangrove) on the Atlantic coast of Florida (Zomlefer et al. 2006, Frazel 2009, Williams et al. 2014). Mangroves are not visible in St. Johns County in Figure 13.2 because land-cover mapping classifies predominant vegetation cover and does not show the extent of individual trees or clusters of mangroves. The primary factor limiting the northern extent of mangroves is temperature. In South Florida, mangrove forests thrive and replace salt marsh vegetation primarily due to shading (Lugo and Snedaker 1974, Odum et al. 1982). The northernmost occurrence of mangrove trees varies depending on the frequency of severe freezes in winter. Cold events in 1962, the late 1970s, and the 1980s led to uneven mangrove mortality along the east coast of Florida as far down as West Palm Beach (Odum and McIvor 1990). As evident in land use/land cover maps created by the St. Johns River Water Management District (SJRWMD), mangrove acreage has increased in recent decades (Table 13.1). This increase in mangrove habitat is likely a response to the reduced occurrence of cold events with air temperature less than −4°C in recent decades (Cavanaugh et al. 2014). The mangrove expansion seen in recent decades (Table 13.1) is in part recovery from the cold-event mortalities of the 1960s through the 1980s (Giri and Long 2014). Much of the current extent of mangrove swamps, particularly the cluster north of the Ponce de Leon Inlet (Figure 13.1), can be seen in 1943 land cover maps created by the SJRWMD. Although parts of the current expansion involves previously occupied mangrove habitats, a comparison between historical records and the current mangrove extent on the east coast have found that their northernmost occurrence is expanding (Williams et al. 2014).

The overlapping distribution of salt marsh and mangrove habitats in the GTMNERR provides a unique opportunity to examine the potential effects of climate change and sea-level rise on the distribution and diversity of emergent intertidal vegetation in this transitional zone. Numerous fish, invertebrate, bird, and reptile species rely upon these diverse estuarine habitats as a refuge from predators and habitat for foraging and reproduction (Odum and McIvor 1990, Kneib 1997, Sheaves 2005). Changes in the habitat ranges for these emergent intertidal marsh vegetation species may significantly impact numerous organisms throughout the estuary, since dominant vegetation is one of the most important factors determining the ecological function of coastal wetlands (Weinstein et al. 1997).

Nassau and Duval counties

Nassau and Duval counties include the largest estuarine marsh system on the east coast of Florida (NPS 1996). The St. Johns River, Fort George River, and Nassau River flow directly into the Atlantic Ocean after collecting water flowing from many meandering tributaries in this extensive salt marsh (Figure 13.3). In 2009, 29% of the area bordering a lake or waterway in the St. Johns River Basin was residential, while 45% was salt marsh or freshwater wetlands (LSJRBR 2014). Although parts of the area are highly populated, the overall proportions of residential land and other land-use categories remained fairly stable from 2000 to 2009. The close association between urban and industrial areas and estuarine wetlands in the St. Johns River Basin results in wetlands receiving freshwater that is low in dissolved oxygen and high in nutrients and other pollutants (LSJRBR 2014).

There are multiple state parks in Nassau and Duval counties (Big and Little Talbot Island, Fort George Island, Kathryn Abbey, and Amelia Island). Preserves include the Nassau River–St. Johns River Marshes Aquatic Preserve and the Fort Clinch State Park Aquatic Preserve. The Timucuan Ecological and Historic Preserve covers

