Climate Change Vulnerability Assessment and Adaptation Opportunities for Salt Marsh Types in Southwest Florida

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June 30,2012

The Charlotte Harbor National Estuary Program is a partnership of citizens, elected officials, resource managers and commercial and recreational resource users working to improve the water quality and ecological integrity of the greater Charlotte Harbor watershed. A cooperative decision-making process is used within the program to address diverse resource management concerns in the 4,400 square mile study area. Many of these partners also financially support the Program, which, in turn, affords the Program opportunities to fund projects such as this. The entities that have financially supported the program include the following: U.S. Environmental Protection Agency

Southwest Florida Water Management District
South Florida Water Management District
Florida Department of Environmental Protection
Peace River/Manasota Regional Water Supply Authority
Polk, Sarasota, Manatee, Lee, Charlotte, DeSoto, and Hardee Counties
Cities of Sanibel, Cape Coral, Fort Myers, Punta Gorda, North Port, Venice,
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Updated 7/20/2012

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Acknowledgements

This project has benefited from the contributions of numerous agencies and individuals that have contributed information, time, and opinion to the contents and recommendations.

FUNDING FOR THIS REPORT WAS PROVIDED BY U.S. ENVIRONMENTAL PROTECTION AGENCY ASSISTANCE GRANT NUMBER CE- 95450310 WITH FINANCIAL ASSISTANCE FROM U.S. ENVIRONMENTAL PROTECTION AGENCY REGION 4. Special assistance was received from Ms. Rhonda Evans, USEPA, Region 4.

The Charlotte Harbor National Estuary Program and the Southwest Florida Regional Planning Council have provided the venue and support for the entire project and regular input in the structure and function of the study.

Internal first draft technical review is provided by the CHNEP TAC, CAC, and Management Committee and Policy Committees.

Information and technical assistance, and site access permission from the CHNEP, SWFRPC, FDEP, SFWMD, SWFWMD, the USFWS, the FWC, the FMRI.

Special thanks to Captain Larry Hendricks for always meeting us a many different locations; excellent work in getting us where we needed to go even when the water was too shallow and we got the boat very dirty; and getting us back to port safe.

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The salt marsh community of the Southwest Florida Ecosystem is one of the most unique salt marsh systems in the United States. The subtropical climate of Florida supports a combination of temperate salt marsh vegetation and tropical mangroves that intermix to form an important transitional ecotone that is subject to extremes of temperature, salinity, winds, evaporation, and storm.

Ecosystem services of salt marshes include a base of the estuarine detrital food pathway, nurseries and escape form predation habitat for many species of aquatic life including the early life stages of game fish and commercial fish , recreational fishing, commercial fishing and harvesting, hunting, migratory bird habitat. bird watching, other forms of ecotourism such as kayaking, carbon sequestration, storm protection, water quality treatment, stabilization of sediment and shorelines, increases in market-based property appraisal values and aesthetic values. From existing scientific literature southwest Florida salt marsh provides habitat to a variety of resident and transient organisms including 301 plant species, 422 invertebrate species, 217 fish species, 11 amphibians, 31 reptiles, and 15 mammals; including 6 federally listed and 27 state listed animal species.

Mangroves primarily dominate the CHNEP shoreline (Drew and Schomer 1984). Monotypic stands of black needlerush (*Juncus roemerianus)* are more common in slightly elevated areas with lower ranges of tidal inundation. dominate salt marsh communities around the mid-estuarine transition zones at the mouths of rivers (**e.g.**, Myakka and Peace Rivers) and creeks (Hancock). Parts of the interior habitat of Sanibel Island have bands of salt marsh dominated by Baker's cordgrass (*Spartina bakeri)* and leather fern *(Acrostichum aureum and danaeifolium).*

Although almost 74 percent of salt marsh habitat is protected in the CHNEP, habitat continues to be lost to human-induced impacts including development, alterations of hydrology, and pollution. Salt marshes in Charlotte Harbor Estuary have been directly destroyed or impacted from construction activities for residential and commercial purposes including construction for seawalls, drainage ditches for agriculture and mosquito control, boat facilities, and navigation channels. Man-made hydrological alterations have reduced the amount of freshwater flow from some rivers (**e.g.**, Peace, Myakka), while artificially increasing the flow through others (**e.g.**, Caloosahatchee).

The primary focus of this project is the extent and nature of salt marshes and the adaptation of salt marshes to climate change. This report includes the results of a new study to inventory and determine the areal extent of salt marsh types throughout the Charlotte Harbor National Estuary Program (CHNEP) study area; determine the vulnerability of those marshes to climate change; identify the need and opportunities for avoidance, minimization, mitigation, and adaptation (AMMA) to climate change, and recommend strategies to implement alternate AMMA.

This report is designed for local for use by governments, stakeholder groups and the public at large in developing coastal and land use planning, and avoidance, minimization, mitigation and adaptation of climate change impacts to salt marshes throughout the CHNEP study area.

Introduction

The primary focus of this project is the extent and nature of salt marshes and the adaptation of salt marshes to climate change. This report includes the results of a new study to inventory and determine the areal extent of salt marsh types throughout the Charlotte Harbor National Estuary Program (CHNEP) study area; determine the vulnerability of those marshes to climate change; identify the need and opportunities for avoidance, minimization, mitigation, and adaptation (AMMA) to climate change, and recommend strategies to implement alternate AMMA.

In the course of the project we identified and evaluated all of the available digital and hard copy salt marsh mapping data sets for the CHNEP. Salt marsh GIS maps were collected from the South Florida Water Managed District (SFWMD), Southwest Florida Water Management District (SWFWMD), Florida Fish and Wildlife Conservation Commission (FWC), National Wetlands Inventory (NWI), and the Charlotte Harbor National Estuary Program (CHNEP). Other map products from other time periods with a baseline from 1954 were also collected.

We inventoried and determined the physical extent of the different types of salt marsh throughout CHNEP study area. This was achieved through a combination of directed site visits to all CHNEP watershed and creeks with a sampling protocol that was developed and placed into a Trimble for data collection (Appendix I). The protocol involved floral and faunal surveys, simple water quality sampling, GPS mapping, and assessment using functional assessment techniques (WRAP, UMAM, and HGM). We have visited forty-nine (49) marsh systems with GPS locations established and data collected. We mapped 14,856.1 acres of salt marsh by salt marsh type. This is the first time this has been done in southwest Florida. The mapped and tabulated location of salt marsh extents by type have been linked into a GIS product. For several marshes a GIS product was created where a cursor click on a marsh brings up the panoramic photographs, species lists, functional assessment scores and other collected data on that marsh

We have identified the significant potential effects on salt marsh ecosystems in the project study area from anticipated climate change in three “severity” scenarios: least case, moderate case, and worst case. We generated an assessment of significant potential effects on the salt marshes in the project study area, resulting from and related to climate change including air temperature and chemistry, altered hydrology, climate instability, geomorphic changes, habitat and species changes, sea level rise, water temperature and chemistry, land use changes, and variable risk.

This study identifies potential opportunities in critical areas for implementation of avoidance, minimization, mitigation, and adaptation (AMMA) options for salt marshes of the CHNEP to address climate change. We have analyzed potential adaptations and developed recommended strategies to implement the AMMA for CHNEP salt marshes. In several cases we also have identified the functional utility of these options for addressing the potential effect of the expected climate impact on the salt marshes of the CHNEP.

The Salt Marshes of the Charlotte Harbor Estuary (CHNEP)

Definition of Salt Marsh for the CHNEP

(or What are a salt marsh?)

Salt marshes are communities of emergent halophytic (salt tolerant) vegetation, periphytic and floating algae, and/or included bare soils in areas alternately inundated and drained by tidal action, often daily but at the extreme seasonally.

Salt marsh community types are characterized by differences in their dominant vegetation, location, and tidal interaction and have been described as low marsh, high marsh, cordgrass marsh, *Spartina* marsh, *Salicornia* marsh , *Juncus* marsh, salt pan, tidal marshes, and transitional zone. The general term "salt marsh" is used in scientific and general literature to include all coastal salt marsh-related habitats (tidal marsh, salt marsh, brackish marsh, coastal marsh, coastal wetlands, tidal wetlands, low marsh, high marsh) with such common species as, *Spartina alterniflora, Spartina patens, Salicornia virginica, Juncus roemerianus*, *Distichlis spicata*, and *Batis maritima;* as well as unvegetated areas associated with these communities including salterns (United Kingdom), salinas (Spanish), salt pans (actually more appropriate for desert habitats), salt pannes (California USA), salt barrens (USGS), and white zone (Davis 1999, Egler 1952); although white zone is also used to identify areas of dried-down periphytic algal freshwater wetlands.

Some authors distinguish the salt marsh from brackish marshes as being frequently or continuously flooded by relatively shallow, high salinity water. The National Wetlands Research Center of the United States Geological Survey defines a saltwater marsh as having a salinity of 15-18 parts per thousand or greater (NWRC 2007), but many other definitions are utilized and accepted by the scientific community.

Brackish salt marshes develop where significant freshwater influxes dilute the seawater to brackish levels of salinity. This commonly happens in estuaries of coastal rivers or near the mouths of coastal rivers with heavy freshwater discharges in the conditions of low tidal ranges A brackish marsh and intermediate marsh are characterized by lesser salinities than full salt marshes. The National Wetlands Research Center defines brackish marshes as those with a salinity range from three (3) to 15 parts per thousand, and an intermediate salt marsh as a marsh occurring where the salinity is about three (3) parts per thousand to 0.5 parts per thousand (NWRC 2007).

Coastal salt marsh is synonymous with the "coastal salt marsh" described by Davis (1967), Hartman (1996), and Cox et al. (1994); and "marine and estuarine tidal marsh" of FNAI (1990). The Florida Natural Areas Inventory (1990) defines salt marshes as "expansive inter- or supra-tidal areas occupied by rooted emergent vascular macrophytes smooth cordgrass (*Spartina alterniflora*), needle rush (*Juncus roemerianus*), swamp sawgrass (*Cladium mariscoides*), saltwort (*Batis maritima*), saltgrass (*Distichlis spicata*), glasswort (*Salsola kali*), and a variety of epiphytes and epifauna."

High marsh is a tidal marsh zone located above the mean high-water line (MHW) which in contrast to the low marsh zone is inundated infrequently during periods of extreme high tide and storm surge associated with coastal storms. The high marsh is the intermittent zone between the low marsh and the uplands, an entirely terrestrial area rarely flooded during events of extreme tidal action precipitated by severe coastal storms.

Salt marshes have been studied extensively for many years with Ragotzkie et al. (1959), Chapman (1960) and Teal and Teal (1969) conducting some of the pioneering work. Thorough descriptions of general salt marsh ecology are given by Ranwell (1972), Adam (1990), Pomeroy and Wiegert (1981), and Mitsch and Gosselink (1986, 1993). Wiegert and Freeman (1990) and Montague and Wiegert (1990) provide overviews on southeast Atlantic and Florida marshes, respectively. The FLUCCS code for all the coastal salt marsh plant communities includes: 642 (saltwater marshes). The Florida Natural Areas Inventory (FNAI) State Rank for salt marsh is S4 For the purposes of this study the term salt marsh will be utilized in the fullest sense that it is applied in the mapping by the CHNEP, FDOT, SFWMD, SWFWMD, and FFWCC and their literature and reports including the saline conditions (0.5 to 100 ppt.) of the habitat and the emergent halophytic vegetation that dominate it (Zedler 1984). For the purposes of this study a salt marsh can possess low-growing halophytic shrubs up to 1.5 meters in height provided the shrubs cover less than 25% of the area.

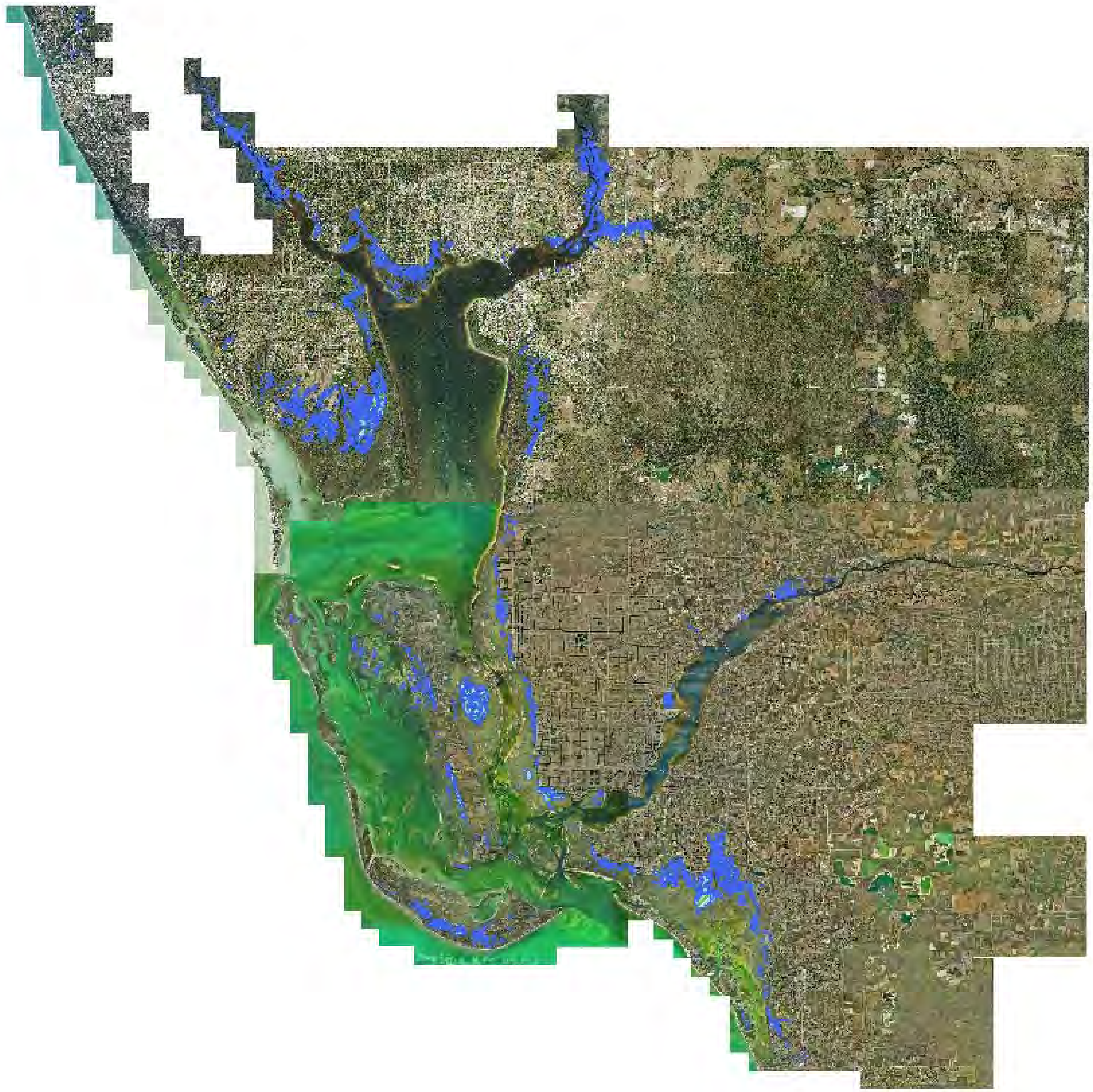

Figure 1: The Salt Marshes of the Charlotte Harbor National Estuary Program (indicated in blue).
Source SWFRPC/CHNEP 2012

Florida Salt Marsh Regions

Salt marsh regions of Florida are characterized by differences in tidal range, wave energy, frequency and amplitude of tides, local topography, and temperature (Montague and Wiegert 1990). The extensive coastal low salt marshes found in the Big Bend area of northwest Florida are replaced by coastal mangrove forests of increasing height in tropical and subtropical regions (between 25^0 N and 25^0 S latitude). Although low salt marshes are more abundant above the normal freeze-line in Florida, they extend into the coastal areas of Southwest Florida where they can fringe and parallel the waterward extents of mangrove-dominated habitats. In the CHNEP, salt marshes are established in coastal areas of Lee, Charlotte, and Sarasota counties.

Hydrogeomorphically, based upon tidal and landscape position, there are two types of saltmarsh in the CHNEP: **fringing** and **high**, The high marshes cover more than twice as much area, 10,457.56 acres (70.4%) as fringing marshes 4,398.54 acres (29.6%).

Salt Marsh Types of the CHNEP

The subtropical climate of South Florida supports a diverse community of both tropical and temperate flora. These conditions create different salt marsh communities than those typical of the southeast Atlantic and northern Gulf of Mexico. The community types and spatial extent vary due to latitudinal and geographic differences (Montague and Wiegert 1990). A transition between the more typical salt marshes and mangrove forests occurs on the east coast at about 30 N (Odum et al.1982). Unlike the common *Spartina* or *Juncus* monotypic stands of north Florida, South Florida salt marsh vegetation is often intermixed with mangroves.

Hydrogeomorphically, based upon tidal and landscape position, there are two types of saltmarsh in the CHNEP: **fringing** and **high**, Form this study we are able to state that the high marshes cover more than twice as much area, 10,457.56 acres (70.4%) as fringing marshes 4,398.54 acres (29.6%).

At the commencement of this project existing literature (USFWS 1999) recognized five (5) types of salt marsh for Florida. In the course of our study and field work we have been able to identify twelve (12) types of salt marsh in the CHNEP boundary in southwest Florida.

The classic zonation of low and high marsh are confused by the wide range of occurrence of salt marsh species such as black needle rush that range over 3 1/2 feet of relative elevation of sea level, essentially spanning the full range of low to highest marsh. The variety of salt marsh communities in Southwest Florida includes (1) **smooth cordgrass**, (2) marshes dominated by **black needle rush**, (3) marsh dominated by **leather fern**, (4) marsh dominated by **saltmarsh bulrush**, (5) high salt marsh-mangrove transition with a **black mangrove shrub** layer (6) high marsh **algal marsh** lacking vascular plants, (7) high marsh **saltern** (salt pan, salinas, white zone), (8) high marsh dominated by **succulents** including glasswort and saltwort, (9) **high marsh mixed** vegetation herbaceous (10) high marsh dominated by salt **grasses**, key grass, knotgrass, (11) high marsh with a shrub layer of **buttonwood**, salt bush, and marsh elder, and a special type of high marsh found on barrier islands dominated by **Baker's cordgrass** and **leather** fern.

SALT MARSH TYPES OF THE CHNEP			
Type	**Combined numeric code for this study**	**FLUCCS Code**	**FLUCCS Manual Description**
smooth cordgrass	10	6421	Cordgrass
black needle rush	21	6442	Needlerush
leather fern	22	none	none
saltmarsh bulrush	23	none	none
shrub mangrove	30	6122	Black mangrove
algal	31	650	Non-Vegetated, including tidal flats, shorelines, intermittent Ponds, Oyster Bars
saltern	32	720	Sand Other Than Beaches, including dunes as the major feature
marsh meadow Succulents	33	643	Wet Prairie
marsh meadow Mixed	34	643	Wet Prairie
marsh meadow grasses	35	643	Wet Prairie
shrub buttonwood	36	6124	Buttonwood

Table 1: Types of Salt Marsh of the CHNEP

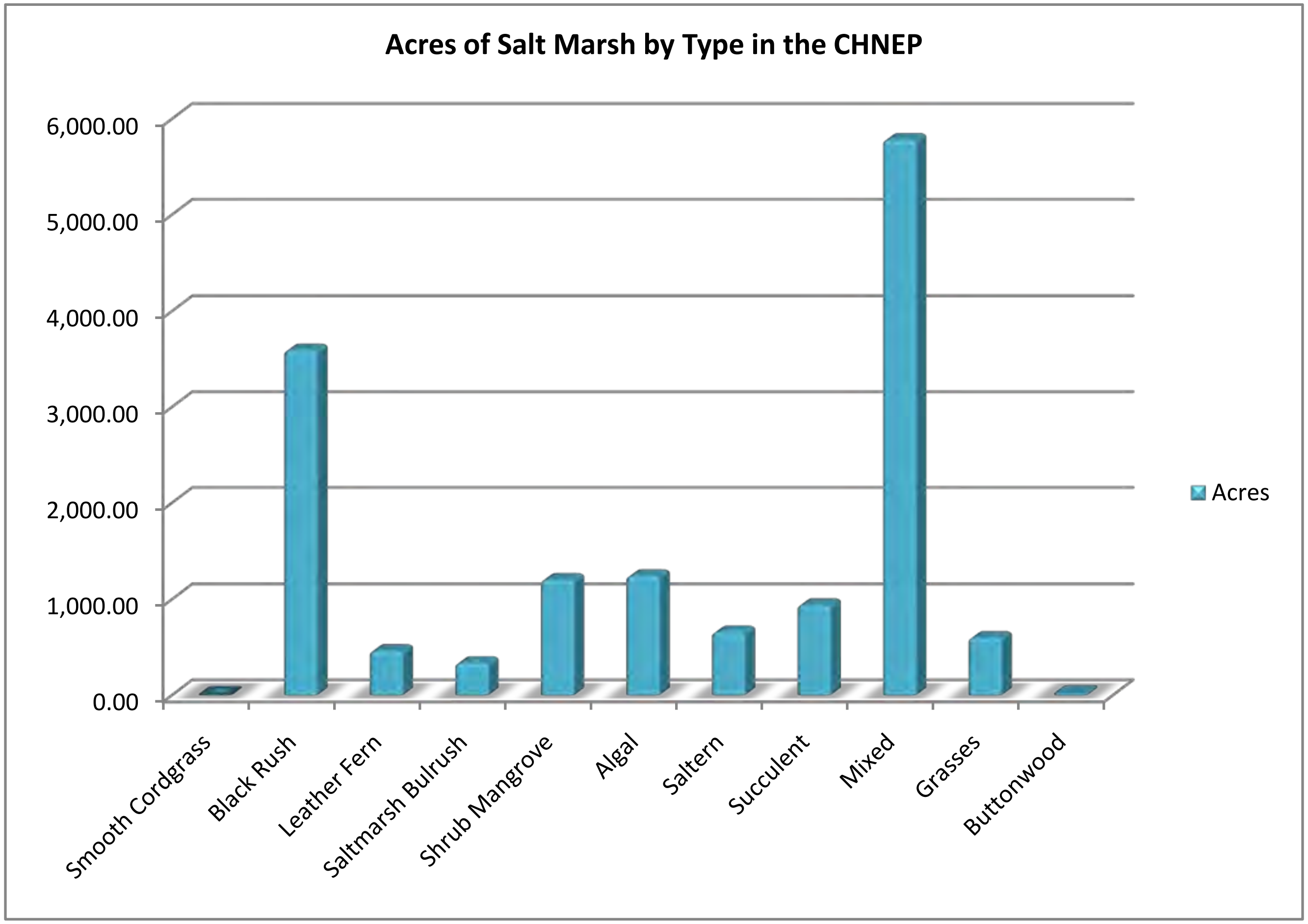

Figure 2: Acres of Salt Marsh by Type in the CHNEP
Source: SWFRPC/CHNEP 2012

Smooth Cordgrass Marsh

Low salt marshes are located at and above the mean-tide line in different relative locations. In the CHNEP smooth cordgrass, *Spartina alterniflora*, does not dominate the low marsh as typically described for temperate marsh systems of northern Florida. Low marsh on tributaries and major rivers of the CHNEP are dominated by black needle rush, leather fern, saltmarsh bulrush (in areas of lower salinity), and mixtures of these species. Smooth cordgrass is the rarest salt marsh type in the CHNEP occupying only 1.14 hectares (2.81 acres) or 0.02% of all salt marsh extents.

The very few areas that now have smooth cordgrass are newly exposed sand or mud shoals that have not yet been colonized by mangrove species. These areas tend to form and have longest persistence in sheltered calm coves in the lagoonal edges of the northern watersheds of the CHNEP. Through time these patch marsh features are often replaced by mangroves as seedlings grow and then shade out the smooth cordgrass. Current examples occur in Lemon Bay on central oyster bar islands, in protected coves of the Alligator Creek tributary of Lemon Bay, and inside the outer mangrove fringes of "doughnut islands" in Pine Island Sound. Doughnut islands are islands that have an open uncanopied area in a center surrounded by red mangrove fringe. These appear to form when previously forested island interiors lose tree cover and the substrates subside and are drowned providing a zone of marsh development or open water.

During resource surveys of southwest Florida's seven Aquatic Preserves in 1988-1989 the principle author observed smooth cordgrass to be more prevalent in Lemon Bay, the Cape Haze area and northern Pine Island Sound. Although no direct measures of physical extent were taken shoreline mapping shows smooth cordgrass in more locations than it occurs in 2011-2012.

Currently smooth cordgrass marsh occurs at an average elevation of 0.25±0.15 meters (0.83 ± 0.50 feet) with a minimum elevation of 0.00 meters or mean tide and a maximum elevation of 0.72 meters at island centers..

At the one location in the center of Lemon Bay where smooth cordgrass was dominant the salinity was 35.21 ppt, dissolved oxygen was 5.06 ppm, pH was 8.15 and the water temperature 25.7 C (78.3 F).

Spartina alterniflora (smooth cordgrass or saltmarsh cordgrass) is a perennial rhizomatous deciduous grass which is found in intertidal estuarine shorelines. It grows 0.6 to up to 2.5 meters tall, and has smooth, hollow stems which bear leaves up to 20-60 cm long and 1.5 cm wide at their base, which are sharply tapered and bend down at their tips. The leaf blades are 1/4 to 3/5 inches wide. The leaves lack auricles and have ligules that consist of a fringe of hairs. The plant is deciduous; its stems die back at the end of each growing season (Ebasco Environmental 1992). .*S. alterniflora* flowers are inconspicuous and are borne in greatly congested spikes; two to three inches long (Hitchcock et al. 1969). It produces flowers and seeds on only one side of the stalk. The flowers are a yellowish-green, turning brown by the winter. It has rhizoidal roots, which, when broken off, can result in vegetative asexual growth. The roots can be are an important food resource for waterfowl.

Under favorable conditions, *S. alterniflora* can reach sexual maturity in three to four months (Smart 1982). Mature plants produce seed in the fall. Seeds require soaking for approximately six weeks to germinate, with most seeds germinating in the spring. The seeds are short-lived (roughly 8 months), so the species does not have a persistent seed bank (Sayce and Mumford 1990). Germination rates are variable.

While seeds are important for colonizing new areas, they appear to be unimportant in maintaining established stands. Studies in Rhode Island suggest that *S. alterniflora* seedlings are unable to survive under adult canopy, and seedling success increases with the size of bare patches (Metcalfe et al. 1986). Therefore, the expansion of established stands is due to vegetative growth. In some areas, *S. alterniflora* has demonstrated the ability to rapidly colonize bare areas due to a high intrinsic growth rate and rapid propagation of stems via rhizomes (Smart 1982). Estimates of lateral growth taken in Washington indicate that clones expand at approximately 0.5 to 1.7 m/yr. (Riggs 1992; Simenstad and Thom 1995; Sayce 1988).

Found in areas of low to moderate wave energy, the species can colonize a broad range of substrates, ranging from sand and silt to loose cobble, clay, and gravel. The species can tolerate a wide range of environmental conditions, including: inundation up to 12 hours a day, pH levels from 4.5 to 8.5, and salinity from 10 to 60 ppt, although 10-20 ppt is optimal (Landin 1991).

S. alterniflora is noted for its capacity to act as a substrate builder and stabilizer. It grows out into the water at the seaward edge of a salt marsh, and accumulates sediment and enables other habitat-stabilizing species, such as mussels, to attach and settle. This accumulation of sediment and other substrate-building species gradually builds up the level of the land at the seaward edge, and other -marsh species can move onto the new higher elevation. As the marsh accretes, *S. alterniflora* moves still further out to form a new edge. *S. alterniflora* grows in tallest forms at the outermost edge of a given marsh, displaying shorter morphologies up onto the landward side of the *Spartina* belt.

S. alterniflora is native to the Atlantic coast of the Americas from Newfoundland, Canada south to northern Argentina, where it forms a dominant part of brackish coastal salt marshes. In its native range, *Spartina alterniflora* exhibits varying growth forms in different salt marsh zones. A tall form occurs at the facing shoreline, along creek banks and drainage channels. Landward of the tall form, an intermediate form occurs, which grades into a stunted form at the marsh interior (Smart 1982). In its native range, *S. alterniflora* typically exclusively dominates low salt marshes (Bertness 1991), growing from 0.7 m below mean sea level to approximately mean high water (Landin 1991).

In its native habitat, *Spartina alterniflora* is valued (Simenstad and Thom 1995; Landin 1991). The species is highly productive, exporting approximately 1300 g/m^2 of detritus annually to the estuarine system (Landin 1991). *S. alterniflora* is also highly regarded for erosion control, as well as fish and wildlife values in its native range (Simenstad and Thom 1995). In these native habitats, some waterfowl and wetland mammals eat the roots and shoots of this plant. In addition, stands of *S. alterniflora* can serve as a nursery area for mangroves, and estuarine fishes and shellfishes.

Because of their ability to trap sediment, *Spartina* species have been planted in many parts of the world for estuary reclamation (Partridge 1987). There are also some economically beneficial uses for *Spartina alterniflora.* The species is palatable to livestock, so the plant's continued spread may increase available pasture. Efforts have also been made to use *S. alterniflora* in paper production (Ebasco Environmental 1993).

Figure 3: Smooth Cordgrass, Big Panther Key, Pine Island Sound.
Source W. Gray SWFRPC, June 1, 2011

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Black Needle Rush Marsh

Black needle rush (*Juncus roemerianus*) is the dominant fringing marsh type of the CHNEP. It is found in all the watersheds of the CHNEP. Extensive waterward facing salt marshes are found in the middle and upper reaches of the estuarine extents of rivers and tributary creeks of all three coastal counties. Large black needle rush marshes are found in the middle brackish estuarine shorelines of the Peace River, the Myakka River, and the Caloosahatchee River and its tidal tributaries. Smaller extents of black needle rush marsh are found on Alligator Creek, Hendry Creek, Mullock Creek, Estero River, and Spring Creek. Black needle rush is the major deltaic stabilizing marsh type on rivers that have not be severely altered. Black needle rush is the second most common salt marsh type in the CHNEP comprising 24.2% of all salt marsh extents.

Black needle rush occurs at an average elevation of 0.56 ± 0.22 meters (1.74 ± 0.72) feet with a minimum elevation of 0.00 meters or mean tide and a maximum elevation of 2.15 meters (7.4 feet). This wide range reflects that black needle rush is found in all marsh hydrogeomorphic settings of the CHNEP from waterfront fringing marshes to middle marsh peat platforms to the waterward edge of high marsh to the landward edge of high marsh. It is also important to understand that as the estuary proceeds up river and stream water courses the water surface gains elevation above sea level in accordance with the elevational gradient of the stream bed so the relative position of a marsh may be the same to relative water surface at a higher location than on the coastal shoreline. In both the Myakka River and Peace River black needle rush is supported on and most likely is responsible for the creation of peat mats that overlay sandier basement sediments evidencing a process of vegetative sourced land building.

Juncus roemerianus is a perennial moderate growing, bunch forming deciduous grass with green flowers in early spring, mid spring and late spring. It grows well in semi-shade, and prefers high levels of water. It is an erect plant and has a clump forming growth form, and has an ultimate height of 1.5 m / 4.9 ft. The leaves are green and tender in summer. Older stems are course and rigid. Leaves are terete, stiff and pungent. Inflorescence appear laterally; involucral bract terete and erect. Perianth usually brownish, 3-3.5 mm long; sepals longer and are more pointed than petals. It is composed of two types of plants based on flower morphology: one form produces perfect (bisexual flowers) and another form produces pistillate (unisexual) flowers. Seeds are dark and 0.6 mm long (May to October). This plant requires a minimum of 200 frost free days to grow successfully. It has no drought tolerance.

In the wild, black needlerush establishes from seed, rhizomes or vegetative divisions from storm derived flotsam. Pistillate-flowered plants produce more seed and seed with higher viability than perfect-flowered plants. Seed germination requires light and seeds will not germinate if covered. Seeds remain viable for over a year. Seeds will germinate when submerged or floating on water. Black needlerush seedlings are found mainly in areas with no or little associated vegetation. Seedlings are seldom found in mature stands of black needlerush or other marsh species. Black needlerush maintains itself in established stands though rhizome growth.

Where soil salinity is low and substrate is organic, black needle grass is robust with leaves reaching over 2.2 m in height. In high saline areas the plants are dwarfed often less than 0.3 m tall. *Juncus roemerianus* grows in soils ranging from a pH of 4 to 7. It is adapted to almost pure sand, clay, silt, loam, silty clay, sandy clay, clay loam, silt loam, sandy loam, silty clay loam and sandy clay loam soils, and prefers medium fertility. It also, grows in highly organic soils including peat soils. It has a high tolerance to anaerobic conditions and a high tolerance to $CaCO^3$.

Dense stands of black needlerush form deep fibrous root systems, which provide very good shoreline protection, filter suspended solids, uptake nutrients, and facilitate substrate oxidation. Ninety percent of the biomass of marsh plants, such as black needlerush, is not consumed by herbivores. Instead, marsh plant biomass is decomposed to microbial biomass. This microbial biomass is available to primary consumers which initiate food webs leading to commercially important fishes and crustaceans

With its range of salinity tolerances, black needlerush is used in tidal estuary restoration along the Atlantic and Gulf coasts. Seed and vegetative parts of black needlerush are utilized by waterfowl, muskrats, nutria, rice rat, marsh rabbit and non-game birds. More than 60 bird species use black needlerush dominated marsh at least seasonally.

As earlier discussed black needle rush is the second most common salt marsh type in the CHNEP comprising 24.2% of all salt marsh extents. in contrast it dominates 20.7% of the marsh in the south Atlantic states and 7.3% of Gulf coast marshes. But, it covers more marsh total area on the Gulf coast than on the Atlantic coast. Its distribution is continuous from Maryland to Florida and westward to southwestern Texas. It is usually restricted to coastal marches and estuaries, but it may extend 10 to 15 miles inland along river estuaries.

Black needlerush dominated plant communities are classified into three generalized categories based on elevation and salinity influences: 1) Saline marsh, which experiences little dilution of tidal waters; 2) Brackish marsh, where tidal waters are routinely diluted, 3) Intermediate marsh, which is transitional between brackish and freshwater marsh. The number of species in association with black needlerush tends to increase as water salinity decreases. In freshwater habitats black needlerush’s growth may be restricted by organisms that feed on its rhizomes.

The percentage germination of seed collected in Mississippi averaged 75 for pistillate flowered plants and 60 for perfect flowered plants. Black needlerush seeds collected from the Mississippi Gulf coast exhibited high percentage germination without a cold-wet stratification. Nursery and greenhouse production are effectively accomplished with seed or vegetative divisions. Seed can be stratified in saturated soil-less potting media with high percentage of fine organics. At the USDA Natural Resources Conservation Service (NRCS) (2007) Cape May Plant Materials Center (PMC), New Jersey, seed and media were thoroughly moistened, placed in zip lock bags and stored at approximately 36 ºF for 60 days. Materials were direct seeded into greenhouse starter trays with diurnal temperatures of 80° F days and 50° F nights and 14 hour photoperiods. Seedling emergence was limited and rate of growth slow. For greenhouse forced materials, vegetative divisions use similar environmental photoperiods and diurnal temperatures listed above. Tissue culture and plant regeneration protocols have been developed for blank needlerush.

Figure 4: Black needle rush marsh at Harbor View, Peace River.
Source: W. Gray, SWFRPC May 14, 2010

Figure 5: Black needle rush marsh on the Myakka River.
Source: W. Gray, SWFRPC, January 13, 2012

Figure 6: Black needle rush marsh at Bonita Bay North, Spring Creek, Estero Bay.
Source: W. Gray, SWFRPC, March 8, 2011

Figure 7: Black needle rush marsh patch as part of a high marsh, Little Pine Island, Matlacha Pass.
Source: J. Beever, SWFRPC September 28, 2011

Leather Fern Marsh

Proceeding up the salinity gradient the low and middle marshes of the CHNEP become leather fern marshes. Both the golden leather fern, (*Acrostichum aureum*)and the giant leather fern, (*Acrostichum danaeifolium*)are found in these marshes. Other components of these leather fern marshes are pond apple (*Annona glabra*), salt tolerant cattails (*Typha domingensis*) and Jamaica swamp grass, (*Cladium mariscus* ssp. *jamaicense*)(FWS 1999).

Leather fern marsh is found in all the watersheds of the CHNEP. The largest extents are found in the middle and upper reaches of the Peace River and the Caloosahatchee River. It is also common on Myakka River and the tributaries of Estero Bay. Leather fern is the eighth most common salt marsh type in the CHNEP comprising 3.1% of all salt marsh extents.

Leather fern marsh occurs at an average elevation of 0.45±0.29 meters (1.46 ± 0.96) feet with a minimum elevation of 0.00 meters or mean tide and a maximum elevation of 2.20 meters (7.23 feet). This wide range reflects that leather fern marsh is found in all marsh hydrogeomorphic settings of the CHNEP from waterfront fringing marshes to middle marsh peat platforms to the waterward edge of high marsh to the landward edge of high marsh.

*Acrostichum aureum***,** the golden leather fern, is a large understory fern that occurs in monotypic marshes, within lower elevation mangrove forests and other estuarine wetlands. In the continental United States, *Acrostichum aureum* is restricted to estuarine wetland areas in south and southwestern Florida. Plants measure approximately 1.2 - 1.8m (4 - 6 feet) in height and are as broad as they are tall. Fronds are usually arching around the periphery of the plant, but tend to be more erect near the center. The thick, leathery leaves are compound and large, measuring over 1m (3.3 feet) in length, and 12 - 50 cm (4.8 - 19.7 inches) in width. There are 24 - 30 pairs of alternate leaflets (pinnae) that are non-overlapping, rounded at the tips, and measure approximately 10 - 34 cm (3.9 - 13.3 inches) in length X 1.3 - 7 cm (0.5 - 2.8 inches) in width. Leaves are shiny and typically dark green above, but paler on the leaf underside. Leaf margins are somewhat uneven and wavy in appearance. No sori are present as in other ferns. Rather, sporangia are distributed over the entire underside of reproductive pinnae (the most distal 5 or more pairs), lending a felt-like texture to these leaves. Sporangia are brick red to rust red in color, with spores measuring 37 - 72 µm in diameter. Additionally, not all pinnae on a frond are reproductive. In *A. aureum*, only 5 -8 pairs of pinnae at the tip of a frond are reproductive. This feature helps distinguish *A. aureum* from another Florida congener, the giant leather fern, *A. danaeifolium*.

Spore germination in the golden leather fern tends to be higher in less saline substrates (Lloyd and Buckley 1986). The growth rate is moderate (Medina et al. 1990). *Acrostichum aureum* is halophytic, but generally requires fresh water for it to become established and grow optimally. It does not grow in areas where soil salinity exceeds 50 ppt, nor does it grow on arid coastlines (Medina et al. 1990). Salinity is the primary environmental stressor and regulator of plant development (Medina et al. 1990). High salinity levels induce changes in plant height, leaf size, and the osmotic pressure of leaf cell sap. Several authors (Tomlinson 1986; Walter 1973) reported that *A. aureum* grows optimally on somewhat elevated grounds that are well protected from frequent tidal influx and have high rainfall, which tends to desalinate upper soil layers.

Two growth forms are recognized. A large form grows to 4m (13.1 feet) in height and is generally confined to the margins of mangrove forests, where it is frequently inundated with freshwater from heavy rainfall. The other form is stunted, growing less than 1m (3.3 feet) in height and inhabiting areas where tides inundate the soil 10 - 28 times per month (Medina et al. 1990).The golden leather fern grows well in nearly all light conditions, from full sun to dense shade (Medina et al. 1990). Maximum rates of productivity, development, and reproductive capacity are observed under full sun exposure; however, *Acrostichum aureum* is highly shade-tolerant and takes advantage of decreased evaporative rates in shade to reduce salt stress in estuarine environments (Medina et al. 1990).In some parts of the World, they have been considered a vegetative pest that interferes with growth and regeneration of mangrove trees (Medina et al. 1990).

Acrostichum danaeifolium, the giant leather fern, is similar in appearance to the golden leather fern, but grows larger, with fronds generally 2m (6.6 feet) or more in length and pinnae set closer together. A more definitive characteristic is the presence of reproductive pinnae on fronds. In *A. aureum*, reproductive pinnae are found only distally, whereas in *A. danaeifolium*, pinnae are reproductive throughout the frond (Lloyd and Greg 1975). The giant leather fern is the more common of the two leather ferns.

Figure 8: Giant leather fern marsh on Popash Creek, Caloosahatchee River.
Source: W. Gray. SWFRPC, October 18, 2010

Figure 9: Leather fern marsh on Caloosahatchee Creek Preserve.
Source: W. Gray. SWFRPC, November 9, 2010

Figure 10: Frost burned leather fern marsh on Hancock Creek, Caloosahatchee River.
Source: J. Beever, SWFRPC, December 21, 2010

Saltmarsh Bulrush

As the salt marshes are significantly influenced by freshwater, an oligohaline saltmarsh bulrush (Schoenoplectus robustus) marsh forms containing a distinct flora composition and ecological role. These plant communities contain a mixture of estuarine plants and plants typically considered to be freshwater plants that tolerate moderate to low salinities. Typical species of these oligohaline marshes are leather ferns, black needlerush, cattails (*Typha domingensis*), sawgrass (*Cladium jamaicense*), bulrush (*Scirpus robustus*), and spider lily (*Hymenocallis palmerii*).

Saltmarsh bulrush marsh was found only in the Peace River watershed and its tributaries. Saltmarsh bulrush is found as a component of high marsh but does not form a dominant marsh type elsewhere in the CHNEP. Leather fern is the ninth most common salt marsh type in the CHNEP comprising 2.3% of all salt marsh extents.

Saltmarsh bulrush marsh occurs at an average elevation of 0.28±0.16 meters (0.91 ± 0.52) feet with a minimum elevation of 0.00 meters or mean tide and a maximum elevation of 0.89 meters (2.93 feet). This narrow range reflects that saltmarsh bulrush is a low marsh type restricted to the oligohaline headwaters of the Peace River and Shell Creek. There are areas of transition from black needle rush marsh where the saltmarsh bulrush with reticulate blended areas in both riparian systems.

Figure 11: Saltmarsh bulrush on Shell Creek.
Source: W. Gray, SWFRPC, February 29, 2012

Figure 12: Saltmarsh bulrush on Peace River.
Source: W. Gray, SWFRPC, March 26, 2012

The High Marshes

High marsh communities are typically located on higher elevations above mean high water and are not regularly flooded by tides (Montague and Wiegert 1990). The fully expressed high marsh ecosystem is expressed as a series of parallel banded associations with characteristic vegetation and structure. These patterns can repeat and be symmetric if elevational differences repeat in progression from the sea to uplands to sea on an island or peninsula. These bands follow an elevational gradient that often is reflected in changes in substrate associated with vegetation contributions, or lack thereof, to surface soils.

The mixed, or combined, high marsh is the most common form of salt marsh in the CHNEP. It is comprised of six different salt marsh types. Not all high marsh communities possess all six types

The classical vegetative pattern from waterward to landward is: high salt marsh-mangrove transition with a black mangrove shrub layer; then high marsh algal marsh lacking vascular plants; then high marsh saltern (salt pan, salinas, white zone) completely lacking in any form of plants; then high marsh dominated by succulents including glasswort and saltwort, then high marsh with mixed vegetation of both herbaceous and grass components; then high marsh dominated by salt grasses, key grass, knotgrass and then high marsh with a shrub layer of buttonwood, salt bush, and marsh elder. This classic pattern is found in large marsh extents flanking Charlotte Harbor on the Cape Haze peninsula and the east wall of the Harbor and eastern Estero Bay including the Hendry Creek watershed.

In the CHNEP salterns are found in association with all salt marsh communities, but are more common and extensive on the mainland fringes of Estero Bay and Charlotte Harbor (Montague and Wiegert 1990).These barrens are often bordered by highly salt-tolerant plants (Stout 1984, Callaway et al. 1990, Wiegert and Freeman 1990, Clewell 1997, Nomann and Pennings 1998, Pennings and Richards 1998) including saltworts, glassworts and *Juncus* spp. (FWS 1999). As typically well-drained areas, salterns should not be confused with salt ponds, which hold standing water in high-latitude marshes (Pennings and Bertness 2001).