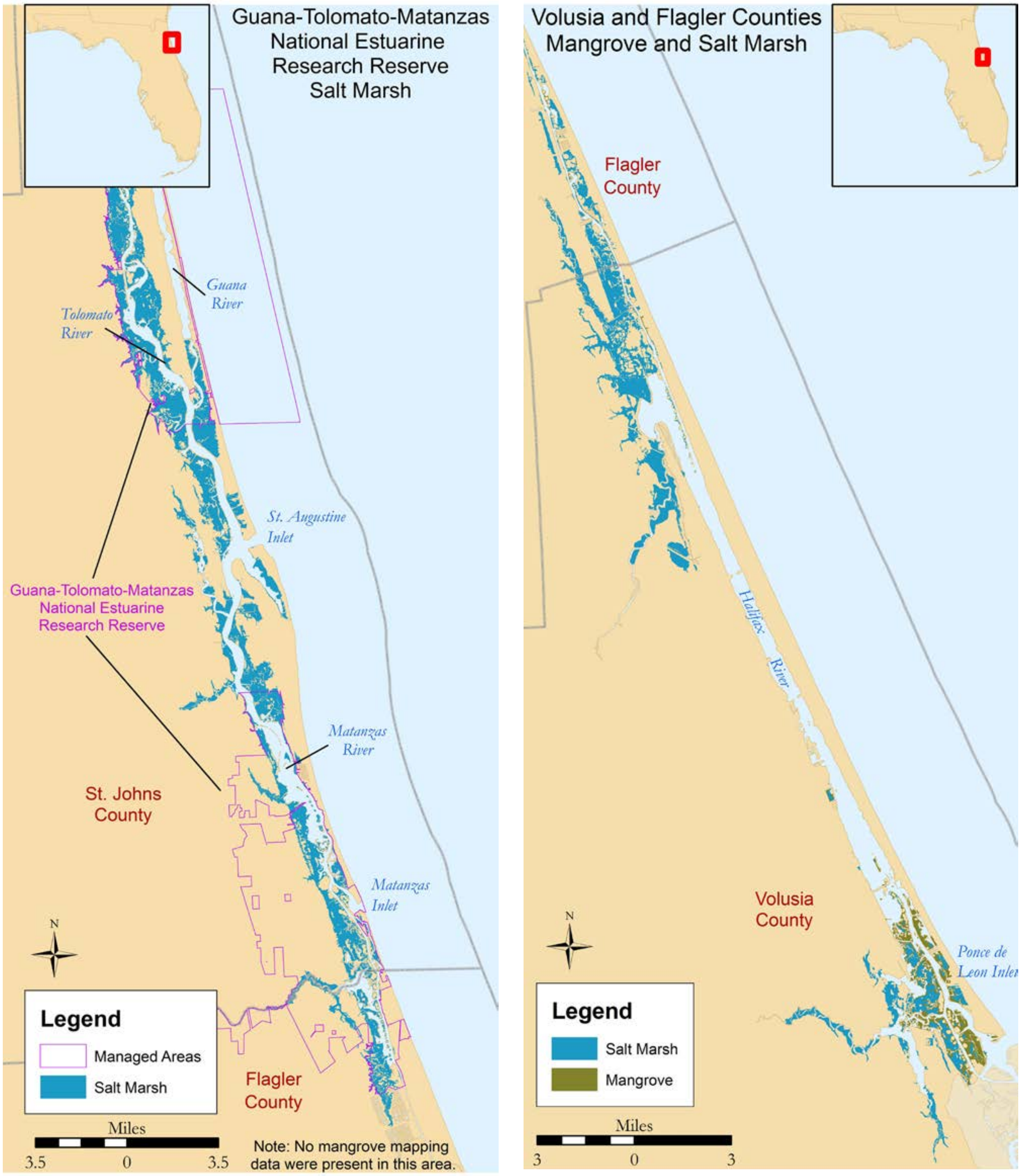

Figure 13.2. Salt marsh and mangrove extent in St. Johns, Flagler, and Volusia counties. Data source: SJRWMD 2009a land use/land cover data, based upon FLUCCS classifications (FDOT 1999, SJRWMD 2009a).

46,000 acres (18,600 ha) and contains extensive *S. alterniflora* and *J. roemerianus* salt marshes (Figure 13.3). The preserve lies in the southeastern reaches of the Atlantic Coastal Plain and includes the outflows of the Nassau and St. Johns rivers (NPS 1996).

Threats to coastal wetlands

- **Coastal development:** Rates of population growth vary widely along the northeastern coast of Florida. Although population growth in Nassau, Duval, and Volu-

Table 13.1. Acreages of mangrove swamps (FLUCCS 6120) and salt marshes (FLUCCS 6420) in Northeast Florida. Data source: SJRWMD 2009a.

Year	Mangrove acres	Salt marsh acres
1990	4	87,515
1995	56	84,800
2000	1,256	83,290
2004	1,360	82,985
2009	1,573	82,489

sia counties was below the statewide average and grew between 5.6 and 7.0% between 2010 and 2015, St. Johns and Flagler counties exceeded statewide rates and grew at 19.3% and 10.1%, respectively, during the same period (U.S. Census 2015). Demand for waterfront access increases with population growth, and construction of marinas and waterfront properties is one of the greatest threats to coastal wetland habitat and water quality (Frazel 2009). Increased urban development harms coastal wetlands due to filling of marshes, construction of docks and bulkheads, increased erosion and water pollution, and a growing demand for freshwater. Mitigation is commonly used as an option for compensating for development of wetland habitat, but the wetlands that are created or restored in mitigation do not always perform as well as the original, undisturbed wetland (Moreno-Mateos et al. 2012, LSJRBR 2014). Damage by vehicles is an additional impact of human use of natural regions. Off-road vehicular traffic is permitted on many beaches in this area, but unauthorized off-road traffic also causes long-term damage in the salt marshes.

- **Climate change and sea-level rise:** Projected sea-level rise is expected to exacerbate shoreline erosion and necessitate landward migration of coastal wetlands. When the Sea Level Affecting Marches Model (SLAMM) was applied to the GTMNERR area with scenarios of 0.7–5.2 ft (0.2–1.6 m) of sea-level rise, it predicted that changes to vegetation land cover would extend 1.2–3.1 mi (2–5 km) inland of the shoreline (Linhoss et al. 2015). Coastal wetland acreage will be lost if sediment accretion does not keep pace with sea-level rise or if topography or coastal development hinders landward migration (Scavia et al. 2002, Linhoss et al. 2015). The St. Johns River has relatively low suspended sediment delivery, making it difficult for sediment accretion to keep pace with the rate of sea-level rise (LSJRBR 2014). Sediment delivery to the marshes lining the Intracoastal Waterway in Northeast Florida is also low, because there are no major tributaries. The altered hydrology brought on by sea-level rise and changes to freshwater availability can decrease overall ecosystem services of wetlands, such as primary productivity and nutrient removal (Scavia et al. 2002, Craft et al. 2009). Additionally, a continued decline in the frequency of cold temperatures is facilitating the northern expansion of mangroves (Cavanaugh et al. 2014). If temperature does not limit mangrove growth, the trees can shade out and eventually replace salt marsh, altering the balance between salt marsh and mangrove swamp in coastal habitats (Lugo and Snedaker 1974, Odum et al. 1982).
- **Altered hydrology:** Hydrology has been altered locally by the construction of mosquito ditches, dikes, dams, and other water-control structures (Frazel 2009). Dredged ditches and channels result in saltwater intrusion into the freshwater zone. Roads and trails (particularly highway A1A) function as impoundments along the shore, preventing natural sheet flow, concentrating runoff, and frequently diverting freshwater runoff from wetlands (FDEP 2008a, FDEP 2008b). As the population in the region grows, the increasing demand for freshwater will likely result in salinity changes for coastal and inland wetlands (SJRWMD 2012, LSJRBR 2014). The predicted increases in salinity may be outside the tolerances of the current vegetation, particularly in freshwater and transitional wetlands.
- **Erosion:** The sandy beaches and barrier islands of Northeast Florida are dynamic and active shorelines. Wave energy, passing storms, boat traffic, and vehicle traffic on the beach all contribute to erosion and modification of the shoreline (Frazel 2009). Coastal erosion is a significant problem along the Intracoastal Waterway due to high wave energy from boat wakes, converting salt marshes and oyster beds into tidal flats and mounds of dead shell. While wave energy, storms, and the migration of barrier islands are natural processes, shoreline migration and erosion threaten development and navigation along the coast, prompting shoreline stabilization and restoration projects. Inlet stabilization and shoreline hardening change the foci of erosional forces, destabilizing other locations and threatening coastal wetlands (Browder and Hobensack 2003).
- **Water quality:** Water quality in the St. Johns River becomes considerably degraded, particularly adjacent to highly industrialized districts including paper mills and landfills. Nonpoint sources of pollution include stormwater runoff and poorly functioning septic systems (NPS 1996, Wicklein 2004). Tidal creeks are characterized by poor flushing, resulting in long pollutant resi-

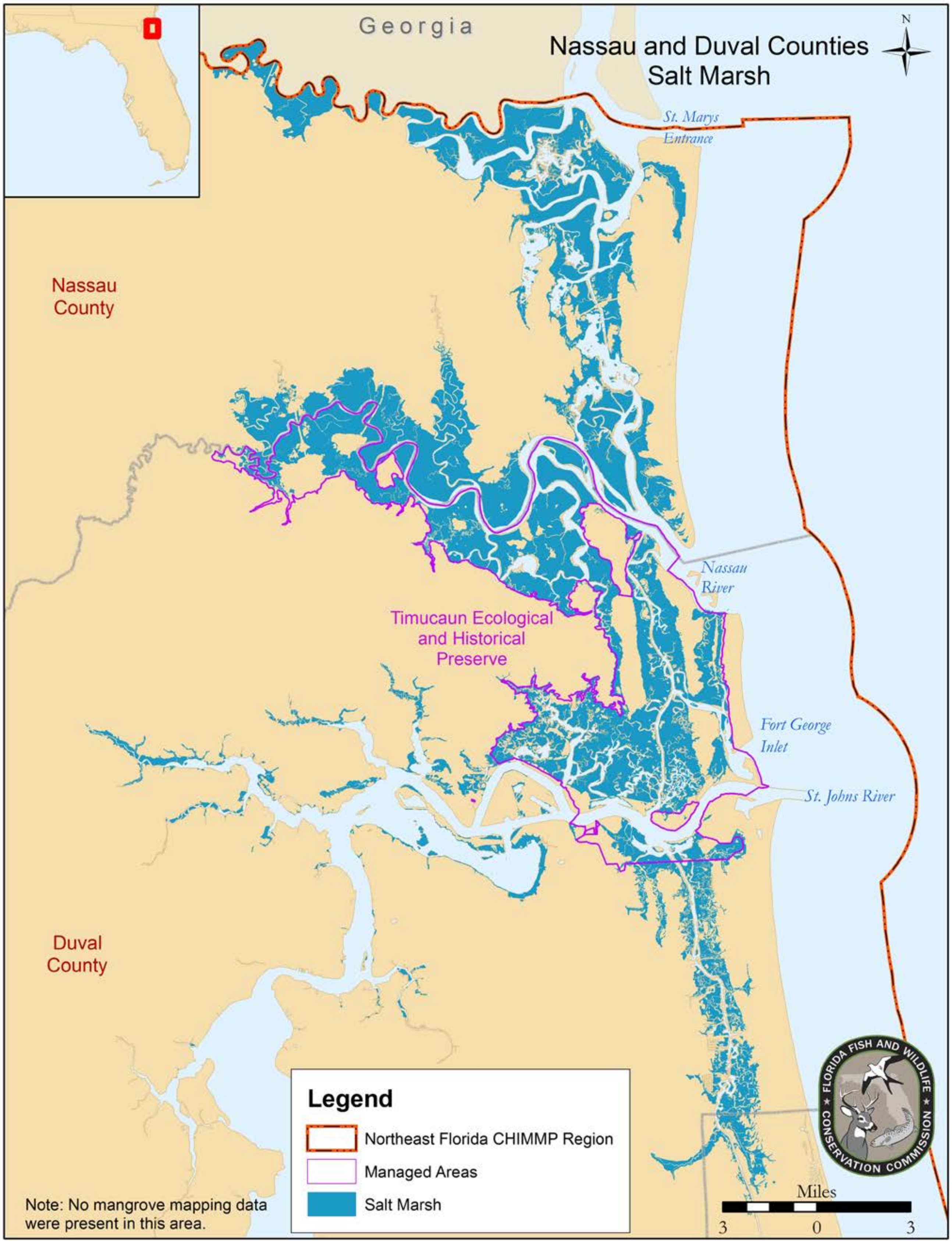

Figure 13.3. Salt marsh extent in Nassau and Duval counties. Data source: SJRWMD 2009a land use/land cover data, based upon FLUCCS classifications (FDOT 1999, SJRWMD 2009a).