Shrub Mangrove Marsh

A distinctive type of high salt marsh in South Florida occurs in association with black mangroves (*Avicennia germinans*) at the landward side of uniform shrub mangrove forests that have continuous canopy coverage. In this marsh type, bare areas of sands, muds, marls, exposed limerock and halophytic marsh vegetation growing in deep marl soils in association with small regions of peat accumulations that support black mangrove (Schomer and Drew 1982). Usually these conditions can be optimal for black mangrove overgrowth, but in areas where black mangroves are not overly dense for a variety of reasons, there are bare areas or halophytic species like *Batis*, *Distichlis*, and *Sarcocornia* flourish. Severe cold fronts or freezes kill or inhibit black mangrove growth, allowing salt marsh vegetation to expand. In southwest Florida, this salt marsh transition community is found in waters protected from high wave energy typically by large buffers of basin black mangrove forest with waterward red mangrove fringes or mixed mangrove fringes. It is found on the landward side of shallow sedimentary estuaries behind barrier islands. Along the southwest coast and in the Ten-Thousand Island-Everglades region, this marsh type is often interspersed as pockets in mangrove transitional areas. This salt marsh type is found in all the watersheds of the CHNEP with the exception of Dona and Roberts Bay. The marsh type appears to be more extensive south to the Ten Thousand Islands and Everglades where marl and limerock exposures become more prevalent..

The largest extents of shrub mangrove marsh are found on the mainland shore high marshes of Matlacha Pass, Charlotte Harbor, and Estero Bay. It becomes uncommon the more northern watersheds. This may relate to changes in shoreline steepness and the lack of marl and rock substrates in these areas. Shrub mangrove marsh is the fourth most common salt marsh type in the CHNEP comprising 8.1% of all salt marsh extents.

Shrub mangrove marsh occurs at an average elevation of 0.38±0.16 meters (1.23 ± 0.54 feet) with a minimum elevation of 0.00 meters or mean tide and a maximum elevation of 1.33 meters (4.38 feet). This wide range reflects that shrub mangrove marsh is found in association with large mangrove forests in combination with certain substrate types that reduce canopy coverage.

Avicennia germinans, the black mangrove, is a species of flowering plant in the acanthus family, *Acanthaceae. A. germinans* grows in tropical and subtropical regions of the Americas, on both Atlantic and Pacific coasts, and on the Atlantic coast of tropical Africa, where it thrives on the sandy and muddy shores that seawater reaches. It can grow to heights of 15 m (49 ft) in the tropics, but becomes small and shrub-like at the northern limits of its range. Black mangrove is common throughout coastal areas of Texas and Florida, and ranges as far north as southern Louisiana and coastal Georgia in the United States. Like many other mangrove species, it reproduces by vivipary. Seeds are encased in a fruit, which reveals the germinated seedling when it falls into the water. It does not grow on prop roots, but possesses pneumatophores that allow its roots to breathe even when submerged. It is a hardy species and expels absorbed salt mainly from its leathery leaves.

The name black mangrove refers to the color of the trunk and heartwood. The leaves often appear whitish from the salt excreted at night and on cloudy days. It is often found in its native range with the red mangrove (*Rhizophora mangle*) and the white mangrove (*Laguncularia racemosa*). White mangroves grow inland from black mangroves which themselves grow inland from red mangroves. The three species work together to stabilize the shoreline, provide buffers from storm surges, trap debris and detritus brought in by tides, and provide feeding, breeding, and nursery grounds for a great variety of fish, shellfish, birds, and other wildlife.

The seeds germinate in midsummer, but may be seen all year on the trees. The seeds can remain viable for over a year, once released.

The heartwood is dark-brown to black, while the sapwood is yellow-brown. It has the unusual property of having less dense heartwood than sapwood. The sapwood sinks in water while the heartwood floats. The wood is strong, heavy, and hard.

Figure 13: Shrub Mangrove High Marsh, Bunche Beach High Marsh, Matanzas Pass, Estero Bay.
Source: J. Beever, SWFRPC, May 7, 2010

Algal Salt Marsh

Within the black mangrove shrub high marsh and landward of it mud barrens and marl pools form in depressions of the high marsh and retain water even during low tide. The salt marsh algae community consists of mud/marl algal flats dominated by several hundred species of benthic microalgae, phytoplankton, and some multicellular seaweed (Pomeroy et al.1981, Wiegert and Freeman 1990, Montague and Wiegert 1990).

Algal salt marsh is found in all the watersheds of the CHNEP with the exception of Dona and Roberts Bay. Algal salt marsh is most common in the Estero Bay watershed where there is an extensive circular marsh on the west side of Hendry Creek, and Charlotte Harbor in the Cape Haze peninsula. Both these areas have a similar geomorphic position in their estuaries with large rounded peninsulas extending north to south. It does not form a large expanse, existing more as a linear band paralleling the shoreline inland elsewhere in the CHNEP. Algal salt marsh is the third most common salt marsh type in the CHNEP comprising 8.4% of all salt marsh extents.

Algal salt marsh occurs at an average elevation of 0.35±0.19 meters (1.15 ± 0.62) feet with a minimum elevation of 0.00 meters or mean tide and a maximum elevation of 2.65 meters (8.70 feet). This wide range is the result of the algal salt marsh being located in both low depressions within basin marshes and sometimes at the top side of a high marsh or the center of a drowned island.

While the total biomass of vascular plants in salt marshes most likely outweighs that of many algal species, algae may be more productive as a whole. Algae growth and decay is more rapid, and organisms can assimilate energy from algal communities more quickly than vascular plants, which often must be broken down by bacterial processes prior to consumption (Adam 1990). In addition to macroalgae providing a habitat and food source for fishes and detrital consumers like snails and fiddler crabs, and filter feeders such as bivalves. Microalgae also play an important role in salt marsh ecosystems. A variety of filter feeders and zooplankton feed on phytoplankton, and benthic diatoms and cyanobacteria form mats that stabilize sediment on mud flats, possibly allowing subsequent colonization of salt marsh vegetation (Coles 1979). The species composition of marsh algae is dependent upon environmental factors like tidal amplitude, local topography, erosion of sediments, and the availability of light and nutrients. Although total species composition is not yet known for Florida salt marshes, common species include the diatoms *Cylindrotheca*, *Gyosigma*, *Navicula*, and *Nitzschia*, filamentous cyanobacteria *Anabaena*, *Microcoleus*, *Schizothrix*, red algae *Caloglossa* and *Bostrychia*; blue-greens *Lyngbya* and *Rivularia*, and green algae *Rhizoclonium*, *Ulva*, and *Enteromorpha* (Hustedt 1955, Pomeroy et al. 1981, Montague and Wiegert1990, Wiegert and Freeman 1990).

Figure 14: High Marsh Algae Estero Bay Preserve Park.
Source: W. Gray, SWFRPC, February 24, 2011

Saltern

Salterns, salt pans, shallow pannes, or salt barrens are bare, exposed, or water-filled depressions in a salt marsh **(**Montague and Wiegert 1990). Salterns form in low-latitude marshes where high soil salinities of up to 100 ppt or greater create bare patches devoid of vegetation. Salterns are prevalent throughout Florida marshes, but are most common along the southwest coast. True salterns of the CHNEP completely lack any vegetation whatsoever. The wide range of salinities experienced at the salt pans prevents most vascular vegetation growth, allowing at most only a few hardy salinity tolerant species like saltworts and glassworts to survive. Sand barrens typically form in the high marsh where evaporation of seasonally accumulated tidal saltwater concentrates large amounts of salts in the substrate. Pans are important habitat for migratory birds, especially shorebirds and waterfowl. Some pans are now associated with human caused retentions and restrictions of tidal flows, where man has impeded natural hydrology or sheet flow by building dams, levees, or impoundments.

Salterns are found in all the watersheds of the CHNEP with the exception of Dona and Roberts Bay. Salterns are most extensive in the Charlotte Harbor, Estero Bay and Pine Island Sound watersheds. This is likely due to a combination of two factors. First these are the least impacted salt marshes in the CHNEP with areas that do not have mosquito control ditches or filling and excavation of the high marsh by prior human development before these marshes were included in preservation land acquisitions. Second the marshes in these watersheds have the most gradual relative elevational lift over a wide area of shoreline. The steeper shore profiles in Sarasota County mad up tributaries to rivers eliminates the opportunity space for salterns to form trapped tidal waters evaporation. Saltern is the sixth ninth most common salt marsh type in the CHNEP comprising 4.4% of all salt marsh extents.

Saltern occurs at an average elevation of 0.38±0.21 meters (1.26 ± 0.69) feet with a minimum elevation of 0.00 meters or mean tide and a maximum elevation of 0.4.2 meters (13.77 feet). This extreme range for saltern occurrence reflects that salterns form whenever saltine waters can be trapped and concentrated. Low elevation salterns form on drowned islands and basin depressions above black mangrove forests, while the highest salterns are created by human barriers that entrap salt water at the very top of the extreme tidal gradient.

Figure 15: Saltern, Bunche Beach Marsh, Matanzas Pass. Estero Bay.
Source W. Gray, SWFRPC. May 21, 2010

High Marsh Meadows

This salt marsh community tends to be at slightly higher elevations and occurs in three forms: succulents only zone characterized by glasswort, saltwort, and sea purselanes; a mixed community of grasses and succulents with the highest plant species diversity of any salt marsh type, and a grass dominated form with one of more of high marsh grasses saltgrass (*Distichlis spicata),* key grass (*Monanthachloe littoralis*), seashore paspalum (*Paspalum vaginatum*), Baker's or sand cordgrass (*Spartina bakeri*), saltmeadow cordgrass (*Spartina patens*), and seashore dropseed (*Sporobolus virginicus*).

Mixed high marsh meadow, succulent meadows and grassy high marsh meadows are found in all the watersheds of the CHNEP with the exception of Dona and Roberts Bay. Mixed high marsh meadow is the most common type of salt marsh found in the CHNEP comprising 38.9% of all salt marsh extents.

Mixed high marsh meadow occurs at an average elevation of 0.42±0.22 meters (1.39 ± 0.71 feet) with a minimum elevation of 0.00 meters or mean tide and a maximum elevation of 1.47 meters (4.83 feet).

Succulent high marsh meadow occurs at an average elevation of 0.50±0.23 meters (1.64 ± 0.77) feet with a minimum elevation of 0.00 meters or mean tide and a maximum elevation of 2.04 meters (6.70 feet).

Grassy high marsh meadow occurs at an average elevation of 0.49±0.22 meters (1.61 ± 0.71 feet) with a minimum elevation of 0.00 meters or mean tide and a maximum elevation of 1.74 meters (5.7 feet).

Figure 16: Mixed meadow high marsh of saltmeadow cordgrass and sea ox-eye daisy, Deep Lagoon Preserve, Cow Pen Slough.
Source: Whitney Gray, SWFRPC, April 28, 2010

Distichlis spicata is a species of grass known by several common names, including seashore saltgrass, inland saltgrass, and desert saltgrass. This grass is native to the Americas, where it is widespread. It can be found on other continents as well, where it is naturalized

Distichlis spicata thrives along coastlines and on salt flats and disturbed soils, as well as forest, woodland, montane, and desert scrub habitats. It can form dense monotypic stands, and it often grows in clonal colonies. Non-clonal populations tend to be skewed toward a majority of one sex or the other. The grass forms sod with its hearty root system. *Distichlis spicata* is a hardy perennial with rhizomes and sometimes stolons. It is an erect grass which occasionally approaches half a meter in height but is generally shorter. The solid, stiff stems have narrow leaves up to 10 centimeters in length, which may be crusted with salt in saline environments. Its rhizomes have sharp points which allow it to penetrate hard soils and aerenchymous tissues, which allow it to grow underwater and in mud. This plant grows easily in salty and alkaline soils, excreting salts from its tissues via salt glands.

Flowers are an inconspicuous yellow and bloom in mid-summer. This species is dioecious, meaning the male flowers and female flowers grow on separate individuals. The pistillate inflorescence may be up to 8 centimeters long, with green or purple-tinted spikelets. The staminate flowers look quite similar, thinner but larger overall and denser. The flower parts of both sexes may be bright pinkish-purple. Fruit in summer with a seed color is brown, Growth rate is slow. The active growth period is Spring, Summer, and Fall, It has a high C: N ratio in it s stems. Mature height is 1.1 feet. It has a long lifespan. It has a high tolerance to anaerobic conditions and $CaCO_3$. Root depth is 2 inches. The precipitation min/max is 5 inches/70 inches. pH min/max is 6.4/10. Temperature, Minimum is -35(°F). The number of Frost Free Days, Minimum is 80.The National Wetland Indicator status is FAC+, FACW+.

Under favorable soil and moisture conditions, studies have shown saltgrass favorable for pastures irrigated with saline water. The total dry matter yields were 9,081 kg/ha with a total protein production of 1,300 kg/ha. Saltgrass is grazed by both cattle and horses and it has a forage value of fair to good because it remains green when most other grasses are dry during the drought periods and it is resistant to grazing and trampling. It is cropped both when green and in the dry state; however, it is most commonly used the winter for livestock feed. Saltgrass along the Atlantic coast was the primary source of hay for the early colonists. (USDA Plants Database, Plant Profile 2007).

Key grass, *Monanthachloe littoralis,* is a perennial salt marsh grass with stolons or runners present, Stems are trailing, spreading or prostrate, Stems nodes are swollen or brittle, Stems are erect or ascending, Stems are geniculate, decumbent, or lax, sometimes rooting at nodes, Stems are caespitose, tufted, or clustered, Stems are terete, round in cross section, or polygonal, Stem internodes are hollow, Stems have an inflorescence less than 1 m tall, Stems, culms, or scapes exceeding the basal leaves, Leaves mostly cauline, Leaves conspicuously 2-ranked, distichous, Leaves sheathing at base, Leaf sheath mostly open, or loose, Leaf sheath smooth, glabrous, Leaf sheath and blade differentiated, Leaf blades very short, 0.5-2 cm long, Leaf blades subulate, needle-like, tip pungent, Leaf blades very narrow or filiform, less than 2 mm wide, Leaf blade margins folded, involute, or conduplicate, Leaf blades mostly glabrous, Ligule present, Ligule a fringe of hairs, Inflorescence terminal, Inflorescence solitary, with 1 spike, fascicle, glomerule, head, or cluster per stem or culm, Inflorescence a single spikelet, Flowers unisexual, Plants are dioecious, Spikelets pedicellate, Spikelets dorsally compressed or terete, Inflorescence or spikelets partially hidden in leaf sheaths, subtended by spatheole, Spikelet less than 3 mm wide, Spikelets with 2 florets, Spikelets with 3-7 florets, Spikelets solitary at rachis nodes, Spikelets unisexual, Spikelets disarticulating below the glumes, Glumes completely absent or reduced to cuplike structure, Lemma coriaceous, firmer or thicker in texture than the glumes, Lemma 8-15 nerved, Lemma glabrous, Lemma apex acute or acuminate, Lemma awnless, Lemma straight, Palea present, well developed, Palea membranous, hyaline, Palea about equal to lemma, Palea 2 nerved or 2 keeled, Palea keels winged, scabrous, or ciliate, Stamens 3, Styles 2-fid, deeply 2-branched, Stigmas 2, Fruit - caryopsis.

Baker's cordgrass, *Spartina bakeri*, also known as sand cordgrass, is a robust bunchgrass that can form clumps that are 18 to 20 feet in diameter and up to 3 to 4 feet tall. Its fine-textured, wiry leaves form a fountain spray pattern. The upper surfaces of the 1/4 in. wide leaves are dark green, but the lower surfaces are light green in color. Its long erect light-green leaves are almost completely rolled and tapered to sharp points making it look somewhat rush-like. The alternate leaves are sandpapery on the upper side. The leaves become tan and then brown in the autumn. It blooms from spring to fall. The obscure flowers of this plant may occur in the early spring but are relatively scarce. The inflorescence is 2-8 in. long, comprised of 3-14 branches that ascend near the axis; flowers are conspicuous, only on the undersides of the branches; spikelets flattened. The plant reproduces mainly by rhizomes. It has soil tolerances for extended flooding; acidic; slightly alkaline; sand; loam; clay and a high drought tolerance. Salt tolerance is for moderate salinities. It prefers full sunlight. This cord grass is frequently found growing in brackish marshes but also will extend into fresh marshes, hydric pine flatwoods, wet prairies, and lake and borrow pit lake margins (Wunderlin 2003) and usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.The seeds are important wildlife food.

Saltmeadow cordgrass, *Spartina patens***,** also known as salt marsh hay, is a species of cordgrass native to the Atlantic and Gulf coast of the Americas, from Newfoundland south along the eastern United States to the Caribbean and northeast Mexico. It can be found in marshlands in other areas of the world as an introduced species and often a harmful noxious weed. It is a hay-like grass found in the upper areas of brackish coastal salt marshes. It is a slender and wiry plant that grows in thick mats 30-60 cm high, green in spring and summer, and turns light brown in late fall and winter. The stems are wispy and hollow, and the leaves roll inward and appear round. Because its stems are weak, the wind and water action can bend the grass, creating the appearance of a field of tufts and cowlicks. Saltmeadow cordgrass produces flowers and seeds on only one side of the stalk. Flowers are a deep purple from June to October and turn brown in the winter months. Saltmeadow cordgrass is found in high marsh zones where it is covered at times by high tides. Specialized cells are able to exclude salt from entering the roots, preventing the loss of fresh water. This grass is, however, less tolerant of saltwater than some other marsh grasses. These grasses provide rich habitat for crustaceans, mollusks, and birds, and serve as a major source of organic nutrients for the entire estuary. Mats of saltmeadow cordgrass are inhabited by many small animals and are an important food source for ducks and Seaside Sparrows. Saltmeadow cordgrass marshes serve as pollution filters and as buffers against flooding and shoreline erosion. During the colonial era, towns scattered from Narragansett Bay to the Gulf of Maine were often settled based on their proximity to salt marshes due to the importance of saltmeadow cordgrass for fodder. It was harvested for bedding and fodder for farm animals and for garden mulch. Before hay was baled and stored under cover, it was used to top the hay stacks in the fields.

Seashore dropseed**,** *Sporobolus virginicus*, is a rhizomatous perennial with lanceolate, spine-tipped leaf-blades growing 15-50 cm tall, erect, from creeping, hard, scaly rhizomes. *Sporobolus virginicus* is known by numerous common names including seashore dropseed, sacaton, marine couch, sand couch, coastal rat-tail grass, salt couch grass, saltwater couch and nioaka, Inflorescence dense, spikelike, up to 15 mm wide with short appressed branches and pale spikelets (Napper, 1965). Leaf- blades usually rolled inward, distinctly two ranked, 3-10 cm long and 1.5-4 mm broad; sheaths mostly overlapping, glabrous except for a few long hairs on either side of the collar The inflorescence is a contracted panicle, spicate, densely flowered; .Spikelets are straw-colored, grayish, or purple tinged, glabrous, shining .The panicle is shorter than many other Sporobolus spp., being not more than 7.5 cm long (Parham, 1955). Its flowers are green or purple from May to October and occasionally to December. It reproduces asexually by use of both stolons and rhizomes. It produces seed several times throughout the year. Fruit is a cryopsis. A caryopsis is a type of simple dry fruit, one that is monocarpelate (formed from a single carpel) and indehiscent (not opening at maturity) and resembles an achene, except that in a caryopsis the pericarp is fused with the thin seed coat. The caryopsis is popularly called a grain and is the fruit typical of the family *Poaceae* (or *Gramineae*).It has a wide range of soils, from clays to sands. It grows on highly saline marsh soils. It makes some growth all the year. It does best if the water level fluctuates from 5 cm above the soil surface to 15 cm below (Leithead, Yarlett and Shiflet, 1971). Prolonged inundation kills it.

Figure 17: High Marsh Meadow Grasses South Spreader Canal, Matlacha Pass.
Source: W. Gray, SWFRPC August 3, 2011

Figure 18: High Marsh Meadow Grasses Sanibel-Captiva Conservation Foundation.
Source: J. Beever, SWFRPC October 13, 2011

Batis maritima (Saltwort, Turtleweed, Beachwort, Pickleweed, Barilla, Planta de Sal, Camphire, Herbe-à-crâbes, and Akulikuli-kai,) is a species of is a evergreen low growing, yellow-green shrub with succulent leaves halophytic flowering plant, native to the coastal salt marshes of warm temperate and tropical. It is prostrate where colonizing new mud or sand, but once rooted, growing bushy 10-100 cm tall, 2 m in lateral extent, and 5 cm in basal diameter. Stems are usually multiple as sprouts from the root crown, and as they become tall and heavy, lie down and root along the stems forming loose mats. Weak roots with light-tan, corky bark form tap and lateral root systems. The bark is grayish white; stem wood is weak and brittle. The glabrous leaves are succulent, linear or narrowly oblanceolate and round or three- to four-angled in cross section. They are bright green, but can also take on a reddish color. The species is dioecious. Tiny, white to yellow-white male and female flowers occur on different plants. The flowers are small, produced in non-showy spikes, flowering from mid-summer to fall. In Florida, saltwort flowers in the spring and fruits in the summer (Long and Lakela 1976). Flowering and fruiting occurs year round in Puerto Rico. Little is known about seed production or germination. Most effective reproduction of the species appears to be vegetative. Sprouting from the root crown occurs with and without disturbance. Layering is a constant process of prostrate stems. New plants can be started by cuttings and probably broken pieces of plants are carried to new habitat by water and machinery. Fruits are axillary drupaceous, yellow-green syncarps 1 to 2cm long (Liogier 1985, Stevens et al. 2001)Some botanists divide *B. maritima* into five species, with *B. californica*, *B. fruticosa*, *B. spinosa* and *B. vermiculatus* split off, but this interpretation is not widely followed.

Batis has the ability to live in salty environments. When other plants are exposed to salty soil or water, they lose most of their stored water, but *Batis* has adapted to this environment and does not have these problems. To help it survive in this salty habitat, its fleshy leaves are covered with very fine hairs that reduce the amount of water the plant loses to the air. Saltwort is uncommon to abundant in low-laying areas near seashores. It grows in salt marshes, at the upper edge of tidal flats, at the edge of mangrove stands, and between scattered mangroves. It is recognized as a major colonizer after mangroves are destroyed by hurricanes. Although it is not a water plant, it can endure brief flooding and long periods of waterlogged soils (Nelson 1996). Saltwort grows slowly in soils with high salt concentrations and areas with seawater overwash where it suffers little competition from other plants. The species manages salts by sequestering them in cell vacuoles and eventually shedding the leaves (Barbuda Turf Company 2002). It also grows in soils without salt but is vulnerable to competition from non-halophytes. The soils are usually sandy, marly, or gravely. Deposits of wrack (dead plant material) by high tides have been shown to be beneficial to the species (Pennings and Richards1998). Saltwort is intolerant of shade. The species is not seriously affected by insects, disease, or grazing. The species is not seriously affected by insects, disease, or grazing. Not many animals can eat it because it is too salty, but white-tailed deer eat *B. maritima* as part of their diet, treating it as a salt lick. Saltwort serves as the larval and adult hosts for the great Southern white and Eastern pigmy blue butterflies (Florida Cooperative Extension Service 2002). *B. maritima* is becoming rare in some areas, and some scientists think it should be added to the United States endangered species list. *B. maritima* was used by Native Americans as a food; the roots were chewed (like sugar cane) or boiled into a beverage while the stems and leaves were eaten raw, cooked or pickled. Saltwort has unexpectedly turned out to be a nutritious food source. An analysis of its peppercorn-sized seeds has revealed that they are extremely nutritious, having high quantities of proteins, oils and starches. According to Massimo Marco from an article published by New Scientist, the seeds are extremely edible, having a nutty taste, and they can be added to salads, toasted, or even made into miniature popcorn. The oil is almost identical to safflower oil, which is used for cooking and in salad dressings, as well as for making margarine. The seeds also contain beneficial antioxidants such as tocopherols, which are thought to fight cancer.

Figure 19: Succulent marsh high marsh, Estero Bay Preserve Park.
Source: W. Gray SWFRPC. February 14, 2012.

Limonium carolinanum, (Sea lavender, Canker root, ink root, marsh root, American sea lavender, seaside thrift, Marsh Rosemary) is a perennial plant growing up to 6 to 24 inches high; branching flower stalks support small, 1 1/4 inch, delicate purple flowers. Dark green, leathery, spoon-shaped leaves surround the base of the plant in rosettes. 5-25(-40) cm; petiole often narrowly winged distally, 0.1-20 cm, usually shorter than blade; blade usually elliptic, spatulate, or obovate to oblanceolate (rarely linear), 5-15(-30) × 0.5-5(-7.5) cm, leathery, base gradually tapered, margins usually entire, sometimes undulate, apex rounded or acute to retuse, cuspidate, cusp 1-3 mm, soon falling; main lateral veins ascending, obscurely pinnate. The leaves of the sea lavender grow upward along its stem in sheaths, forming a tubular envelope that surrounds the stem. The sheath causes the flower to appear alternately and delicately arranged. The entire plant turns brown in the fall and winter. Inflorescences: axes not winged, 10-60(-95) cm × 1-5 mm, glabrous; nonflowering branchlets absent; spikelets loosely to moderately densely aggregated along branches, internodes 0.5-10 mm; subtending bracts 2-6 mm, obtuse, surfaces and margins glabrous; flowers solitary or 2-3(-5) per spikelet. Flowers: Its branches produce small, fragrant, pale purple flowers along one side. Sea lavender flowers originate from basal leaves that rise up directly from the plant's roots. calyx whitish, obconic, 4-6.5(-7.5) mm; tube 2.5-5 mm, glabrous or densely pilose along ribs; lobes erect, to ca. 2 × 1 mm; petals lavender (rarely white), slightly exceeding calyx. Utricles 3-5.5 mm. $2n = 36$. J. L. Luteyn (1976, 1990) discussed the more or less continuous variation in this polymorphic species. He noted that seedling establishment is rare, and that populations spread primarily by vegetative means from horizontal rhizomes. Moisture: Moist Wet. Soil pH: 6-8.5.Soil type: Clay Loamy Sandy. Salinity: 0-30 ppt

Lycium carolinianum, (Christmas berry, Carolina desert-thorn, Carolina wolfberry), *is* a small shrub that is commonly found in the southeastern United States at the edge of salt marshes and on sandy shell mounds. This 6- to 10-foot-tall shrub has rigid branches that are sharply thorn-tipped. The tiny deciduous leaves of this plant are succulent and linear to oblanceolate in shape; green, alternate, simple, entire, evergreen, less than 2 inches. Leaf venation is absent or difficult to see. There is no fall color change

The new branches may have 1-centimeter-long thick spines, or be unarmed; older branches, however, are spiny. The bisexual flowers are solitary in the leaf axils and are borne on slender flower stalks. Flowers are blue; white, yellow, or lavender and have purple streaks. They are summer flowering to fall flowering Flowers are bee pollinated. The flowers are followed by large, bright, lustrous red oval, 3 to 6 inches long, fleshy berries that ripen in late autumn or early winter. Birds love to eat the ripe berries. It resembles a tomato and was eaten raw or dried by Native Americans. It is relished by whooping cranes and other wild fowl. *Lycium carolinianum* contributes 21-52% of crane energy intake early in the wintering period Fruit can be eaten by humans raw or cooked. Rather pleasant eating, the fruit has a slightly salty taste. The fruit is a berry up to 12mm in diameter. Only the fully ripe fruits should be eaten. The fruit is a very rich source of vitamins and minerals, especially in vitamins A, C and E, flavanoids and other bio-active compounds. It is also a fairly good source of essential fatty acids, which is fairly unusual for a fruit. It is being investigated as a food that is capable of reducing the incidence of cancer and also as a means of halting or reversing the growth of cancers. The Christmas berry is very tolerant to salt spray and drought conditions. In addition to its native sandy dune habitat, Christmas berry can be found naturally along the edges of ponds, salty marshes and waterways. On a well-drained or wet site that receives full sun or partial shade. Plants drop leaves in dry weather as a drought avoidance mechanism, but the next wet period bring new leaves. Growth is thin and the plant forms an open canopy in the shade. Suckers regularly form at the base of the trunks, creating a multi-trunked thicket. New plants develop from secondary branches and the whole plant moves itself along the ground. It grows well in semi-shade, and prefers high levels of water. This plant requires a minimum of 250 frost free days to grow successfully. It has no drought tolerance.

Lycium carolinianum grows in soils ranging from a pH of 5.5 (very acidic ranges from 5.2 to 5.5) to 9 (very alkaline ranges from 8.6 to 9). It is adapted to clay, silt, sand, loam, silty clay, sandy clay, clay loam, silt loam, sandy loam, loamy sand, silty clay loam and sandy clay loam soils, and prefers low fertility.

Salicornia is a genus of succulent, halophyte (salt tolerant) plants that grow in salt marshes, on beaches, and among mangroves. *Salicornia* species are native to North America, Europe, South Africa, and South Asia. Common names for the genus include glasswort, pickleweed, and marsh samphire**.** The common name glasswort came into use in the 16th century to describe plants growing in England whose ashes could be used for making soda-based (as opposed to potash-based) glass (OED 2007). The Salicornia species are small, usually less than 30 cm tall, succulent herbs with a jointed horizontal main stem and erect lateral branches. The leaves are small and scale-like and as such the plant may appear leafless. Many species are green, but their foliage turns red in autumn. The hermaphrodite flowers are wind pollinated, and the fruit is small and succulent and contains a single seed.

Salicornia species can generally tolerate total immersion in salt water. They use the c4 pathway to take in carbon dioxide from the surrounding atmosphere.

Figure 20: Annual glasswort , Estero Bay Preserve Park.
Source W. Gray, SWFRPC. February 14, 2012.

Figure 21: Perennial glasswort, Shell Point Preserve
Source W. Gray, SWFRPC. May 20, 2010.

Salicornia species are used as food plants by the larvae of some Lepidoptera species including the *Coleophora* case-bearers *C. atriplicis* and *C. salicorniae* (the latter feeds exclusively on *Salicornia spp*).
Salicornia virginica (American Glasswort, Pickleweed) is a halophytic perennial dicot which grows in various zones of intertidal salt marshes and can be found in alkaline flats. It is native to various regions of the Northern Hemisphere including both coasts of North America from Canada to Mexico. The plant is one of the *Salicornia* species being tested as biofuel crop as it is composed of 32% oil and being a halophyte can be irrigated with salt water. *S. virginica* is classified as an *Obligate Wetland* (OBL) species which: "Occurs almost always (estimated probability 99%) under natural conditions in wetlands".

Salicornia bigelovii is a species of flowering plant in the amaranth family known by the common names dwarf saltwort and dwarf glasswort. It is native to coastal areas of the eastern and southern United States, as well as southern California and coastal Mexico. It is an annual herb producing an erect, branching stem which is jointed at many internodes. The fleshy green to red stem can reach about 60 centimeters in height. The leaves are usually small plates, pairs of which are fused into a band around the stem. The inflorescence is a dense sticklike spike of flowers. Each flower is made up of a fused pocket of sepals enclosing the stamens and stigmas; there are no petals. The fruit is a utricle containing tiny fuzzy seeds. The southern part of the species range is represented by the Petenes mangroves of the Yucatan, where it is a subdominant plant associate in the mangroves (WWF 2010).

Both species are occasionally sold in grocery stores or appear on restaurant menus as *Sea Beans*. These plants are gaining scientific attention for the potential to serve as an oil crop that can be grown in desert environments and maintained with water containing high levels of salts. It is the source of Salicornia oil. The plant is up to 33% oil (Glenn et al. 1991). The oil contains up to 79% linoleic acid and is functionally similar to safflower oil

(Anwar et al. 2002). It can be used as cooking oil and a replacement for more valuable oils in chicken feed. Domestic animals can be fed the plant as forage (Bashan et al. 2000). The plant could also be a source of biofuel. Since the plant is a halophytic coastline species which grows in saltwater, it can be irrigated with seawater, making it a potential crop for landscapes that can support few other crop plants (Glenn et al. 1991, Bashan et al. 2000). . The plants can also be watered with high-salt drainage water, such as the effluent from farmland in California's Central Valley (Grattan et al. 2008). Fields of the plant have been grown in wastewater from aquaculture farms in Eritrea and harvested for animal feed (Dickerson 2008).

There are two sea-oxeye daiseys encountered in the marshes of the study area: *Borrichia frutescens* and *Borrichia arborescens*. *Borrichia frutescens*, sea daisy, also called sea-oxeye, is an evergreen shrub that sprouts bright yellow flowers in the spring and summer. Sea daisy is a low, erect, evergreen shrub, usually less than 4' tall. It spreads into a thick clump by rhizomes. The leaves are simple, opposite and elliptical in shape. They are about 1" to 4" long and are very thick, almost succulent. The margins are usually entire but might have coarse teeth. The leaves are covered with dense fuzz that causes the leaf surfaces to appear gray. Bright yellow flowers are at the ends of the branches, in heads about 1" across. Flower centers are darker yellow. Below the flowers are leaf-like, spiny bracts. The fruit is a flat, gray, angled four-sided achenes, about ½" long. Sea Oxeye requires full sun and is drought tolerant but will not bear over-watering or overfertilizing. It takes breakage and shearing well.

*Borrichia arborescens***,** sea ox-eye, also known as tree oxeye, silver sea ox-eye, oxeye daisy, sea daisy, seaside tansy, gull feed, clavelón de playa, and fleur-sorleil bord de mar, is an evergreen, low shrub usually 1 m or less in height with stem diameters of 1 cm, which forms mounds and mats. Older plants have numerous stems. The plants are supported by short rhizomes and a moderate number of lateral roots. The stems are gray with a white, brittle wood and a 3-mm pith. Twigs bear deep leaf scars. The foliage tends to be crowded at ends of twigs. The simple, opposite, sessile leaves are fleshy and yellow-green, light-green, or gray green, oblanceolate to spatulate, entire, and 3 to 8 cm long. The foliage is resinous and aromatic. Sea ox-eye flowers are usually solitary, terminal heads about 2.5 cm across on peduncles 2 to 5 cm long. The corolla and the ray florets are bright yellow and the disk florets are orange-yellow. The black achenes are 3 to 4 mm long with a pappus in the form of a dentate cup less than 1 mm long. The chromosome number is 2n = 28 (Howard 1989, Liogier 1997, Long and Lakela 1976, Nelson1996).*Borrichia x cubana* of southern Florida is believed to be a natural hybrid of sea ox-eye and *Borrichia frutescens* (L.) DC. (Nelson 1996).

In addition to being in the landward side of high marshes natural sea ox-eyes can also grow immediately near the seashore on sandy substrates, usually within the influence of salt spray. Because the species is low in stature, grows slowly, and is intolerant of shade, it must occupy areas with low competition from other shading vegetation. It finds these conditions on headlands, seaside rocks, dunes, beach strands, low hammocks, and the edges of mangroves and brackish high marshes. Sea ox-eye will grow in more favorable conditions if artificially protected from shade competition. Almost any soil will do, including both acid and alkaline soils. Sea ox-eye tolerates both excessively drained and poorly drained conditions. Mean annual rainfall may range from 900 to 1500 mm. It is drought resistant (Gillman 1999).

Both sea ox-eyes bloom in spring and summer in Florida (Long and Lakela 1976) and throughout the year in Puerto Rico and the Caribbean. It is pollinated by insects. Seed dispersal appears to be by water (storm surges) and strong winds. Once established, plants widen by constant layering of the semiprostrate stems. New clumps probably are established by the rooting of broken stems moved by storms. Growth of sea oxeye is slow. Branch extension is about 10 to 30cm/year. Although, stems and branches die, as long as conditions remain favorable, clonal plants may live almost indefinitely.

Figure 22: Seas ox-eye daisy in mixed high marsh, Deep Lagoon Preserve, Cow Pen Slough, Caloosahatchee River.
Source: W. Gray, April 28, 2010

Saltmarsh goldenrod, *Solidago sempervirens*, is a succulent, herbaceous perennial that reaches heights of 4–6 feet. Flowers are found in radiate heads, which make up a terminal, paniculiform inflorescence with recurved-secund branches. This species blooms in late summer and well into the fall. Its fruits are wind-dispersed achenes. *S. sempervirens* is a maritime plant, and is accordingly found along the ocean from Mexico north to Newfoundland. It is naturally found inland along the St. Lawrence Seaway and the Great Lakes, and has expanded its range further inland along roadsides over the past 30 years. It is highly tolerant of both saline soils and salt spray, and is usually found growing on coastal dunes and in salt marshes. *S. sempervirens* is a maritime plant with a high salinity tolerance. It is a poor competitor and very shade intolerant. *Solidago sempervirens* is native throughout eastern coastal North America from Newfoundland to Florida and the Bahamas. It is also native along the Gulf Coast and southward to Tobasco, Mexico. It has become naturalized in the Great Lakes regions and in the Azores. *S. sempervirens* grows naturally along roadsides, in pinewoods, coastal marshes, estuarine and bay shores and in dry to damp soils. It is a wetland species that has high saline soil and salt spray tolerance are produced below the terminal inflorescence but without the pyramidal shape. Flowering stems are from 18 inches to 10 feet tall. The mass of the inflorescence is made up of many secunds (arranged on one-side of the axis only) that are somewhat backward curving (recurving). Individual secund appear at the leaf axis. Flowering begins at the top of the inflorescence and works its way down. When laden with flowers, the stem is inclined to arch downwards at or near the ground. The flowers are quickly replaced by masses of fine white bristles known as pappi.

Seaside goldenrod pollen is too heavy and sticky to be blown far from the flowers, and is mainly pollinated by insects. It is a nectar plant for several butterfly species including the clouded sulphur, purplish copper, gray hairstreak, snout butterfly, silver bordered fritillary, pearl crescent, viceroy, wood nymph, monarch and eastern tailed blue.

Figure 23: Seashore goldenrod, Sanibel-Captiva Conservation Foundation.
Source: W. Gray, SWFRPC, October 13, 2011

Sea blite, *Sueda linearis*, is an annual herb found in the beaches, mangroves, and salt marshes of Florida, being most common in the southern part of the states. It is found in coastal plains from southern Canada, south to Florida and west to Texas. This annual plant appears in the spring, blooms in the summer, turns color in the fall and will die off in the late fall/early winter

Sea blite is a straggly, herbaceous annual with a waxy appearance. It may be reclining or erect, from 1' to 3' tall, and heavily branched. The leaves are simple, alternate, ½" to 2" long, and linear to elliptical. They are dark green and fleshy with a smooth, waxy surface and entire margins. Leaves generally lack a stem and are directly attached to the stem. The flowers are tiny, whitish, button-like blooms that appear from July to October. The fruit is a round sac containing many, glossy, black seeds. Sea blite has a succulent, somewhat woody stem that is pale green to almost white. This plant requires a salty environment and grows saltwater marshes, mangroves, and along beaches and dunes.

Native Americans in Florida used sea blite to add flavoring to foods and they ground the seeds into a flour to make bread. Both Native Americans and colonial settlers chewed the roots of the plant as a cure for diarrhea. Leaves were used to treat and bind wounds. Young leaves and stem tips are still used as culinary herbs today.

Figure 24: High Marsh Succulents on Big Panther Key, Pine Island Sound.
Source: W. Gray, SWFRPC, June 1, 2011

High Marsh Shrub Buttonwood

High Marsh Shrub Buttonwood, *Conocarpus erectus*, or Buttonwood Flats are patchily forested wetlands. The assemblage is associated with hypersaline flats susceptible to storm wash, evaporation, and subsequent hypersaline soil conditions. These flats are inhospitable to most vascular plants. Buttonwood flats are found (landward) between the lower elevation mixed, grassy, and succulent high marshes and (waterward of) tropical hammock, freshwater marshes/ wet prairies, and hydric pine flatwoods. Buttonwood, saltwort, glasswort, salt grass, seaside dropseed grass, keys grass, sea oxeyes, Christmas berry, sand cordgrass and the occasional black mangrove are typical vegetation.

Saltmarsh bulrush is found only in the Peace River watershed and its tributaries. Saltmarsh bulrush is found as a component of high marsh but does not form a dominant marsh type elsewhere in the CHNEP. Leather fern is the ninth most common salt marsh type in the CHNEP comprising 2.3% of all salt marsh extents.

Saltmarsh bulrush marsh occurs at an average elevation of 0.28±0.16 meters (0.91 ± 0.52) feet) with a minimum elevation of 0.00 meters or mean tide and a maximum elevation of 0.89 meters (2.93 feet). This narrow range reflects that saltmarsh bulrush is a low marsh type restricted to the oligohaline headwaters of the Peace River and Shell Creek. There are areas of transition from black needle rush marsh where the saltmarsh bulrush with reticulate blended areas in both riparian systems.

Conocarpus erectus is a mangrove shrub and tree in the family Combretaceae growing on shorelines in tropical and subtropical regions around the world, including Florida, Bermuda, the Bahamas, the Caribbean, Central and South America from Mexico to Brazil on the Atlantic coast and Mexico to Ecuador on the Pacific coast, western Africa and in Melanesia and Polynesia. It was introduced in Kuwait because it can thrive in high temperatures and absorbs brackish water. English common names include buttonwood, buttonbush, button mangrove, button-tree, false mangrove, Florida button, Florida buttonwood, green buttonwood, grey mangrove, sea mulberry and Zaragoza mangrove. *Conocarpus erectus* is known by a variety of other names in various localities, including asokolo, asopolo, botoncahui, botoncillo, botonillo, chene guadeloupe, conocarpe droit, estachahuite, geli, gra mangrove, grignon, grijze mangle, grijze mangrove, iztac-cuahuitl, jele, kaba, kan-chik-inche, kanche, kank-ank-che, kank-che, madre de sal, mangel, mangel blancu, mangle blanco, mangle boton, mangle botoncillo, mangle cenizo, mangle garbancillo, mangle gris, mangle jeli, mangle lloroso, mangle marequita, mangle negro, mangle pinuelo, mangle prieto, mangle roche, mangle torcido, mangle zaragoza, manglier, manglier Gris, mangrovia grigia, mangue, mangue branco, mangue de botao, maraquito, N Ja, paletuvier, paletuvier gris, pash-chuhnul, pataban, saragosa, taabche, tabche, witte mangel, witte mangro, wortelboom, x-kanche, xtabche, yana and zaragosa.

There are two varieties, not accepted as distinct by all authorities: *Conocarpus erectus var. erectus* - green buttonwood, leaves thinly hairy or hairless and *Conocarpus erectus var. sericeus* - silver buttonwood, leaves densely silvery-hairy.

C. erectus is usually a dense multiple-trunked shrub, 1–4 m (3.3–13 ft) tall, but can grow into a tree up to 20 m (66 ft) or more tall, with a trunk up to 1 m (3.3 ft) in diameter. The United States National Champion green buttonwood is 35 ft (11 m) tall, has a spread of 70 ft (21 m), and a circumference of 207 in (530 cm) (Florida Division of Forestry. 2009).

The root system consists mainly of laterals and fine roots that are dark brown, weak and brittle, and have a corky bark. The plant usually has an erect trunk or multiple trunks, but it may assume a prostrate form and have limbs that layer and become new individuals.

The bark is gray or brown, furrowed, fibrous, and moderately thin (about 8 mm). The inner bark is dark cream in color. Stem wood (specific gravity of 1.0) is hard, heavy, and strong. Branches are brittle. The twigs are slender, yellow-green, angled, flattened, or winged. The twigs are brittle, and angled or narrowly winged in cross-section. The leaves are alternately arranged, simple and oblong, 2–7 cm (0.79–2.8 in) long (rarely to 10 cm/3.9 in long) and 1–3 cm (0.39–1.2 in) broad, with a tapering tip and an entire margin. They are dark green and shiny on top, and paler with fine silky hairs underneath, and have two salt glands at the base of each leaf (US Forest Service) with petioles 3 to 9 mm long. Inflorescences are terminal or axillary panicles of tiny greenish-white flowers grouped in spheroidal heads 3 to 5 mm in diameter. The fruits are button-like (from which the common names derive), 5–8 mm (0.20–0.31 in) diameter, with no petals; they are produced in stalked panicles of 35-56 flowers. The fruit is a cluster of red to brown, small scaly, two-winged cone-like seeds, 5–15 mm (0.20–0.59 in) long. The thin, dry, 5- to 15-mm, two-winged seeds are densely packed into globose clusters (Howard 1989, Liogier 1994, Little and Wadsworth 1964, Nelson1996, Pennington and Sarukhan 1968, Stevens et al. 2001). The seed heads burst when ripe, and the seeds are dispersed by water.

It is generally found growing in brackish water in tidal lagoons and bays, but can grow in inland habitats, with records at up to 745 m (2,444 ft) altitude in Costa Rica (US Forest Service). It is observed that this plant thrives well even under high temperature (40-45 C).