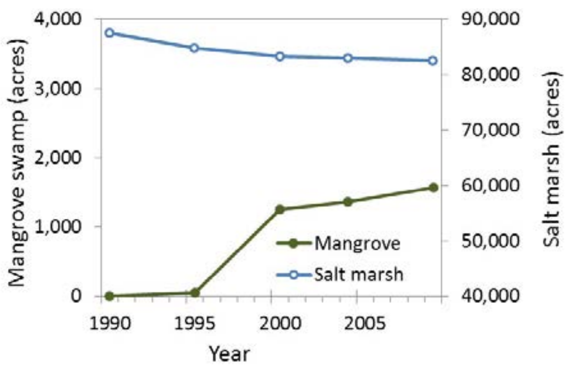

Figure 13.4. Acreages of mangrove swamps and salt marshes in northeast Florida. Source: SJRWMD 2009a.

dence times. Poor water quality ratings due to elevated levels of phosphorus and nitrogen were observed in the upstream reaches of the Nassau River, St. Johns River, and Clapboard Creek (Gregory et al. 2011). High concentrations of heavy metals were found in sediments along the St. Johns River in Duval County. Other water-quality concerns include excess nutrients, organic priority pollutants, bacterial growth, and high turbidity due to increased suspended solids (NPS 1996, Wicklein 2004, LSJRBR 2014). Improvements have been made to water quality in some areas, and there have been overall declines in fecal coliform bacteria and nutrient levels in the St. Johns River, although algal blooms remain frequent (LSJRBR 2014).

Other regions with concern for water quality include Pellicer Creek, located between Flagler and St. Johns counties, and the dredged canals along the Palm Coast (SJRWMD 2003, FDEP 2008c). High densities of sewage-treatment systems along the Palm Coast contribute to water-quality concerns. The concentrations of heavy metals, nutrients, coliform bacteria, and dissolved oxygen fall outside of recommended limits. Sedimentation, a growing number of septic systems, and the quality of urban stormwater runoff are also concerns along the Guana, Tolomato and Matanzas rivers (SJRWMD 2003, FDEP 2008c).

Mapping and monitoring efforts

Water management district mapping

SJRWMD has conducted regular land use/land cover sampling since 1990 using aerial orthophotography (Table 13.1, Figure 13.4). These efforts have also used wetland assessments from the late 1980s with the assumption that regions identified as wetlands were still wetlands if they had not been developed. Exceptions occurred in areas in which wetlands had been drained or experienced prolonged dry conditions (SJRWMD 2009a). In 2004, imagery had a 2-ft (0.62 m) ground sample distance resolution, captured from a height of 20,000 ft (6,096 m). The minimum mapping unit for wetlands was 0.5 acre (0.2 ha). Land features were categorized according to the Florida Land Use and Cover Classification System (FDOT 1999) and outlined in the SJRWMD photointerpretation key (SJRWMD 2009b).

Guana Tolomato Matanzas National Estuarine Research Reserve monitoring

Salt marsh and mangrove sites are monitored in the GTMNERR as part of the national System-Wide Monitoring Program, which is designed to study ecological characteristics and dynamic responses to local and global changes (NOAA 2011). The GTMNERR's emergent intertidal vegetation monitoring protocol is a combination of protocols from National Estuarine Research Reserve System Biological Monitoring (Moore 2013), National Park Service Southeast Coastal Network Salt Marsh Monitoring (Curtis and Asper 2012) and the Louisiana Department of Natural Resources Coastal Resource Division (Folse and West 2004). Components of monitoring include permanent emergent intertidal vegetation plots, which are used to determine canopy height and species percent cover (see full description in Chapter 1). Rod Surface Elevation Tables (RSETs) and marker horizons are also used to monitor marsh elevation and accretion (Cahoon et al. 2002a, 2002b). Initial results indicate that most sites are dominated by *S. alterniflora*, with *J. roemerianus* becoming more prevalent in the high marsh. Transects have shown that from shore to upland, *S. alterniflora* becomes shorter, and *J. roemerianus* increases in height.

Mangroves are monitored following Moore (2013). Trunk diameter and formation, vegetative ground cover, canopy height, and canopy characteristics are recorded in mangrove plots. Additional monitoring evaluates spatial and temporal patterns in vegetation and soil pore-water chemistry. Initial results found that when mangroves were present, *A. germinans* was predominant.

Weather (e.g., temperature, wind speed and direction, light, and precipitation) and water quality parameters (temperature, salinity, dissolved oxygen, pH, Secchi depth, total suspended solids, turbidity, chlorophyll *a*, nitrate, nitrite, ammonium, total Kjeldahl nitrogen, orthophosphate, total phosphorus, and fecal coliform) are also monitored throughout the reserve using standard NERRS protocols. Data and metadata are available at www.nerrsdata.org and may also be obtained by contacting the research coordinator at GTMNERR.

National Park Service salt marsh elevation monitoring and vegetation mapping

The National Park Service's Southeast Coast Network monitors soil salinity and rates of sediment accretion or subsidence in several salt marshes across the southeastern United States. Monitoring includes the deployment of RSETs following a version of the Louisiana Department of Natural Resources Coastal Resource Division protocol (Folse and West 2004). Monitoring occurs at eight locations including the Timucuan Ecological and Historic Preserve and Fort Matanzas National Monument in Northeast Florida. A full description of the program can be found at science.nature.nps.gov/im/units/secn/monitor/saltmarsh.cfm.

The Ocean and Coastal Resources Branch of the National Park Service recently completed a geospatial mapping project to classify and quantify the extent of *J. roemerianus* and *Spartina* spp. in the preserve. These data can be used to quantify changes in the community from year to year and to predict future change. Other classes such as water, trees, other upland vegetative communities, and salt flats were also quantified. Color infrared orthoimagery (2012), LiDAR data (2007), and Trimble eCognition software were used to accomplish this object-based image analysis. This technique groups neighboring homogeneous pixels and then uses contextual properties to enable the analyst to accurately classify a landscape (Cantor 2014). The data set can be downloaded at data.doi.gov/dataset/timucuan-ecological-and-historic-preserve-salt-marsh-classification.