It is an important host plant for epiphytes. The wood is sometimes used in cabinets; it is difficult to work but takes a smooth finish. It is also used as firewood, and is reported to be good for smoking meat and fish, as it burns very hot and slowly; it also makes high quality charcoal. The bark is high in tannin, for which it has been harvested commercially.

Button mangrove is native to Bermuda, both coasts of southern Florida, the Bahamas, the West Indies, both coasts of Mexico, Central America, South America (through Ecuador and Brazil), and the Galapagos Islands. It is also native to coastal areas of Tropical West Africa (Howard1989, Little and Wadsworth 1964). The species has been planted widely as an ornamental and has naturalized in at least Hawaii (Pacific Island Ecosystems at Risk 2002).

Button mangrove is intolerant of shade. It is almost always open-grown or in co dominant stands. It will tolerate competition by plants of similar size but will not grow under the canopy of taller trees. The species grows above the high tide line, along beaches and just landward of *Laguncularia racemosa* and other mangroves. The soils in these situations are usually sandy or marly but sometimes loamy or clayey. Button mangrove is particularly adaptable as an ornamental because it tolerates compacted soil, air pollution, poor drainage, and drought (Gilman and Watson 1993). It also tolerates saltwater overwash from storm surges and heavy salt spray. The species grows, although much less commonly, on the lower floodplains of rivers and in upland forests. Herbarium samples have been collected at elevations of 745 m in Costa Rica (Instituto Nacional de Biodiversidad 2002).

Button mangrove blooms throughout the year in México (Pennington and Sarukhan 1968) and from March to September in Florida (Nelson 1996). Tomlinson (1986) maintains that this species is dioecious. It is a consistent and abundant seed producer throughout most of its range. The fruit heads may contain from 35 to 56 fruits each

(Masís et al.et al. 1999).Seeds collected in Puerto Rico averaged 250,000seeds/kg. Seeds from this collection began germinating on moist filter paper in 9 days but were only 12 percent viable (Francis and Rodriguez 1993). The seeds are dispersed by water (Pacific Island Ecosystems at Risk 2002). Button mangrove can be propagated by partially burying large stakes in moist ground for living fence posts (Little and Wadsworth 1964).

Button mangrove has a medium growth rate (Gilman and Watson1993) and may live for several decades. Information is not available on wild land plantation establishment. The planting of potted or containerized seedlings seems the safest approach. The species is not aggressive or invasive and only requires control when land is converted to other uses.

Button mangrove provides food and cover for wildlife (various species of crabs and insects). It protects the soil during storm surges and helps “fix” dunes (Popp et al. 1989). Both button mangrove and silver buttonwood (*C. erectus* var. *sericeus* Griseb.) are widely planted as ornamentals in yards, parking lots, streets and parks (Gilman and Watson 1993, Nelson 1996). It can be trained to form hedges. Potted plants are used to form bonsai (Gilman and Watson 1993).Button mangrove wood is reported to be ideal for smoking fish and meat (Gilman and Watson 1993).The wood is durable but susceptible to dry-wood termites, (*Cryptotermes brevis* (Walker) and is used to make railroad ties, posts, for turnery, boatbuilding, fuel, and charcoal. The bark and leaves have been used in tannery (Little and Wadsworth1964). Bark from Belize contains 18 percent tannin (Burkill 1985). Extracts of the bark are used to treat bleeding gums, vaginal bleeding, colic, and skin ulcers (Liogier 1990).

Figure 25: Buttonwood high marsh with sea ox-eye daisy, San Carlos Bay.
Source: W. Gray, SWFRPC, June 7, 2010

Iva frutescens is a perennial, deciduous shrub commonly growing between 3-8 feet high. Common names include marsh elder, high-tide bush, high-water shrub, bigleaf sumpweed, and Jesuit's bark,

The succulent leaves are dull green egg-shaped to narrowly lance-shaped and have serrate margins. Leaves are oppositely arranged except for the upper reduced leaves. The lower leaves grow 4-6 inches long and 1-2 inches wide. The roughly pubescent leaves have three prominent veins originating together at the base of the leaf. They bow away from each other and partially come back together near the tip of the leaf. Many greenish-white flower heads are arranged on terminal stems subtended by tiny green, leaf-like appendages. Flowers are abundant and appear from July to September. The small fruits are dark purplish brown achenes that are covered with pale dots of resin. Growth rate is moderate. The plant grows in full sun on well-drained; extended flooding; slightly alkaline; sand; loam; clay soils**,** drought tolerance is good and the soil salinity tolerance is good

Iva frutescens is native to Florida's coastal marshes and shores and requires a full-sun position in the landscape. It grows in well-drained basic (high pH) soils but is moderately tolerant of drought and wetness. Its ability to grow in brackish water makes it a good candidate for embankment restoration and stabilization. The marsh elder is normally associated with the mid to high marsh ecosystem, forming the last line of defense for shoreline erosion control. These plants usually only occur at elevations where their roots are not subject to prolonged water table flooding, such as the upland border of salt marshes. However, there are occasional exceptions where these associated plants are found at lower elevations associated with drainage ditches and canals. More recently this species has become associated with the lower marsh system by colonizing the dredged material resulting from construction of ditches and ponds for mosquito control.

During extreme high tides, both small mammals and birds have been reported to use emergent vegetation as island of refuge. The marsh elder would readily serve this purpose. Marsh elder also provides suitable nesting habitats for various species of birds, like the red-winged blackbird and the marsh wren.

Baccharis halimifolia is a fall-flowering evergreen perennial native to the Atlantic and Gulf Coast in the southwestern United States although it may be found as far north as Maine. It has been introduced in Europe (France), Australia. Common names include Eastern Baccharis, Groundsel Bush, Consumption Weed, Cotton-seed Tree, Groundsel Tree, Saltbush, Sea Myrtle, Menguilié and Silverling. It is found in open sandy places, wet fields, marshes, beaches, disturbed sites, roadsides, old fields. pH range is 5.5 to 7.8. Precipitation range is 36 to 60 inches per year. Minimum frost free days are 180. Air temperature minimum is -3 F. It has a high tolerance for salt and anaerobic conditions. This plant is highly resistant to salt spray and flooding.

Height is 100–300(–600) cm (freely branched). Stems are erect to ascending, slender, striate-angled, glabrous or minutely scurfy, sometimes resinous.

Baccharis halimifolia has broad, distinctly rhombic, coarsely serrate basal leaves, pyramidal, leafy arrays, and cypselae with large fluffy pappi. Leaves are alternate, semi-evergreen, variable in shape, ranging from obovate to narrowly oblong, with some nearly diamond-shaped, 1 to 2 1/2 inches long. The upper half of leaf has a few coarse teeth, leaves from upper crown and near ends of twig often lack teeth, shiny green above, may be sticky, paler beneath. Leaf blades are elliptic to broadly obovate or rhombic, main cauline rhombic, 30–50(–80) × 10–40(–60) mm (thick and firm), bases cuneate, margins entire proximally, usually coarsely serrate distal to middles (teeth 1–3 pairs), faces glabrous, gland-dotted, resinous (distal reduced, entire). Seed heads are 3–4 in loose pedunculate clusters in (terminal, leafy-bracted) broad paniculiform arrays. Involucres are campanulate; staminate 3–5 mm, pistillate 3–5 mm. Phyllaries are ovate to lanceolate, 1–4 mm, margins scarious, medians green, apices obtuse to acute.

Baccharis has small heads of white flowers in stalked clusters that form terminal leafy infloresences. The fertile heads are very showy and cotton-like. It is dioecious with male and female flowers are found on separate plants. Flowers are feathery white tufts, sometimes purplish. Both male and female flowers occur in terminal, branched clusters, on separate plants. Flowers are about 1/4 to 1/2 inch long. The number of staminate florets is 25–30; corollas 3–4 mm. Pistillate florets are 20–30; corollas 2.5–3.5 mm. Cypselae are 1–1.8 mm, 8–10-nerved, glabrous; pappi are 8–12 mm. Baccharis flowers late August to November. Leaves are present at flowering and are short-petiolate or sessile. *Baccharis* fruits late September to late October.

Hybrids between *B. halimifolia* and *B. angustifolia* are known in Florida. Forms with relatively narrow leaves are may be the result of hybridization and introgression with *B. angustifolia*.

Distribution of Salt Marshes in the CHNEP

Mangrove trees are the most dominant emergent vegetation in the CHNEP study area and mangrove forests form a distinctive broad margin around the estuaries of the CHNEP. They cover 63,831.96 acres and may extend inland several kilometers (miles) from open water. Mangroves primarily dominate the CHNEP shoreline, Ninety-three percent of the shoreline in Pine Island Sound and Matlacha Pass is mangrove fringe. Estero Bay (83%) and Charlotte Harbor (82%) are also dominated by mangrove shorelines. The Caloosahatchee River and Lemon Bay both have 62% mangrove shoreline. The Myakka River and Dona and Roberts Bays have 53% mangrove shorelines. The Peace River is the only CHNEP watershed with less than 50% mangrove shoreline at 34% mangrove shoreline.

Salt marshes are the most common emergent habitats in the middle and upper large riverine portions of the study area, and exist to some extent throughout the estuary. Fringing emergent native salt marsh wetland shorelines can constitute a significant part of Myakka River and Peace River watershed shorelines. The Peace River marshes clearly dominate the distribution of directly tidal salt marshes in the CHNEP. High salt marsh communities occur in the transitional areas between mangroves, and fresh water marshes or coastal uplands.

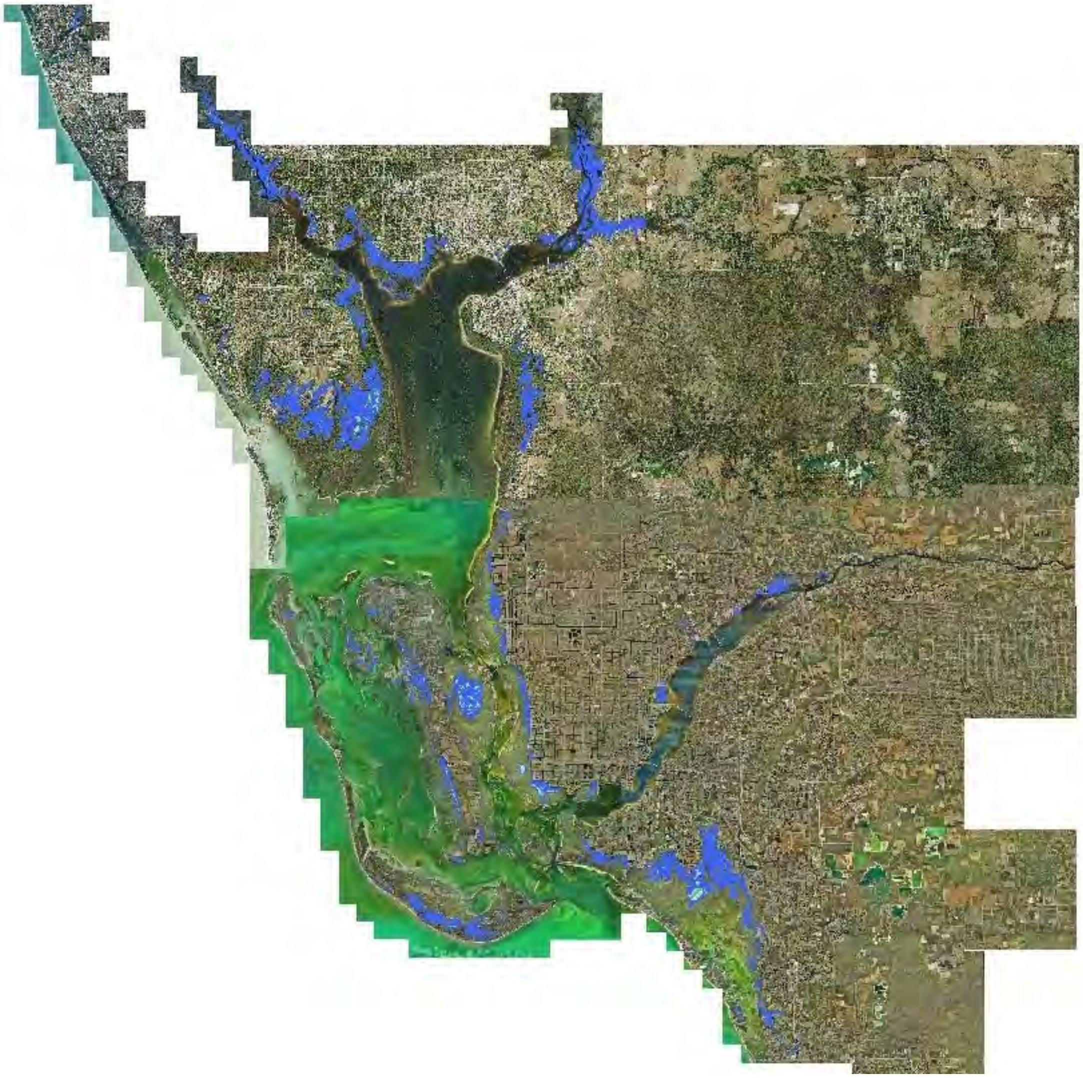

Figure 26: Distribution of Salt Marshes in the CHNEP Study Area in 2011.
Source: D. Cobb and J. Beever, SWFRPC 2012

Figure 27: Location of Directed Site Visits of Salt Marshes in This Study

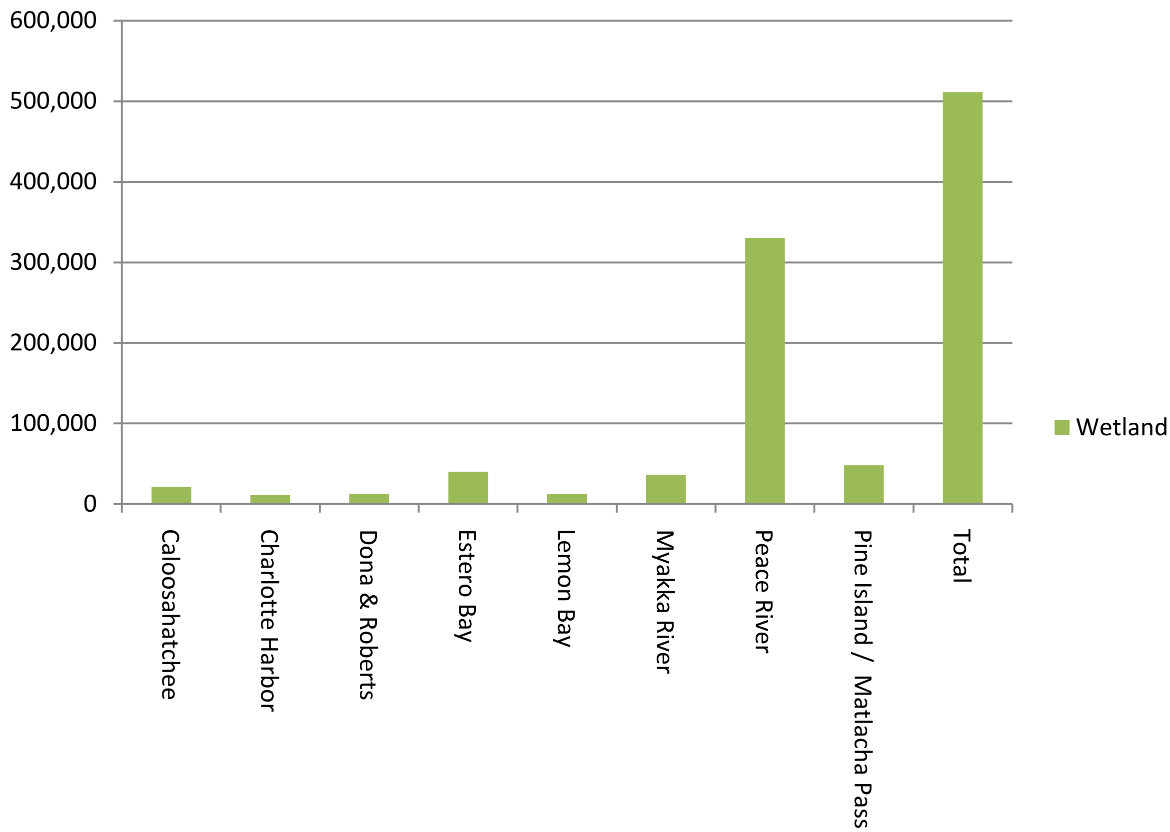

Figure 28: Meters of fringing salt marsh shoreline by watershed.
Source: CHNEP 2007

These tidal fringing salt marshes constitute 23% of the Peace River shoreline, 11% of the Myakka River shoreline, 6% of the Caloosahatchee River, 5% of the Dona and Roberts Bays shorelines, 5% of the Estero Bay shoreline, 4% of the Pine Island Sound, Matlacha Pass and Lemon Bay shorelines and 1% of the shoreline of Charlotte Harbor proper.

The types of fringing marsh are skewed in their extent with black needle rush dominating at 82% of all fringing marshes, followed by leather fern (11%), saltmarsh bulrush (8 %) and smooth cordgrass at 1%.

Multiple factors interact to determine the formation, structure, and ecological processes of salt marshes including (1) climate, (2) hydrology, and (3) physical factors. Climatic factors include temperature and rainfall; hydrologic factors include tidal inundation, wave energy, climate, rainfall, freshwater flow, and evapotranspiration; and physical factors include elevation and slope, sediment and soil composition, and surface water and soil salinity.

Climate

(or Hot, cold, and wet is just right)

The mild subtropical climate in southwest Florida influences the distribution and unique composition of salt marsh communities found in the CHNEP. Many subtropical and tropical types of vegetation, especially mangroves and leather ferns, are sensitive to the degree, duration, and frequency of low temperature events.

Freezes are an erratic year-to-year event in Florida, occurring more frequently and severely in northern and inland areas (Duever et al.1994). Freezes inhibit or kill mangroves, allowing for the colonization and/or dominance by salt marsh vegetation like *Juncus*. Droughts can also have adverse effects on the composition and structure of salt marsh communities and depending on the severity of the drought, can lead to the death of plants. Precipitation provides the a major source of freshwater to the upland headwaters of the rivers, creeks, and streams that drain to coastal fringing salt marshes. In contrast high marshes depend upon direct precipitation and sheet flow run-off form adjacent uplands for their fresh water sources. The absences of fresher waters in pats of larger high marshes provide the conditions for hyper-salinities and formation of salterns.

Salt Marsh Formation

(or The dynamically calm tidal dance)

The formation of the sediment platforms where the salt marshes of the CHNEP are found is a response to the dynamics of depositions and erosions from two diametrically opposite oriented hydrologic forces: the tides and coastal storms from the Gulf of Mexico, adjacent bays, harbor, or sound and the freshwater inputs from rivers, creeks and sheet flows of adjacent contributing watersheds. Salt marshes of the CHNEP are found in calmer, protected waters usually within the protection of barrier islands, estuary, or along low-energy shorelines of rivers and tributaries.

The most influential hydrologic factor of a salt marsh is tidal inundation, where the frequency and duration of tidal flooding determines the extent of the intertidal zone. Other factors that affect the hydrologic regime of a marsh are wave energy; Salt marshes experience the physical and chemical effects of both salt and fresh water. Tidal effects are greatest on marsh areas at and below mean low water, while more upland high marshes are influenced by seasonal high-high tides and seasonal freshwater sources. Daily tides flush saline waters over the intertidal zone; seasonal tides can extend further inland to the landward most boundary of brackish water and hypersaline communities.

Rivers, creeks, and overland sheetflow carry freshwater in from upland sources, transporting sediments and run-off nutrients that support the vegetation growth and formation of a marsh system. Within the low-lying protected areas, halophytic plants grow and establish root systems. As tide waters flood over a marsh and then retreat, suspended sediments and organic particles settle-out and accumulate around the stems of plants and in periphytic algae. Rivers and other upland sources also contribute sediments to the marsh by transporting and redepositing sediment. In the early development of a marsh, sedimentation increases and promotes the establishment and growth of additional plants. As the marsh matures, accretion slows and stabilizes with the surrounding sediment source, tidal regime, and topography.

The underlying theories of formation and zonation of salt marshes have been extensively reviewed (e.g., Pomeroy and Wiegert 1981, Adam 1990, Montague and Wiegert 1990). One theory suggests salt marsh vegetation has the ability to trap and accumulate sediment and is responsible for its own development and zonation. The alternate theory suggests local physical and geological processes that influence topography, elevation, and water movement are responsible for the formation and zonation of salt marsh vegetation. In this view, marsh plants are not significant land builders but instead are opportunistic species that colonize those areas in which they are adapted. Both theories show evidence for the importance of both environmental and biological factors in determining the formation and structure of salt marshes.

Hydrologic factors play an important role in the formation, composition and structure of salt marshes. Tidal exchange between the marsh and estuary promotes the necessary exchange of sediments, nutrients and organic matter, drainage, and vegetation zonation (Broome 1990, Seneca and Broome 1992, Mitsch and Gosselink 1986). The hydrologic cycle in salt marshes is dominated mostly by tides, but is also influenced by oceanic currents, evaporitic processes, winds, freshwater flow, and catastrophic events. Tidal amplitude and wave energy have the greatest effects.

In the CHNEP, tidal amplitude plays an important role in lower and upper limits of a marsh by influencing its physical, chemical, and biological processes. Low tidal ranges produce daily tides that are insufficient to enter the upper reaches of intertidal salt marshes, where high tidal amplitudes are able to extend further into the marsh and can form natural levees or berms. Low tidal amplitudes are more common in the CHNEP causing most of the salt marshes to be above mean high water. The smaller tidal amplitudes create only small levees or none at all.

Most salt marsh species are not able to withstand heavy and continual wave action. High wave energy causes erosion of sediments and prevents the establishment of seeds and roots (Mitsch and Gosselink 1993). The long-term stability of marsh vegetation depends on its protection from excess wave activity. Wave energy is relatively low along the southwest coast and Everglades region (Montague and Wiegert 1990).

The presence of freshwater can influence the abundance and diversity of plants and enhance plant growth. Freshwater flows from mainland to coastal areas through drainage basins, groundwater, and rainfall. Strong discharges occur during the wet season and during storms and hurricanes. The amount of freshwater is controlled by several factors, such as levels of rainfall, proximity to salt water, permeability of subsurface sediments, and elevation above sea level (Schomer and Drew 1982). Most of the salt marshes in the CHNEP have been influenced by alterations in upland freshwater flow caused by human activities for coastal construction, mosquito control, retention of freshwater for agricultural and human uses, and flood control. Flood control structures prevalent along the west coast concentrate and divert freshwater flows away from salt marshes, also altering their composition and zonation.

Elevation and topography are important in determining the composition of the salt marsh substrate, affecting moisture content and salinity, which influence plant growth. Most halophytic plants grow over a range of intertidal elevations and slopes, with each species dominating areas best suited for its growth. Salt marsh vegetation usually establishes in protected or low wave-energy areas, where the deposition and accumulation of sediments create gentle sloping formations. Most salt marshes are relatively flat with slopes between 1 to 3 percent and little topography except near tidal creeks and in the upper marsh area (Zedler 1984). A gradual slope provides stability for the establishment and growth of vegetation and allows for inundation by tides.

Salt marsh sediments originate from upland runoff, reworking of marine derived sediments, and organic production occurring within the marsh. Since marshes are formed from land and sea sources, the sediments display physical and chemical characteristics of both. Marsh sediments are mostly anaerobic, with a biogeochemical composition resembling sediment originating from the sea. The anaerobic environment within most sediments causes high levels of H_2S and low pH (Pomeroy and Wiegert 1981). Organic matter accumulation varies in different areas of the marsh depending upon the degree of plant, animal, and microbial activity. Large amounts of organic matter generally do not accumulate in smooth cordgrass low marshes because of tidal flushing, rapid litter turnover, and high rates of oxidation. Organic matter influences the sediment properties, availability of nutrients, soils, growth rates of marsh plants, and presence and abundance of invertebrates associated with sediments. Exchange between sediments and flooding waters occurs through diffusion, bioturbation, and seepage (Wiegert and Freeman 1990).

Although marsh sediments are mostly anaerobic, a thin layer of aerobic soil can form on the substrate surface and around plant stems. These soils are a combination of recently formed minerals and organic matter. The inorganic substrate contains a mixture of sand, silt, and clay, but sediment composition varies along a gradient from intertidal to high marsh. Soils are fairly uniform in grain size fractionation and tend to be a lightish brown-gray color.

In order for marsh plants to colonize an area, the soils have to be fairly stable until their root systems can contribute to the stabilization. The stability of salt marsh soils derived from marine sediment is affected by the soil's salinity, acidity, moisture and nutrients (Gallagher 1980). Saline waters flooding the marsh, elevation of marsh, soil texture, climatic factors (temperature, evaporation and rainfall), and vegetation composition all interact to influence soil salinity, ultimately influencing its stability.

The acidity of the soil, especially low pH, can affect plant establishment and development. Elevated moisture contents can increase flow characteristics of soil and reduce soil stability.

The availability of nutrients is also a determining factor on soil stability. Finer sands tend to be higher in nutrients than coarser grain soils. In the CHNEP, most marsh sediments contain fairly high amounts of organic matter mixed with inorganic estuarine material (Schomer and Drew 1982). Nutrient availability is important in maintaining high productivity of salt marsh vegetation. Salt marsh systems tend to be eutropic and have the ability to assimilate and store large amounts of phosphorous in the sediment (Whitney et al.et al.1981). Phosphorus is readily available for direct plant uptake and plants are able to obtain most of their phosphorous needed for growth directly from the sediments. The growth of marsh plants is also dependent on the availability of nitrogen. Marshes tend to have a limited supply of nitrogen and the amount of nitrogen is determined by tides, physical and chemical exchanges with water and air, and biological activity (Whitney et al.1981, Seneca and Broome 1992).

Area of Salt Marsh in CHNEP

(It is there but mostly out of sight)

Mangroves primarily dominate the CHNEP tidal shoreline, although there are patches of transitional salt marsh habitat. Within these zones, dominant species include cordgrasses (*Spartina spp.*), saltgrass (*Distichlis spp.*), glasswort (*Salicornia spp.*), and sea purslane (*Sesuvium* spp.) (Drew and Schomer 1984). Salt marshes of the CHNEP occur in several different hydrogeomorphic settings. Small patches of low marshes are found in protected coves in Dona Bay, Roberts Bays, Lemon Bay, and tributary rivers and streams. Needlerush dominates salt marsh communities of the major rivers (e.g., Myakka and Peace Rivers). Expansive black needle rush low and middle marshes are found in the Myakka and Peace Rivers and in smaller representation in the creeks tributary to Lemon Bay, Charlotte Harbor, Caloosahatchee River, and Estero Bay, often replaced by leather fern and saltmarsh bulrush marsh in fresher water estuarine streams and river oligohaline zones. Monotypic stands of black needlerush (*Juncus roemerianus*) can be common in slightly elevated areas with less tidal inundation. High salt marshes form parallel to the main estuaries' shorelines at the landward side of mangrove fringes starting in shrub black mangroves, extending into open algal marsh, open salt barrens and blending into salt meadows or algal marshes. The high marshes form narrow linear bands on islands like Sanibel Island and Pine Island and as larger expanses on the mainland shores of Cape Haze, Charlotte Harbor, Matlacha Pass, and Estero Bay, often several kilometers from the open shoreline. The interior wetland habitat of Sanibel Island has linear bands of lower salinity brackish marsh dominated by Baker's cordgrass and leather fern.

Our study has mapped 14,852.95 acres of salt marsh of all types within the CHNEP study area boundaries. This includes 35.7 acres in the Dona and Roberts Bay watersheds, 162.2 acres in the Lemon Bay watershed, 1,291.7 acres in the Myakka River watershed, 2,301.6 acres in the Peace River watershed, 4,222.7 acres in the greater

Charlotte Harbor watershed, 1,346.2 acres in the Pine Island Sound watershed, 2,329.4 acres in the Matlacha Pass watershed, 389.3 acres in the Caloosahatchee River watershed, and 2,773.9 acres in the Estero bay watershed.

We believe the apparent differences in salt marsh acreage from earlier mapping by FWC and the WMDs is not the result of an actual increase in salt marsh extents as much as it is a result of the improved mapping methods of this study. Significant areas of salt marsh were mapped as mangrove forest in the earlier mapping efforts and areas of mangrove were designated as salt marsh. In some watersheds areas of freshwater marsh and bare sand upland areas were mapped as salt marsh.

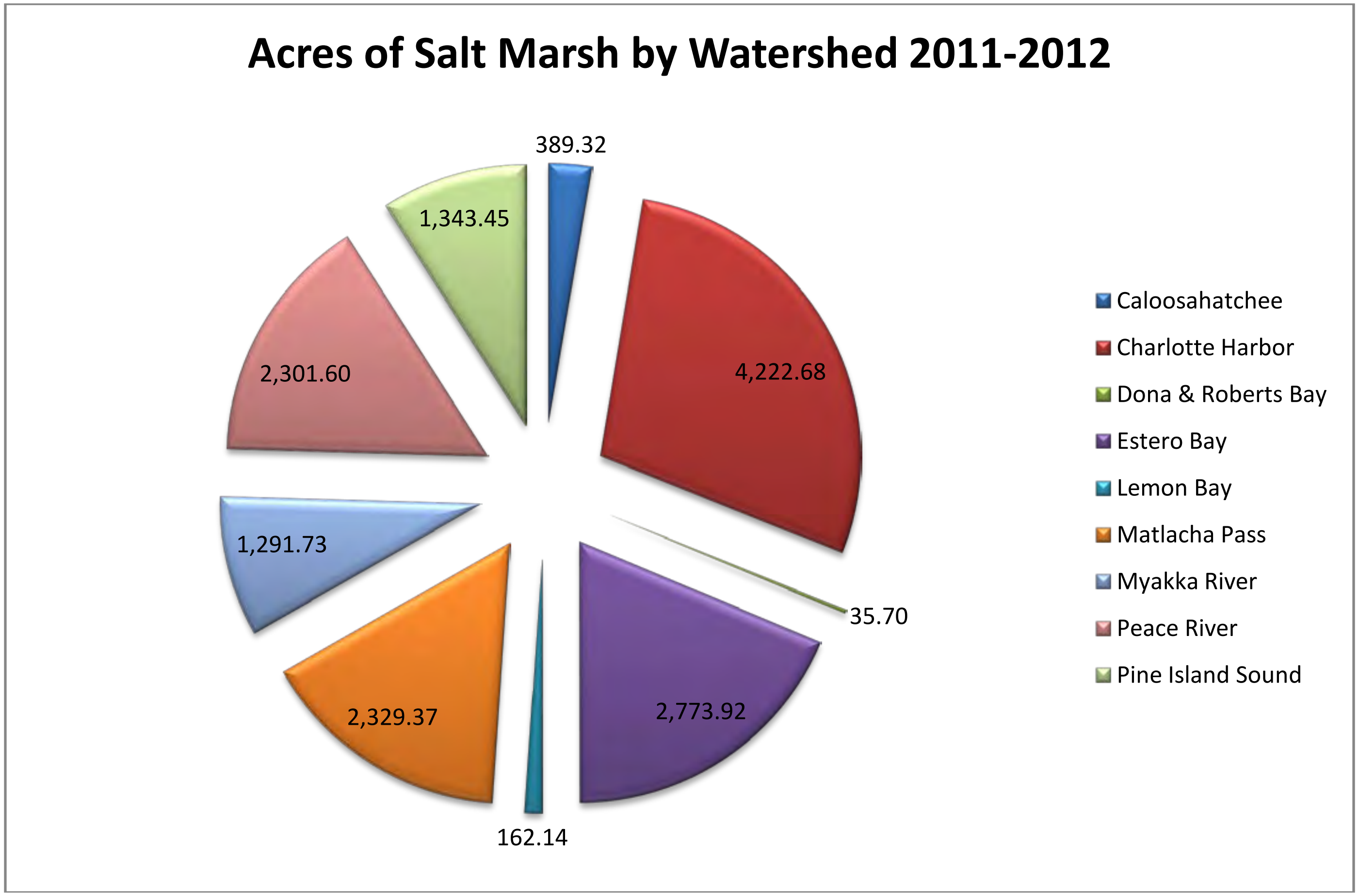

Figure 29: Acres of Salt Marsh by Watershed in the CHNEP.
Source D. Cobb and J. Beever SWFRPC

Salt Marsh Type Area Total by Watershed	Cordgrass	Black needle rush	Saltmarsh Bulrush	Saltern	Scrub Mangrove	Algal	Saltern	Succulents	Mixed	Grasses	Shrub Buttonwood
Caloosahatchee	0.00	138.51	76.54	0.00	45.72	6.58	11.16	4.32	66.33	40.16	0.00
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
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
Estero Bay	0.00	726.26	38.58	0.00	246.95	532.74	198.45	167.15	779.50	65.57	18.71
Lemon Bay	0.04	10.62	37.82	0.00	1.37	12.28	11.01	21.59	25.10	42.35	0.00
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
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
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
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
Totals	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

Table 2: Acres of salt marsh by type mapped in the CHNEP 2010-2012.
Source: D. Cobb and J. Beever SWFRPC April 30, 2012

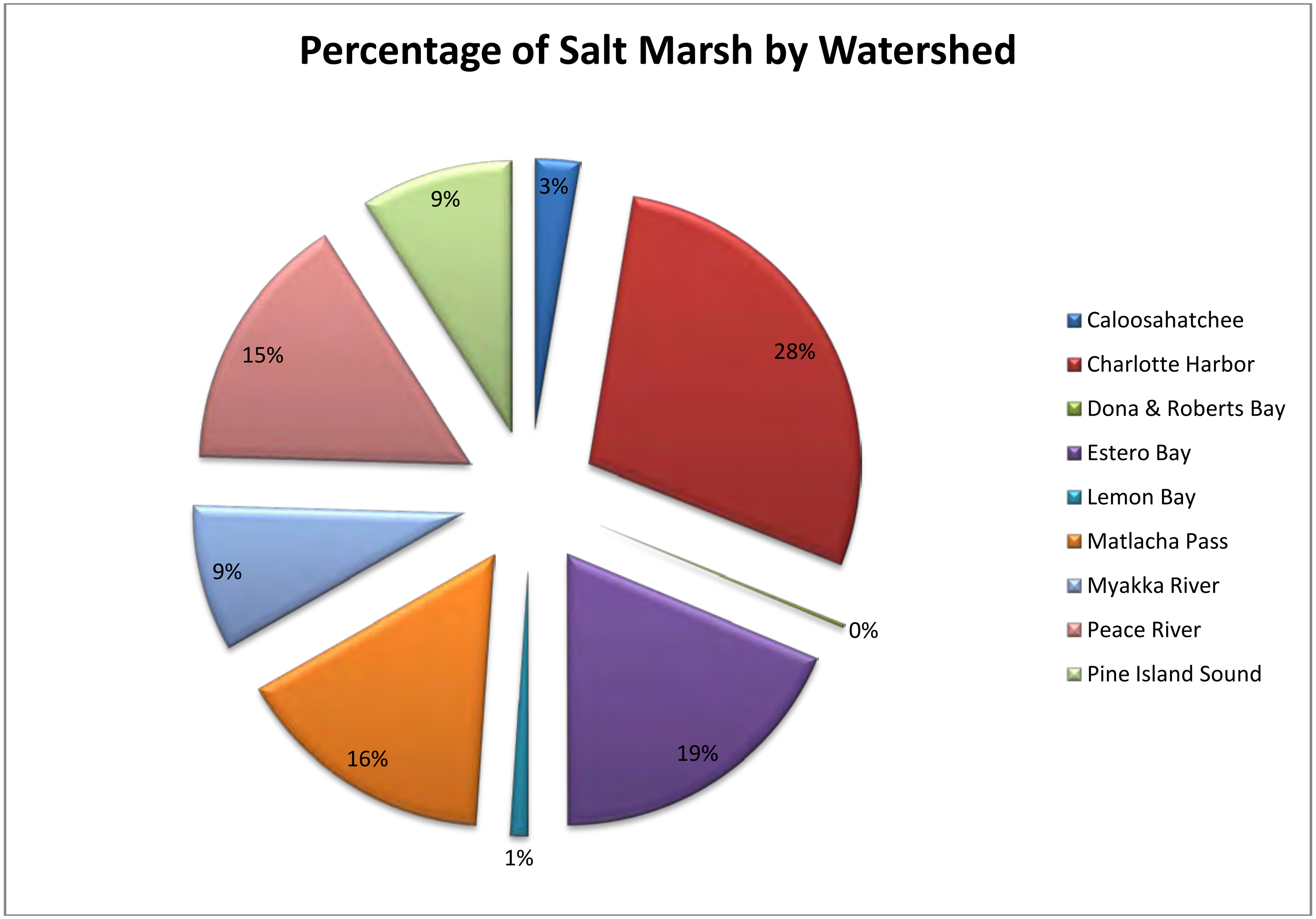

Figure 29: Percentage of Salt Marsh by Type By Watershed in the CHNEP.
Source D. Cobb and J. Beever SWFRPC

The salt marshes of the CHNEP are unequally distributed with the most in the Charlotte Harbor Proper watershed (28%), 19% in Estero Bay watershed, 16% in the Matlacha Pass watershed, 15% in the Peace River watershed, 9% each in the Pine Island Sound and

Myakka River watersheds, 3% in the Caloosahatchee River watershed, 1% in the Lemon Bay watershed, and 0.2 % in the Dona and Roberts Bays watershed.

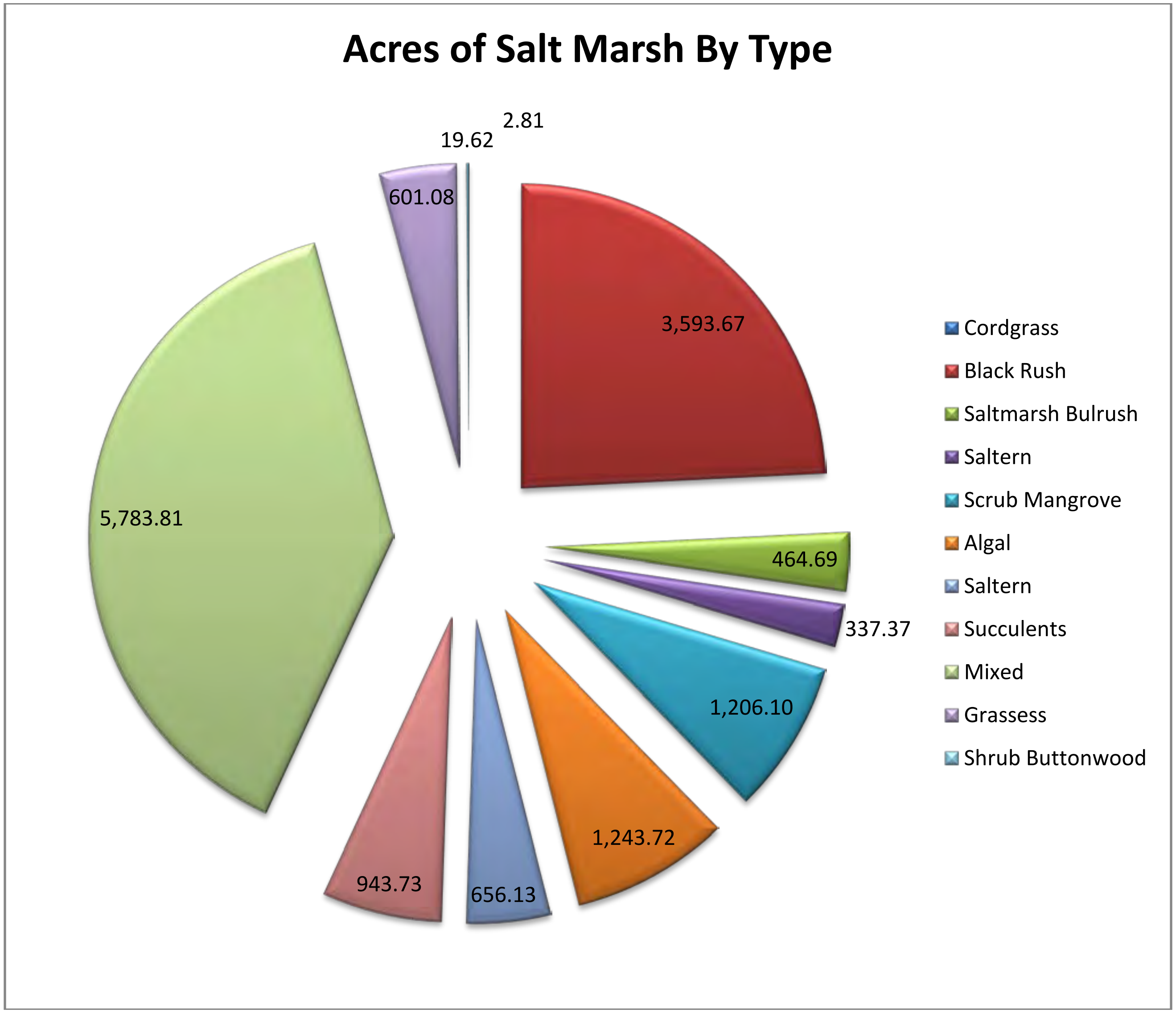

Figure 30: Acreage of each Salt Marsh Type in the CHNEP.
Source: D. Cobb and J. Beever SWFRPC April 30, 2012

MIxed high marsh is the most common form of salt marsh in the CHNEP (5,783.81 acres) comprizing 38.93 % of total salt marsh extents among all watersheds. Balck needle rush marsh is second at 3,593.67 acres (24.19%) including both fringeing and high marsh ecotypes of black needle rush. Algal marsh is 1,243.72 acres (8.38%). Shrub mangrove high marsh is 1,206.10 acres (8.12%).

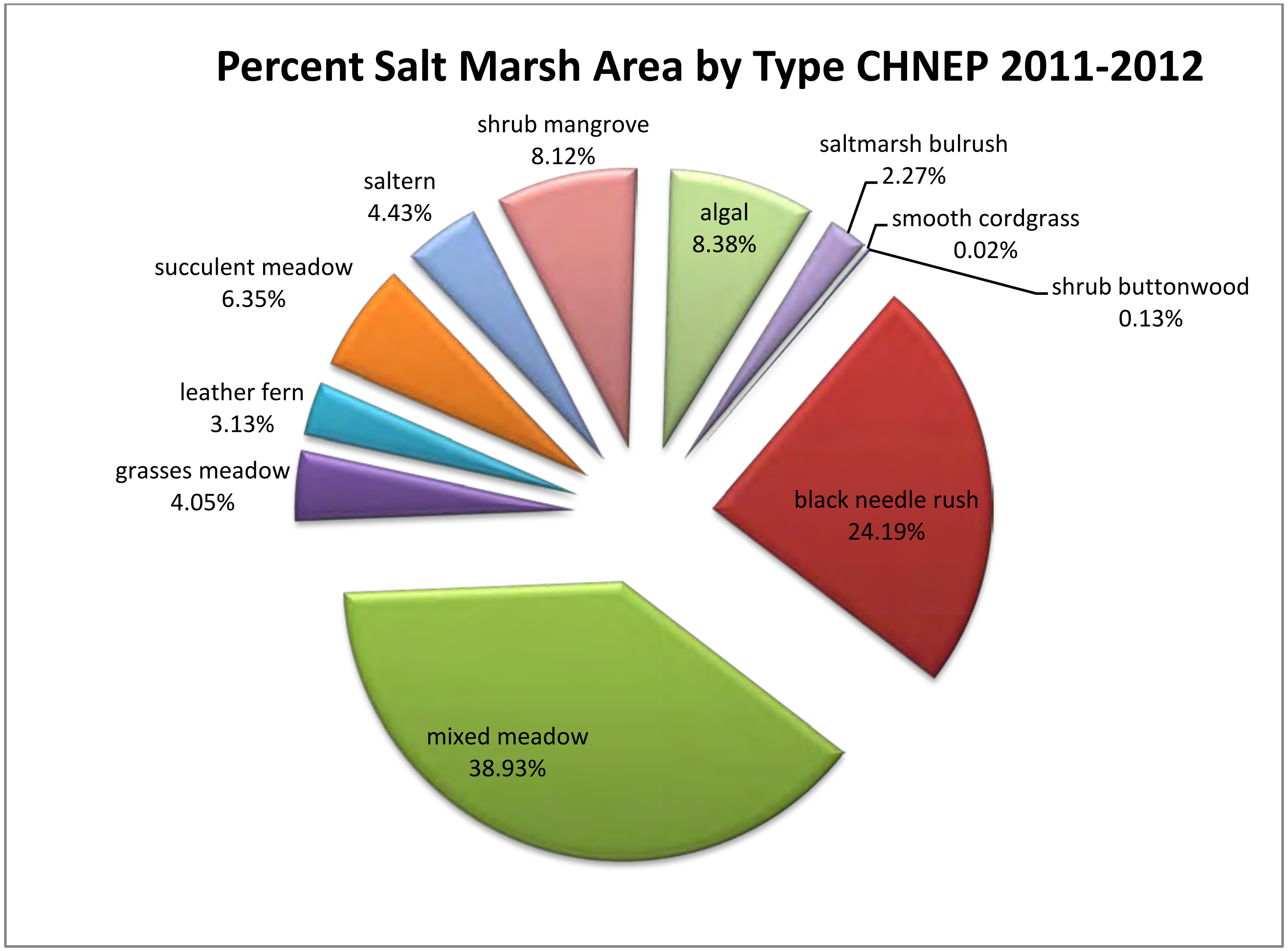

Figure 31: Relative proportion of salt marsh types in the CHNEP Study Area
Source: D. Cobb and J. Beever SWFRPC April 30, 2012

Salt Marsh Type Area Total by Watershed	Cordgrass	Black needle rush	Saltmarsh Bulrush	Saltern	Scrub Mangrove	Algal	Saltern	Succulents	Mixed	Grasses	Shrub Buttonwood
Caloosahatchee	0.0%	3.9%	16.5%	0.0%	3.8%	0.5%	1.7%	0.5%	1.1%	6.7%	0.0%
Charlotte Harbor	0.0%	5.3%	1.8%	0.0%	26.1%	20.0%	49.9%	32.6%	45.3%	33.7%	0.0%
Dona and Roberts Bay	0.0%	0.8%	1.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Estero Bay	0.0%	20.2%	8.3%	0.0%	20.5%	42.8%	30.2%	17.7%	13.5%	10.9%	95.4%
Lemon Bay	1.5%	0.3%	8.1%	0.0%	0.1%	1.0%	1.7%	2.3%	0.4%	7.0%	0.0%
Matlacha Pass	0.0%	0.4%	0.1%	0.0%	37.3%	6.3%	7.1%	13.1%	25.4%	24.8%	4.6%
Myakka River	0.0%	28.6%	11.3%	0.0%	0.4%	1.3%	1.2%	0.7%	2.2%	7.4%	0.0%
Peace River	1.5%	40.2%	51.3%	100.0%	4.3%	0.6%	0.2%	3.5%	3.1%	0.9%	0.0%
Pine Island Sound	97.0%	0.2%	1.6%	0.0%	7.5%	27.4%	7.9%	29.7%	8.9%	8.5%	0.0%
Totals	0.0%	24.2%	3.1%	2.3%	8.1%	8.4%	4.4%	6.4%	38.9%	4.0%	0.1%

Table 3: Percentage of Salt Marsh by Type By Watershed in the CHNEP.
Source D. Cobb and J. Beever SWFRPC

SM Type	% of total
10 (Smooth Cordgrass)	0.02%
21 (Rush)	24.19%
22 (Leather Fern)	3.13%
23 (Bulrush)	2.27%
30 (Shrub Mangrove)	8.12%
31 (Algal)	8.38%
32 (Saltern)	4.43%
33 (Succulents)	6.35%
34 (Meadow Mixed)	38.93%
35 (Meadow Grasses)	4.05%
36 (Shrub Buttonwood)	0.13%
Total Low and Middle Marsh	30%
Total High Marsh	70%

Table 4: Relative Percentages of Each Salt Marsh Type mapped in the CHNEP 2010-2012.
Source: D. Cobb and J. Beever SWFRPC April 30, 2012

Location of Salt Marshes By CHNEP Watershed

(Different proportions of fringe and high)

Dona and Roberts Bay

The salt marshes in the Dona and Roberts Bay are located east of US 41 on the Curry Creek, Fox Creek and Shakett Creek. Black needle rush brackish marsh is the dominant type with some leather fern marsh. Small patches of high marsh are found on Shakett Creek. As defined by the CHNEP this watershed also includes Alligator Creek at northern Lemon Bay. Alligator Creek has black needle rush brackish marsh in its middle reaches.

Almost all of the salt marshes of Dona and Roberts Bay are low and middle tidal marshes dominated by black needle rush and leather fern.

Figure 32: Mixed Marsh, Shakett Creek and Fox Creek, Dona and Roberts Bay Watershed
Source W. Gray, SWFRPC, December 9, 2011

Figure 33: Black rush marsh on Curry Creek, Dona and Roberts Bay Watershed
Source: W. Gray, SWFRPC, December 9, 2011

Figure 34: Map of the Salt Marshes of Dona and Roberts Bay Watershed as Defined by the CHNEP
Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

Lemon Bay

The salt marshes of Lemon Bay are principally associated with the tributary creeks of the Bay including Gottfried Creek, Rock Creek, Oyster Creek, Buck Creek, and Coral Creek. Parallel marshes are found on mainland opposite Don Pedro Island, south of Stump Pass opposite the mouth of Buck Creek, as patches on mangrove islands north of Stump Pass, and on Cedar Point. The largest most natural extents of salt marsh are high marsh paralleling the east branch of Coral Creek in association with the Charlotte Harbor Preserve State Park. There are at least two areas where smooth cordgrass appears to have been planted by humans as an alternative shoreline treatment to hardening and/or mangroves.

The marshes of Lemon Bay include in descending order: grassy high marsh (42.4 acres), leather fern marsh (37.8 acres), mixed high marsh (25.1 acres), herbaceous high marsh (21.6 acres), algal marsh (12.3 acres, saltern (11 acres), black needle rush marsh (10.6 acres), shrub mangrove marsh (1.4 acres) and smooth cordgrass marsh (0.04 acres). This is a total of 162.2 acres. Thirty percent of the salt marshes of the Myakka River watershed are tidal low or middle marsh.

Figure 35: Black needle rush marsh, Rocky Creek, Lemon Bay.
Source: W. Gray February 9, 2012

Figure 36: Smooth cordgrass and Great Blue Herons on and oyster bar island. Lemon Bay.
Source: J. Beever. SWFRPC, November 17, 2011

Figure 37: Smooth cordgrass Gottfried Creek. Lemon Bay.
Source J. Beever. SWFRPC, November 17, 2011

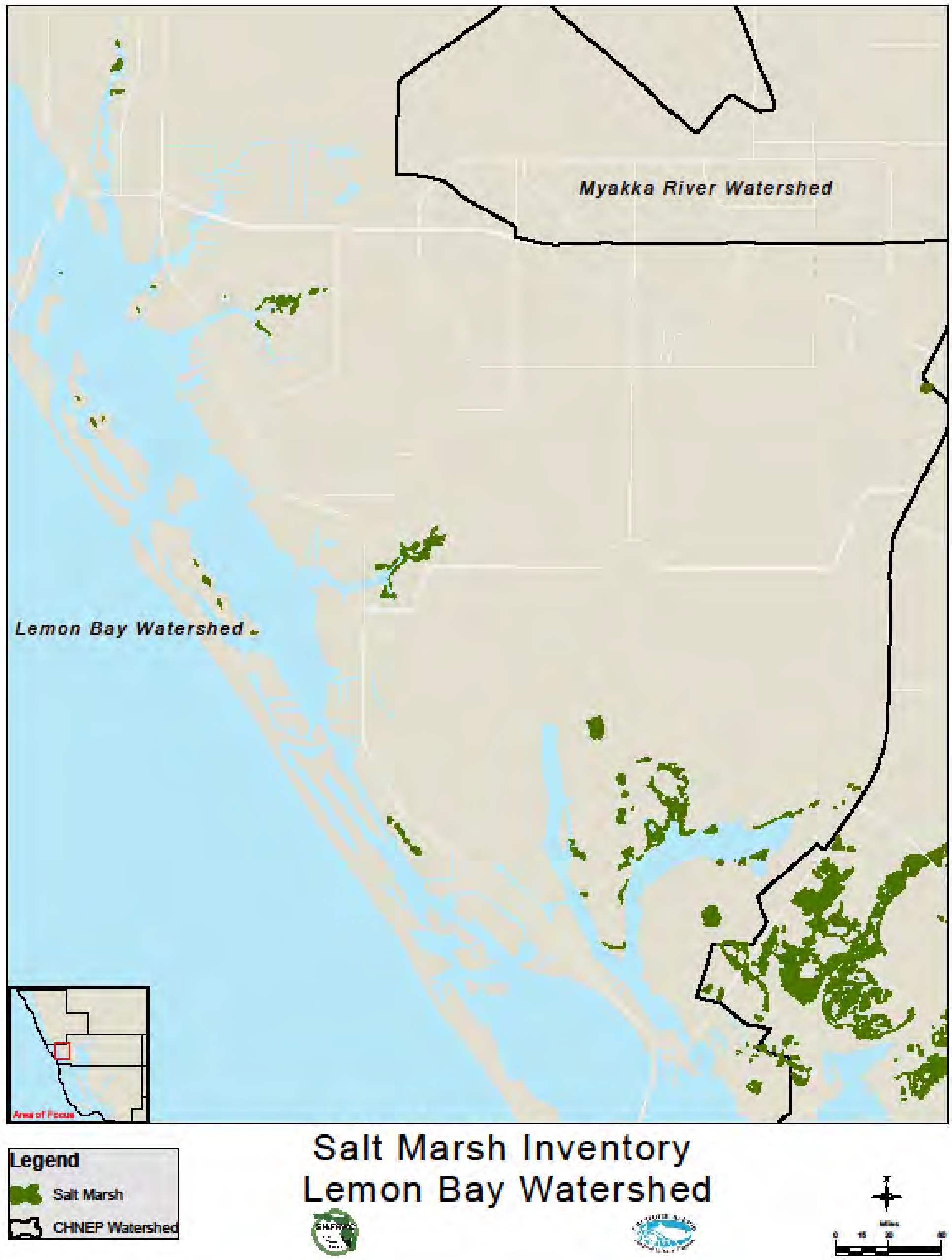

Figure 38: Map of the Salt Marshes of Lemon Bay Watershed as Defined by CHNEP
Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

Myakka River

The salt marshes of the Myakka River extend 17.4 miles upstream from the mouth of the river. The salt marshes of the Myakka River watershed are found throughout the upper tidal River with a disjuncture occurring on the west bank at Tarpon Point southward where this side of the river has been modified by finger canals and bulkheads. Wide marshes continue along the east shoreline south to the shoreline of the Riverwood Development of Regional Impact (DRI). The black needle rush marsh established on alluvial islands and wide oyster bars is healthy and appears to be building organic peats over sandy base sediments underneath its root mass. Salt marshes are present at the mouth of Deer Prairie Creek, Warm Mineral Springs Creek, Big Slough Creek, and the Rock Creek Waterway. Significant salt marshes flank the Tippecanoe Bay and Tippecanoe Creek.

The marshes of the Myakka River watershed include in descending order: black needle rush marsh (1,029 acres), mixed high marsh (129.4 acres), leather fern marsh (52.4 acres), grassy high marsh (44.4 acres), algal (16.7 acres), saltern (8.2 acres), succulent high marsh (6.7 acres), and shrub mangrove marsh (5 acres). This is a total of 1,291.7 acres of salt marsh. Eighty-four percent of the salt marshes of the Myakka River watershed are tidal low or middle marsh.

Figure 39: Black needle rush marsh with oyster bars, Myakka River.
Source: W. Gray, SWFRPC, January 13, 2012

Figure 40: Close view of peat/sand interface underneath riverine black needle rush, Myakka River.
Source: W. Gray, SWFRPC, January 13, 2012

Figure 41: Black needle rush marsh looking east showing red mangrove seedlings in the foreground and shrubby white mangrove in the mid-ground., The substrate is a muddy peat that showed bioperturbation from mud crabs, raccoons and possibly feral hogs, Myakka River.
Source: W. Gray, SWFRPC, January 13, 2012

Figure 42: Map of the Salt Marshes of Myakka River Watershed as defined by CHNEP
Source: D. Cobb and J. Beever, SWFRPC, March 31, 2012

Peace River

Salt marsh extends 15.2 river miles upriver from the mouth of the Peace River at Punta Gorda. The salt marshes of the Peace River are found in two distinct areas (Hog Island/Edgewater/Alligator Bay and up river of the Us 41 and I-75 bridges) separated by an urban area with a highly modified estuarine shoreline. All the western Peace River salt marshes are found on the north shore waterward of the Manchester Waterway and other man-made canal excavations interlaced with mangrove forests of varying density and composition. There are small patch marshes associated with the old shoreline of the towns of Charlotte Harbor and Solana. Substantial salt marsh begins at the north shoreline where the I-75 bridge crosses the Peace River from Harborview to Thornton Branch. Black needle rush dominated the upper river until the Mary Point area where it begins co-dominance with saltmarsh bulrush. Saltmarsh bulrush is also the main salt marsh type between the bridge crossing by State Road 17 and the dam on Spring Creek.

The marshes of the Peace River watershed includes in descending order: black needle rush marsh (1,446.1 acres), saltmarsh bulrush marsh (337.4 acres), leather fern marsh (238.3 acres), mixed high marsh (181.0 acres), shrub mangrove marsh (51.3 acres), succulent high marsh (33.0 acres), algal marsh (7.9 acres) and saltern (1.4 acres). This is a total of 2,301.6 acres of salt marsh. Eighty-eight percent of the salt marshes of the Peace River watershed are tidal low or middle marsh. Review of historical (1954) aerial photographs indicate that the relative absence of saltern is the result of areas where saltern was present being filled or excavated by coastal development practices in this watershed.

Figure 43: Giant leather fern in the foreground and black needle rush in the background, Peace River
Source: W. Gray, SWFRPC, December 14, 2011

Figure 44: Black needle rush marsh with freeze killed red mangrove, Harborview, Peace River
Source: W Gray, May 14, 2010

Figure 45: Black needle rush marsh, Harbor Heights, showing water level marks, Peace River
Source: W. Gray, SWFRPC March 27, 2012

Figure 46: Map of the Salt Marshes of Western Peace River Watershed as defined by CHNEP

Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

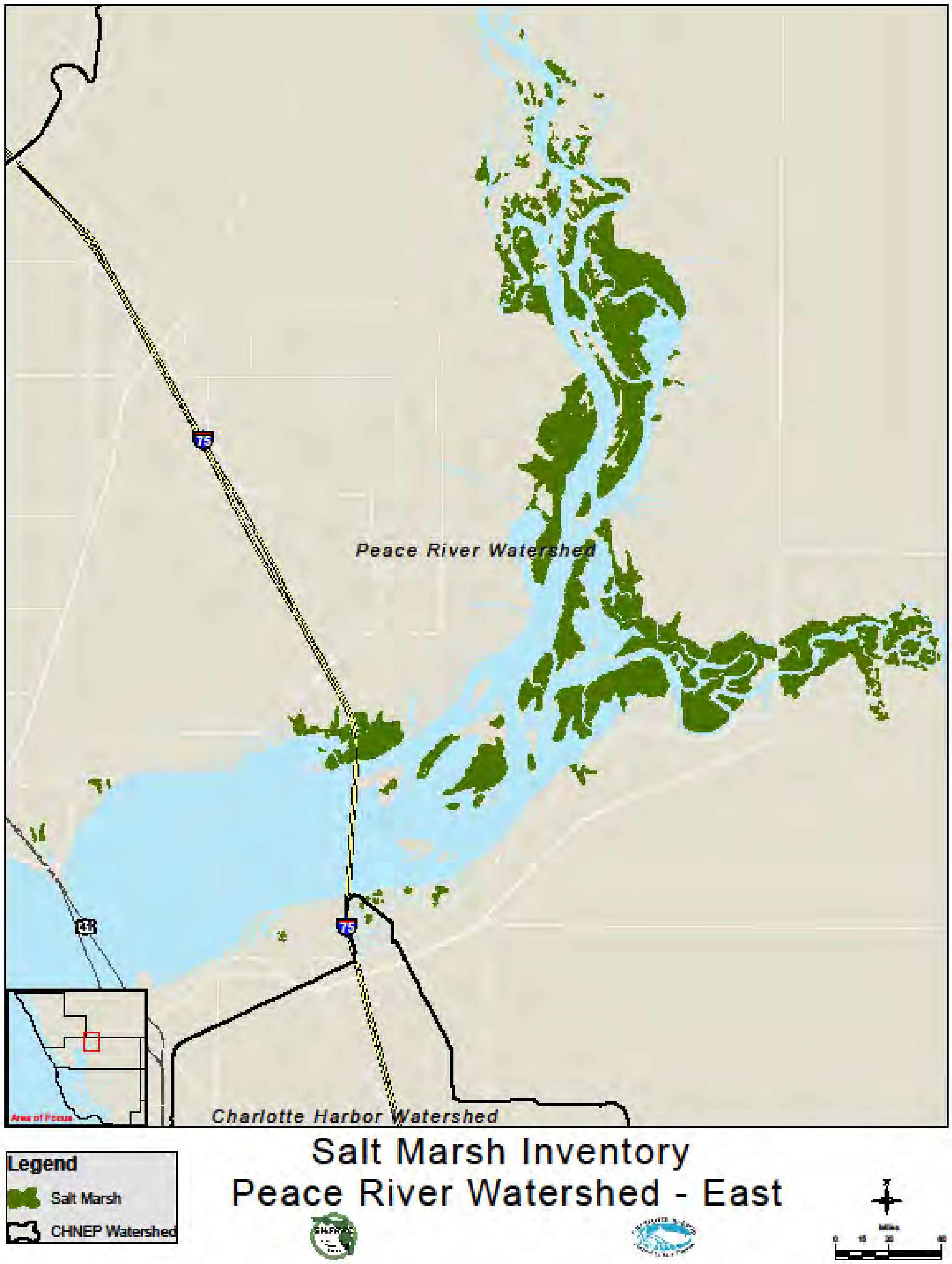

Figure 47: Map of the Salt Marshes of Eastern Peace River Watershed as defined by CHNEP
Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

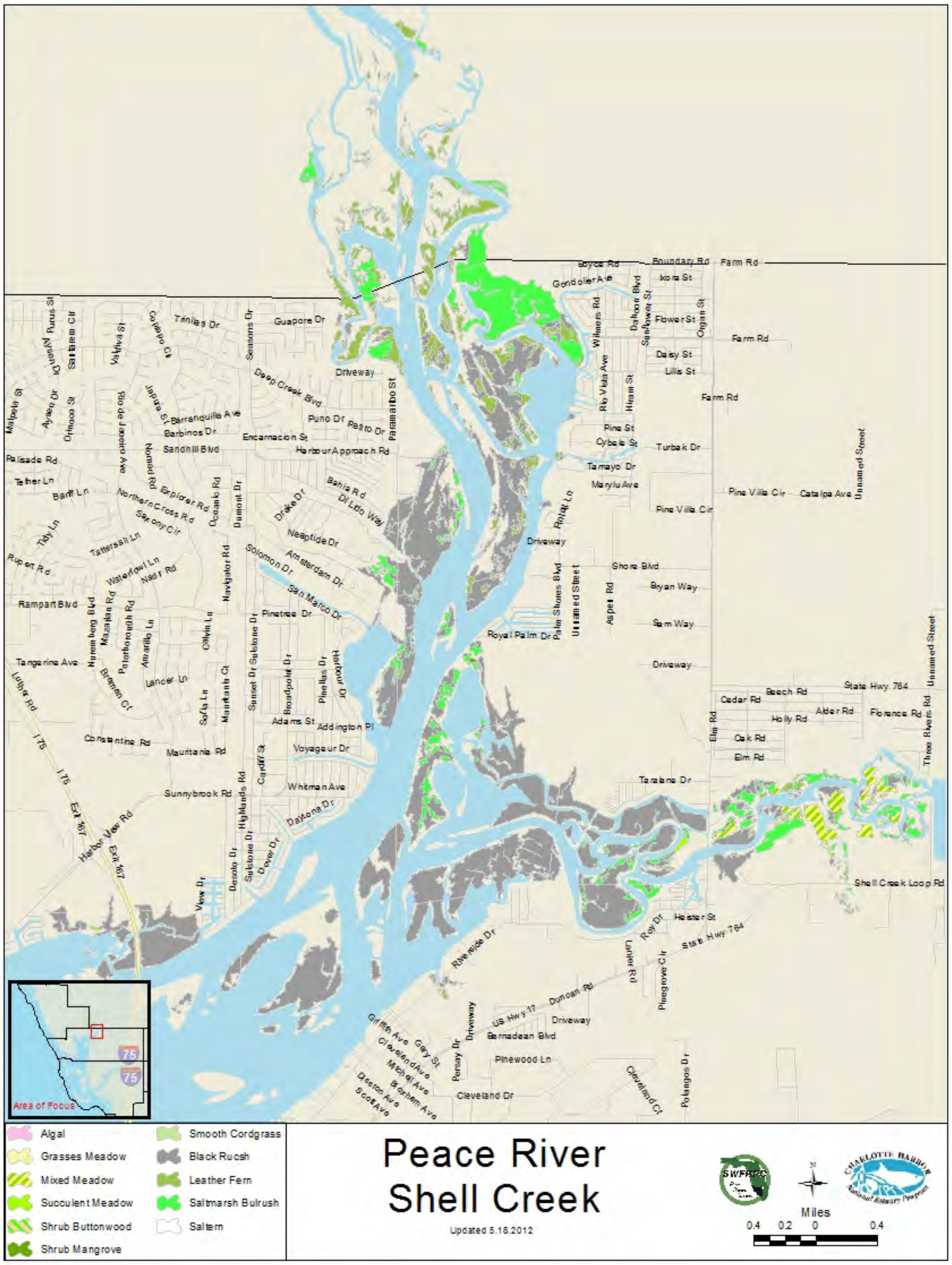

Figure 48: Map of the Salt Marshes by Type of Eastern Peace River Watershed as defined by CHNEP

Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

Charlotte Harbor Proper

The salt marshes of the Charlotte Harbor Proper watershed are divided into two distinct areas: the Cape Haze Peninsula with the west shoreline of the harbor and the eastern shoreline of the Harbor often referred to locally by watermen as the "East Wall". The salt marshes of the Charlotte Harbor Preserve State Park are the most extensive with the largest contiguous expanse dominated by a variety of high marshes.

The eastern salt marshes parallel the harbor shoreline with two major gaps. Reviewing historical (1954) aerial photography it is clear that the salt marshes of the north part of the east shoreline were eliminated by the dredge and fill development of Punta Gorda Isles. The second gap occurs from north of Pirate Harbor to the north terminus of the north spreader canal of Cape Coral. Reviewing historical (1954) aerial photography it is evident that some of this absence of marsh was natural for a portion of the shoreline that experience heavy wave action form fetches that extended form the Gulf of Mexico through Boca Grande Pass across the entire width of Charlotte Harbor this area lacked both mangrove and salt marshes and appeared to be a bare sandy part of the shoreline. Most of the lack of marshes on the eastern side of Charlotte Harbor is the result of human development however including dredge and fill. The North Spreader Canal was sited and constructed at the landward edge of the mangrove forest of Charlotte harbor and Matlacha Pass in the high salt marsh zone. The portions of high marsh that remain in that area are found on the waterward side of the North Spreader Canal.

The marshes of the Charlotte Harbor Proper watershed includes in descending order: mixed high marsh (2,622.7 acres), saltern (327.4 acres), shrub mangrove marsh (315.3 acres), succulent high marsh (307.2 acres), algal marsh (248.4 acres), grassy high marsh (202.8 acres), black needle rush marsh (190.5 acres and leather fern marsh (8.3 acres) . This is a total of 4,222.7 acres of salt marsh. Ninety-five percent of the salt marshes of the Charlotte Harbor Proper watershed are high marsh. Review of historical (1954) aerial photographs indicates that the relative absence of low marsh is natural and this watershed was mangrove lined except at the previously mentioned sandy location as far back as the period that we have photography.

Figure 49: Saltern in Charlotte Harbor State Preserve State Park, Cape Haze, Charlotte Harbor
Source: W. Gray, SWFRPC March 8, 2012

Figure 50: Grassy high marsh with shrub mangrove high marsh in background in Charlotte Harbor State Preserve State Park, Cape Haze, Charlotte Harbor
Source: W. Gray, SWFRPC March 8, 2012

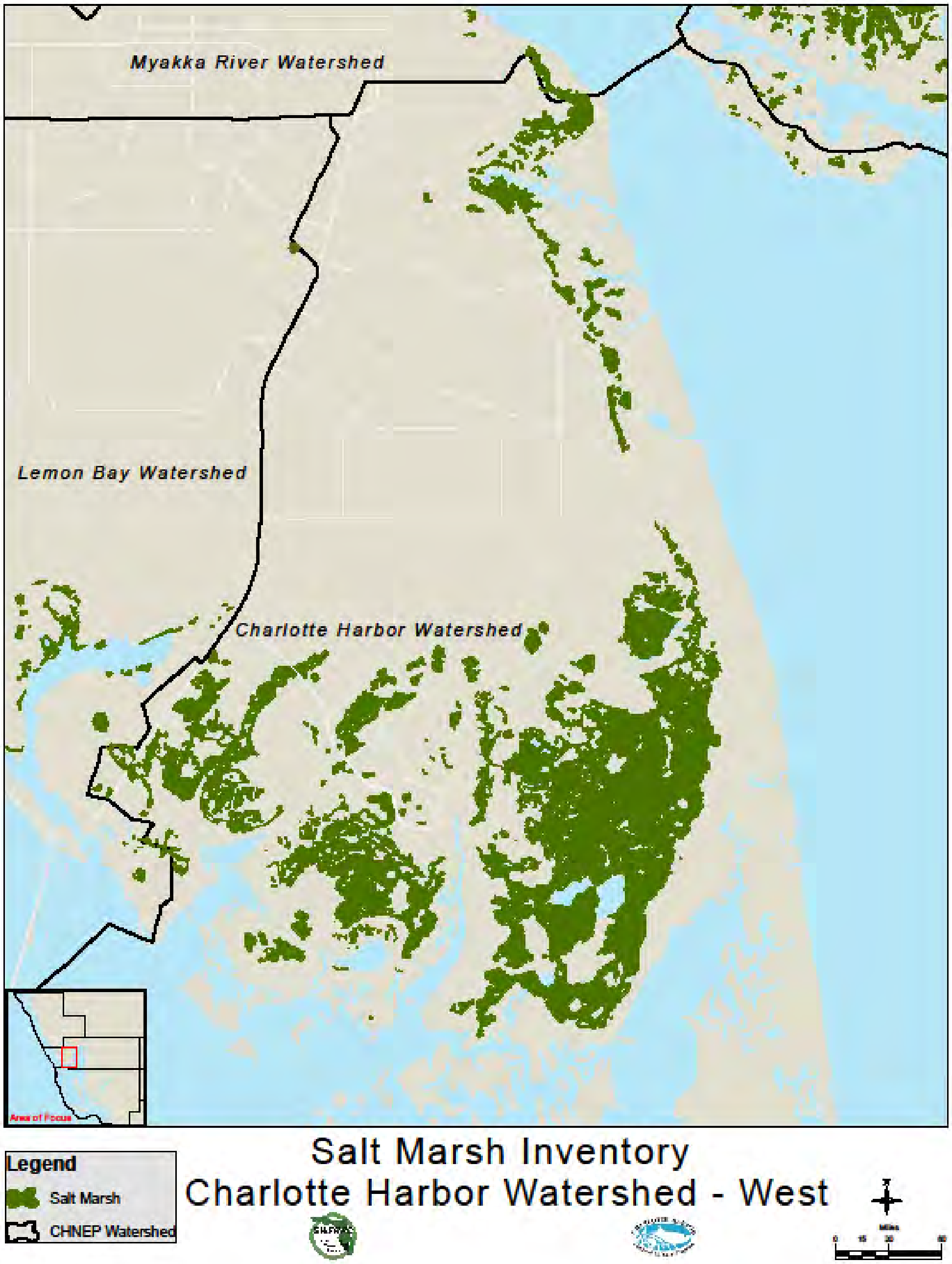

Figure 51: Map of the Salt Marshes of the Western Charlotte Harbor Watershed as defined by CHNEP

Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

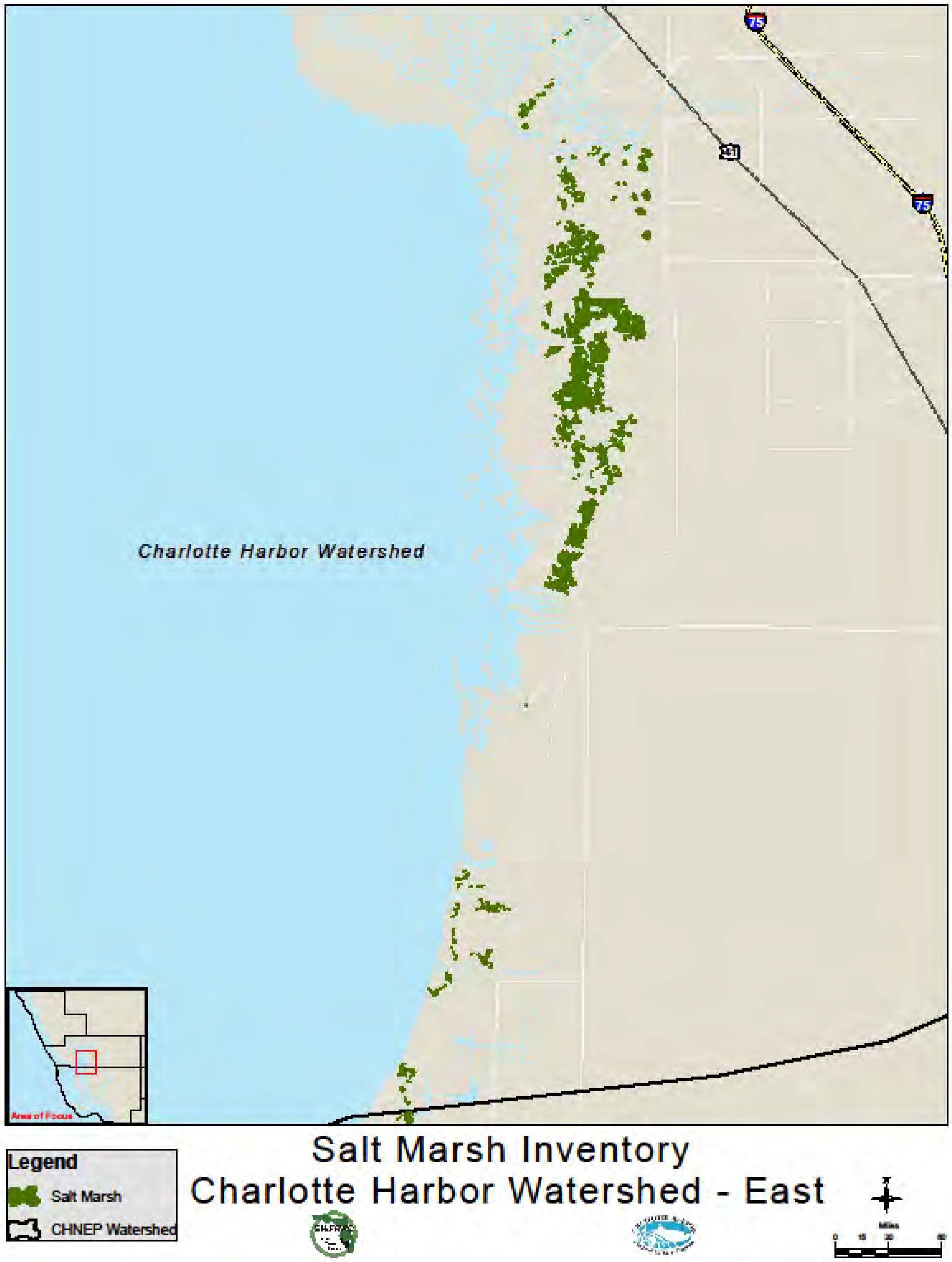

Figure 52: Map of the Salt Marshes of the Eastern Charlotte Harbor Watershed as defined by CHNEP

Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

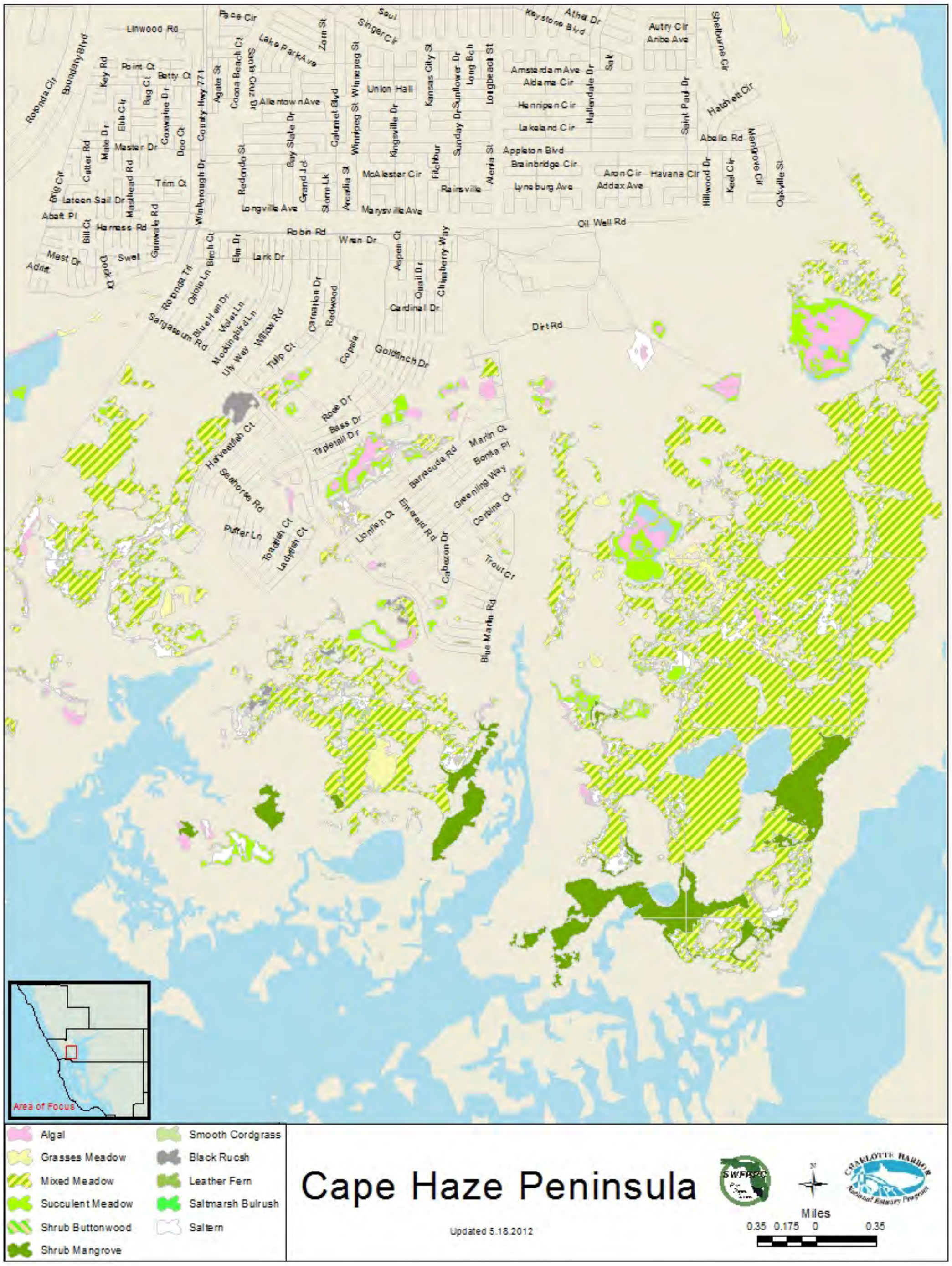

Figure 53: Salt Marshes by Type of the Cape Haze Peninsula, Charlotte Harbor
Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

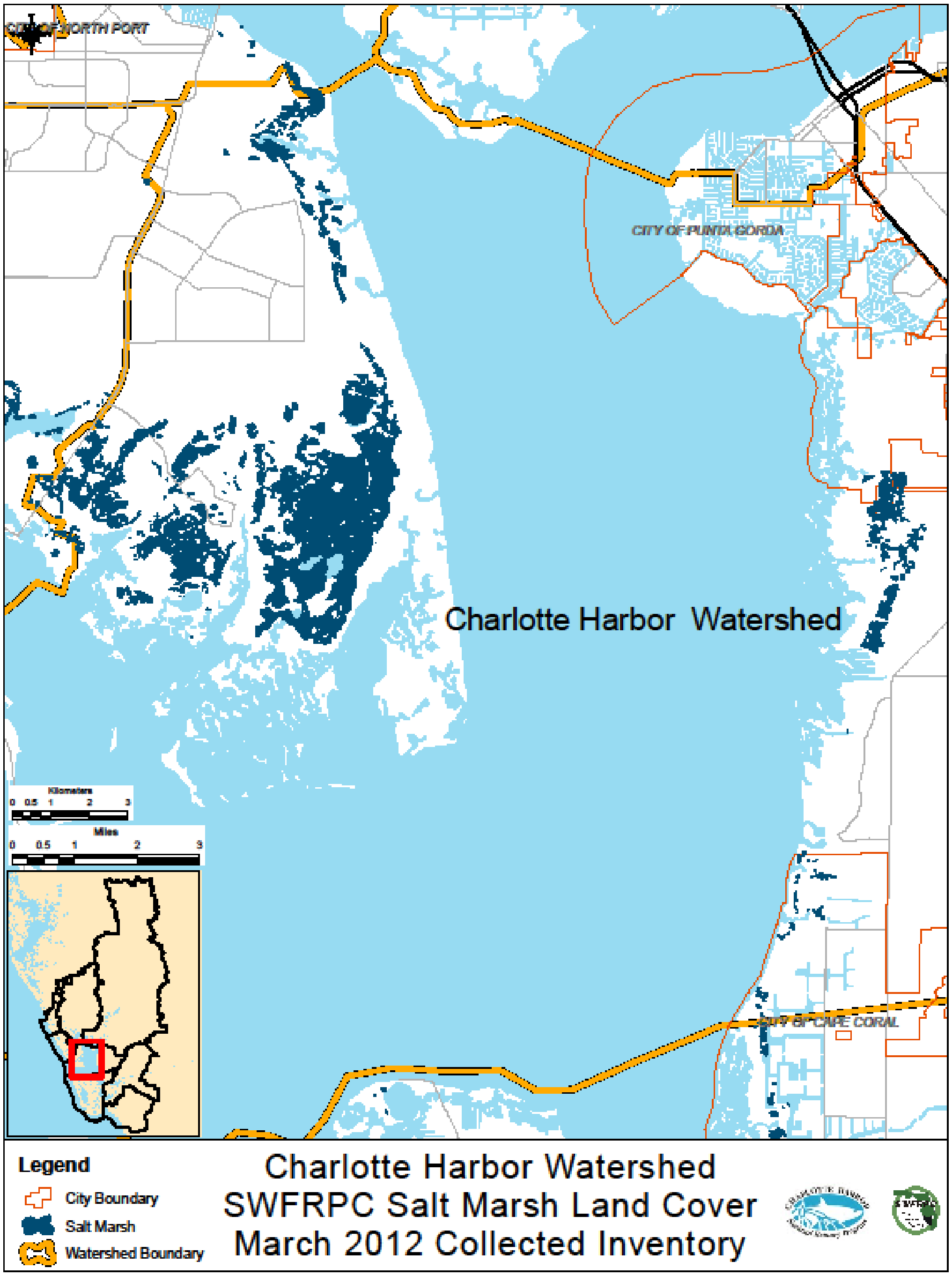

Figure 54: Total View of Charlotte Harbor Salt Marshes
Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

Pine Island Sound

The salt marshes of Pine Island Sound can be categorized into three geographic locations: barrier island marshes, in Sound island marshes, and Pine Island marshes.

Salt marshes are found on Cayo Costa Island, North Captiva Island and Sanibel Island. Cayo Costa salt marshes are high marshes found on the Sound side of the island behind mangrove and buttonwood forests. There is one small saltern on North Captiva Island on the Sound side of the island

On Sanibel Island marshes have been completely removed east of Causeway Boulevard. West of the Causeway Boulevard small areas of high marsh occur between mosquito control ditches (MCD). Some small marshes are north of Serenity Lane. Narrow high marshes are found on the south side of Tarpon Bay in a line that runs through the ranger house east of Tarpon Bay Road. Some high marsh is found within the black mangrove basin on the northwest shore of Tarpon Bay. Thin high marshes appear intermittently between the MCD that run south to north on the north side of Sanibel Island within J.N. "Ding" Darling National Wildlife Refuge. Small pockets of high marsh have formed in areas of mangrove death on Silver Key and the peninsula that extends into Old Blind Pass.

The salt marshes on islands within Pine Island Sound tend toward succulent and algal high marsh with areas of smooth cordgrass. These marshes appear to have formed in island centers that were slightly higher than the fringing mangroves that flank the shorelines of these islands. On several of these island former black mangrove basin forest has died where tidal water stands have over topped the black mangrove pneumatophores. with the death of the mangroves the open canopy has allowed a spread of Batis and other succulents and the formation of algal pools. Smooth cordgrass has grown on the interior pools of some islands apparently performing the pioneering stabilizer function that has been more familiar on sand bars and oyster islands in the past. The source for these smooth cordgrass plants is likely the shoreline at Pineland on the Pine Island where it has been maintained by human mangrove removal for a view at a small public park.

The salt marshes on Pine Island are linear features that parallel the mangrove fringe shoreline and are principally composed of algal marsh and saltern boundaries with adjacent hydric pine flatwoods or agriculturally modified lands. In the 1972 it was possible to walk salterns from the Galt Island area to Pineland (Beever, J. 1972 personal experience) but this continuum has now been disrupted. Interruptions in the pattern occur where human development form dredge and fill, agricultural ponds, and mosquito control ditches have eliminated these salt marshes.

The marshes of the Pine Island Sound watershed includes in descending order: mixed high marsh (512.9 acres), algal high marsh (340.7 acres), succulent high marsh (280.5 acres), shrub mangrove high marsh (91.0 acres), saltern (51.6 acres), grassy high marsh (51.3 acres), black needle rush marsh (8.3 acres), leather fern marsh (7.2 acres), and smooth cordgrass (2.72 acres). This is a total of 1,346.2 acres of salt marsh. Ninety-nine percent of the salt marshes of the Pine Island watershed are high marsh. Review of historical (1954) aerial photographs indicates that the relative absence of low marsh is natural and the estuarine shorelines of this watershed were mangrove lined.