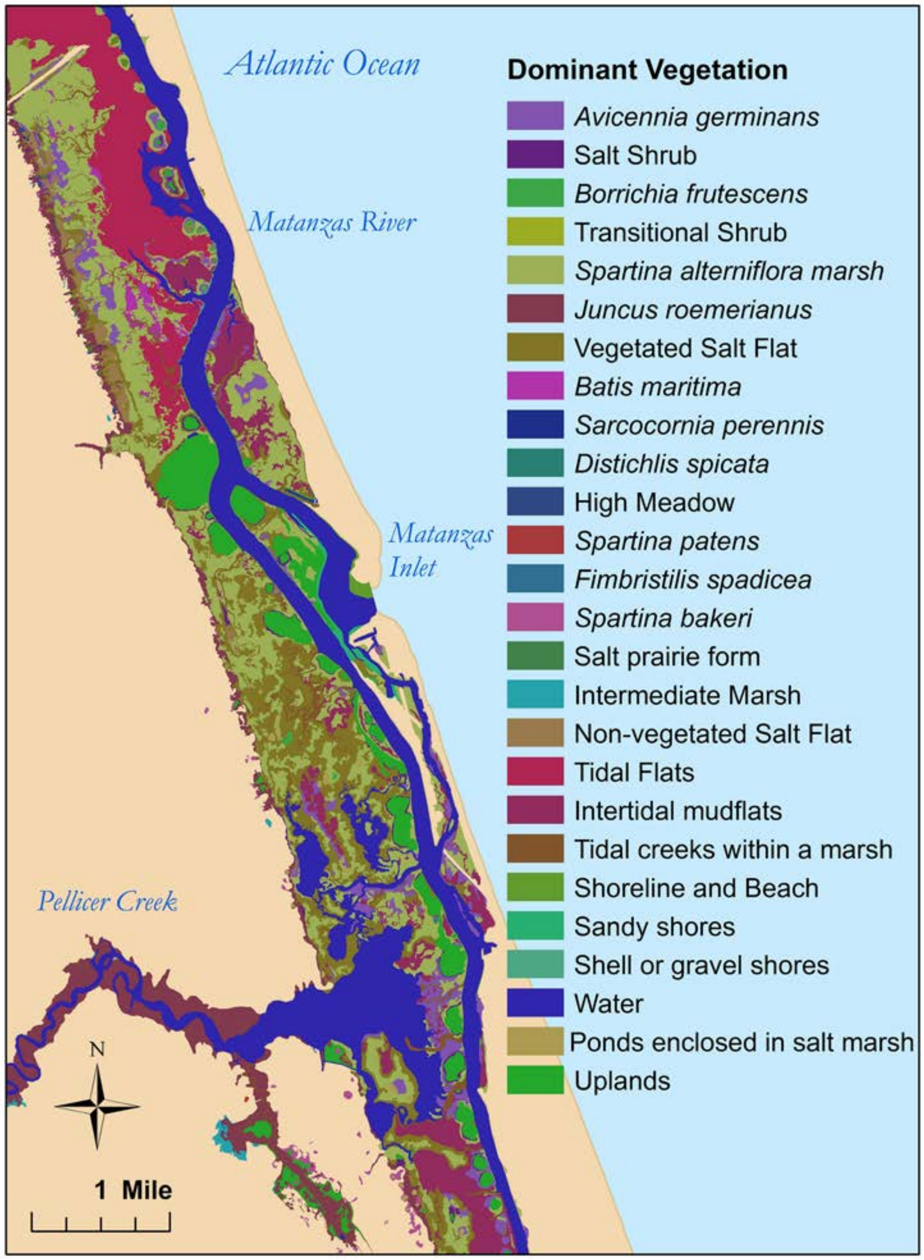

Figure 13.5. Example of detailed land cover and emergent vegetation mapping performed by the SJRWMD in the GTMNERR (Kinser et al. 2007).

SJRWMD and GTMNERR detailed emergent vegetation mapping

Salt marsh and other tidal communities were mapped by the St. Johns River Water Management District within the GTMNERR using 2006 orthophotography and 2004 digital orthophoto quarter quads (DOQQs). Classifications of land cover were species-specific for mangroves and herbaceous plants (Kinser et al. 2007). Figure 13.5 shows an example of the detail and high resolution of this mapping effort.

Recommendations for protection, management, and monitoring

The numerous parks and preserves in this region list specific recommendations for their area of concern. Selected examples are listed below. Most common recommendations include restoring the natural hydrology, controlling sediment, converting armored shorelines into living shorelines, and restoring or protecting wetlands.

- Prevent unauthorized traffic by off-road vehicles in salt marshes by educating the public and erecting signs and fences. When damage occurs, restoration efforts may help the salt marsh recover more rapidly (GTMNERR 2009).
- Coastal Northeast Florida differs from many other regions of the state in that invasive vegetation such as *Schinus terebinthifolius* (Brazilian pepper) and *Casuarina* spp. (Australian pines) are not well established. Active vigilance is required to ensure that these and other nonnatives do not proliferate (FDEP 2008a, GTMNERR 2009).
- The Lower St. Johns River Basin Report recommends intensive monitoring of impacts to wetlands to determine the cumulative effect of incremental wetland loss to overall function and ecosystem services (LSJRBR 2014). The remaining wetlands need to be preserved, enhanced, or restored as needed.
- Goals of the 2008 Surface Water Improvement and Management Plan (SWIM) for the Lower St. Johns River Basin include improving water quality, restoration/protection of natural systems, preserving the flood plain, maintaining natural hydrology, and erosion control (SJRWMD 2008).
- Water quality and hydrology are critical components to maintaining the estuary in the Timucuan Ecological and Historic Preserve. Needs identified by the National Park Service include hydrologic modeling and monitoring of the three rivers, continuous water quality monitoring, and the restoration and protection of living shorelines (Gregory et al. 2011, NPS 2012).
- Goals listed within the management plans of Fort George Island Cultural State Park and Amelia Island State Park include monitoring and protection of natural resources that have altered hydrology due to the construction of ditches and roads. Specific goals include salt marsh restoration and continued monitoring and removal of invasive vegetation (FDEP 2008a, FDEP 2008b).

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Chapter 14
Conclusions and Recommendations

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Multiple priorities and recommendations for the mapping and monitoring of Florida's salt marshes and mangroves emerged during the writing of this report and as outcomes of three workshops (held in 2014, 2015, and 2017) that brought together statewide coastal wetland experts and stakeholders. Region-specific priorities and needs were addressed individually in each of chapter of this report. Several priorities and needs were frequently identified as being important for the management, mapping, and monitoring of coastal wetlands habitats across the state.

Priorities and recommendations for ecosystem management of Florida's coastal habitats

- **Freshwater management is critical to maintaining coastal wetlands:** Surface water drainage structures concentrate freshwater flow into culverts and rivers, leading to highly variable flow and rapid changes in the salinity of tidal creeks and coastal waters. Additionally, reduced flow of surface and groundwater facilitates saltwater intrusion accompanying sea-level rise, allowing for higher salinities in surface and pore waters. Increasing agricultural and urban demand for freshwater will exacerbate this issue. Lack of freshwater can cause stress or mortality to coastal wetland plants if salt concentrations exceed their salinity tolerance (Jimenez et al. 1985, Silliman et al. 2005). Also, the high sulfate concentrations of seawater will increase rates of organic matter decomposition in peat previously exposed to low-salinity conditions, making it more difficult for coastal wetlands to accrete substrate and maintain elevation in the face of sea-level rise (Snedaker 1993). Peat collapse due to vegetation mortality and subsequent loss of living root structure can heighten the stress on ecosystems (DeLaune et al. 1994). Reliable freshwater flow lessens saltwater intrusion and its subsequent consequences in coastal wetlands. The reestablishment or protection of natural sheet flow allows for slower changes and less variability in the salinity of coastal wetlands.
- **Establishment of buffer zones and habitat connectivity:** Salt marshes and mangroves can migrate inland in response to sea-level rise if adjacent habitat buffer zones with appropriate elevation are available. Pervasive shoreline development reduces the area available for these buffer zones and restricts landward migration and adaptation of coastal wetlands, particularly in areas with shoreline hardening. Federal, state, and local governmental agencies and nonprofit groups must cooperate to coordinate connectivity among preserved land and to establish or maintain buffer zones for landward migration of coastal wetlands.
- **Strategic regulations and enforcement:** As coastal development and the population of Florida continue to expand, remaining coastal wetland habitat needs to be protected. Because the majority of Florida's population lives near the coast, human development and coastal wetlands are often close to and at odds with each other. This proximity necessitates strategic planning to establish appropriate hydrology, water quality, natural shorelines, natural buffer areas upslope, and enforcement of mangrove trimming regulations. Strict enforcement of the no-net-loss policy is critical for coastal wetlands, but evaluation of ecosystem quality and function should also be taken into account, as should acre-for-acre mitigation.
- **Early identification of stress:** Some regions in Florida have seen localized die-offs in salt marshes and mangroves due to stressors such as erosion, pollution, and altered hydrology. A lack of flushing can cause stress

Table 14.1. Acreage of mangrove and salt marsh in the Everglades, per SFWMD LULC data (SFWMD 2009).

Year	Mangrove	Salt marsh
1995	296,372	8,144
1999	345,908	45,188
2005	348,018	45,335

Table 14.2. Acreage of mangrove and salt marsh in Biscayne Bay according to SFWMD LULC data (SFWMD 2009).

Year	Mangrove	Salt marsh
1995	14,526	1,155
1999	16,261	641
2005	15,184	586
2009	17,455	5,623

in the form of stagnation, anoxia, or hypersalinity. Stressed vegetation is more vulnerable to secondary stressors such as fungal infections or excessive herbivory (Silliman et al. 2005, Elmer et al. 2012). Human-induced stressors such as altered hydrology and pollution act slowly and can be remedied when identified early (see examples in Chapter 7).

- **Combat invasive vegetation:** Invasive vegetation, particularly *Schinus terebinthifolius* (Brazilian pepper), and *Casuarina* spp. (Australian pines) encroach on the boundaries of coastal wetlands. Preventing further spread of established invasives and early recognition of new invasive species require constant effort and vigilance.

Mapping priorities and recommendations

- **Map expansion of mangroves:** Land classification schemes are not designed to identify a mixture of salt marsh and mangrove vegetation. This categorical classification system hinders tracking the rates and range of mangrove expansion, as mangroves often occur as individuals or clusters scattered in a salt marsh. A presence/absence mapping (or monitoring) technique is needed for accurate tracking of the expansion of mangrove habitat northward and landward in Florida.
- **Map invasive species:** Invasive species are seldom mapped in traditional land cover efforts unless they merit their own land-cover category. Without this species-specific detail, it is difficult to quantify the acreage and spread of invasive vegetation.
- **Increase ground-truthing efforts:** Land cover maps are generally created from aerial or satellite imagery, then classified with supervised or unsupervised classification techniques. The accuracy must be verified with ground-truthing. These efforts are time-consuming and expensive, but extensive ground-truthing data reveal significant differences from land-use maps created exclusively from airborne or satellite remote sensing data (see Chapter 6 for example in Charlotte Harbor).
- **Employ consistent mapping techniques and land-cover categories:** Fortunately, many land cover data sets are available for Florida and most of them use land cover categories that include salt marsh and mangroves in some way (full descriptions available in Chapter 1). But the use of different methodologies between mapping efforts (or within any mapping effort) hinders temporal and spatial comparisons.