Figure 55: Dead spot in dense groundcover of saltwort – GIS analyst Dan Cobb for scale, Jocelyn Island, Pine Island Sound.
Source: W Gray, SWFRPC, July 14, 2011

Figure 56: Marsh interior of Big Panther Key, Pine Island Sound
Source: W Gray, SWFRPC, June 1, 2011

Figure 57: Succulent high marsh interior of York Island, Pine Island Sound

Source: W Gray, SWFRPC, June 1, 2011

Figure 58: Mixed high marsh with mowed access path, J.N. Ding Darling National Wildlife Refuge, Sanibel Island, Pine Island Sound

Source: J. Beever, SWFRPC, October 13, 2011

Figure 59: Succulent high marsh, J.N. Ding Darling National Wildlife Refuge, Sanibel Island, Tarpon Bay
Source: W. Gray, SWFRPC, October 31, 2011

Figure 60: Mixed high marsh, Sanibel-Captiva Conservation Foundation, Sanibel Island, Central Slough
Source: W. Gray, SWFRPC, October 13, 2011

Figure 61: Example of Interior Island Salt Marsh, Big Panther Key, Pine Island Sound
Source: Google Earth 2012

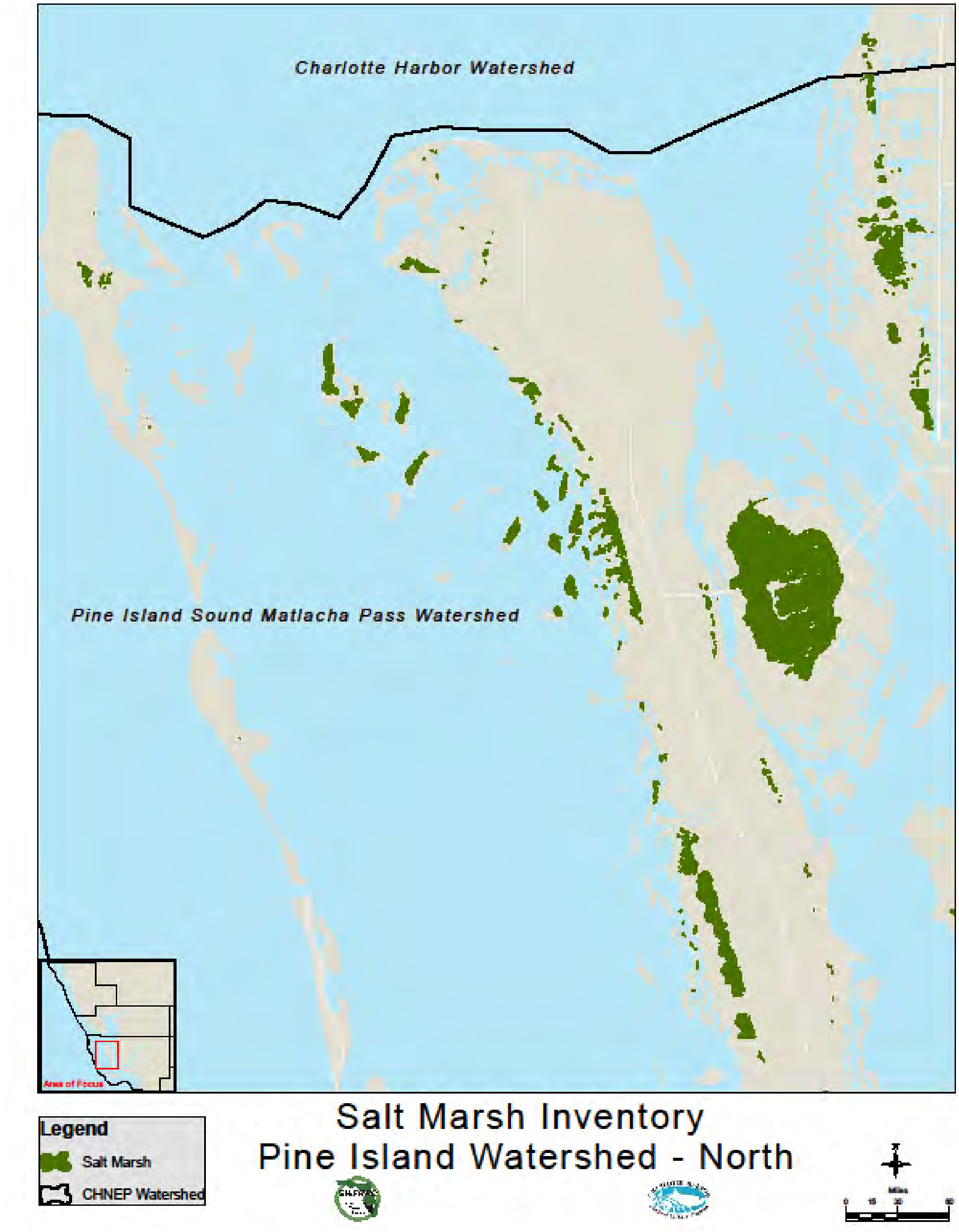

Figure 62: Map of the Salt Marshes of the Northern Pine Island and Matlacha Pass Watersheds as defined by CHNEP
Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

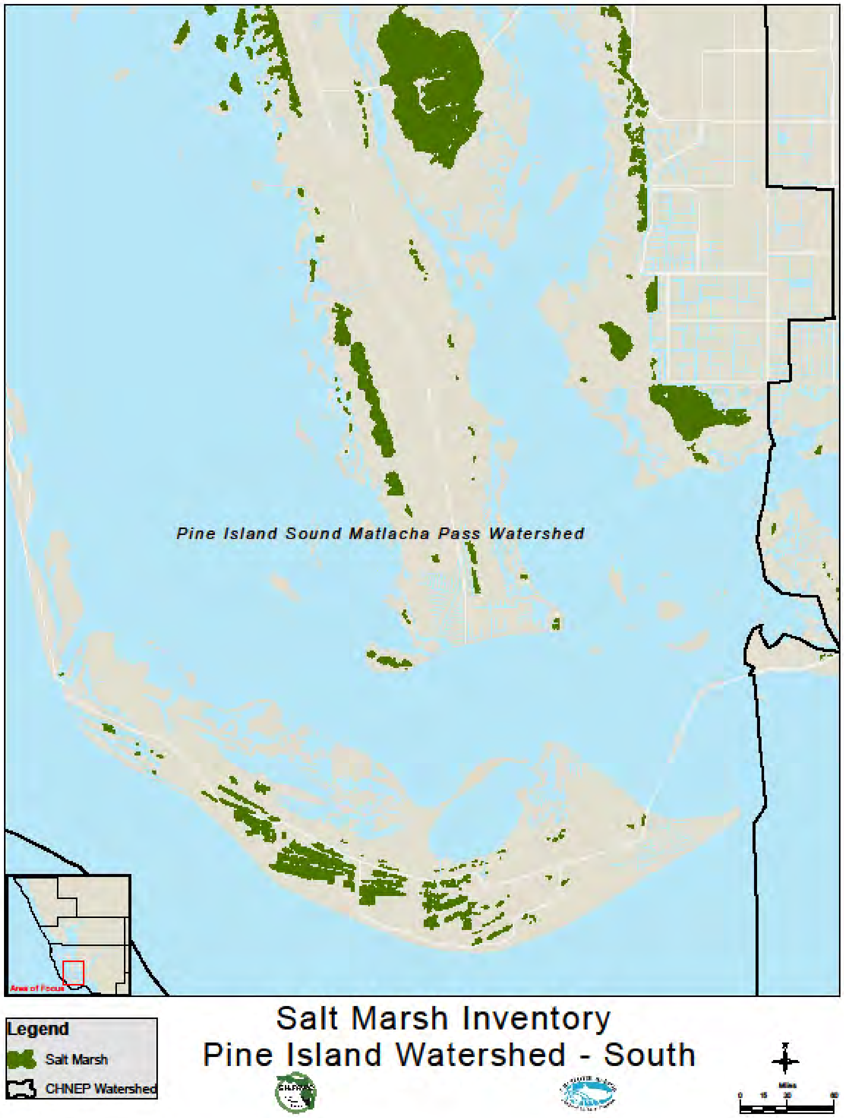

Figure 63: Map of the Salt Marshes of the Northern Pine Island and Matlacha Pass Watersheds as defined by CHNEP
Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

Matlacha Pass

The salt marshes of Pine Island Sound can also be categorized into three geographic locations: Little Pine Island interior island salt marshes, Mainland Matlacha Pass State Preserve Park salt marshes and Pine Island east shore salt marshes.

Beginning in the 1960s, exotic plant species, principally melaleuca (*Melaleuca quinquenervia*), invaded Little Pine Island, displacing native plant species and wildlife so aggressively that the island's wetland functions were severely reduced. Under private ownership, the island's wetlands were drained by ditches. Soon, the island became dominantly infested with exotic plant species. As the exotics proliferated, the variety of native birds and animals plummeted. Little Pine Island was acquired by the state of

Florida and established as part of the Charlotte Harbor Preserve Sate Park Preserve. The state of Florida established wetland mitigation banks in 1990, in order to create a regional, master-planned approach to wetland restoration and management. The Little Pine Island Restoration and Mitigation Bank was created in 1994, when Mariner Properties nominated the property to become its mitigation project. In 1996, Mariner Properties entered a public-private partnership with the state of Florida to restore 633 hectares (1,565 acres) of the island's 1900+ hectares (4,700 acres), of which about 1254 hectares (3,100 acres) are protected mangroves. The bank was formally established February 1996 by Permit Number 362434779. Mariner Properties Development, Inc., with the guidance of scientists and the oversight of state and federal agencies, began the job of removing the exotic plants. Working with chainsaws and other hand tools, work teams began removing an average of 30 tons of exotic biomass per acre - an amount roughly equal to the full cargo capacity of a tractor-trailer. Although laborious and time-consuming, hand-removal ensures millions of exotic plant seeds are taken away, reducing their regeneration on the island. Birds and animals began returning, and native seeds which had lain buried and dormant for 30 years began sprouting anew. Today, most of the high marsh of Little Pine Island has been cleared of exotic plant species and major hydrologic alterations restored.

On Pine Island proper a band of salt marsh historically extended parallel to the Pass the length of the island from south of Jug Creek Point to St. James City. Today the marsh system is highly fragmented by a combination of mosquito control ditching, areas of dredge and fill development, and agricultural development. There is a interesting phenomena of short mangrove forest that has greater than 25% that appears to be in decline and browning form freeze and water level effects. It is possible these areas will be future salt marshes if mangrove canopy continues to die and defoliate.

The mainland salt marshes exist in parallel to the east Matlacha Pass shoreline typically west of the waterward bank of the two Cape Coral spreader waterways or Veterans Parkway. The two Spreader Waterways were constructed on the landward edge of the Matlacha Pass east shoreline mangrove forest and thereby sited principally in the salt marshes that were found landward of the mangrove forest. The only area where the full expression of salt marsh zonation is present is in the mile where Veterans Parkway flanks the marsh and the spreader waterway was not constructed. The remaining salt marshes are in the Charlotte Harbor Preserve State Park.

The marshes of the Matlacha Pass watershed includes in descending order: mixed high marsh (1,466.9 acres), shrub mangrove high marsh (449.5 acres), grassy high marsh (149.2 acres), succulent high marsh (123.3 acres), algal marsh (80.1 acres), saltern (48.5 acres), black needle rush marsh (14.0 acres), and leather fern marsh (0.3 acres). This is a total of 2,332.7 acres of salt marsh. Ninety-nine percent of the salt marshes of the Matlacha Pass watershed are high marsh. Review of historical (1954) aerial photographs indicate that the relative absence of low marsh is natural and the estuarine shorelines of this watershed were mangrove lined.

Figure 64: Mixed high marsh and great egrets, North Spreader Waterway, Charlotte Harbor Preserve State Park
Source: J. Beever, SWFRPC, August 11, 2011

Figure 65: Mixed high marsh, saltern, succulent marsh, and shrub mangrove marsh with fringing mangrove forest in far distance, Charlotte Harbor Preserve State Park at Veterans Parkway where the Spreader Waterway is not present.
Source: J. Beever, SWFRPC, August 11, 2011

Figure 66: Mixed high marsh grassy high marsh, and shrub mangrove marsh with fringing mangrove forest in far distance, Little Pine Island Mitigation Bank, Charlotte Harbor Preserve State Park.
Source: J. Beever, SWFRPC, September 28, 2011

Figure 67: Saltern, succulent, algal, and mixed high marsh, South Spreader Waterway, Charlotte Harbor Preserve State Park
Source: W. Gray, SWFRPC, August 3, 2011

Figure 68: Mixed, grassy and succulent high marsh photographed while standing in saltern, South Spreader Waterway, Charlotte Harbor Preserve State Park
Source: W. Gray, SWFRPC, August 3, 2011

Figure 69: Mixed high marsh, Ms. Rhonda Evans, EPA, St. Jude Trail Preserve, Pine Island
Source: W. Gray, SWFRPC, August 3, 2011

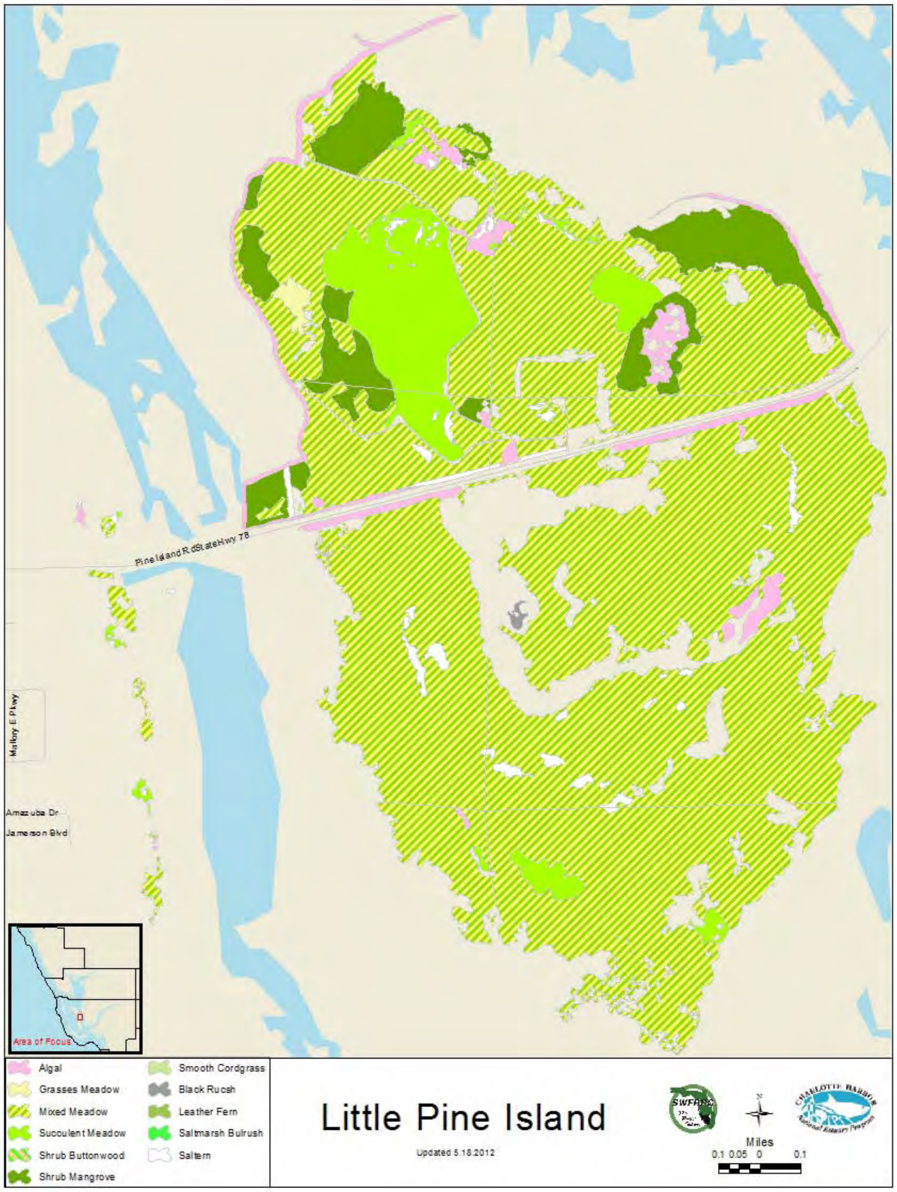

Figure 70: Map of Salt Marshes by Type, Little Pine Island, Charlotte Harbor Preserve State Park.

Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

Caloosahatchee River

The Caloosahatchee River Watershed is the most altered watershed with regard to salt marshes in the CHNEP. Most of the historical marshes that flanked the Caloosahatchee River itself have been eliminated by shoreline development that was initially agricultural and ultimately urban and suburban residential. Extensive dredge and fill alteration of the shoreline removed salt marshes along the river length excepting a few preserves or in tributaries principally on the north shore of the River where land uses remained more rural east of Cape Coral. Even with all this alteration salt marshes extend almost as far as the S-79 locks and water control structure, 24.7 river miles upstream of the mouth of the River at Shell Point. It is possible that his greater penetration up-river is the result, in part, of the unnatural hydrologic cycles imposed upon the Caloosahatchee River by the pattern of lock openings and closures. There are periods when no fresh water was admitted past the locks during past dry seasons salinating the Caloosahatchee River to the foot of the dam.

Salt marshes are found in the Caloosahatchee river Watershed in Shell Point Preserve, Deep Lagoon Preserve, Glovers Bight/Piney Point, Four-Mile Cove/Eco-Park, Hancock Creek, Powell Creek, Marsh Point Creek, Daughtry's Creek, Caloosahatchee Creek, Popash Creek, Stroud Creek, Orange River, and Trout Creek Oxbow.

The marshes of the Caloosahatchee River watershed includes in descending order: black needle rush (138.5 acres), leather fern marsh (76.5 acres), mixed high marsh (66.3 acres), shrub mangrove high marsh (45.7 acres), grassy high marsh (40.2 acres), saltern (11.2 acres), algal high marsh (6.6 acres), and succulent high marsh (4.3 acres). This is a total of 389.3 acres of salt marsh. Fifty-five percent of the salt marshes of the Caloosahatchee River watershed are low and middle marsh.

Figure 72: Leather fern marsh with freeze damaged pond apple, Popash Creek
Source: W. Gray, SWFRPC, October 18, 2010

Figure 71: Leather fern marsh, Caloosahatchee Creek
Source: W. Gray, SWFRPC, October 18, 2010

Figure 72: Leather fern marsh with freeze damage, Daughtry's Creek
Source: W. Gray, SWFRPC, October 1, 2011

Figure 73: Leather fern marsh, Orange River
Source: W. Gray, SWFRPC, April 18, 2011

Figure 74: Mixed high marsh, Deep Lagoon Preserve
Source: W. Gray, SWFRPC, April 28, 2010

Figure 75: Saltern and shrub black mangrove marsh, Shell Point Preserve
Source: W. Gray, SWFRPC, May 28, 2010

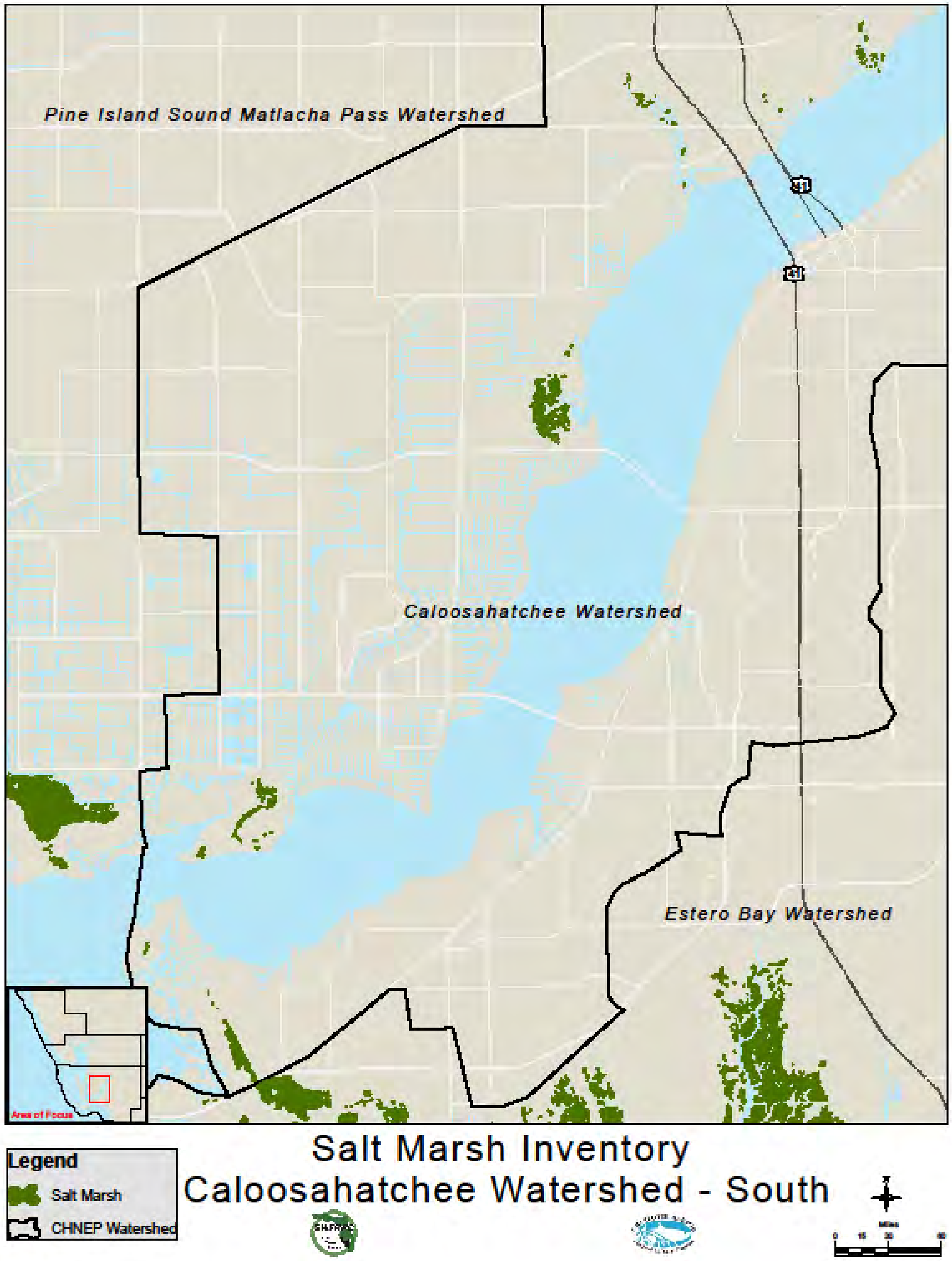

Figure 76: Map of the Salt Marshes of the Southwestern Caloosahatchee River Watershed as defined by CHNEP

Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

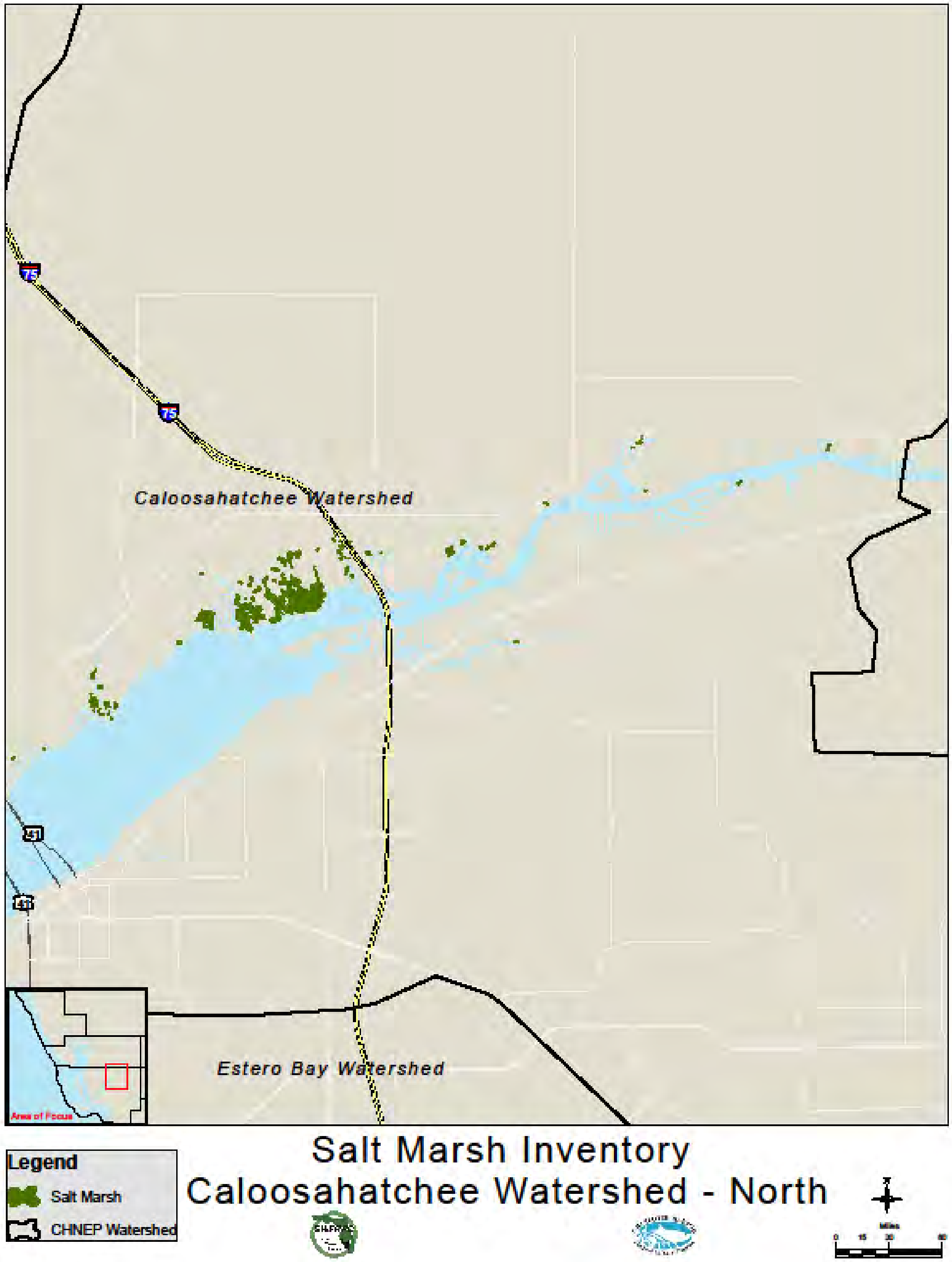

Figure 77: Map of the Salt Marshes of the Northeastern Caloosahatchee River Watershed as defined by CHNEP

Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

Estero Bay

The salt marshes of the Estero Bay watershed are predominantly found on the mainland forming a band of varying width paralleling the mainland fringing mangroves of Estero Bay, Matanzas Pass and the Bunche Beach/ san Carlos Bay shoreline. small elements of salt marsh are found on interior and barrier islands. Unique features of Estero Bay watershed salt marshes include shrub buttonwood salt marsh and the roughly circular algal marsh/saltern located west of Hendry Creek on the peninsula flanked by Rocky Bay and Hurricane Bay.

The marshes of the Caloosahatchee River watershed includes in descending order: mixed high marsh (779.5 acres), black needle rush marsh (726.3 acres), algal high marsh (532.7 acres), shrub mangrove high marsh (247.0 acres), saltern (198.5 acres), succulent high marsh (167.1 acres). grassy high marsh (65.6 acres), leather fern marsh (38.6 acres), shrub buttonwood high marsh (18.7 acres). This is a total of 2,773.9 acres of salt marsh. Seventy-two percent of the salt marshes of the Caloosahatchee River watershed are high marsh.

Salt marshes of the barrier islands forming the west shoreline of Estero Bay are associated with the bayward facing east side of Big Hickory Island, flanking the Estero Boulevard on the island, in the center of Charlie Key. The last remnant of high marsh on Estero Island is found on the preserves on both sides of Island Pine Way. High salt marsh has been removed by fill on Bonita Beach, Long Key, Black Island, Lovers Key, and most of Estero Island.

On the mainland shoreline of Estero Bay, spot marshes are found within the mangrove fringe forest west of Marina Isle Court and Bonita Bay Boulevard in the Bonita Bay Development. In the Imperial River there is salt marsh on both sides of the US 41 bridge. An open marsh is flanking the boardwalk at the nature center park west of Pond Apple Court in Bonita Bay. Large areas of high marsh are found above Nesting Court and the high elevation golf course hole extending north on a peninsula separating Spring Creek from Estero Bay.

There are extensive black needle rush marshes flanking Spring Creek and its south tributary coming from the central slough of the Bonita Bay Development. Black needle rush marshes flank Spring Creek on both sides to an areas 800 meters west of US 41 bridge. Salt marsh extends in the center of the peninsula that flanks Spring Creek at southwest Pelican Landing. High marsh is found on the west of the Via Castella Drive and Pelican Colony Boulevard in Pelican Landing and 255 meters west of the Castella at the Colony development. There is a high marsh 162 meters south of the Hyatt Regency Coconut Point Resort Hotel. A thin band and a large high marsh feature are located west and north of Coconut Point Resort.

High marsh flanks the end of Bridge Rub Court. There are linear and patch high marshes west of West Bay Boulevard, West Bay Club. Saltern marshes parallel the east shore of Estero Bay along West Bay Club up to the Estero River. Salt marshes are also found in to Halfway Creek to 950 meters upstream of the mouth of the creek. Black needle rush marshes are on peninsulas formed by the serpentine Estero River path 1,750 meters from the Estero River mouth. Very thin salterns parallel the west side of the Estero Bay Scrub Preserve/FKA Sahdev and appear to be significantly reduced by the paralleling mosquito control ditch (MCD) that cut through the center of the marsh. This has created an unnatural pattern of red mangroves between the saltern and other high marsh. A long linear saltern, large aggregations of black needle rush and maritime meadow marshes are found north of the Estero River from its north shoreline to the south shoreline of Mullock Creek.

A network of MCD fragments the high marsh west of the northwest corner of Shadowwood Preserve. Black needle rush marshes flank the mouth of Ten-Mile Canal and extend through the peninsula formed between Mullock Creek and Hendry Creek. Large high marshes and black needle rush marshes flank the east and west sides of Hendry Creek. South of Winkler Road large and extensive high marsh and the largest algal marsh in the CHNEP extend into a large peninsula forming the west bank of Hendry Creek. A large marsh complex is located between two mangrove arms of Cow Pen Slough’s connection to the large mangrove shoreline of Estero Bay. High marsh flanks both side of Cow Pen Slough north to Kelly Road.

The "length" of saltern parallel banding along Estero Bay is approximately 8.57 miles. The longest contiguous segment of salt barrens in the Estero Bay watershed is 2.68 miles from immediately south of Mullock Creek to the north shoreline of Spring Creek.

Along Matanzas Pass, salt marshes are found paralleling the north shoreline east of San Carlos Boulevard in the mainland. Perhaps one tiny salt marsh pool is located on the south shore of San Carlos Island. Two large finger fill canal residential developments were built in the high marshes on both sides of San Carlos Boulevard. High marshes occur west of Seminole RV Park north of Siesta Isles west to John Morris Road. A large borrow pit was constructed out of high marsh south of the Mastique high rise development.

High marsh extends between John Morris Road and Summerlin Road on the former "Estuaries" site which is now part of the San Carlos Bay Bunche Beach Preserve. High marshes are found west of Shell Point Road. Patch high marshes flank both sides of Summerlin Road. Those on the north side are part of the tidal Caloosahatchee River watershed. There was a salt marsh and a marsh mitigation area at the tip of Bowditch Point Park on Estero Island. This area is now submerged.

Figure 78: Black rush marsh with leather fern, Hendry Creek
Source: W. Gray, SWFRPC, October 5, 2011

Figure 79: Black rush marsh, Hendry Creek east bank
Source: W. Gray, SWFRPC, October 5, 2011

Figure 80: Saltern, algal marsh, and shrub black mangrove, Bunche Beach high marsh.
Source: W. Gray, SWFRPC, May 7, 2010

Figure 81: Mixed high marsh of perennial glasswort, sea oxeye daisy, and saltgrass, San Carlos Bay.
Source: W. Gray, SWFRPC, June 7, 2010

Figure 82: Saltern, algal marsh, and tidal water, Estero Bay west of Hendry Creek.
Source: W. Gray, SWFRPC, February 24, 2011

Figure 83: Succulent salt marsh, Estero Bay Preserve State Park, South of Winkler Road.
Source: W. Gray, SWFRPC, February 21, 2012

Figure 84: Black needle rush marsh, Bonita Bay, Halfway Creek, Estero Bay.
Source: W. Gray, SWFRPC, March 8, 2011

Figure 85: Aerial View of the Algal Salt Marshes and Salterns West of Hendry Creek, Estero Bay Watershed
Source: Google Earth 2010

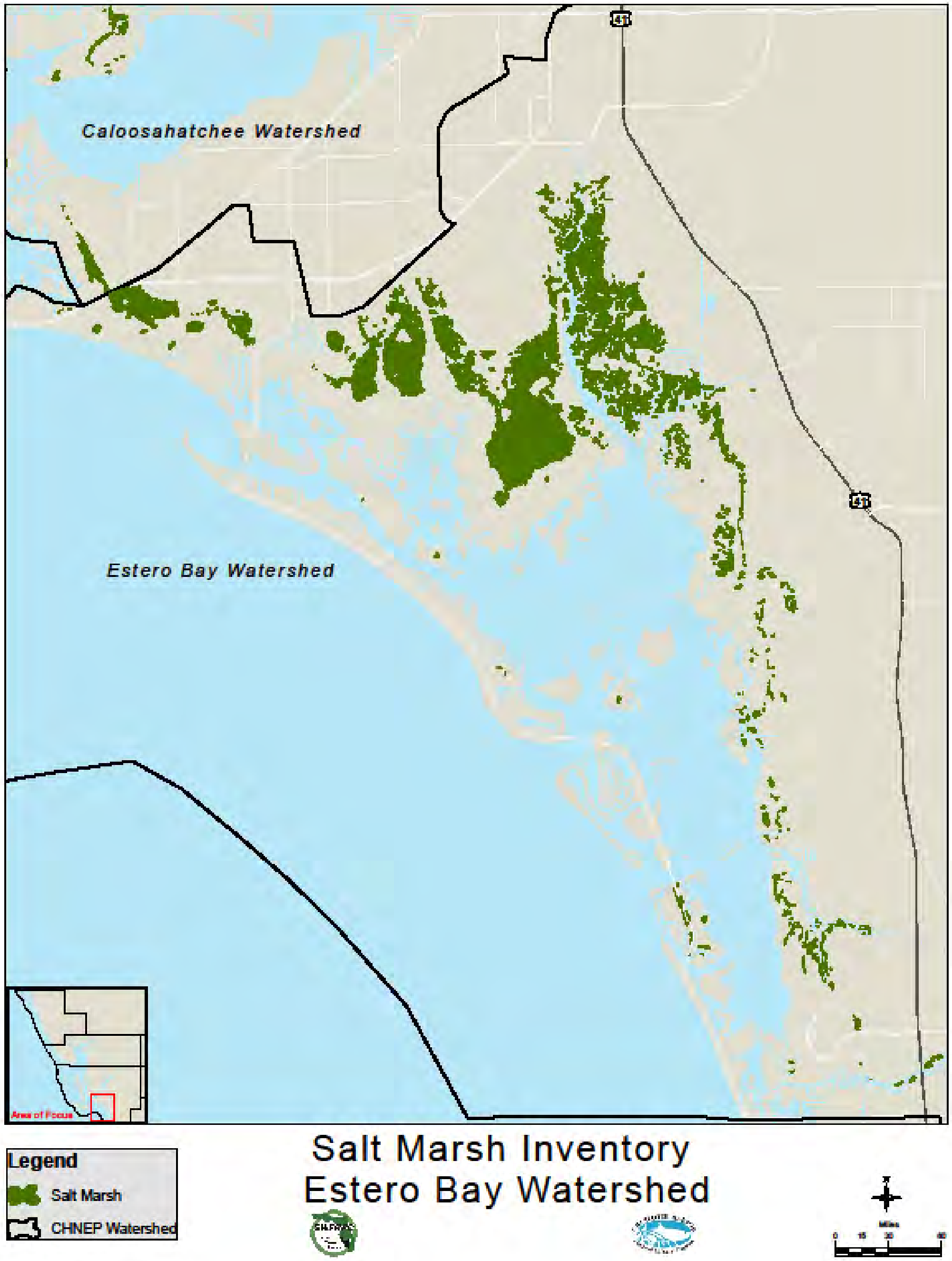

Figure 86: Map of the Salt Marshes of the Estero Bay Watershed as defined by CHNEP
Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

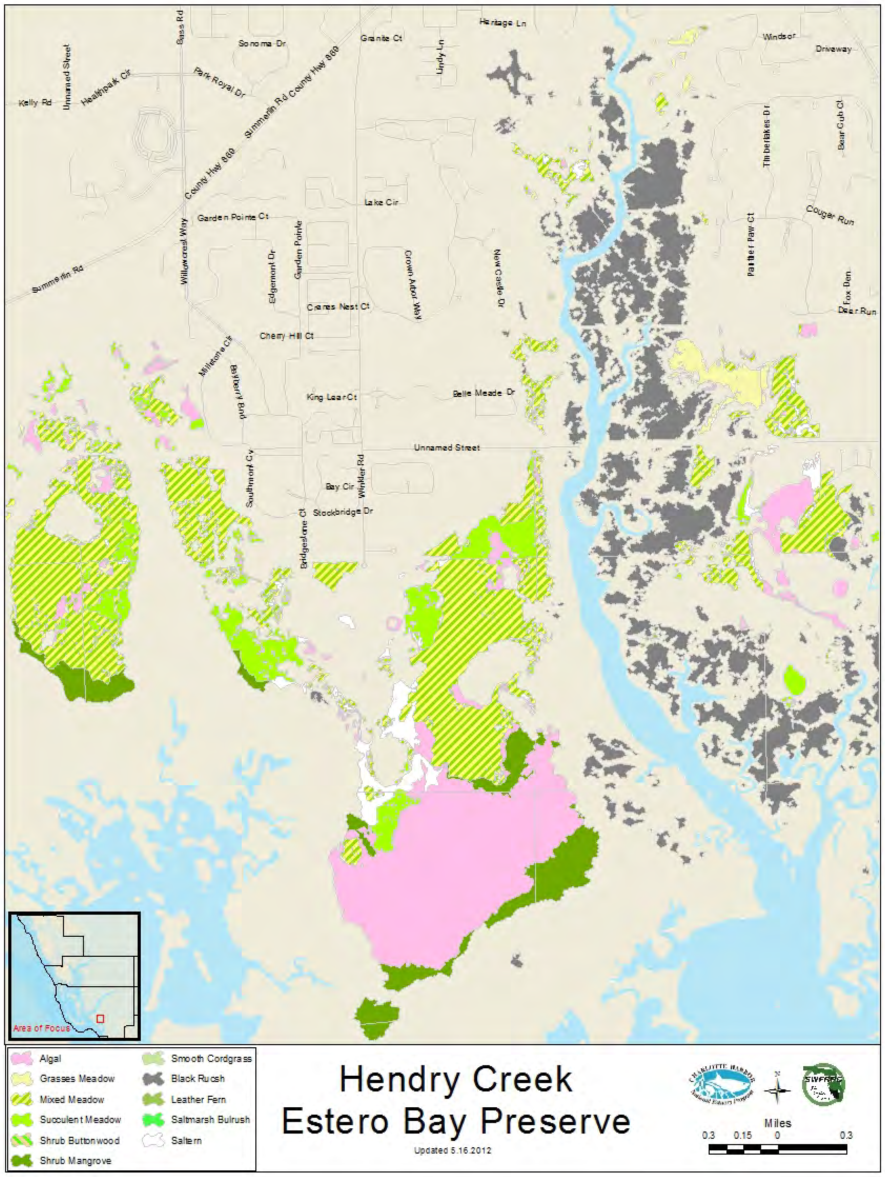

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Figure 87: Map of the Salt Marshes By Type of the Hendry Creek Area, Estero Bay Watershed as defined by CHNEP

Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

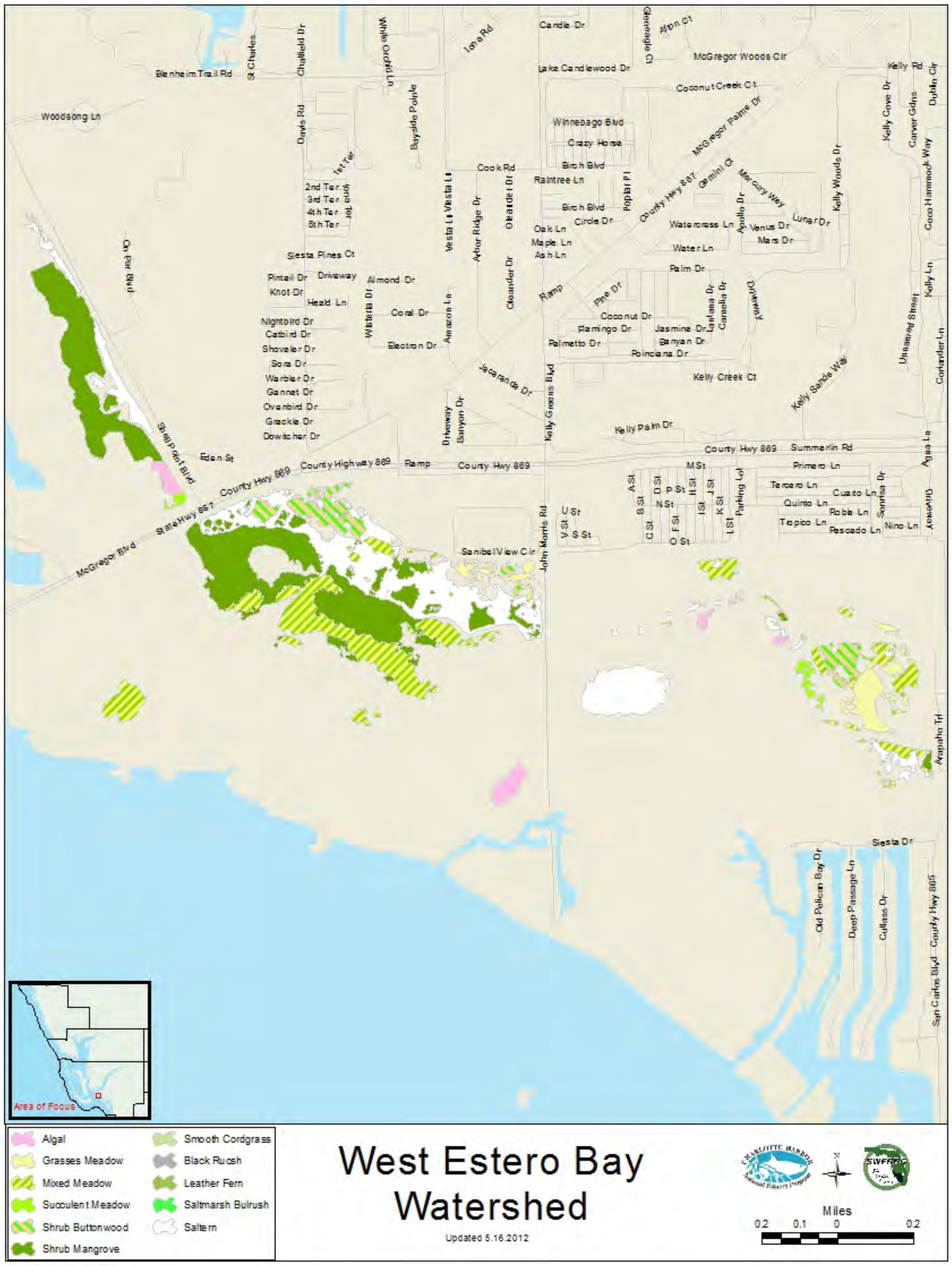


Figure 88: Map of the Salt Marshes By Type of the Bunche Beach/San Carlos Bay and Shell Point Preserve, Estero Bay and Caloosahatchee River Watersheds as defined by CHNEP
Source: D. Cobb and J. Beever, SWFRPC, Marsh 31, 2012

Water Chemistry of CHNEP Salt Marshes

(As extreme as expected)

Fresh, brackish, and saline waters are distributed in a salt marsh along a gradient from the upland headwaters to the marine environment. Salt marshes occur in areas where salinities in the overlying water range from 0.5 ppt. to that of seawater (30 to 32 ppt.) or greater (Wiegert and Freeman 1990). The salinity varies from moderate at flood tide, to high following evaporation at low tide, to low during rains at ebb tide (Gallagher 1980, Pomeroy et al.1981). Halophytic plants are adapted to tolerate the salinities of both the overlaying water and soil waters. Tidal creeks have salinities similar to adjacent saline waterbodies.

The salinity within the soils is also similar to that of overlying water bodies and depends on several factors including the frequency of tidal inundation, rainfall, drainage slopes and tidal creeks, soil texture, vegetation, depth to water table, freshwater inflow, fossil salt deposits (Mitsch and Gosselink 1993). Salt marsh soil salinities range from 10 to 20 ppt., and can exceed 100 ppt. in salterns and barrens (Wiegert and Freeman 1990).

Evaporation and concentration of salts is usually greater in the high marsh causing soil salinities to be higher than in regularly flooded salt marshes. As a result, the level of freshwater input, tidal inundation, and evaporation controls species composition and the level of productivity. Both *Spartina* and *Juncus* grow best in fresh water, but are able to withstand saline conditions. *Spartina patens* can tolerate salinities up to 28 ppt. *Juncus* can withstand higher soil salinity, but growth becomes impaired at too high salinities.