For instance, water management district (WMD) land use/land cover (LULC) mapping data were used to present acreage and distribution data for many regions in this report. The benefit of these WMD data sets is that they offered nearly continuous coverage of Florida regions with many datasets spanning multiple years. But these WMD data sets were not without their drawbacks. While WMD maps can be compiled for every region in Florida, the maps are not always directly comparable between WMDs. The most recent years of data, minimum mapping units, and pixel size from aerial photography vary among WMDs. Even within WMDs, methodology varied from year to year, so some temporal changes were due to methodology rather than a change in land cover.

Time-series data were not included in this report for much of the South Florida Water Management District due to drastic fluctuations in acreages that were largely the result of different methodologies. For example, salt marsh acreage in the Everglades appears to have increased fivefold from 1995 to 1999 (see Table 14.1; 2009 data are not included due to insufficient coverage of the Everglades). Similar issues were observed in LULC data around Biscayne Bay (Table 14.2), as salt marsh acreage increased tenfold from 2005 to 2009. This increase in acreage results from regions, previously classified as freshwater marshes, tidal flats, or mangroves, being reclassified as salt marsh. Small annual changes in salt marsh and mangrove extent do occur as a result of restoration projects, mangrove encroachment into salt marshes, and small amounts of permitted development, but such drastic changes indicate differing mapping methodology.

LULC categories used by the WMDs were also modified from year to year, particularly in early WMD mapping efforts. For instance, the mixed scrub–shrub wetland classification (FLUCCS code 6460) was not used in the 1994–1995 Northwest Florida Water Management District LULC data, yet it proliferated in mapping data thereafter (NWFWMD 2010). Florida is fortunate to have so many available data sets describing coastal wetland acreage, but variability in methodology and categories requires careful attention of the end user to accurately interpret data.

Monitoring priorities and recommendations

As fully described in the introduction of this report, more than a dozen monitoring methods are commonly used in Florida's coastal wetlands. This hinders direct comparison between monitoring efforts among sites or regions. Additionally, monitoring efforts are too often short term due to funding limitations. In the face of ecological shifts due to sea-level rise, long-term statewide monitoring is needed to track the responses of vegetation and sediment accretion in coastal wetlands.

Many monitoring efforts are challenging in salt marshes and mangroves, as these habitats are naturally difficult to access. The dense trunks and prop roots hinder access on foot, while vegetation trampling in salt marshes makes it challenging to monitor nondestructively. Moreover, many of the monitoring methods originally developed for terrestrial forests are difficult to apply to mangroves due to the plants' unusual growth patterns. The classic measurements of tree density, diameter at breast height, and biomass are often problematic with mangroves because the trunks can grow at any angle, even horizontal. While certain metrics can be acquired only through field measurements, alternative methods such as the use of drones, LiDAR, or citizen scientists can address some monitoring and ground-truthing needs.

Another identified priority in monitoring is the need to find metrics that recognize an ecosystem's stability and ability to recover from disturbances (ecosystem resistance and resilience). These metrics may vary depending on whether the wetland is natural, restored, or actively managed and on the level of disturbance or ecosystem stress that the wetland has experienced.

Conclusion

The Coastal Habitat Integrated Mapping and Monitoring Program will continue efforts to coordinate, facilitate collaboration, and address gaps in coastal habitat mapping and monitoring programs in Florida. The information compiled in this report is designed not only to facilitate decision-making for the mapping and monitoring of coastal wetland habitats, but also to recommend priorities for the adaptive management of these unique coastal ecosystems and the numerous threatened and endangered species that depend on them. Knowledge of the region-specific extent, trends, and threats to salt marshes and mangroves is crucial for the long-term management of these economically and ecologically valuable habitats.

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Appendix A
Acronym List

Acronym	Meaning
ANERR	Apalachicola National Estuarine Research Reserve
BMI	Battelle Memorial Institute
C-CAP	Coastal Change Analysis Program
CCHA	Critical Coastal Habitat Assessment
CCMP	Comprehensive Conservation and Management Plan
CERP	Comprehensive Everglades Restoration Plan
CHIMMP	Coastal Habitat Integrated Mapping and Monitoring Program
CHNEP	Charlotte Harbor National Estuary Program
CLC	Cooperative Land Cover
CRG	Coastal Resources Group Inc.
CSFP	Central and Southern Florida Project
CSF	Conservancy of Southwest Florida
DEM	Digital Elevation Model
DOQQs	Digital Orthophoto Quarter Quads
EAA	Everglades Agricultural Area
ELVes	Everglades Landscape Vegetation Succession
ENP	Everglades National Park
ETM+	Enhanced Thematic Mapper Plus
FCE	Florida Coastal Everglades
FCE LTER	Florida Coastal Everglades Long Term Ecological Research
FDEP	Florida Department of Environmental Protection
FDER	Florida Department of Environmental Regulation (now FDEP)
FDOT	Florida Department of Transportation
FGCU	Florida Gulf Coast University
FLUCCS	Florida Land Use and Cover Classification System
FNAI	Florida Natural Areas Inventory
FWC	Florida Fish and Wildlife Conservation Commission
GAP	National Gap Analysis Program
GCPO LCC	Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative
GIS	Geographic Information System
G-LiHT	Goddard's LiDAR, Hyperspectral, and Thermal Imager
GTMNERR	Guana Tolomato National Estuarine Research Reserve
HGM	Hydrogeomorphic Methodology
HyspIRI	Hyperspectral Infrared Imager
ICW	Intracoastal Waterway

Acronym	Meaning
IPCC	Intergovernmental Panel on Climate Change
IRC	Institute for Regional Conservation
IRL	Indian River Lagoon
LANDFIRE	Landscape Fire and Resource Management Planning Tools
Landsat	Land remote-sensing satellite
Landsat TM	Landsat Thematic Mapper
Landsat ETM+	Landsat Enhanced Thematic Mapper Plus
LC	Land Cover
LiDAR	Light Detection and Ranging
LTER	Long Term Ecological Research
LULC	Land Use/Land Cover
LWL	Lake Worth Lagoon
MAP	Monitoring and Assessment Plan
MFL	Minimum Flows and Levels
MRGIS	Marine Resources Geographic Information System
NASA	National Aeronautics and Space Administration
NCSU	North Carolina State University
NDVI	Normalized Difference Vegetation Index
NERR	National Estuarine Research Reserve
NERRS	National Estuarine Research Reserve System
NLCD	National Land Cover Data
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRPA	Natural Resource Protection Area
NVCS	National Vegetation Classification Standard
NWFWMD	Northwest Florida Water Management District
NWI	National Wetlands Inventory
NWR	National Wildlife Refuge
PACE	Pre-Aerosol Clouds and ocean Ecosystem
PBCERM	Palm Beach County Department of Environmental Resources Management
PLC	Preliminary Land Cover
PSRP	Picayune Strand Restoration Project
PSSF	Picayune Strand State Forest
RBAP	Rookery Bay Aquatic Preserve
RBNERR	Rookery Bay National Estuarine Research Reserve
RSET	Rod Surface Elevation Table

Acronym	Meanng
SALCC	South Atlantic Landscape Conservation Cooperation
SBEP	Sarasota Bay Estuary Program
SECN	Southeast Coastal Network
SET	Surface Elevation Table
SFCN	South Florida/Caribbean Network
SFNRC	South Florida Natural Resources Center
SFWMD	South Florida Water Management District
SJRWMD	St. Johns River Water Management District
SLAMM	Sea Level Affecting Marshes Model
SLE	St. Lucie Estuary
SRWMD	Suwannee River Water Management District
SWFRPC	Southwest Florida Regional Planning Council
SWFWMD	Southwest Florida Water Management District
SWIM	Surface Water Improvement and Management
SWMP	System Wide Monitoring Program
TBEP	Tampa Bay Estuary Program
TM	Thematic Mapper
TNC	The Nature Conservancy
UMAM	Uniform Mitigation Assessment Method
UME	Unusual Mortality Event
USEPA	United States Environmental Protection Agency
USFSP	University of South Florida St. Petersburg
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
USNPS	United States National Park Service
WAP	Wetland Assessment Procedure
WMD	Water Management District
WRAP	Wetland Rapid Assessment Procedure
WRIA	Water Resource Inventory and Assessment

Appendix B
Species List

Scientific name	Common name
Acer rubrum	red maple
Acrostichum danaeifolium	giant leather fern
Acrostichum spp.	leather ferns
Aedes spp.	marsh mosquitoes
Ammodramus maritimus mirabilis	Cape Sable Seaside Sparrow
Arundo donax	giant cane
Aureoumbra lagunensis	microscopic alga; causes brown tide
Avicennia germinans	black mangrove
Baccharis angustifolia	saltwater false willow
Baccharis spp.	sea myrtle/groundsel shrubs
Batis maritima	saltwort
Borrichia arborescens	seaside tansy
Borrichia frutescens	sea oxeye daisy
Callinectes sapidus	Atlantic blue crab
Carya aquatica	water hickory
Casuarina spp.	Australian pines
Catoptrophorus semipalmatus	Willet
Cinnamomum camphora	camphor tree
Cladium jamaicense	sawgrass
Cladium mariscoides	smooth sawgrass
Coccoloba uvifera	sea grape
Colubrina asiatica	latherleaf
Conocarpus erectus	buttonwood
Crassostrea virginica	eastern oyster
Crocodylus acutus	American crocodile
Cytospora rhizophorae	mangrove fungus
Distichlis spicata	saltgrass
Eichornia crassipes	water hyacinth
Eleocharis cellulosa	Gulf Coast spikerush
Fimbristylis spadicea	marsh fimbry
Juncus roemerianus	black needlerush
Juniperus silicicola	southern red cedar
Juniperus virginiana	red cedar
Laguncularia racemosa	white mangrove
Lygodium japonicum	Japanese climbing fern
Lygodium microphyllum	Old World climbing fern
Malaclemys terrapin	diamondback terrapin
Melaleuca quinquenervia	melaleuca

Scientific name	Common name
Monanthochloe littoralis	Key grass
Mycteria americana	Wood Stork
Nerodia fasciata	salt marsh snake
Odocoileus virginianus clavium	Key deer
Pandion haliaetus	Osprey
Pedinophyceae	chlorophyte microalgae
Phragmites australis	common reed
Platalea ajaja	Roseate Spoonbill
Quercus virginiana	live oak
Rhizophora mangle	red mangrove
Salicornia bigelovii	dwarf glasswort
Salicornia spp.	glassworts
Sarcocornia ambigua	perennial glasswort
Sabal palmetto	cabbage palm
Salix caroliniana	coastal plain willow
Sarcocornia ambigua	perennial glasswort
Schinus terebinthifolius	Brazilian pepper
Scirpus pungens	three-square bulrush
Scirpus spp.	bulrushes
Schoenoplectus robustus	saltmarsh bulrush
Spartina alterniflora	smooth cordgrass
Spartina bakeri	sand cordgrass
Spartina patens	saltmeadow cordgrass
Spartina spartinae	Gulf cordgrass
Sporobolus virginicus	seashore dropseed
Taxodium distichum	bald cypress
Taxodium spp.	cypresses
Thalassia testudinum	turtle grass
Triadica sebifera	Chinese tallow
Typha spp.	cattails