As intertidal habitats, much of the vegetation in salt marshes experiences periodic tidal flooding. Low and mid marsh areas can be submerged for hours, and high marshes can experience storm surge that can affect more upland vegetation. The frequency and duration of flooding events, as well as the tolerance of individual species to saltwater submersion, can be a major determinant of salt marsh zonation, but soils salinities and anoxic saturation also play long term roles

Most angiosperms have a limited ability to thrive in saline waters, and diversity of vegetation decreases with increasing salinity (Odum 1988, Odum and Hoover 1988). Seeds and seedlings are especially vulnerable to salt stress, further contributing to zonation in plants. However, many salt marsh plants have developed mechanisms to tolerate high salinities. Some plants increase succulence by retaining water or exclude salt at the roots, while others excrete salt through specialized glands or sequester it into leaves that are shed periodically (Poljakoff-Mayber 1975, Rozema et al. 1981, Hacker and Bertness 1995, Mitsch and Gosselink 1993, Dawes 1998). One of the greatest stresses for salt marsh plants to overcome is the difficulty of roots to take up water due to the lowered water potential of salty soil, which averages 10 to 20 ppt, but may exceed 100 ppt in some areas (Wiegert and Freeman 1990). Many marsh plants adjust to this physiological strain by accumulating sugars and other organic solutes in their tissues, thereby increasing the vascular pressure needed to absorb water from the soil (Flowers et al. 1977, 1986; Rozema et al.. 1985).

During the site visits of this study if the salt marsh had water at the time of the visit we collected date on salinity, dissolved oxygen, pH, and water temperature with a YSI meter. The water sampling was done with a YSI 6060000 Professional Plus full featured multiparameter instrument meter equipped with a Dual ISE/Cond/DO/Temp 1 or 4 meters cable Model 1001 pH sensor assy with a Model 5203 Plarographic DO sensor, a Model 1001 pH sensor.

The YSI 6060000 Instrument was calibrated prior to each field day visit and recalibrated on return to office. The frequency for each sampling event was directly connected to the site visit. The analysis and measurement technique, as well as associated acceptance criteria and corrective actions, will follow the documented YSI 6050000 Instrument protocols. Calibration of the YSI 6060000 Instrument and membrane replacements on probes was maintained per the QA/QC schedule. No instrument anomalies occurred in the course of the study. It is notable that batteries for the YSI meter were used at a rapid rate lasting a average of three months.

All sampling was done on-site. Depending on the site samples would be taken if water was present in different marsh types. A minimum of 5 replicate samples were collected at each site on the same day. In some cases the YSI meter continued to record after the meter was removed from the water for a short period of time even when the stop sample button had been depressed. Data from these air-sample replicates were discarded in the analysis.

The mean salinities, dissolved oxygen, pH and water temperature data from this study are found on Table 5 for each marsh type and for all marsh types combined. Table 6 reports the minimum and maximum readings for each marsh type and for all marshes combined. It is important to note that these data are representative of the marsh on the day of the site visit in that particular season and tide. At other times these marshes could have very different water quality in these parameters.

For all salt marshes visited the salinity was 14.05 + 15.91 PPT. There was a difference in salinities between marsh types as would be expected. Grassy high marsh was 2.05 ±1.01 PPT while salterns were 54.00 ± 13.71 PPT. The most common mixed high marsh has salinity of 7.45 ± 4.47 PPT. The most common low marsh, black needle rush, had a salinity of 10.95 ± 8.43. During summer when tributaries and rivers flow at high volumes salt marshes can experience much fresher water with low salinities.

For all salt marshes visited the dissolved oxygen was 3.76 + 1.96 ppm. There was a difference in dissolved oxygen between marsh types, with lower dissolved oxygen the higher in the tidal gradient a marsh was. Grassy high marsh was 1.36 ±1.39 ppm while fringing marshes were 3.87± 1.87 ppm for black needle rush. The most common mixed high marsh has salinity of 4.48 ± 1.26 ppm. The highest average dissolved oxygen readings were for saltmarsh bulrush at 4.85±1.30 ppm and a single smooth cordgrass site in Lemon at 5.06 ppm. The lowest dissolved oxygen readings came from stagnant pools entrapped on high marshes.

For all salt marshes visited the pH was 7.59 ±0.32 ppm. There was a difference in pH between marsh types was not as pronounced for pH. Grassy high marsh was 7.14 ± 0.15 while fringing marshes were 7.59 ± 0.32 for black needle rush. The most common mixed high marsh has salinity of 7.48 ± 0.42. The highest average pH readings were for succulent high marsh at 7.83 ± 0.12 and a single smooth cordgrass site in Lemon Bay at 8.15.

For all salt marshes visited the water temperature was 25.63 ± 4.62 C. There was a difference in water temperature between marsh types was not as pronounced. Leather fern salt marsh was 23.28 ± 5.29 C while succulent high marsh was32.83 ± 4.43 C. The most common mixed high marsh has salinity of 27.72 ± 4.91 C. The most common low marsh, black needle rush, had a water temperature of 25.48 ± 3.14 C. The wide range of temperature form 37.68 to 14.81 reflects on the study involving sampling during all seasons with the highest readings (37.68 C) coming from pools in high marsh during summer.

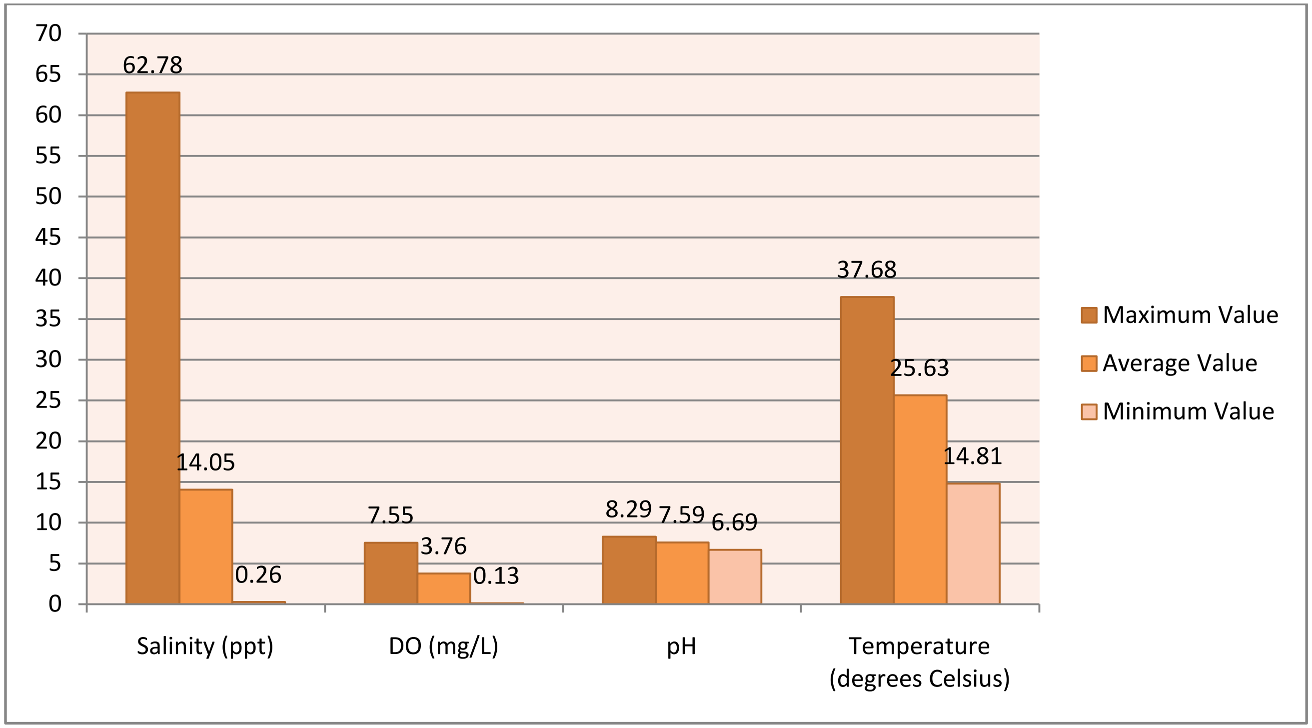


Figure 89: Water quality data from all sampled salt marshes including salinity, dissolved oxygen, pH, and temperature maxima, minima and means.

Source: J. Beever and W. Gray, SWFRPC 2010-2012

Type of Marsh	Salinity in PPT	Dissolved Oxygen in ppm	pH	Temperature in (c)
Smooth Cordgrass	35.21	5.06	8.15	25.70
Black Needle Rush	10.95 + 8.43	3.87+ 1.87	7.59 + 0.32	25.48 + 3.14
Leather Fern	5.60 + 3.27	4.63 + 1.66	7.74 + 0.20	23.28 + 5.29
Saltmarsh Bulrush	9.44+2.16	4.85+1.30	7.63+0.14	29.26+2.69
Shrub Mangrove	35.73 + 21.72	2.74 + 2.58	7.29 + 0.29	28.94 + 2.12
Saltern	54.00 + 13.71	1.47 + 2.41	7.52 + 0.25	24.84 + 6.03
Succulent High Marsh Meadow	40.86 + 2.91	3.04 ++ 0.57	7.83 + 0.12	32.83 + 4.43
Mixed High Marsh Meadow	7.45 + 4.47	4.48 + 1.26	7.48 + 0.42	27.72 + 4.91
Grassy High Marsh Meadow	2.05 +1.01	1.36 +1.39	7.14 + 0.15	25.10 + 2.24
All Salt Marsh Types	14.05 + 15.91	3.76 + 1.96	7.59 + 0.32	25.63 + 4.62

Table 5 Water quality data from all sampled salt marshes by type including salinity, dissolved oxygen, pH, and temperature mean and standard deviation. smooth cordgrass is a single sample.

Source: J. Beever and W. Gray, SWFRPC 2010-2012

Type of Marsh	Salinity in PPT	Dissolved Oxygen	pH	Temperature (c)
	Minimum/Maximum	Minimum/Maximum	Minimum/Maximum	Minimum/Maximum
Black Needle Rush	0.41/27.74	0.94/6.50	6.69/7.96	20.04/29.80
Leather Fern	0.26/9.99	2.93/7.55	7.22/8.07	14.81/29.53
Saltmarsh Bulrush	7.64/11.83	3.44/5.99	7.55/7.79	24.03/25.10
Shrub Mangrove	15.99/5	0.17/5.55	7.03/7.61	16.03/31.76
Saltern	33.57/62.78	0.13/5.07	7.24/7.84	16.03/29.61
Succulent High Marsh Meadow	38.03/43.84	2.38/3.39	7.74/7.97	29.00/37.68
Mixed High Marsh Meadow	0.62/13.14	3.82/5.87	6.97/7.92	20.64/32.29
Grassy High Marsh Meadow	0.83/3.26	0.33/3.78	7.01/7.39	22.50/28.10
All Salt Marsh Types	0.26/62.78	0.13/7.55	6.69/8.15	14.81/37.68

Table 6: Water quality data from all sampled salt marshes by type, including salinity, dissolved oxygen, pH, and temperature minima and maxima. Smooth cordgrass is not included since it is a single sample site. Source: J. Beever and W. Gray, SWFRPC 2010-2012

Plant Species and Diversity of the Salt Marshes of the CHNEP

(High in the high marsh)

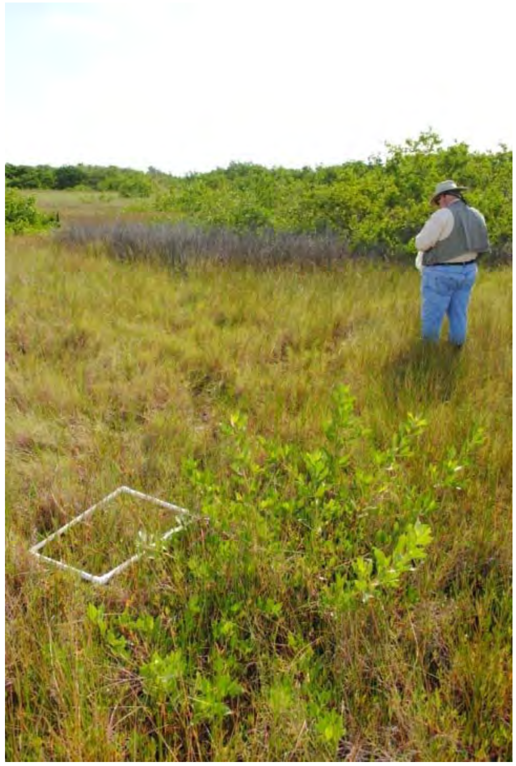


Figure 90: Measuring plant species cover and diversity, principal investigator with meter square, Little Pine Island
Source: W. Gray, SWFRPC

Salt marsh plants are salt-tolerant or halophytic species that have developed biological and physiological mechanisms to adjust to a range in environmental conditions. In South Florida, these plants have adapted to tolerate the stresses of salinity changes, periodic inundation, and extremes in temperature that are unique in the South Florida environment. Although most salt marsh species have a broad range of distribution in the intertidal zone, their abundance differs depending on the unique hydrological and physical characteristics discussed above.

Salt marsh plants normally distribute themselves along the elevation gradient from the creek bank or estuary shoreline to upland depending on their tolerance and adaptability (Montague and Wiegert 1990, Wiegert and Freeman 1990). Along the landward upper edge of the high marsh, common species include marsh elder (*Iva frutescens*), saltbush (*Baccharis halimifolia*), seaside golden rod (*Solidago sempervirens*), seablite (*Sueda linearis*), and Christmas berry (*Lycium carolinianum*). Many species are found in the high marsh above the mean high water level: salt grass (*Distichlis* spicata), saltwort (*Batis maritima*), glassworts (*Salicornia* spp.), leather fern (*Acrostichum aureum*), sea oxeyes (Borrichia sp.), cordgrasses (*Spartina* spp.), coastal dropseed (*Sporobolus virginicus*), key grass (*Monanthachloe littoralis*), salt jointgrass (*Paspalum vaginatum*), and seablite. Typical species located from the low to high marsh are smooth cordgrass

(*Spartina alterniflora*), black needlerush (*Juncus roemerianus*), and sea lavender (*Limonium carolinanum*). In the salt marsh-mangrove transition zone, dominant mangrove species include red (*Rhizophora mangle*), black (*Avicennia germinans*), and white (*Laguncularia racemosa*) mangroves, and the buttonwood (*Conocarpus erectus*) (Tomlinson 1986).

In order to catalogue plant species found in each salt marsh, lists of species were generated. Plants, both native and exotic, were listed in two tiers: salt marsh species found in Florida; and salt marsh species found in southwest Florida (Lee Charlotte and south Sarasota Counties). Due to the cosmopolitan nature of coastal southwest Florida, it is important not to rule out species that may not be vouchered in the study area specifically. Additionally, many commercially available exotic species escape into the wild, becoming common locally or becoming invasive. These species have been accounted for in the lists and were be catalogued during the project.

The statewide salt marsh plant list includes 385 species. Sources for this list include the University of Florida Institute of Food and Agricultural Sciences (UF IFAS) Center for Aquatic and Invasive Plants, the Florida Department of Environmental Protection Wetland Evaluation and Delineation Program, "Florida Wetland Plants: An Identification Manual" by Dr. John D. Tobe, et al, the Institute for Systematic Botany's Atlas of Florida Vascular Plants, and the Lee County Deep Lagoon Preserve Stewardship Plan.

The southwest Florida salt marsh potential plant list includes 301 species that were narrowed down from the statewide list by checking for vouchered species from the counties in the study area. The Institute for Systematic Botany's Atlas of Florida Vascular Plants contains this information. At the conclusion of this study. We find some of the potential candidate species suspect for occurring in salt marshes. A number of the species listed are not typically species that would be expected in salt marshes and would be more commonly found in freshwater marshes and swamps such as papyrus, water lilies, swamp dogwood, and pop ash.

In the course of this study we confirmed 118 plant species in the salt marshes of the CHNEP during the 68 marsh sites visited following the project protocol (Appendix I).

The mean number of plant species per saltmarsh is 9.78 + 8.66. The maximum number of plant species at any site is 47 in a mixed high marsh, and the smallest number is 2 species. of plants in black needle rush marsh. The most frequently occurring species in the salt marshes of the CHNEP include the expected dominate salt marsh plants by which the marsh types are identified but there is also a high representation of shrub and young mangroves, and two exotic plant species. The mangroves are part of the shrub high marsh but also appear to be moving up-gradient into salt marshes. In contrast the exotic plants are located on spoil piles principally created by mosquito control ditching and navigation canal excavation or moving off manmade fill barriers including roadway toe and rip-rap.

Common Name	*Genus*	*species*	*% occurrence*
red mangrove	*Rhizophora*	*mangle*	59%
giant leather fern	*Acrostichum*	*danaeifolium*	41%
black mangrove	*Avicennia*	*germinans*	41%
Brazilian pepper	***Schinus***	***terebinthifolius***	37%
white mangrove	*Laguncularia*	*racemosa*	35%
green buttonwood	*Conocarpus*	*erectus*	30%
perennial glasswort	*Sarcocornia*	*ambigua*	28%
black needle rush	*Juncus*	*roemerianus*	28%
saltwort	*Batis*	*maritima*	24%
pond apple	*Annona*	*glabra*	24%
seashore dropseed	*Sporobolus*	*virginicus*	22%
shoreline sea-purslane	*Sesuvium*	*portulacastrum*	20%
saltgrass	*Distichlis*	*spicata*	20%
sabal palm	*Sabal*	*palmetto*	20%
bushy sea oxeye	*Borrichia*	*frutescens*	20%
Australian pine	***Casuarina***	***equisetifolia***	20%
salt-bush	*Baccharis*	*halimifolia*	19%
Christmas berry	*Lycium*	*carolinianum*	17%
Silverhead or marsh samphire	*Blutaparon*	*vermiculare*	15%

Table 7: The top twenty most common plant species in the site visited salt marshes.
Non-native species are indicated in **bold**. Source: W. Gray and J. Beever, SWFRPC 2012.

The full list of all observed plant species is located in Appendix II. Eight of the species or 7% of the plant species are non-native species. Fifteen of the species had not been reported from southwest Florida salt marshes in the CHNEP study area in reference literature before.

The submerged, emergent, and dry portions of the salt marsh plants provide many different functions for living organisms in the estuary. The emergent tops of the marsh plants provide hunting cover for animals such as bobcats and gray foxes; nesting sites for unique aquatic mammals such as rice rats; nesting sites, hunting and display perches for birds such as redwing blackbirds, boat-tailed grackles, and green herons; and protective cover for many animals such as raccoons and marsh rabbits. The submerged portions of the marsh plants provide attachment sites for sessile organisms including mussels, oysters, tunicates, barnacles, and epiphytic algae; cover for intertidal aquatic animals such as fiddler crabs, marsh crabs, mosquito fish and killifish; and retain rich deposits of detrital food.

Salt Marsh Primary Productivity and the Detrital Food Web

(Food for everyone: grasshoppers, crabs, snook, and people.)

Photosynthesis is the main production activity of the marsh grasses, herbaceous marsh plants and of the macroalgae and microalgae in the marsh. Photosynthesis is called *primary production* because it is the foundation of most food webs on earth the biological energy that sustains other forms of life. Photosynthesis by green plants uses energy from the sun to produce food, and that food sustains consumers (small animals, bacteria and fungi) that are eaten by other consumers, which are eaten by even other consumers. During the process of photosynthesis, inorganic carbon in the form of carbon dioxide is converted by energy from the sun into organic carbon in the form of carbohydrates which provide nourishment for the plants. The green pigment chlorophyll, contained in structures called chloroplasts in the plants cells, enables the reactions to take place (Weis and Butler 2009).

In tidal marshes, the power of the sun is supplemented by the power of the tides and watershed run-off. Tides and watershed hydrologic flow bring in nutrients needed by the plants and transport excess nutrients and wastes back to the estuary as they ebb and flow. This delivers oxygen-rich water to marsh soils as well as the suspended sediments necessary for the continued vertical growth of the marsh sediments and platform(Weis and Butler 2009).

Primary productivity of marsh plants and other marine plants is generally limited by the amount of nutrients available and climate. Marsh plants obtain most of their nutrients from the soil, and scarce nutrients reduce plant growth. The availability of nutrients in sediments depends on particle size and organic content and on the hydrologic characteristics of the marsh. Nitrogen and phosphorus are the two major nutrients that control plant growth in coastal marshes. Salt-marsh plants are generally limited by nitrogen and respond with increased growth to additional nitrogen that comes into estuaries as a result of human activities such as the input of sewage or fertilizers. The forms of nitrogen that are usable by marsh plants are inorganic nitrate ($N0^3$), nitrite ($N0^2$), and ammonium (NH^4). These substances can be taken up by the plants and converted to amino acids and other biologically essential substances. Organic nitrogen consists of all the nitrogen bound up in living or dead animals and plants, including protein, DNA, RNA, and chlorophyll. These materials eventually get broken down into inorganic nitrogen by the activities of the microbial decomposers. The excess nitrogen enrichment *(eutrophication)* of estuaries can alter marsh zonation patterns and ecology (Weis and Butler 2009). We did not observe evidence of eutrophication in any of the salt marshes we observed during site visits in this study.

While nutrient supply is widely thought to regulate primary production of salt marshes. An experiment by Silliman and Bertness (2002) manipulated of the dominant marsh grazer (the periwinkle, *Littoraria irrorata*) and its consumers (e.g., blue crabs, *Callinectes sapidus*, terrapins, *Malaclemys terrapin*) in Virginia salt marshes. This study demonstrates plant biomass and production are largely controlled by grazers and their predators. In Virginias, periwinkle grazing can convert one of the most productive grasslands in the world into a barren mudflat within 8 months. Marine predators regulate the abundance of this plant-grazing snail. Top-down control of grazer density is a key regulatory determinant of marsh grass growth. The discovery of this simple trophic cascade implies that over-harvesting of snail predators (e.g., blue crabs) may be an important factor contributing to the massive die-off (tens of km^2) of salt marshes in parts of the southeastern United States.

The overall productivity of salt marshes is very high, comparable to tropical rain forests, which are among the most productive areas on earth. Salt marshes can produce up to ten tons of organic matter per acre in a year, which is higher than what is produced by many agricultural systems. Georgia's salt marshes are some of the most biologically productive natural systems on earth, four times more productive than the most carefully cultivated cornfields, according to the Georgia Department of Natural Resources (Weis and Butler 2009).

Rapid growth of marsh vegetation and utilization of incoming nutrients make salt marshes highly productive systems, often yielding 2 kg of aboveground production per square meter, annually (8.9 tons per acre per year) (Marinucci 1982, Dame 1989).

Unlike tropical rain forests, the diversity in salt marshes and estuaries is not high due to the harsh and variable environmental conditions (Weis and Butler 2009).

Marshes are extremely productive for a variety of reasons: light is direct and bright, unlike in regions where water is deeper; nutrients are in abundant supply, which promotes plant growth; the tides mix the waters, diluting and removing waste products and making nutrients available to plankton and other producers. Abundant nutrients are brought in by the fresh water inflows sheet flow, creek and river and salt waters form the associated estuary, and some nutrients are produced in the marsh by nitrogen-fixing bacteria. Tyler et al (2003) suggest that both benthic microalgae and marsh grasses are N limited, and that this limitation decreases as the marsh matures. The high rates of N fixation by autotrophic and heterotrophic bacteria in the sediment could provide an important source of N for primary producers during marsh development. N fixation was sufficient to provide a substantial source of N for primary producers during marsh development.

Nutrients tend to be recycled very quickly rather than being stored in non-labile organic materials (wood in trees, for example), where they remain for many years. The productivity of salt marshes in the southern parts of the United States is much higher than those in temperate areas because in the south the marsh plants remain alive and active all year, while in temperate areas they die back in the fall and grow again in the spring. In the north, only the algae remain active throughout the year (Weis and Butler 2009).

In contrast to some terrestrial grassland areas, where large populations of grazing animals eat the plants; there are relatively few species and numbers of animals that consume living marsh grasses. These plants have a high salt content and their leaves consist of tough cellulose and silica. Fringing marsh grasses leaves contain chemicals called *phenols*, which make them unappetizing to many herbivores. Grasshoppers, sucking bugs, and some mud crabs do eat living marsh grass leaves, but most of the grass is not eaten directly when it is alive. About 90 percent of the primary productivity of salt marsh grasses is utilized at the end of the growing season when the leaves and stems of the plants die and decompose. The decay actually begins when the plants are dead but still standing, and it is carried out at that point primarily by fungi. Unlike animals, certain bacteria and fungi can utilize cellulose, which is the main structural component of cell walls of the plants. Later on, when the leaves fall off onto the marsh surface, bacteria in the mud and water continue the process of decomposition. The breakdown is helped by the chewing action of small invertebrates, such as amphipods and isopods, which break up large pieces into smaller pieces that are then more rapidly broken down by the microbes. The food value of the plant material increases during decomposition because as detritus particles decrease in size, they increase their protein content due to the presence of bacteria and fungi (Weis and Butler 2009).

Salt marshes produce several tons of detritus per acre per year, of which much is washed into the estuary and is consumed by small invertebrates and fish, which are, in turn, consumed by larger animals. Detritus production varies by plant species, with the greatest production by the shorter marsh grasses and herbaceous succulents. Many commercial species of fish are ultimately dependent on this detrital food web. While most of the detritus of directly fringing marshes is washed away, most of the detritus from middle and higher marshes remains in p1ace under the following year's growth, decomposing in place and providing food for small animals on the marsh surface and in the marsh soils. The detritus that stays within .the marsh system combines with sediments to produce marsh peat, which is the substrate on which the marsh continues to grow. The peat has dense roots and rhizomes intermingled, so it is both tough and permeable. When plant tissues decompose, they may do so under aerobic (oxygenated) conditions on the marsh surface or they may become buried in sediment and decompose under anaerobic (no oxygen) conditions. In the absence of the decay, bacteria use sulfate from seawater and reduce it to sulfide, which is precipitated as iron sulfide or pyrite. Anaerobic decomposition is incomplete, so plant material accumulates as peat. When plants are actively growing and oxidizing the sediment, much of the pyrite is oxidized and exported to the waters of the creeks, where it provides a substrate for the growth of sulfur bacteria. Subsequently the marsh surface remains sandy without organic accumulation (Weis and Butler 2009).

CHNEP Salt Marsh Vegetation Zonation

(It's different in the subtropics)

The standard zonation of Charlotte Harbor and southwest Florida consists of red mangroves in the lower and middle intertidal zone, black mangroves in the upper intertidal areas that are occasionally flooded and white mangroves in patches on higher elevations that is less frequently flooded. Buttonwoods are located further inland in areas that are within the limits of the highest tides (Tomlinson 1986).

Mangrove forests are different than other vegetative communities in that there is an absence of traditional plant succession. Instead, mangrove communities experience replacement succession primarily as a function of sea level rise, where mangroves must either keep up with the rise in sea level or retreat from rising water levels. On shorter time scales, the mangrove community can experience fluctuations in habitat type and species composition as a result of changes in such factors as hydrologic patterns, hurricanes, and freeze events. A typical zonation with adjacent uplands is shown in Figure 91:

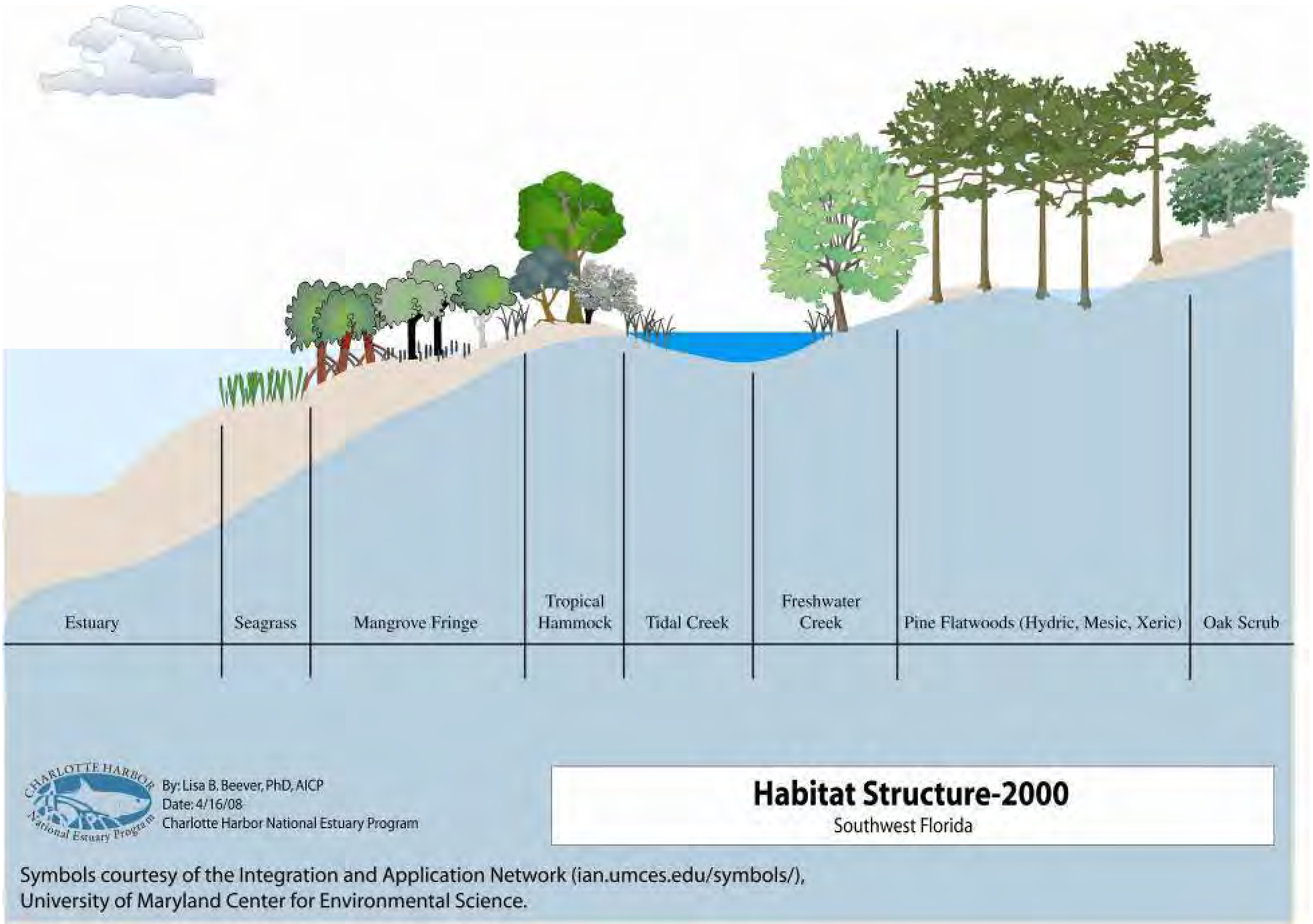


Figure 91: Typical coastal habitat zonation for Charlotte Harbor, Year 2000

The unique topographic features of Southwest Florida affect the degree of submergence, which in turn influences the zonation of plant species. Zonation occurs when various salt marsh plant species thrive in specific elevation ranges. Lower limits of plant zonation are usually set by environmental tolerances, while upper limits can be the result of interspecific competition (Pennings and Bertness 2001). The zonation of the various vegetation species which form the basis of the salt marsh community is highly dependent on each species' tolerance to inundation (partial submergence), the regular and annual salinity of adjacent waterbodies, and the range of salinities encountered.

Biological interactions among neighboring marsh plant species combine with physical factors to control patterns of zonation. Indicated models of causality based either upon correlative physical evidence or upon competition experiments in a single habitat are likely to be inaccurate. Interspecific competition is more intense and important at the more benign end of each species' range and the severity of the physical environment is dependent idiosyncratically upon the tolerance of each species to flooding and salinity, and possible other correlated factors (Pennings and Callaway 1995).

Some plants, such as *Spartina alterniflora*, can withstand and are limited to areas that receive substantial flooding (Montague and Wiegert 1990). Other vegetation, like *Juncus roemerianus*, prefers less frequent flooding (Eleuterius and Eleuterius 1979). Submersion in water can create a host of problems for vegetation including increased intake or loss of salts through tissues and greater exposure to aqueous toxins (Adam 1990). Waterlogged soil and high levels of decaying material can deplete oxygen, creating anoxic sediments and producing toxic sulfides (Ponnamperuma 1972, Drake 1989, Adam 1990, Pezeshki 1997). Most plants that grow in anoxic soil produce adventitious roots near the sediment surface to facilitate oxygen uptake. For example, frequently flooded plants like *S. alterniflora* grow roots in the top 3 cm of the sediment that help oxygenate deeper roots (Anderson 1974). Some plants also have a well-developed system of air passages called aerenchyma tissue, which transfer oxygen from the atmosphere to submerged roots (Ponnamperuma 1972, Armstrong 1979).

On the Atlantic and northern Gulf of Mexico coast salt marsh plant communities are characterized by clear, striking zonal patterns across elevation gradients. In a study conducted in Georgia, black needlerush dominated the high elevation marsh and smooth cordgrass (*Spartina alterniflora*) dominated the middle and low elevation marsh. Black needlerush did not occur naturally in the cordgrass zone and performed poorly when transplanted there. The poor performance of black needlerush occurred whether or not cordgrass neighbors were removed, which indicates the poor performance was caused by physical stress. In contrast, although smooth cordgrass occurred naturally at low densities in the black needlerush zone, it performed well there only if the black needlerush neighbors were removed. The excellent performance of smooth cordgrass only where black needlerush neighbors were removed indicates that performance is limited by competition from black needlerush (Penning et al.et al.2005) investigated the factors producing zonation patterns of the dominant plants in southeastern USA salt marshes where *Juncus roemerianus* dominates the high marsh, and *Spartina alterniflora* the middle and low marsh. *Juncus* did not occur naturally in the *Spartina* zone and performed poorly when transplanted there, irrespective of whether neighbors were present or removed, indicating that its lower limit was set by physical stress. In contrast, although *Spartina* occurred naturally at low densities in the *Juncus* zone, it performed well if transplanted there only if neighbors were removed, indicating that its upper limit was set by competition. Parallel laboratory and field manipulations of flooding, salinity and competition indicated that the lower limit of *Juncus* was mediated by both flooding and salinity, but not by competition.

Penning and Moore (2001) explored the generality of the processes mediating shrub zonation in western Atlantic salt marshes by comparing the results of experiments in Georgia, USA with previous studies from Rhode Island, USA. The shrub *Borrichia frutescens* dominates the terrestrial border of many Georgia salt marshes. Within the shrub zone, physical stress increased at lower elevations, shrubs at lower elevations were stunted, and experimentally reducing physical stress reduced shrub stunting. Below the shrub zone, physical stress increased further, and the grass *Spartina alterniflora* dominated. Transplant and neighbor-removal experiments indicated that the lower border of the shrub zone was set more by physical stress than by competition, but that the upper border of the grass zone was set primarily by competition with shrubs. Laboratory experiments indicated that *S. alterniflora* seedlings survived best and shrub seedlings worst in the flooded, salty treatment that mimicked low-marsh conditions. These processes are similar to those maintaining zonation patterns between the shrub *Iva frutescens* and the rush *Juncus gerardi* in Rhode Island salt marshes. However, markedly different processes appear to occur further to the north, where woody shrubs are absent from coastal marshes, and further to the south, where woody plants (mangroves) dominate coastal wetlands.

Levine et al.et al. (1988) examined the effects of nutrient availability on the competitive interactions of the New England salt marsh perennials that occupy discrete vegetational zones parallel to the shoreline. Fertilized and unfertilized plots of pair-wise mixtures and monocultures of *Spartina alterniflora*, *S. patens* and *Juncus gerardi* were compared in order to assess the effects of nutrient addition on the competitive dynamics of these species in the field. Levine et al.et al. (1988) examined competition between some of these species and *Distichlis spicata*, a species common to disturbed marsh habitats. After two growing seasons, changes in above-ground biomass of the species indicated that in fertilized plots, *S. alterniflora* outcompeted *S. patens*, *S. patens* outcompeted *J. gerardi*, and *D. spicata* outcompeted both *J. gerardi* and *S. patens*. This was the reverse of the interactions seen under ambient marsh conditions, and suggested that, under conditions of nutrient limitation, competitive dominance may result from efficient competition for nutrients. Using a conceptual model of salt marsh zonation as a function of competition, physical stress and nutrient limitation, Levine et al (1988) hypothesize that a nutrient-induced reversal in the competitive dynamics among salt marsh perennials may result in modification of the pattern of plant zonation in this and similar marshes.

Although a great deal of research has focused on the effects of nutrient supply on plant competition, few studies have explored how these processes interact with non-resource factors to determine community-level patterns. Emery et al.et al. (2001) examined how resource competition interacts with physical stress to structure salt-marsh plant communities across a natural gradient in tidal stress. First, nutrient additions at naturally, occurring species borders at zonal and patch boundaries in two Rhode Island (USA) marshes revealed that competitive outcomes were typically reversed when nutrients were abundant. These results, which are consistent with earlier findings in a third southern New England marsh, suggest that a nutrient-dependent competitive hierarchy is a general characteristic of salt marshes in this region. To test whether these shifts in competitive outcomes occur only at naturally occurring species borders or can lead to more significant shifts in zonation patterns, lower marsh species were transplanted into the matrix of each zonal species at higher tidal elevations, and the outcomes of plant competition in fertilized plots and unfertilized plots were compared. Results of this experiment indicate that nutrient effects on the competitive relations of marsh plants were independent of where the interactions took place along the tidal gradient. The stress-tolerant species were consistently the best competitors in fertilized treatments, showing that an increase in nutrient availability can lead to drastic shifts in the distributions of plants across marshes. Finally, a third experiment examined the interaction between nutrient supply and the aboveground and belowground components of plant competition using a reciprocal transplant design coupled with nutrient-addition and neighbor-removal treatments. Results suggest that competition is primarily belowground under ambient marsh conditions but is aboveground at high nutrient levels. Thus the mechanism underlying the nutrient-dependent competitive hierarchy, may be driven by a trade-off between belowground and aboveground competitive abilities, although the potential interaction between above- and belowground effects was not examined. Together, the results of these experiments suggest that nutrient supplies may significantly affect the competitive dynamics between salt-marsh perennials and their resultant zonation across an environmental gradient in tidal stress. The result that stress tolerators can be dominant competitors is not predicted by any current model of plant competition and must be considered in future empirical and theoretical studies.

The general mechanisms producing zonation patterns of vegetation in coastal salt marshes may be universal, as suggested by previous discussed studies, but the importance of particular factors is likely to vary geographically. In particular, salinity stress probably plays a much more important role in mediating plant zonation patterns at lower latitudes. Our results suggest that the nature of ecological interactions is likely to vary geographically because of variation in the physical environment, and this variation must be taken into account in order to successfully generalize the results of field studies across geographical scales.

For example in Venice Italy the distribution of halophytes in salt marshes indicates that plants are not responding to simple rules dictated by elevation, the tidal cycle, or to salinity, and that such factors, when singularly considered, cannot explain the observed spatial distribution of halophytes. The different detailed zonation patterns observed could not be explained solely in terms of local elevation, flooding periods or induced soil salinity, but are related to spatial heterogeneities of soil properties and to the interplay between evapotranspiration patterns surface water and subsurface water flow. On the basis of observations and modeling results it is was concluded that a combination of multiple factors, likely dominated by saturated/unsaturated flow in the soil, may be responsible for the observed macrophyte distribution in that part of the Adriatic (Silvestri et al.et al. 2004) .

In our study we found that the while the different salt marsh types had different mean elevational distribution the dominate species are able to occur over a range of overlapping elevations with other salt marsh types. This creates a marsh zonation that is more complex than most North American marsh systems.

Saltern, black needle rush and algal salt marshes have the widest range of distribution on the elevational gradient.

Salterns and algal marshes form at the waterward, landward and within fringing and high marshes wherever the combination of edaphic factors that generate high soil salinities or pools that are too harsh for vascular plants occur.

The black needle rush displays different morphology at different elevations. As a fringe marsh on organic substrate the black needle rush attains its maximum height in the CHNEP moving up-gradient and on progressively less organic substrates the black needle rush has less height and looses dominance becoming a component of mixed high marshes.

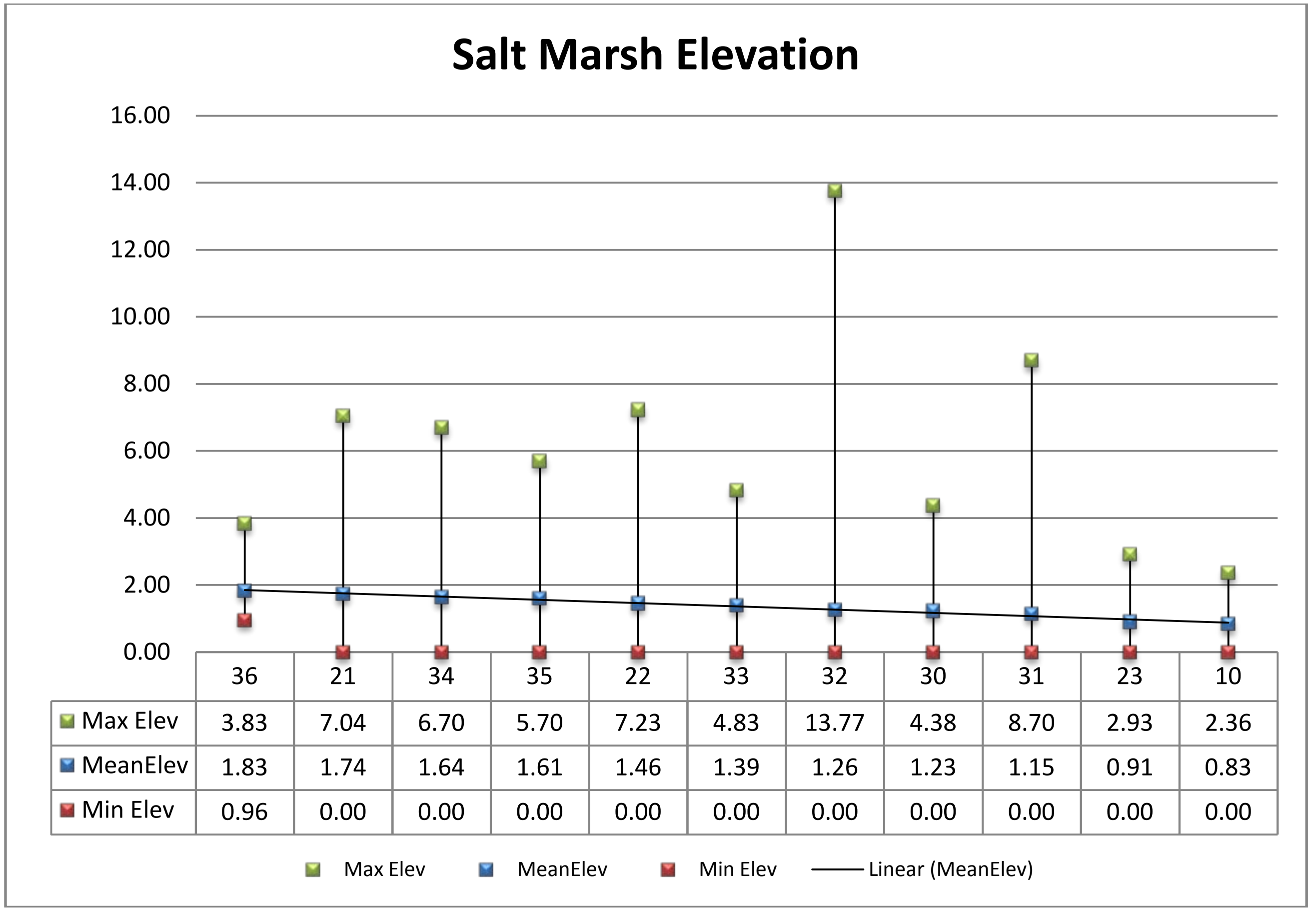
The patterns of salt marsh zonation differ in the different watersheds of the CHNEP with the effects of colder winter temperatures affecting northern watersheds and salt marshes at their upstream limits. In contrast other plant species become important in southern watershed particularly at the landward edge of the high marshes.

Salt Marsh Type	Mean Elevation By Type	Median Elevation
10 (Smooth Cordgrass)	0.83	0.78
21 (Black needle rush)	1.74	1.80
22 (Leather Fern)	1.46	1.28
23 (Saltmarsh Bulrush)	0.91	0.87
30 (Shrub Mangrove)	1.23	1.18
31 (Algal)	1.15	1.13
32 (Saltern)	1.26	1.19
33 (Succulents)	1.39	1.31
34 (Meadow Mixed)	1.64	1.54
35 (Meadow Grasses)	1.61	1.50
36 (Shrub Buttonwood)	1.83	1.77
Total Acres	1.42	

Table 8: Elevations of salt marsh by type mapped in the CHNEP 2010-2012.
Source: D. Cobb and J. Beever SWFRPC April 30, 2012

Salt Marsh Type	Maximum Mean Elevation	Minimum Mean Elevation	Range of Elevation
10 (Smooth Cordgrass)	2.36	0.00	2.36
21 (Black needle rush)	7.04	0.00	7.04
22 (Leather Fern)	7.23	0.00	7.23
23 (Saltmarsh Bulrush)	2.93	0.00	2.93
30 (Shrub Mangrove)	4.38	0.00	4.38
31 (Algal)	8.70	0.00	8.70
32 (Saltern)	13.77	0.00	13.77
33 (Succulents)	4.83	0.00	4.83
34 (Meadow Mixed)	6.70	0.00	6.70
35 (Meadow Grasses)	5.70	0.00	5.70
36 (Shrub Buttonwood)	3.83	0.96	2.87

Table 9: Maximum, minimum, and range of elevations of salt marsh by type in the CHNEP 2010-2012.
Source: D. Cobb and J. Beever SWFRPC April 30, 2012



	36	21	34	35	22	33	32	30	31	23	10
Max Elev	3.83	7.04	6.70	5.70	7.23	4.83	13.77	4.38	8.70	2.93	2.36
MeanElev	1.83	1.74	1.64	1.61	1.46	1.39	1.26	1.23	1.15	0.91	0.83
Min Elev	0.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 92: Elevation of Salt Marsh Types in the CHNEP measured in feet
Number Key Corresponds with Tables 8 and 9.
Source: D. Cobb and J. Beever SWFRPC

The salt marshes of Dona and Roberts Bay have a simple pattern of black needle rush landward of a thin fringe of red mangrove or black needle rush fringe marshes with a small mixed high marsh, if present, landward.

The Lemon Bay salt marshes have a characteristic zonation from water to landward of smooth cordgrass, in the few areas it is present, black needle rush fringing both the bay or creek and tidal channels; and then high marsh.

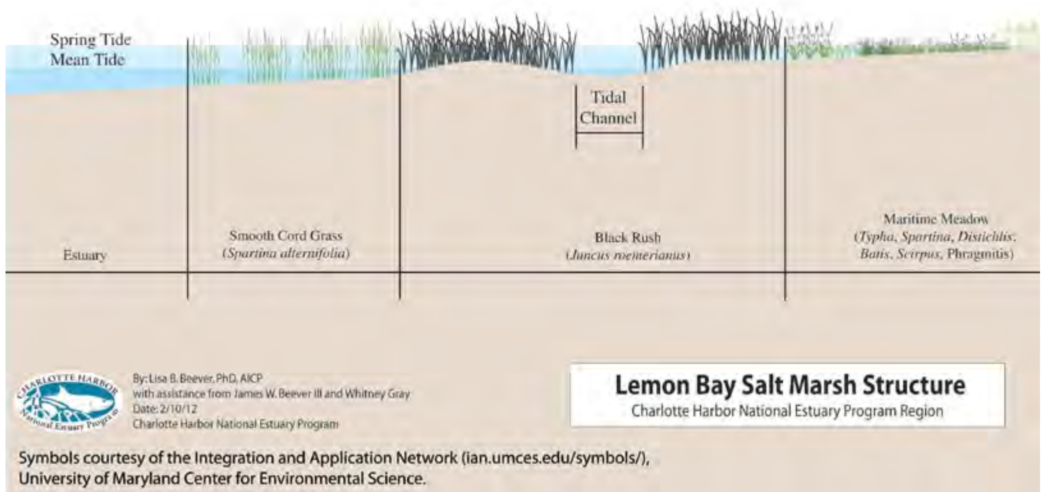


Figure 93: Lemon Bay Salt Marsh Zonation
Source: L. Beever, CHNEP, 2012

Myakka River salt marshes have a pattern of black needle rush landward of a thin fringe of red mangrove or black needle rush fringe marshes with a small mixed high marsh, if present, landward. Black needle rush also occurs as entire monocultural islands surrounded by braided channels.

The Upper Peace River salt marshes have a pattern of fringing saltmarsh bulrush, then black rush, with high marsh most landward. Leather fern marshes can fringe interior channels or occur as part of the mixture of fringing marsh.

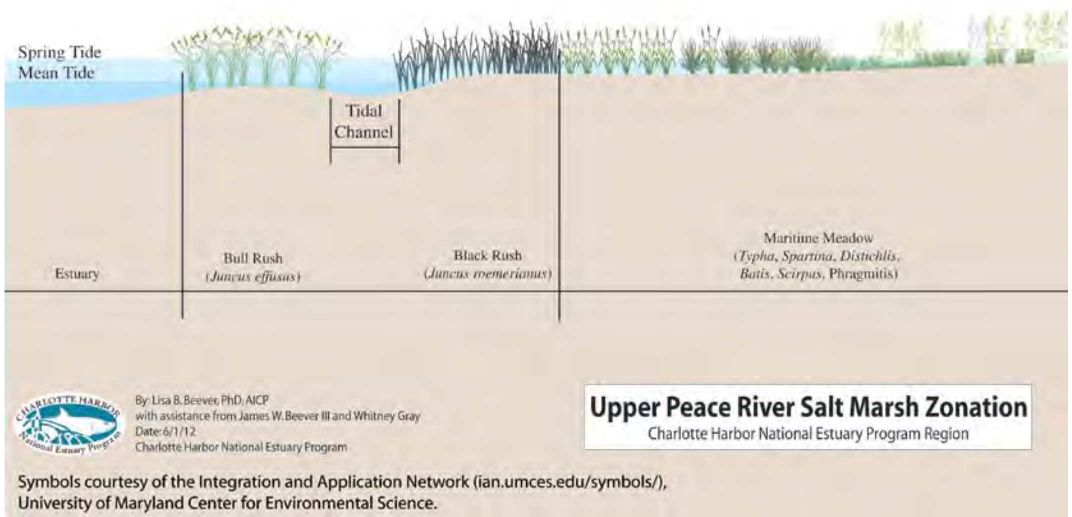


Figure 94: Upper Peace River Salt Marsh Zonation
Source: L. Beever, CHNEP, 2012

The Middle Peace River salt marshes have a pattern of red mangrove fringe; then black needle rush, and then high marsh. There are also islands fringed in red mangrove with the interior a black needle rush marsh. Admixtures of leather fern with black needle rush occur but are not common.

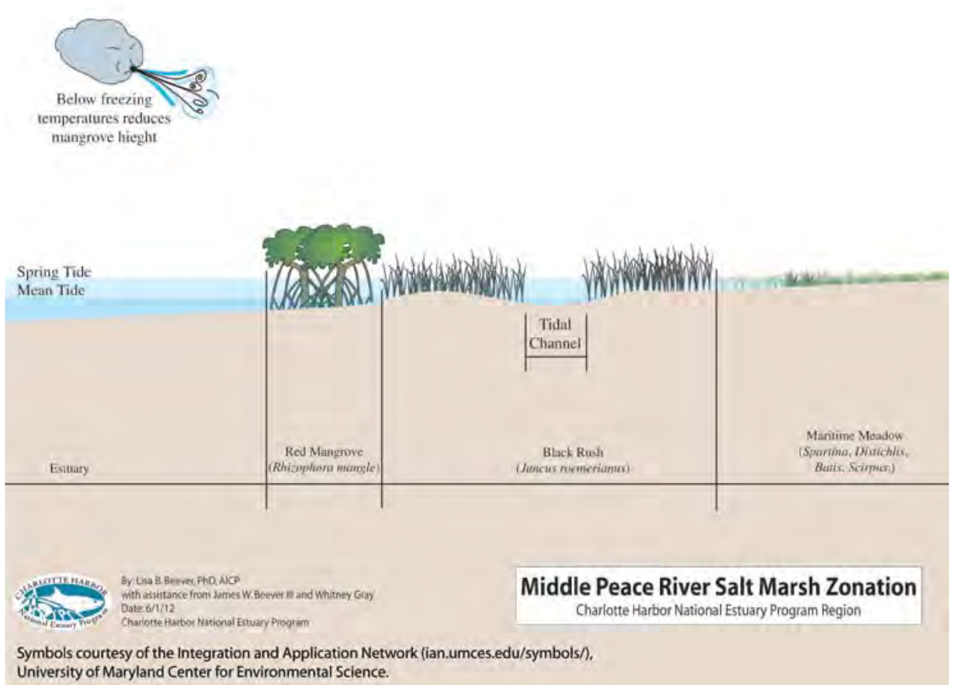


Figure 95: Middle Peace River Salt Marsh Zonation
Source: L. Beever, CHNEP, 2012

The Caloosahatchee River salt marshes have zonation that has fringing re mangrove most waterward backed by a black needle rush marsh; then leather fern; and a admixture of pond apple with leather fern or alone; then most landward the high marsh. Further up creeks black needle rush and leather fern can be directly fringing on the creek shoreline without mangrove presence.

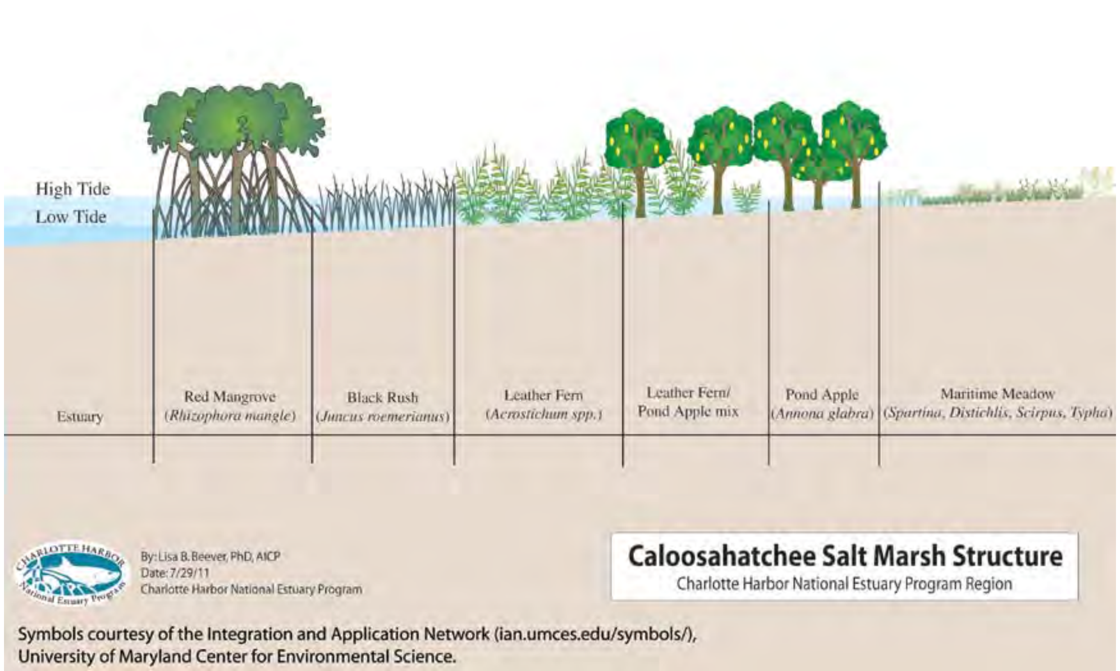


Figure 96: Caloosahatchee River Salt Marsh Zonation
Source: L. Beever, CHNEP, 2012

The Estero Bay shoreline zonation on the mainland shorelines have a zonation of red mangrove most waterward; typically a low shell ridge unless pierced by a creek channel,; a black mangrove basin forest; then a zone of shrub black mangrove that becomes a shrub mangrove marsh; then an algal salt marsh; then a salt or succulent high marsh; then saltern; then a mixed high marsh; then a grassy high marsh; and then most landward a shrub buttonwood marsh. This full zonation can only be found in preserve areas. Upstream on tributaries patterns of black needle rush and leather fern marsh similar to the Caloosahatchee River watershed is found except for the absence of pond apple.

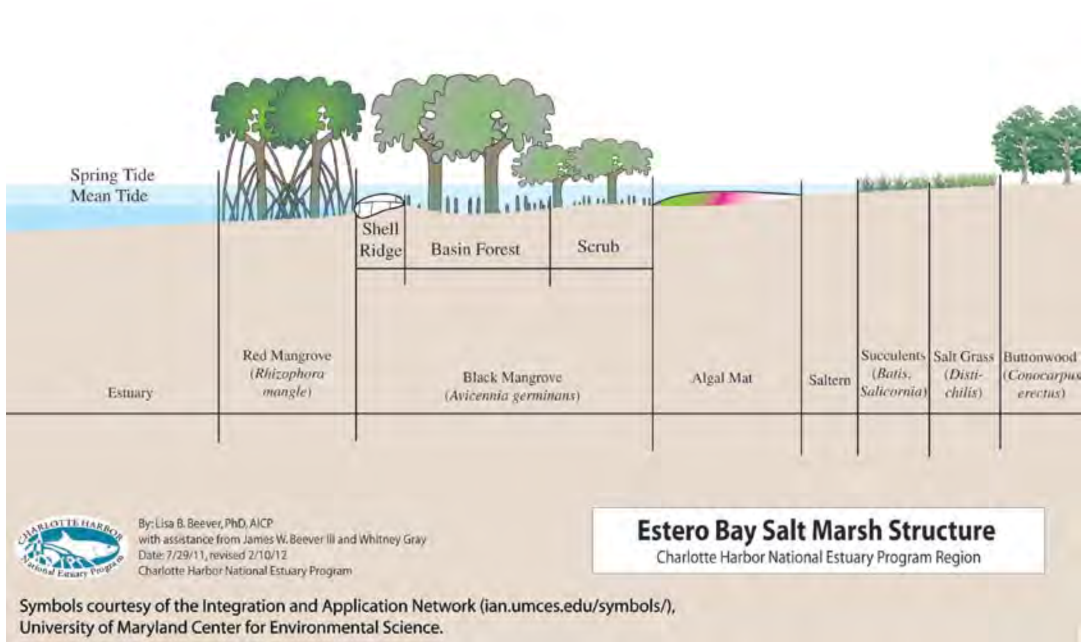


Figure 97: Estero Bay Salt Marsh Zonation
Source: L. Beever, CHNEP, 2012

Animals of the Salt Marshes of the CHNEP

(A land of arthropods and visiting birds)

Few animals have obligately adapted to the high salinities and water conditions of the salt marsh environment, causing species endemic diversity to be lower than adjacent terrestrial habitats. Few species of fish, reptiles, or mammals are permanent residents of the salt marsh. However the animals that have adapted are often quite abundant. Specific information on faunal communities of South Florida salt marshes is sparse (Odum et al.1982, Montague and Wiegert 1990). Most information comes from studies of north Florida marshes or other States. Larger, long-lived species usually cannot adapt to the extreme environmental fluctuations, but instead are transient inhabitants. For many species the salt marsh is an important place to visit, particularly for food, but they do not permanently live there.

The primary users of the marsh include eight species of mammals, 11 bird species, and 6 reptile taxa (Cox et al.1997, Enge et al.1997). Mammals include rodents, minks, rabbits, and raccoons; primary birds include rails, sparrows, wrens and numerous egrets, herons, and ibis; and common reptiles include salt marsh snakes and terrapins. Over 500 species of insects have been reported in Florida salt marshes and 88 species of non-insect macroinvertebrates reported in the northeastern Gulf of Mexico (excluding oligochaete worms) (Montague and Wiegert 1990).

Natural salt marsh processes include biotic interactions, primary production, decomposition, organic export, and energy flow. Little information is available to determine if humans are able to create or restore these natural processes. Although it is fairly easy to count the number of organisms in restored marshes, it is much more difficult to determine if restored marshes successfully re-establish ecological processes. It takes time and effective restoration techniques to attain structures and compositions comparable to natural marshes. Even with creation, enhancement or rehabilitation actions, man may not be able to create marsh systems that support ecological processes.

Salt marsh ecosystems are important habitat for several mammals, birds, reptiles, fish, and amphibians and provide areas for breeding, nesting, foraging, and shelter. Like the salt marsh vegetation, animals have developed biological or behavioral adaptations to tolerate fluctuating, harsh environmental conditions. Many of these species are not restricted to this community type, but are part-time users. Mangroves do not exemplify the close interdependence between plant and animals as other communities, but some species are totally dependent upon mangroves to survive. Fish and invertebrates from marine habitats are frequent visitors to salt marsh communities, as are birds and other organisms from nearby terrestrial systems. Salt marshes are important because they supply nutrients, provide habitat and structure, act as nurseries, and protect inshore habitats from sediment pollution. Reviews on salt marsh habitat and related fauna are provided by Montague and Wiegert (1990); Wiegert and Freeman (1990); and Mitsch and Gosselink (1986, 1993). The following summaries characterize the ecology of three general salt marsh microhabitat types common in the South Florida Ecosystem.

The salt marsh aerial habitat is similar to the terrestrial environment and provides habitat to both resident and transient species. The stems and leaves of salt marsh plants provide habitat for breeding, feeding, and shelter of numerous insects, spiders, snails, and crabs. Many of these organisms use the stems as a refuge from rising water levels. A variety of wading birds and migratory waterfowl feed on the aerial invertebrate community.

The primary inhabitants of the benthic community include fungi and bacteria, meiofauna and megafauna; with each group playing an important part in the food web. Microbial fungi and bacteria live in and at the surface of the sediment and are the primary consumers of the benthic habitat. Meiofaunal organisms like protozoa, nematodes, and annelids forage on the primary consumers, and are then fed upon by larger invertebrates. Foraging invertebrates like polychaetes, gastropod mollusks, crustaceans, and amphipods forage along the sediment surface for algae, detritus and meiofauna. Filter feeders such as mussels, clams, and oysters filter food from the water column. Several species of reptiles, amphibians, birds, and mammals forage in these areas during periods of low water. During low tide, remnant small pools of water concentrate organisms, making it easy for predators to capture prey. The leaves and stems of salt marsh plants are used as nesting materials for some resident bird species and mammals. As water levels change with daily tides and seasonal influences, some organisms migrate to adjacent permanent upland habitats.

Smith et al. (2009) studied the effects of fiddler crabs (*Uca rapax* and *Uca pugilator)* on the growth of white Mangroves in a restored Florida marsh. They found that the presence of crab burrowing increased final tree height by 27%, final basal trunk diameter by 25%, and final leaf production by 15% over mangroves growing where crabs were removed and excluded. They also observed significant positive associations between mangrove production and crab burrow density. Crab burrows accounted for 24, 29, and 16% of the variation in mangrove height, trunk diameter, and leaf production, respectively.

Tidal creeks and pools provide an aquatic component to the salt marsh habitat. They are especially important to marine fish and invertebrates that spend part or all of their life in the salt marsh (Odum et al.1982). Tidal creeks and pools also provide aquatic organisms from nearby oceanic or estuarine habitats access to the salt marsh. A multitude of predatory birds, fish, crustaceans, mollusks, reptiles, and mammals use this avenue to hunt and capture available prey in the salt marsh.

Species Observed in the Salt Marshes of the CHNEP

In order to catalogue plant and animal species found in each salt marsh, lists of species were generated. Plants, both native and exotic, were listed in two tiers: salt marsh species found in Florida; and salt marsh species found in southwest Florida (Lee Charlotte and south Sarasota Counties). Native and exotic animals were listed in three tiers: state; southwest Florida; and salt marshes of southwest Florida. Due to the cosmopolitan nature of coastal southwest Florida, it is important not to rule out species that may not be vouchered in the study area specifically. Additionally, many commercially available exotic species escape into the wild, becoming common locally or becoming invasive. These species have been accounted for in the lists and will be catalogued during the project.

The statewide salt marsh plant list includes 385 species. Sources for this list include the University of Florida Institute of Food and Agricultural Sciences (UF IFAS) Center for Aquatic and Invasive Plants, the Florida Department of Environmental Protection Wetland Evaluation and Delineation Program, "Florida Wetland Plants: An Identification Manual" by Dr. John D.

Tobe, et al, the Institute for Systematic Botany's Atlas of Florida Vascular Plants, and the Lee County Deep Lagoon Preserve Stewardship Plan.

The lists of animals are broken down by taxa. Thus, there is a potential Florida marsh list and a confirmed salt marsh southwest Florida list each for invertebrates, fish, amphibians, reptiles, birds, and mammals.

In the course of this study we confirmed 273 animal species in the salt marshes of the CHNEP during the 68 marsh sites visited following the project protocol (Appendix I).

The numbers of species in each taxa is found in the graph below.

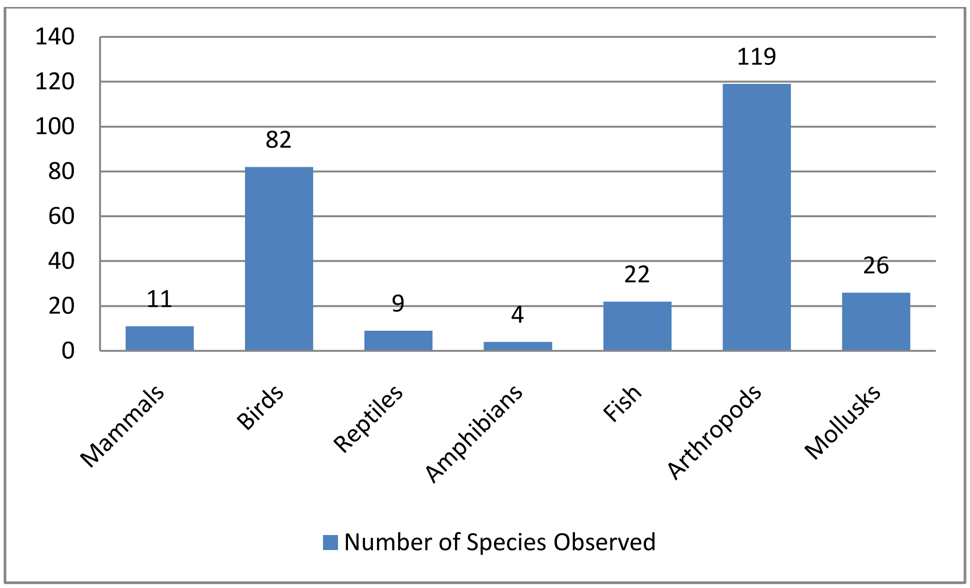


Figure 98: Number of animal species observed during salt marsh site visits in the CHNEP 2010-2012
Source: J. Beever and W. Gray, SWFRPC, 2010-2012

Mammals Observed

Eleven mammal species were observed directly, determined by track sign, foraging sign and or scat. Both marine mammals were directly observed in salt marsh channels. This is 73% of the reasonable potential mammal species and subspecies for the CHNEP. Raccoons were the most frequently observed mammal followed by the feral hog. Top predators are the river otter and bobcat. In past surveys rarer carnivorous mammals, including Florida black bear, Florida panther, mink and gray fox   have been observed in CHNEP salt marshes but these have been rare events not captured in normal survey protocols. More potential rodent species are undoubtedly present, but since this study did not undertake rodent trapping detection of their presence was unlikely. In other studies of CHNEP salt marshes marsh rice rat, Pine Island rice rat, Sanibel Island rice rat and Florida cotton mouse have been trapped in directed studies.

Figure 99: Manatee (*Trichechus manatus latirostris*) swimming under the bridge over Shakett Creek.
Source: W. Gray, SWFRPC, December 9, 2011

Birds Observed

Eighty-two bird species were observed directly in the salt marsh and salt marsh channels of the CHNEP. This includes 23 passerine birds, 16 shorebirds, 9 raptors, 6 ducks, coots, or grebes; 13 wading birds (herons, egrets, roseate spoonbill, white ibis, wood stork), both pelicans, 2 swallows, 2 doves, anhinga, belted kingfisher, common nighthawk, double-c rested cormorant, fish crow, least tern, red-bellied woodpecker, and clapper rail. This is 25% of the potential bird species for the CHNEP. Osprey, little blue heron and red-winged blackbird were the most frequently observed species across salt marsh sites. Shorebirds occurred in the greatest individual abundance at sites where they were observed. Highest bird species diversity was observed on high marshes, particularly the algal marshes of Estero Bay. We observed least tern, black-necked stilt, common nighthawk and red-winged black bird nesting in high marshes. The least ten, stilt, and nighthawk all nested directly n the sands of saltern.

Figure 100: White Pelicans, black-necked stilts, algal high marsh, Estero Bay State Preserve State Park
Source: W. Gray, SWFRPC

Figure 101: Mixed high marsh, roseate spoonbills and immature little blue heron, North Spreader Waterway, Charlotte Harbor Preserve State Park
Source: J. Beever, SWFRPC, August 11, 2011

Figure 102: Little blue heron (Egretta caerulea) Deep Lagoon Preserve)
Source: W. Gray, SWFRPC April 28, 2010

Figure 103: Black duck/mallard hybrids *(Anas rubripes + palyrynchus)*, South Spreader Canal, Matlacha Pass
Source: W. Gray, SWFRPC

Figure 104: Juvenile red-tailed hawk (*Buteo jamaicensis*). Deep Lagoon Preserve
Source: W. Gray, SWFRPC April 28, 2010

Reptiles and Amphibians Observed

Nine reptile species were observed directly and as hatched eggs in the salt marsh and salt marsh channels of the CHNEP. This includes the American alligator, Florida box turtle, green and brown anoles, 3 water snakes, black racer, and corn snake. Although we looked very thoroughly we did not observe terrapins or water moccasins which we have encountered in mangrove ecosystems in other studies. This is 29% of the reasonable potential reptile species and subspecies for salt marsh the CHNEP. Reptiles were observed in both fringing black needle rush and high marshes.

Figure 105: American alligator, Shell Creek, saltmarsh bulrush marsh area.
Source: W. Gray February 29, 2012

Four amphibian species were observed directly in the high marsh of the CHNEP. This is 36% of the potential amphibian species list for the salt marshes of the CHNEP. Salt marsh environments are very harsh for the amphibian metabolism and life cycle, unless specifically adapted to saline conditions. We did not encounter the marine toad in the course of this study. We did not perform specifically directed breeding season surveys or evening site visits that could have added to the species list by surveying for amphibian vocalizations and increased species numbers. Directed survey work performed by the principle investigator in past studies for the Frog Listening Network identified 9 other frog and toad species using high marsh at least at some point in the year.

Fish Observed

Twenty fish species were observed through direct observation, glass fish trap collection, limited single line collection, and one cast netting. The glass fish trap was successful in collecting small forage fish when baited with a dog food based on six species of fish meal. Mosquito fish were far and away the most abundant and most commonly encountered salt marsh species in all marsh types except smooth cordgrass. Mullet were the second most abundant and frequently sighted species. Mullet ranged in size from fingerling to full adults. Large predatory fish (snook, long-nosed gar, tarpon and spotted seatrout) were observed/collected in marsh channels and adjacent to marsh shorelines. We collected only one exotic fish species, the African jewelfish, on one occasion at one location CR432925c**.**

Figure 106: Use of glass fish trap in retrieval with Whitney Gray.
Source: J. Beever 2010

Figure 107: Use of fish viewing window by James Beever III at Deep Lagoon Preserve
Source: W. Gray, SWFRPC

Figure 108: Mosquitofish (*Gambusia holbrooki)* with red breeding color on fins. Daughtry's Creek Leather Fern Marsh
Source: W. Gray, March 1, 2011

Figure 109: Sheepshead minnow (*Cyprinidon variegatus*), Estero Bay Preserve State Park, near Koreshan State Historical Site)
Source: W. Gray, SWFRPC, February 14, 2012

Figure 110: Caught and released snook at Myakka River black needlerush marsh with Captain Larry Hendricks.
Source: W. Gray, SWFRPC

Figure 111: African jewelfish from Daughtry's Creek, Leather Fern and Mixed High Marsh, Caloosahatchee River watershed
Source: W. Gray, SWFRPC March 1, 2011

Arthropods Observed

One hundred and nineteen arthropods were observed in the salt marshes of the CHNEP. Among the insects (82 species) this includes 15 species of dragonfly, 3 species of damselfly, 11 species of grasshoppers and katydids; 9 species of sucking bugs; 11 species of day-flying butterflies and moths, 3 species of bee, 6 species of wasp, 6 species of ant, 6 beetle species; and 12 species of flies. In general insect abundance and diversity is an attribute of the high marshes, particularly the mixed and grassy high marshes. Insects observed in fringing marshes were in transit, feeding on black needle rush, or foraging on aerial prey or low tide food sources. In contrast the high marsh provides host plants, larval aquatic habitat, and escape cover for a wide range of resident species.

The mangrove buckeye, great Southern white and Eastern pygmy blue were the most common butterflies across and within sites. Seasonally abundant large numbers of these butterflies could be observed on the high marsh. High marshes provide nectar sources and host plants, some of them obligate, for these species. Other characteristic butterflies of the high marsh such as the Gulf fritillary and mangrove skipper were frequently encountered in high marsh. The larger butterflies were observed to cross fringing marshes but did not otherwise utilize them. Since the study was not specifically targeting lepidopteron diversity we did not search by season and locations to further expand the butterfly list.

Figure 112: Eastern pygmy blue butterfly (*Brephidium pseudofea*) perched on glasswort, Shell Creek Preserve

Source: W. Gray, SWFRPC, May 28, 2010

Figure 113: Mangrove buckeye
Source: W. Gray, SWFRPC,

The seaside dragonlet, Eastern pondhawk, and scarlet skimmer were the most common dragonflies. Rambur's forktail was the most common damselfy. It is of interest that the literature review prior to the project indicated the only the seaside dragonlet would be found in south Florida salt marshes. This may be the result of a strict definition of salt marsh to only include low marsh. We found a high diversity and number of dragonflies, often with four to five species on a given high marsh. and it is unique to this study to document so many species on the range of salt marsh types in the CHNEP. It is also interesting how different male and female dragonflies of the same species can be in color and also juveniles can be yet again a different pigmentation.

Figure 114: Seaside Dragonlet Male
Source: W. Gray, SWFRPC

Figure 115: Seaside Dragonlet Female
Source: W. Gray, SWFRPC

Figure 116: Seaside Dragonlet Juvenile
Source: W. Gray, SWFRPC

Figure 116: Eastern Pondhawk Male

Source: W. Gray

Figure 117: Eastern Pondhawk Female
Source: W. Gray

Figure 118: Scarlet Skimmer Male
Source: W. Gray, SWFRPC

Figure 119: Scarlet Skimmer Female
Source: W. Gray, SWFRPC

Figure 120: Rambur's Forktail Male
Source: W. Gray, SWFRPC

Grasshoppers and katydids are the main consumers of vascular plant biomass in solid form in the above-water salt marsh ecosystem. Grasshoppers could be locally abundant seasonally and sparse in other times of the year. The seaside katydid is the most common species across sites. pc

Leafhoppers and sharpshooters as a common consumer of vascular plant fluid biomass these insects occur in high abundance in high marshes. Aphids could occur abundantly in patches on shrubs within high marshes. We encountered water beetles and on vegetation beetles in high marshes. Green-eyed, syrphid and bee flies were the most dependable flies of the high marshes. Biting flies including mosquitoes were seasonal. We did not commonly encounter mosquitoes. Those we did observe and were bitten by were found in association with isolated pools that formed in and around spoil piles of the spreader waterways and mosquito control ditches. This may be because most of the salt marshes we visited have a hydrology that supported mosquito predators in the water and in the air.

Figure 121: Paper wasp (*Polistes dorsalis*), Deep lagoon Preserve
Source: W. Gray, SWFRPC April 28, 2010

Figure 122: Water boatman (Hesperocorixa atopodonta)
Source: W. Gray, SWFRPC

Spiders are important above water predators of the other above water arthropods of the salt marsh (Dobel et al. 1990) and 19 species were observed in the course of the study. Orb weavers and garden spiders were the most common across sites and the most visually observed.

Figure 123: Garden spider, Deep Lagoon Preserve
Source: W. Gray, SWFRPC, April 28, 2010

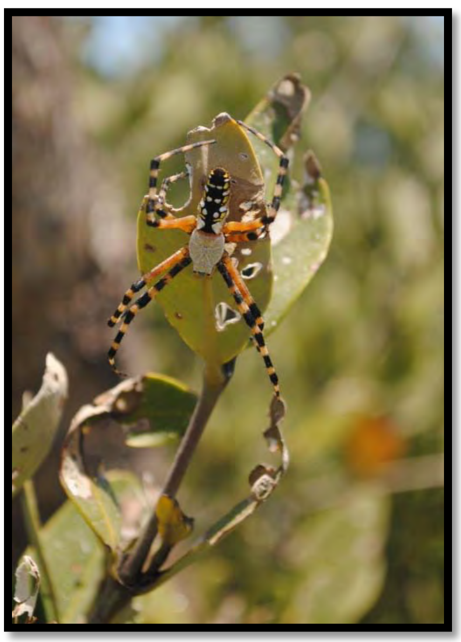


Figure 124: Golden Orb Weaver spider, Deep Lagoon Preserve
Source: W. Gray, SWFRPC, April 28, 2010

Crustaceans Observed

Eighteen species of crustaceans were observed in the salt marshes of the CHNEP. Fiddler crabs, barnacles, mud crabs, and blue crabs were the most common across sites and abundant at any given site.

Figure 125: Juvenile blue crab (*Callinectes sapidus*) from black needle rush marsh. Myakka River
Source J. Beever, SWFRPC, January 13, 2012

Figure 126: Fiddler crabs in a biopeterbed saltern interior of Galt Island, Pine Island Sound
Source: W Gray, SWFRPC, June 1, 2011

Mollusks Observed

Twenty-six species of mollusk were observed in the salt marshes of the CHNEP. Ladder horn snails and several species of Melampus snails were common and abundant in both fringing and high marsh. marsh periwinkle was common but less abundant. The Carolina marsh clam was the most abundant bivalve followed by Atlantic rangia. Eastern oysters could be even more abundant in particular parts of tributary rivers and streams including the Peace River, Myakka River, and tributaries of Lemon Bay. Larger gastropods and bivlaves were occasionally encountered in fringing marshes of Pine Island Sound.

Figure 127: Coffee snails in high marsh.
Source: Whitney Gray

Wildlife Species of Concern

As of October 2011 the CHNEP study area provides habitat for 56 State Listed Species with 20 of these also Federally Listed (FWC 2011). At least 10 species of fishes, 11 reptiles, 33 birds, 12 mammals, and 5 vascular plants are considered to be rare or endangered in Florida salt marshes FNAI (1997). In the CHNEP salt marsh listed species includes 5 species of fishes, 7 reptiles, 14 birds, 5 mammals, and 1 vascular plant are considered to be rare or endangered Federally listed animal species that depend upon, utilize, or visit at some point in their life history the salt marsh communities. These Federal species include gulf sturgeon, shortnose sturgeon, smalltooth sawfish. American crocodile, American alligator, green sea turtle, hawksbill sea turtle, Kemp's ridley sea turtle, leatherback sea turtle, loggerhead sea turtle, piping plover, wood stork, Florida panther and West Indian manatee. State listed threatened and endangered species that depend upon, utilize, or visit at some point in their life history the salt marsh communities in the CHNEP include: Atlantic sturgeon, rivulus, American oystercatcher, black skimmer, brown pelican, least tern, little blue heron, reddish egret, roseate spoonbill, snowy egret, snowy plover, southwestern American kestrel, tricolored heron, white ibis, Everglades mink, Florida black bear and the Sanibel Island rice rat. The FWC (2012) is planning to de-list several of these species including the brown pelican, Florida black bear, rivulus, snowy egret, and white ibis. The de-listing reports do not include the effects of sea level rise and climate change on salt marsh habitats and the potential loss of salt marsh habitats as a consideration in the status of these species.

Mangrove rivulus is a small fish living only in and around mangrove areas as far north as Indian River County south through the Keys and north to Tampa Bay on the west coast of Florida (Taylor and Snelson 1992). It is the only species of *Rivulus* in North America and has adapted to conditions of varying water levels and low oxygen levels of the mangrove community. It is an important link in the food chain, as it has been found to constitute part of the diet of many organisms including the wood stork (Ogden .et al. 1976). It is listed as a species of special concern by the state because of its limited distribution and vulnerability to loss of its habitat.

A wide variety of shorebird species forage on the mudflats of and channels of fringing salt marshes and in the high marsh. Among the State listed species are the threatened least tern; the black skimmer, a species of special concern; and the American oystercatcher, a species of special concern. Least terns and roseate terns require open beach or bare substrates for nesting near areas where schools of forage fish concentrate. American oystercatchers utilize oyster bars and mudflat areas in the estuary and nest on bare unvegetated shores associated with salt marshes and mangroves. Foraging occurs throughout the year with seasonal movements tracking warmer conditions Charlotte Harbor is an important area for the American oystercatcher North Gulf Coast population.

The black skimmer (*Rynchops niger*) utilizes the coastal salt marsh community in South Florida for breeding and loafing. Black skimmers are colonial nesters and are highly vulnerable to human disturbance and predators. In addition, a significant cause of breeding failure is flooding of nesting colonies by high tides. The major predators of black skimmer eggs and chicks include the raccoon (*Procyon lotor*), and laughing gulls (*Larus atricilla*). The State of Florida has listed the black skimmer as a species of special concern.

The State listed least tern (*Sterna antillarum*) utilizes coastal salt marsh in South Florida. There are no current reliable estimates of numbers of breeding least terns in Florida. In the CHNEP, least terns can be found nesting wherever open, sandy habitat is available, including saltern. Least terns are colonial breeders that depend upon camouflaged eggs and group mobbing by adult birds for defense. The species adaptation to artificial sites such as dredged-material islands, construction sites, surface-mined lands, and roofs has expanded its local distribution. We observed least terns nesting on saltern in the Bunche Beach marsh in the course of this study. The State has listed the least tern as a threatened species.

Tricolored heron, little blue heron, white ibis, and snowy egret nest in mangroves and forage in mangroves, salt marshes and sea grass beds of the CHNEP as well as inland freshwater marshes. Little blue herons and white ibis are the most common of the listed wading bird species observed in the salt marshes of southwest Florida (Beever 1992). Diet consists of small fish, crustaceans, insects, frogs, and lizards (Ogden 1978a). Nesting in mangroves typically occurs on overwash islands. The little blue heron forages throughout the wet and dry season in salt marshes. Adjacent tidal wetlands are used throughout the year with greater emphasis during low tides on seagrass beds. The snowy egret forages throughout the wet and dry season in salt marsh wetlands of the proper depth to allow for their foraging methods. Snowy egrets are the third most abundant listed wading bird observed. Preferred foraging areas are the seagrass beds and mudflats adjacent to the salt marshes. Their diet consists of crustaceans, insects, and small fish (Ogden 1978c).

Reddish egrets and roseate spoonbills are obligate mangrove breeders. Reddish egrets forage on the sandbars and mudflats adjacent to and within salt marshes, in an active fashion with spread wings and rapid steps over unvegetated bottoms. Reddish egrets are the least abundant of the listed wading birds associated with salt marshes. Reddish egrets utilize a limited set of saltwater habitats that allow for use of their unique foraging method. Diet consists of crustaceans and small fish. Kale and Maehr (1991) indicate that red mangrove rookeries are used during the December through June breeding period. Roseate spoonbills use dry-down pools in the high marsh, and during low tides, adjacent to salt marshes. Preferred foraging areas included sheltered coves. They have a preference for algal marsh and flooded salterns. They often forage in groups and with other wading birds including wood storks, great egret (*Casmerodius albus*), white ibis, and snowy egret. Roseate spoonbills nest exclusively in mangrove forests, typically on overwash islands, and forage wherever concentrations of small fish and crustaceans allow the birds to utilize their unique bills for feeding (Ogden 1978b).

The eastern brown pelican, a state species of special concern, nests predominantly on overwash mangrove islands in the CHNEP and forages over open water, mudflats, and seagrass beds in the shallow waters of estuaries, creeks, and nearshore areas. Brown pelican rookeries are located on isolated red mangrove islands with a substantial water depth barrier that protects the nests from mainland predators. Diet consists of fish of all sizes. Foraging consists of plummeting dives, short plunges, and swimming scoops of fish. Historically, brown pelican populations were reduced as a result of pesticides. Today, the greatest threats to brown pelicans are still human-caused. Brown pelicans and their nesting/roosting/loafing sites are vulnerable to disturbance from construction activities and monofilament line entanglement. Brown pelicans are especially susceptible to death and injury caused by sport fishing equipment. It has been estimated that over 500 individuals die each year as a result of entanglement with fishing tackle (Schreiber 1978).

The Deep Water Horizon oil leak is estimated to have killed 7,258 seabirds including 192 brown pelicans in the Gulf of Mexico (DOI_ERDC NRDA 2011).

The Florida black bear (*Ursus americanus floridanus*), is a forest habitat generalist with seasonal preference for wherever food is most available, such as the seasonal abundances of propagules and insects. Occasionally, fish and carrion are also eaten. Black bears utilize all the natural forested systems of south Florida, with a decided preference for ecotones, including the boundaries between mangroves, salt marshes, and other plant communities. Documented movements of radio collared Florida black bears in Lee and Collier counties and documented signs/sightings of Florida black bears in Charlotte, Collier, and Lee counties indicate that the large areas of relatively undisturbed coastal wetlands, in combination with hydric and mesic forests and the major wetland basins, provide the principal habitat of the black bear in southwest Florida (Maehr 1984, Brady and Maehr 1985, Maehr et al. 1988, Maehr and Wooding 1992, Beever and Dryden 1992). Movement by individuals can be extensive and may be related to both mating and food availability. Black bears will swim between islands in Collier County (Dryden and Beever 1994). Recently a young male black bear found its way onto Sanibel Island. and black bear tracks were observed on Marco Island on June 13, 2012 (Staats, 2012). The Florida black bear was listed as threatened by the state throughout the majority of this 3 –year study. The FWC delisted the Florida black bear on June 27, 2012. Because the population of bears in Florida is fragmented into several subpopulations, it was inappropriate to use the IUCN criteria for decisions regarding the long-term conservation of black bears within the State. Some of the bear subpopulations, including the southwest Florida population, would meet the IUCN criteria for listing if the criteria were applied to them regionally. Removing black bear from the listed species classification removed an important umbrella species for large scale landscape corridor conservation which is essential for providing landscape scale habitat migration corridors in the face of sea level rise. The adopted FWC management plan does not consider the effects of climate change and sea level rise on the availability of future black bear habitat. The management plan appears to be driven by the apparent increase of bear/human interactions principally because humans mismanage garbage and are intruding into bear territories with residential development.

The Everglades mink (*Mustela vison evergladensis*) is found in the Big Cypress Swamp, the western edge of the Everglades, southern Lee County, Collier County, and mainland Monroe and Miami-Dade counties (Allen and Neill 1952, Humphrey and Setzer 1989, Humphrey 1992). Mink are nocturnal and crepuscular predators of mammals, reptiles, birds, amphibians, fishes, and eggs. The species does not appear to be numerous and, given its period of activity, the literature on distribution is based primarily on road kills. The Everglades mink is found in a wide variety of shallow wetland systems, including salt marshes. The principle author has observed everglades mink in salt marshes of the Estero Bay Preserve State Park within the CHNEP, and the Rookery Bay National Estuarine Research Reserves and Collier-Seminole State Park in earlier wildlife surveys for the Southwest Florida Aquatic Preserves.

The endemic Sanibel Island Rice Rat has a limited distribution in the interior Baker's cordgrass and leather fern high marshes of a barrier island. It is in the direct path of increased sea levels, increased storm frequency, and increased storm severity. In addition these delimited marshes may be disrupted by climate instability resulting in fire increases and declines in food base and overtopping flooding from increased precipitation during more severe wet seasons. The species may o need relocation to maintain viable populations.

Functional Assessment Evaluations of Salt Marsh Site Visits

The functional assessment process begins with the selection of a salt marsh site to visit. General data from the site was entered into spreadsheets that summarize information available form site aerials.. Aerial photos for the project site were found on the county websites. Aerials going back to 1998 for Lee County, and 2002 for Charlotte and Sarasota Counties were reviewed and the most recent aerials ranging from 2009 to 2011 were downloaded and saved as part of the project file for each site and the most current photos were printed for field reference.

Access to the site was then determined. Some sites were located on public lands, where special permission was obtained through permits at the commencement of the study. For sites located on private property, the property owner was contacted to secure permission to access the site. The sites were assessed from the nearest public access: a road, a right-of-way, or a waterway. A route to the site was determined, or, if the site was to be assessed from the water, a charter boat was arranged for.

The UMAM data sheet Part 1 was also completed prior to the field visit. A hard copy file was established for each project site.

Equipment used in the field included:

- Trimble GPS unit with Arc Pad ArcGIS software
- Digital camera
- Functional assessment field data sheets
- Functional assessment “cheat sheets”
- Clipboard
- Field guides
- Binoculars
- Aerial photos
- YSI water quality sensor

Field personnel included the Principal Planner and the Environmental Scientist. On several visits the GIS Specialist also participated in field mapping. All field personnel wore protective clothing appropriate for the conditions anticipated, including hats and sunscreen to protect from prolonged exposure to the sun.

On reaching the site, the Trimble unit was booted up. Some time was required for this device to acquire contact with satellites and triangulate a GPS position. Once the position was acquired, longitude and latitude were recorded on the data sheets.

A site ID was given to each site based on the Township Range and Sections and the number of sites assessed that day. The data sheets for each assessment method were filled out simultaneous with entering the same information into the tables set up on the Trimble unit. Flora and fauna observed at the site were recorded. Photographs of the site were taken, with special emphasis on the cardinal points with a GPS camera, any wetland vegetation, any alterations of vegetation, and any wildlife observed. Surrounding conditions were recorded to put the site into context spatially. Water quality measurements of water temperature, dissolved oxygen, pH, and salinity were taken.

The total time utilized at each site doing the wetland assessments utilizing all three functional assessment methods was approximately one hour.

Following the field visit, several processes were required to gather and store all the data recorded. Photos were downloaded and stored digitally in files. These photos were analyzed to properly record any flora or fauna that could not be identified in the field. The data recorded on the Trimble unit, digital versions of the functional assessments, were downloaded into a database and added to the Arc Map file established for the project. Water quality data were downloaded into databases and the equipment rinsed and maintained according to the manufacturer's recommendations.

Since some information on the functional assessment data sheets was better determined from the desktop, the data sheets were completed. Scores from the functional assessments were then entered into databases that summarized wetland impacts and mitigation.

Finally, a narrative in a standard format was written for each site. The narrative summarized the conditions at the time of assessment; the wildlife, wetland vegetation and groundcover observed at the site; the habitat support around the site; and the hydrology of the site.

Wetland Rapid Assessment Procedure (WRAP)

E-WRAP is a modified version of WRAP designed for use in the assessing estuarine systems and contains different descriptors in the models for the estuarine environment and policy guidance for the assessment of sites in mosquito impoundments. The Wetland Rapid Assessment Procedure (WRAP) was designed to provide a consistent, timely regulatory tool for evaluating wetlands that have been created, enhanced, preserved, or restored through the regulatory programs of the South Florida Water Management District and the Environmental Resource Permit process. M-WRAP is a modified version of WRAP designed for use in reviewing mitigation banks and to aid in determining the number of credits.

Professional understanding of functions in Florida wetland ecosystems and familiarity with flora and fauna with respect to specific ecosystems are required to effectively utilize WRAP.
The categories assessed include **s**ix variables: wildlife utilization; overstory/shrub canopy of desirable species; wetland vegetative ground cover of desirable species; adjacent upland/wetland buffer; field indicators of wetland hydrology; and water quality input and treatment.
The user(s) review(s) existing information (e.g., identify land uses adjacent to the site and on-site hydrology), visits the wetland area, and completes the data sheet. The data sheet (a) identifies the variables, (b) lists three or more calibration descriptors for each variable, and (c)

assigns a score (range 0 to 3) to each description. Scores for each variable are summed and divided by the maximum possible score to derive a WRAP score (scale 0.0-1.0) for the wetland.

The output of WRAP is a measure of functionality based on anthropogenic activities for a site. The estimated time for use of the method is *1 hour per acre of site* for in-office evaluation (step 1), which includes identifying the project site and adjacent land uses; and *1 hour* for field evaluation (step 2) and to score the wetland (step 3).

A particular system is evaluated on its own attributes and is not to be compared to a different type of system (i.e., marsh not be compared to a mangrove swamp). Also, WRAP is not intended to be used as a guide to design wetland mitigations or restorations.

Uniform Mitigation Assessment Method (UMAM)

The Florida Department of Environmental Protection (FDEP) and water management districts (WMDs), in cooperation with local governments and the relevant federal agencies, developed the Uniform Mitigation Assessment Method (UMAM) in Chapter 62-345, Florida Statutes (F.S.), in order fulfill the mandate of subsection 373.414(18), F.S., which required the establishment of a state-wide uniform mitigation assessment method to determine the amount of mitigation required for regulatory permits to offset adverse impacts to wetlands and other surface waters and to award and deduct mitigation bank credits. Although the state of Florida directive did not include the US Army Corps of Engineers (USACOE) and other federal agencies, the USACOE Jacksonville office conducted a study of the method and recommended UMAM to be used for federal wetland regulatory purposes in Florida starting August 1, 2005. (However, the USACOE continues to use its own time lag table rather than the state's time lag table.)

UMAM applies to all wetland impacts subject to review under Section 373.414, F.S., excluding subparagraphs 373.414(1)(a) 1, 3, 5, and 6 and paragraph 373.414(1)(b) 3, F.S. UMAM provides a standardized procedure for assessing the functions provided by wetlands and other surface waters, the amount that those functions are reduced by a proposed impact, and the amount of mitigation necessary to offset that loss. It does not assess whether the adverse impact meets other criteria for issuance of a permit, nor the extent to which such impacts may be approved.

The UMAM rule superseded existing ratio guidelines and other state of Florida requirements concerning the amount of mitigation required to offset an impact to wetlands or other surface waters. Upon a determination by a State agency that mitigation is required to offset a proposed impact, UMAM must be used to quantify the acreage of mitigation or the number of credits from a mitigation bank or regional offsite mitigation area required to offset the impact. UMAM is also used to determine the degree of improvement in ecological value of proposed mitigation bank activities. The rule state that when applying UMAM, reasonable scientific judgment must be used.

UMAM is designed to be used in any type of impact site or mitigation site in any geographic region of the state of Florida. The inherent flexibility required for such a method is accomplished in a multi-part approach that consists of a qualitative characterization of both the impact and mitigation assessment areas (Part I) that describes the assessment area, identifies its native community type, and the functions provided to fish and wildlife and their habitat; and a quantitative assessment (Part II) of the impact and mitigation sites and the use of numerical scores to compare the reduction of ecological value due to proposed impacts to the gain in ecological value due to proposed mitigation; and to determine whether a sufficient amount of mitigation is proposed.

The purpose of the qualitative characterization (Part I) is to provide a framework for comparison of the assessment area to the optimal condition and location of that native community type. It provides a descriptive framework to characterize the assessment area and the functions provided by that area. Another purpose is to note any relevant factors of the assessment area that are discovered by site inspectors, including use by listed species.

Part II of this method provides indicators of wetland and other surface water function, which are scored based on the framework developed in Part I. Part I must be completed and referenced when scoring the assessment area in Part II. An impact or mitigation site may contain more than one assessment area, each of which is independently evaluated under this method.

Three categories of indicators of wetland function (location and landscape support, water environment and community structure) are scored to the extent that they affect the ecological value of the assessment area. Upland mitigation assessment areas shall be scored for location and community structure only.

The Part II score for an impact, wetland, or surface water mitigation assessment area is determined by summing the scores for each of the indicators and dividing that value by 30 to yield a number between 0 and 1. For upland mitigation assessment areas, the Part II score is determined by summing the scores for the location and community structure indicators and dividing that value by 20 to yield a number between 0 and 1.

Hydrogeomorphic Approach (HGM)

The primary purpose of the hydrogeomorphic (HGM) approach is to assess wetland functions in the federal 404 Regulatory Program as well as other regulatory, planning, and management situations.

An interdisciplinary team of experts are required during development phase. The application phase should be done by individual(s) who have personal knowledge and field experience with the regional wetland subclass under consideration and review.

HGM is applicable to all wetland habitats types in the United States. However, not all wetland types in the United States have fully developed and USACOE approved assessment models.

A wide variety of wetland functions are assessed in HGM. The list of which functions are evaluated depends upon the wetland regional subclass model. These can include functions related to hydrologic processes, biogeochemical processes, and habitat.

There are two main phases in the specific HGM model for a specific wetland habitat type: development and application. During the development phase, an interdisciplinary team of experts (known in-house as the A-team) develops a guidebook with models for assessing functions of the wetlands in a regional subclass. The application phase consists of applying the models to an actual project following three steps: characterization; assessment; and analysis. The user(s) visits a wetland assessment area (WAA), and/or reviews plans for predicted future conditions, and completes data sheets that (a) identify the individual model variables, (b) list direct or indirect measures of model variables, (c) assign a subindex (scale 0.0-1.0) to conditions for each variable, and (d) include the equation for calculating the functional capacity index (FCI). The functional capacity units (FCUs) are also calculated for each function and all results are analyzed.

The output of HGM is a measure of the functional capacity of a wetland site relative to wetlands from the same regional wetland subclass.

The designers of HGM estimated that the time needed to assess a 1-acre site is a total of 1 to 2 hours per wetland assessment area (WAA) (if models are available) for characterization (step 1), assessment (step 2), and analysis (step 3). If models must be developed, the USACOE estimates that 320 hours (2 months of work) are needed for the development phase.

HGM can directly compare wetlands within the same regional subclass (e.g., emergent tidal wetlands of the eastern Gulf of Mexico). It cannot be utilized to directly compare wetlands from different subclasses (e.g., closed depression wetland and upper riverine wetland within same region) or from different regions. However, results from assessing different regional subclasses utilizing the separate subclass models can be used to aid in regulatory and conservation decisions.

To date, draft regional guidebooks that are approved by the USACOE have been completed for 25 major wetland habitat types. For this project we utilized the National Guidebooks for tidal fringe wetlands (Shafer and Yozzo1998) and the regional HGM guidebook for the northwest Gulf of Mexico tidal fringe wetlands (Shafer, D. J., et al. 2002);

WRAP **6 Variables**	**UMAM** **3 Variables**	**HGM** **14 Variables**
Wildlife Utilization	Location and Landscape Support	Degree of marsh dissection
Wetland Canopy	Water Environment	Proportion of tidally connected edge to total edge
Wetland Ground Cover	Community Structure (Vegetation and/or Benthic	Total Effective Patch Size

	Community)	
Habitat Support/Buffer		Hydrologic Regime
Field Hydrology		Percent cover by typical plant species
Water Quality Input and Treatment		Nekton Habitat Complexity (# different habitat types)
		Wildlife Habitat Complexity (total # different habitat types)
		Surface roughness (Manning's) (3 sub-components)
		Mean Total Percent Vegetative Cover
		Mean Vegetative Structure Index
		Mean width of marsh
		Relative Exposure Index (Fetch)
		Distance to navigation channel or 2m depth
		Soil texture

Table 10: Comparison of the variables evaluated by the three functional assessment methods.
Source: Beever et al. 2011

Functional Assessment Scores of the Salt Marsh Wetlands of the CHNEP

The mean salt marsh wetland functional assessment score for all site visit salt marshes is 0.82 with a standard deviation of 0.20 using EWRAP functional wetland analysis. The mean salt marsh wetland functional assessment score for all site visit salt marshes is 0.89 with a standard deviation of 0.15 using UMAM functional wetland analysis. The mean salt marsh wetland functional assessment score for all site visit salt marshes is 0.83 with a standard deviation of 0.17 using HGM functional wetland analysis

An Assessment of Significant Potential Effects On the Salt Marshes in the CHNEP Resulting From and Related to Climate Change.

The salt marshes of the CHNEP are currently experiencing climate change. The natural setting of southwest Florida coupled with extensive overinvestment in the areas closest to the coast have placed the salt marshes of the CHNEP at the forefront of geographic areas that are among the first to suffer the negative effects of a changing climate. More severe tropical storms and hurricanes with increased wind speeds and storm surges have already severely damaged both coastal and interior communities of southwest Florida. Significant losses of salt marshes, mature mangrove forest, water quality degradation, and barrier island geomorphic changes have already occurred. Longer, more severe dry season droughts coupled with shorter duration wet seasons consisting of higher volume precipitation have generated a pattern of drought and flood impacting both natural and man-made ecosystems. Even in the most probable, lowest impact future climate change scenario predictions, the future for southwest Florida will include increased climate instability; wetter wet seasons; drier dry seasons; more extreme hot and cold events; increased coastal erosion; continuous sea level rise; shifts in fauna and flora with reductions in temperate species and expansions of tropical invasive exotics; increasing occurrence of tropical diseases in plants, wildlife and humans; destabilization of aquatic food webs including increased harmful algae blooms; increasing strains upon and costs in management of public conservation lands; and increased uncertainty concerning variable risk assessment with uncertain actuarial futures.

Maintaining the status quo in the management of salt marshes and other estuarine ecosystems in the face of such likely changes would result in substantial losses of ecosystem services and economic values as climate change progresses. In the absence of effective avoidance, mitigation, minimization and adaptation, climate-related failures will result in greater difficulty in addressing the priority problems identified in the Charlotte Harbor National Estuary Program (CHNEP) Comprehensive Conservation and Management Plan (CCMP): hydrologic alteration, water quality degradation, fish and wildlife habitat loss, and stewardship gaps relating to salt marshes and other estuarine resources.

Known Air Temperature and Air Chemistry Changes and Events

Over the last 650,000 years, levels of atmospheric carbon dioxide have both increased and decreased. The rate of change in increases in carbon dioxide has been about 100 times faster in recent decades than over the past 650,000 years. Concentrations of other gases, such as methane and nitrous oxide, have also increased significantly.

Concentrations of greenhouse gases, especially carbon dioxide, have increased. Since the Industrial Revolution, atmospheric carbon dioxide (CO_2) levels have increased by more than 30 percent, reaching concentrations higher than any observed in the last 420,000 years (Petit et al. 1999). These increasing levels of CO_2 and other greenhouse gases have contributed to a rise in global temperatures of about 0.7 to 1.4 degrees Fahrenheit since 1900, with the warmest temperatures occurring in the past 20 years (Houghton et al. 2001). Carbon dioxide emissions grew by 80 percent between 1970 and 2004. Eleven of the last 12 years have seen the warmest temperatures since 1850 (FOCC 2009). Mean global atmospheric temperature has increased by more than 0.6 degrees Celsius since 1901 (IPPC 2007b). Since the 1980s, the atmospheric column average water vapor concentration has increased by 1.2 percent (IPPC 2007b). All this being said, coastal air temperature observations around Florida since the 1830s do not show any statistically significant trend (Maul and Sims 2007).

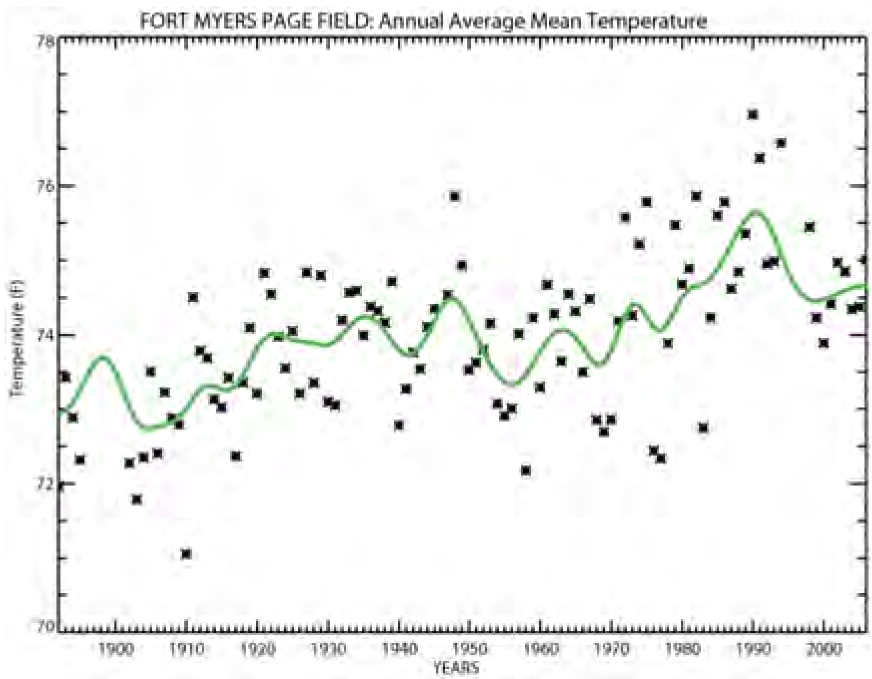


Figure 128- Fort Myers Average Temperature, 1892-2008
(Zierden 2009)

Potential Future Temperature and Air Chemistry Climate Changes

Southwest Florida's future climate depends on overall emissions of greenhouse gases today and in the decades to come, and, because carbon dioxide persists in the atmosphere for a century or more, on the impacts of accumulated past emissions (Stanton and Ackerman 2007). If the world fails to achieve reductions in GHG emissions, the business-as-usual case assumes steadily *increasing* emissions, along with uncertain extreme weather, in which atmospheric concentrations of carbon dioxide exceed the critical 450 parts per million (ppm) threshold by 2030 and reach 850 ppm by 2100. Reaching this threshold is considered "likely" by the IPCC, so understanding that air temperature and air chemistry are interrelated is critical. Ocean acidity, global average temperatures, smog formation, heat waves, humidity (water vapor) and other conditions are affected by air chemistry and air temperature.

	2025	2050	2075	2100
Best Rapid Stabilization Case	0.6	1.1	1.7	2.2
Worst Case	2.4	4.9	7.3	9.7

Table 11: Two future climate scenarios for Florida annual average temperature in degrees F above year 2000 temperature
Source: Stanton and Ackerman 2007

Elevated atmospheric carbon dioxide will increase dissolved carbon dioxide in the oceans and waters associated with coastal areas and wetlands. This can be expected to acidify these waters and increase the frequency of algal blooms (Holman 2008; Ebi et al. 2007; Uhland 2007; Lee County Visitor and Convention Bureau 2008). Carbonate deposition in marine shell-forming taxa will be reduced, causing reductions in the health of and populations of animals ranging from conchs to barnacles to corals. Changes in plant growth and plant biomass turnover with a near-term increase in vegetative biomass at early stages (Holman 2008; Ebi et al. 2007; Uhland 2007; LCVCB 2008) might be expected in marsh monocots and dicots.

Climate Scenario	Pre-development	1891-1995	2009	2025	2050	2100
With Mitigation	73.6	73.8	74	74.6	75.1	76.2
Least	73.6	73.8	74	75.1	74.5	77.1
Moderate	73.6	73.8	74	75.5	77	80.4
Worst	73.6	73.8	74	76	78.9	83.7
“Worstest”	73.6	73.8	74	76.4	78.9	84.4

Table 12: Mean annual temperature changes for southwest Florida (In degrees Fahrenheit)
Derived from Intergovernmental Panel on Climate Change (IPCC) (2007b), Florida Oceans and Coastal Council (FOCC) 2009, Stanton, E.A., and F. Ackerman 2007

Water vapor, the most abundant greenhouse gas, is an important factor causing uncertainty in climate prediction models. As air temperature increases, the capacity of the air to hold water vapor increases. However, clouds can have a cooling or heating effect, and cloud processes are one of the largest sources of uncertainty in climate change projections. Correctly characterizing the effects of water vapor greatly complicates climate forecasts (FOCC 2009).

In the worst case outlined above, southwest Florida's average annual temperatures will be 5° F higher in 2050 than today, and 10°F higher in 2100. The timing of seasonal temperature changes is expected to be disrupted with earlier springs, shorter winters, unseasonable freezes, and extended droughts (Peterson et al. 2007).

Increased air temperatures will affect hydrology, water quality and habitats in saltwater wetlands with surface freshwater supplies decreasing and drought in some portions of the region. Altered salinity gradients, altered species distributions, negative species interactions and increased metabolic activity; increased risk of disease and parasitism; creation of opened niches for invasive tropical and subtropical species; and increased evaporation of surface water are all expected to occur (USEPA CRE 2008; Harvell et al. 2002, Holman 2008; FOCC 2009).

Warming effects will likely be greatest and most apparent in the more northern parts of the CHNEP area (FOCC 2009). Air temperature in south Florida may also increase because of changes in land use and land cover, such as urbanization and the reduction of coastal salt marsh wetlands (Pielke et al. 1999; Marshall et. al. 2003), multiplying the effect of climate change. Heat waves will become more severe and more common, with new record temperatures and a gradual decline in nighttime cooling. The average "heat index" (temperature combined with humidity) in summer will be 15–20 percent higher in much of the state. Southwest Florida is estimated to become several degrees hotter than today's Bangkok (probably the world's hottest, most humid major city at present), and daily highs will exceed 90 degrees F nearly two-thirds of the year (Stanton and Ackerman 2007).

Increases in surface air temperatures will affect coastlines and salt marsh species by a reduction in water quality due to increased growth of nuisance algae and lower oxygen levels. Extirpation of cooler-water species, altered reproductive rates and maturation leading to declining fish and animal populations, and increased evaporation of surface water, can be expected (USEPA CRE 2008, Rubinoff et al. 2008; Holman 2008; USNOAA 2008)

Timing of seasonal temperature changes will disrupt the flora and fauna of estuaries resulting in disturbance of predator/prey availability, food and reproductive cycles, life-cycles and upstream migration, temperature-driven behavior, photoperiod-driven behavior and, biological ocean-estuary exchanges (Peterson et al. 2007).

The response of salt marsh function to climate change depends on its ability to keep pace with sea level rise by expanding both horizontally and vertically through peat accumulation and primary productivity. Climate change is expected to regionally warm the air, soil, and water as well as change tide cycles and the intermittency and volume of precipitation. This will strongly alter the ability of salt marsh ecosystems to export biomass and nutrients, filter runoff, sequester carbon, and protect coastlines from flooding and erosion. Charles and Dukes (2009) studied the effect of precipitation and environmental warming by manipulating the habitats of two salt marsh plant communities, marsh hay/spike grass and cod grass. They analyzed the differences between total above ground biomass, stem height, decomposition rates, and flowering patterns for each treatment plot that differed by the amount of precipitation and increase in temperature. Their research found that salt marsh communities are able to withstand slight increases in temperature and large changes in precipitation.

Healthy salt marsh ecosystems are a balance between salt tolerant and fresh water plants that correspond to a salinity gradient defined by tidal inundations and ground water circulation. Charles and Dukes tested two plant communities, representing salt tolerant and water loving *Spartina alterniflora* as well as *Spartina patens and Distichlis spicata* that prefer less saline soils and higher ground. The habitat of each plant community was monitored under five different treatments that consisted of a control (ambient climate), doubled precipitation, no precipitation, warming up to 1.17°C, and the interaction between warming and doubled precipitation.

Open-top warming chambers were created by wrapping “greenhouse plastic” around a PVC pipe frame. This reduced the side effects of closed warming chambers like the increase in humidity but did not allow the warming chambers to maintain heat during the night. The double precipitation treatment was performed by watering plots directly after storms with the same quantity of water that fell, to double the average amount of precipitation. Drought treatments used plastic shields and funnels to completely divert water away from the designated plant communities. Charles and Dukes measured the response of each treatment by observing the total above ground biomass, height of the tallest stems, number of flowering stems, decomposition rate of leaf litter, and the pore water chemistry related to nutrient availability and soil salinity.

The researchers believed that doubling precipitation would increase plant growth by decreasing the salinity of the soil. However the doubled precipitation treatment showed no significant decrease in the overall salinity, even though the added fresh water did temporarily decrease the salt concentration. The soil salinity was restored to 5 ppt after 2 hours and 10 ppt after 4 hours. This could explain why, with increased precipitation, the overall productivity of each plant community declined. The effects of doubled precipitation reduced overall stem growth and total above ground biomass for both plant communities, effecting *S. alterniflora* the most significantly. The possible increase in soil water logging may have offset any of the positive effects of decreased salinity by means of increased precipitation. It remains unclear to the researchers why there was an increase in primary productivity during the drought treatment. They postulated that the absence of water allowed for increased soil aeration and nutrient availability because fewer nutrients were leached from the soil due to tidal inundations and runoff. In addition, the interaction between warming and a decrease in precipitation led to a 53% increase in total biomass compared to the 24% increase from warming alone. The more productive a salt marsh is the greater ability it has to trap sediment during tidal flushing and directly contribute organic inputs into the soil through the decomposition of leaf litter. A slow rate of decomposition is important for the gradual uplift of salt marsh topography because plant litter helps to trap sediment from the flowing water. The results showed that, under a period of drought and environmental warming, salt marsh productivity was at its highest. This can be explained by the decrease in decomposition and the increase in above ground biomass, which allow for the salt marsh ecosystem to expand horizontally and vertically. However, precipitation significantly increased the rate of decomposition because microbes decompose wet matter more quickly. Warming had no effect on the rate of decomposition and flowering rates were not affected by the warming or precipitation treatments. As long as salt marshes are not completely submerged as a result of sea level rise, increases in above ground biomass and stem heights suggests that salt marsh plants may become increasingly more productive under future climate projections.

Water temperature and chemistry

Known Water Temperature and Water Chemistry Changes and Events

Florida, situated between the Gulf of Mexico and Atlantic Ocean, is subject to contrasting environmental effects because each body of water has its own characteristic temperature regimes and patterns of change (FOCC 2009), but there has been a cyclical rise in sea level and global ocean temperatures (Wang and Enfield et al. 1998). As well, ocean chemistry is changing at least 100 times more rapidly today than at any time during the 650,000 years prior to the industrial era (Kleypas et al. 2006).

As oceanic carbon dioxide has increased in recent decades, the world's oceans have become more acidic, with pH decreasing by 0.1 standard units since 1750 (Archer 2005). This represents a 30 percent increase in ocean acidity.

Additionally, global average sea-surface temperature has risen 1.1 degrees Fahrenheit (0.6 degrees Celsius) over the past 100 years (IPCC 2007b). Water temperatures at the sea surface rose by an average of 0.3 degrees Celsius between the 1950s and 1990s in tropical and subtropical waters (Wilkinson and Souter 2008; Florida Oceans and Coastal Council (FOCC) 2009). The year 2005 was the warmest in the wider Caribbean than any in the last 100 years, and coincided with the area of sea surface temperatures known as the Western Hemisphere Warm Pool being in an expanded state (Wang and Enfield et al. 1998; Wilkinson and Souter 2008).

Warm water holds less dissolved oxygen than cold water, thus, hypoxia, or low oxygen, occurs when the levels of oxygen dissolved in water fall with rising water temperatures to levels injurious to ocean and coastal life. This can lead to what is called a "dead zone." Excess nutrients can cause or exacerbate hypoxic conditions by causing certain organisms to proliferate, leading to further decreased dissolved oxygen as they die and decay. Terrestrial nutrients are introduced into the marine environment through precipitation and runoff, thus, hypoxia can occur as a natural phenomenon and also as a human-induced or exacerbated event (Turner et al. 2006). Precipitation and runoff amounts and distribution have changed over recent years and will continue to change as climate change progresses (UNEP 2006). Over the past 30 years, increased sea surface temperatures have led to episodic die-offs of sponges, sea grasses, and other important components of coastal and marine ecosystems (FOCC 2009).

Potential Future Climate Changes

Sea-surface temperatures will continue to rise at least at the rate at which they have been rising for the past 100 years (IPCC 2007b). It is probable that water temperatures at the sea's surface will continue to increase at the average rate of 0.3 degrees Celsius over 40 years in tropical and subtropical waters (FOCC 2009). If Florida's ocean temperatures increase at the same rate that the IPCC models predict for the Gulf of Mexico and Atlantic as a whole, they would increase by 2 degrees Celsius over the next 100 years (IPCC 2007b).

As sea-surface temperatures continue to rise, the coastal and marine environments most stressed by nutrients from land-based sources of pollution will be most adversely affected (Wilkinson and Souter 2008). Increased stormwater runoff in some parts of the state, coupled with human population increases, will increase the transport of nutrients to coastal waters, contributing to hypoxia (low oxygen) and eutrophication (FOCC 2009).

More oxygen-poor (hypoxic) waters in areas like Charlotte Harbor may occur as a result of human development depending on the amount of nitrate-laden freshwater discharged by the Peace River. The complex interaction of nutrient load and amount of runoff will make future projections challenging. A 20 percent increase in river discharge, as some climate models project, could increase the risk of hypoxia and expand the oxygen-poor “dead zone” (Twilley et al. 2001; Ebi et al. 2007; USNOAA 2008; FOCC 2009; USEPA CRE 2008).

Increased sea surface temperatures will lead to increased temperature stratification and changed water current circulation with reduced dissolved oxygen (USEPA CRE 2008; NOAA 2008; FOCC 2009). Gulf of Mexico currents may shift (Wilkinson and Souter 2008).

The average pH of the world’s oceans may decrease by as much as 0.1 to 0.4 pH units over the next 90 years, due to increasing absorption and solution of carbon dioxide into warmer ocean waters (Royal Society 2005: 29; Kuffner et al. 2008; Ishimatsu et al. 2005). Evidence from studies in the waters surrounding volcanic vents shows that, around the vents, pH fell as low as 7.4, the number of species was 30% less than neighboring areas, coral was absent, and species of algae that use calcium carbonate were displaced in favor of species that do not use it. Snails showed signs of dissolving shells. There were no snails at all in zones with a pH of 7.4. Meanwhile, sea grasses thrived, perhaps because they benefit from the extra carbon in the water (Martin et al. 2009).

Increased acidification of marine waters will cause increased trace metal toxicity and dissolution of carbonate structures, like marine animal shells (Peterson et al. 2007, SCCP 2008, Florida Oceans and Coastal Council (FOCC) 2009, USEPA CRE 2008, Orr et al. 2005).

Higher numbers indicate alkalis, lower values signify acidic liquids	
13	Bleach
10	Soap
8.2	Pre-1750 oceans (average)
8.1	Current oceans (average)
7.8	Oceans in 2100 (projected average)
7	Pure water
3	Vinegar
0	Battery acid

Table 1**3**: The pH Scale *Source: NMEA*

Average Water Temperature in the Peace River

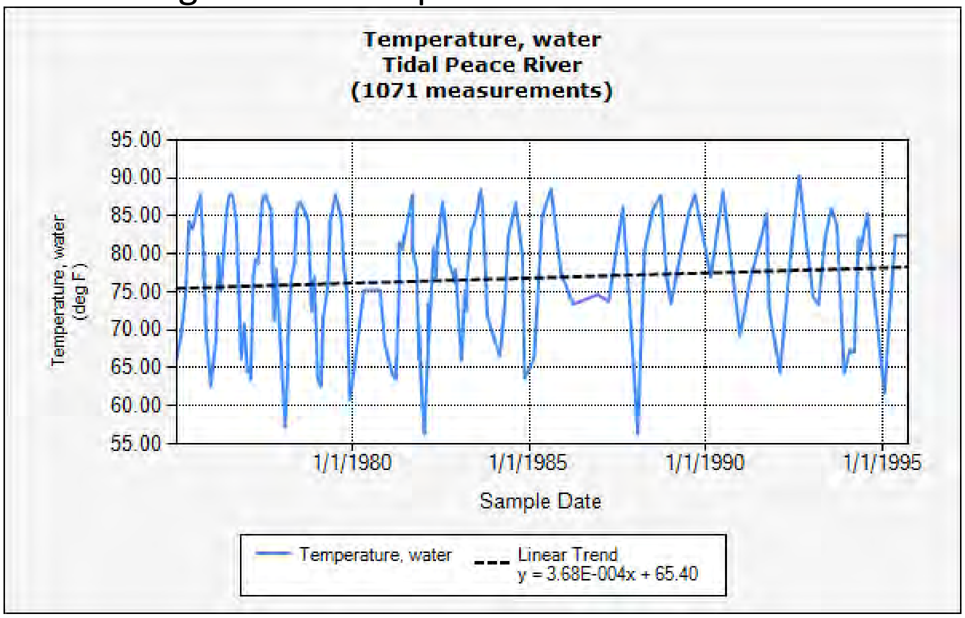


Figure 129: Average Water Temperature of the Peace River

Known Hydrologic Changes and Events that Have Occurred

McKee et al (2004) suggests that increases in temperature and decreases in rainfall associated with climate change may dramatically affect tidal marshes. They observed extensive dieback of salt marsh dominated by smooth cordgrass occurred throughout the Mississippi River deltaic plain during the year 2000. More than 100,000 ha were affected, with 43,000 ha severely damaged. The sudden dieback could have been caused by a coincident drought. There were multiple dieback sites and reference sites were established along 150 km of shoreline in coastal Louisiana. Aerial and ground surveys were conducted from June 2000 to September 2001 to assess soil conditions and plant mortality and recovery. Dieback areas ranged in size from ~300 m^2–5 km^2 in area with 50–100% mortality of plant shoots and rhizomes in affected zones. Co-occurring species such as *Avicennia germinans* and *Juncus roemerianus* were unaffected. Historical records indicate that precipitation, river discharge, and mean sea level were unusually low during the previous year. Although the cause of dieback is currently unknown, plant and soil characteristics were consistent with temporary soil desiccation that may have reduced water availability, increased soil salinity, and/or caused soil acidification (via pyrite oxidation) and increased uptake of toxic metals such as Fe or Al. Plant recovery 15 months after dieback was variable (0–58% live cover), but recovering plants were vigorous and indicated no long-lasting effects of the dieback agent.

These findings have relevance for global change models of coastal ecosystems that predict vegetation responses based primarily on long-term increases in sea level and submergence of marshes. The results suggest that large-scale changes in coastal vegetation may occur over a relatively short time span through climatic extremes acting in concert with sea-level fluctuations and pre-existing soil conditions.

Sea levels in Florida are expected to eventually rise to the degree that saltwater intrusion will threaten the aquifers that currently supply much of the base through flow to southwest Florida estuaries. This problem will be exacerbated by increased human withdrawals of water for the anticipated increase in Florida's population.

Shallow coastal aquifers are already experiencing saltwater intrusion. As rising water levels submerge the land, the low-lying portions of the coast will become more saline, decreasing the recharge area and increasing saltwater intrusion (IPCC 2007c).

Gulf Coast ecosystems are linked by the flow of water from the uplands through freshwater lakes, rivers, and wetlands to the coastal and marine systems downstream. Vast wetland areas of the region require periods of flooding to maintain healthy habitats and sustain food webs. While there remains some uncertainty about how global climate change will affect rainfall, stream flow, soil moisture, and overall water availability, human consumption of water resources is almost certain to increase as a result of the region's population growth under higher temperature regimes.

Water resources are affected by changes in precipitation as well as by temperature, humidity, wind, and sunshine. Thus, changes in stream flow tend not just to reflect, but to magnify changes in precipitation. Water resources in drier climates tend to be more sensitive to climate changes, and, because evaporation is likely to increase with warmer climate, lower river flows and lower lake levels could be expected, particularly in the summer. If stream flow and lake levels drop, groundwater also could be reduced.

A critical factor in Florida's human development, especially in southern Florida, has been availability of freshwater. Although south Florida receives an annual average of 54 inches of rain, annual evaporation sometimes can exceed this amount. Rainfall variability from year to year is also high, resulting in periodic droughts and floods. Competing demands for water — for residences, agriculture, industry, and for the Everglades and other natural areas — are placing stress on southwest Florida's water resources.

Potential Future Hydrologic Changes Resulting From Climate Changes

Rising air and sea temperatures combined with a rising sea level will change future hydrology. By 2200, the worst case scenarios estimate the mean sea level to rise over 177 inches (14.74 feet), inundating most of Monroe County and two-thirds of Miami-Dade County. The Everglades south of I-75, including the Everglades National Park, will no longer be a freshwater ecosystem, causing a major environmental changes for the species and habitats inhabiting that area. Flooding will result from changes in the intensity of precipitation and will cause stream bank erosion. Changes in the frequency of precipitation and increases in evaporation will cause drought. The sea level rise, lower water levels in the surface and groundwater result in salt water intrusion(Stanton and Ackerman 2007). .

Increases in precipitation, including heavy and extreme precipitation events, affects all land surfaces and receiving water bodies. Precipitation is expected to increase five to 10% over the levels of the 20th century. The altered timing of seasonal hydrologic changes will affect coastlines and salt marsh wetlands. An increase of freshwater in rivers and estuaries will lead to more severe sediment-loading and flash flooding that results in can damage to fish and wildlife resources Changes in timing of the dry and wet seasons change the flow of pollutants and will affect river discharge balance (University of Washington 2007; USNOAA 2008; SCCP 2005; FOCC 2009; USEPA CRE 2008).

Rising sea temperatures are also expected to increase the frequency of droughts and floods, causing changes to hydroperiod and to water quantity especially during dry periods. The changing timing of seasonal temperature cycles may also disrupt the hydrologic run-off cycle (Peterson et al. 2007). Changes in the volume and intensity of precipitation contribute to erosion, flooding, and run-off at coastlines. Drought from decreased precipitation will cause lower stream flows and result in erosion and subsidence of stream banks (UWCSES 2007; USNOAA 2008; USEPA CRE 2008).

The increased salinity of riverine and estuarine ecosystems is an effect of drought. Increased penetration of saltwater from upstream tidal movement of marine waters will truncate isohaline ecotones. Pollutants from urban runoff are expected to be more concentrated in estuarine and fresher water systems due to lower water levels. Increased water temperatures and reduced dissolved oxygen will occur. Marine exotics will spread and some freshwater exotics will be advantaged while native species suffer (University of Washington Center for Science in the Earth System 2007; USNOAA 2008; USEPA CRE 2008).

Known and Potential Climate Instability Resulting From Climate Changes

The development of tropical storms and hurricanes depends not only on sea-surface temperature and water vapor content, but also on factors such as wind shear, which plays a significant role. Wind shear appears to have an inverse relationship with storm intensity. Recent examples of rapid storm intensification are associated with storms passing over deep, warm ocean pools and through regions of low wind shear (Shay et al. 2000). Storm frequency and intensity may, therefore, decrease with increasing sea-surface temperatures (Knutson et al. 2008) because wind shear will increase in a warming planet (Vecchi and Soden. 2007; Wang and Lee 2008.). Other studies indicate that severe hurricanes (Category 3 or higher) may become more frequent with increasing sea-surface temperatures (Webster et al. 2005), and that rising sea temperatures are expected to causes a 5 to 10% increase in hurricane wind speeds (USNOAA 2008; FOCC 2009; USEPA CRE 2008).

Higher water temperatures in the Gulf of Mexico and Atlantic Ocean may cause more intense hurricanes, which will cause more damage to coastal and inland habitations, infrastructure and human economy (Elsner 2006; Peterson et al. 2007; USNOAA 2008; USEPA CRE 2008).

Damage will multiply as the effects from more intense hurricanes are added to more severe storm surges resulting from higher sea levels. More intense hurricanes will cause more damage to both coastal and inland habitations and will increase the devastating effects of hurricanes to infrastructure and human economy (Elsner 2006; Peterson et al. 2007; USNOAA 2008; USEPA CRE 2008). Damage will multiply as the effects from more intense hurricanes are added to more severe storm surges resulting from higher sea levels. This increased magnitude of coastal storms will cause geomorphic shifts in barrier islands and habitats at coastlines through coastal erosion and inundation. There will be habitat loss/migration due to erosion/inundation (University of Washington Center for Science in the Earth System 2007; Peterson 2007; FOCC 2009; USEPA CRE 2008; USEPA 2008; USNOAA 2008). Clearly, climate change effects will magnify the effects of hurricanes and tropical storms.

Salt marshes can usually recover quickly from natural disturbances such as fire and hurricanes. However, when disturbance events occur in close succession, they may have lasting effects on the salt marsh ecosystem (Sweat 2009). Hurricanes produce storm surges, wind and waves that can impact salt marshes in several ways. High marshes can experience an influx of seawater at a salinity to which vegetation is not accustomed, causing dieback of several plant species. Wind can strip trees and bushes of foliage and damage the trunks. In addition, lower elevations can experience extreme rates of sedimentation or erosion. Sediment erosion can wash away much of the vegetation, reducing habitat acreage. However, sediment accretion could be more harmful, essentially covering salt marsh and mangrove areas (Rejmanek et al. 1998) and smothering sessile benthic invertebrates. One example of rapid sedimentation occurred in the upper Chesapeake Bay, when over a 70-year period 50% of the sediment accumulation was attributed to one flood event and a single hurricane (Schubel and Hirschberg 1978). Regeneration of mangrove forests following substantial storm damage may take decades, and restored swamps may have altered biodiversity and plant zonation (Ellison and Farnsworth 1990).

Figure 130: Red mangrove fringing forest killed by Hurricane Charley August 2004. This is a site of CHNEP restoration effort studies.
Source: CHNEP 2008

With climate change, higher, stronger coastal storm surges will reach farther inland. This may lead to saltwater intrusion in zones not tolerant of higher salinity, causing plant and animal mortality and salinization of surface and aquifer waters. The higher waves, wave action, and hydrodynamic pressure will lead to deeper flooding. A 20 to 25% increase in the 100-year floodplain area is expected. Salt deposition from such surges and flooding can lead to physical and chemical changes of habitats. Larger floating debris and increased beach erosion will have negative impacts on adjacent upland habitats (USCCSP 2008; Fiedler et al. 2001; Peterson et al. 2007; USNOAA 2008; USEPA CRE 2008). This will provide new niche space for salt marshes if barriers are not present to impair connection to low gradient open ground.

Rainfall over the Florida peninsula depends on the winds (e.g., sea breezes), especially in the summer, and on hurricanes and tropical storms. Rainfall variations are highly cyclical (Enfield et al. 2001). Climate change, land use, and other factors may result in greater variations in observed patterns, conflicting trends, and regional differences within the state. Distinguishing Florida-specific rainfall and runoff trends from future global trends is a critical research need (FOCC 2009).

Since 1979, there has been a change in the type of rainfall in the tropics, with more frequent heavy and light rains, and less frequent moderate rains (Lau and Wu 2007). Air pollution also may cause more rainfall during weekdays (Bell et al. 2008). An increase in precipitation of 5-10% over the levels of the 20th century, including heavy and extreme precipitation events could be expected, affecting all land surfaces and receiving waterbodies in the entire area of southwest Florida (UWCES 2007; USNOAA 2008; SECCP SDRT LCCP 2005, FOCC 2009, USEPA CRE 2008). If the frequency of extreme rainfall events increases, or if river volume increases and the timing of freshwater flows to estuaries changes, it will exacerbate already altered conditions in estuaries such as increased nutrient delivery and eutrophication (Alber 2002; Peterson et al. 2008; Easterling et al. 2000). However, as mentioned previously, rainfall in south Florida also may be decreasing from changes in land use and land cover, such as urbanization and the reduction of wetlands (Pielke et al**.** 1999). Climate change effects will be variable, and in some cases, will combine to create even more complex and/or extreme outcomes.

Higher maximum temperatures should be expected, with more hot days and heat waves over nearly all land areas. This will negatively affect wetlands and freshwater bodies. Due to increased evaporation and evapotranspiration, the volume of bodies of freshwater will be reduced. This will concentrate the solutes in same waters increasing toxic effects (Ebi et al. 2007; USNOAA 2008; SCCP 2005; FOCC 2009; USEPA CRE 2008). Increases in hot extremes will be associated with heavier precipitation (FOCC 2009); storm intensity, even when not associated with tropical systems, will likely increase (FOCC 2009); and periods of drought between these rain systems may be longer (FOCC 2009).

Higher humidity will result from increased atmospheric/aquatic temperatures, allowing more water vapor to exist in the air column. This will result in increased heat stress for plants and animals; growth of harmful molds leading to increased negative health consequences; and more bacterial infections (FOCC 2009).

Wildfires, resulting from higher atmospheric temperatures in combination with increased drought, will destroy habitat and allow increased erosion from a lack of vegetative cover. Decreased air quality from particulates and other air pollutants released by the fires (USNOAA 2008; USEPA CRE 2008) can also be expected. Rising air temperatures increase evaporation, contributing to dry conditions, especially when accompanied by decreased precipitation. Even where total annual precipitation does not decrease, precipitation is projected to become less *frequent* in many parts of the country (Gutowski et al. 2008). Drought is expected to be an increasing problem in southwest Florida.

Although little documentation exists on the natural fire regime in salt and brackish coastal marshes, lightning-ignited fires in other communities were likely to spread into the coastal marshes during the growing-season. There is also a long history of human ignition of fire in southeastern coastal marshes. People often burned these sites to promote wildlife resources (especially for waterfowl), increase forage for cattle and enhance ease of access for hunting and trapping.

To date, almost all research on fire effects in coastal marsh habitats has focused on burns during the dormant season. Although effect of dormant season fire on marsh vegetation appears to be short-lived, it remains unclear how growing season burns affect marsh vegetation. Growing-season burns may alter vegetation structure and/or availability of insects compared to the results of dormant season fires. These resources may be important for nesting success of many marsh birds.

Prescribed fire is a common management tool used in coastal marsh ecosystems of the southeastern U.S. It is often used as a cost-effective way to reduce fuel and, when coupled with impoundments, is viewed as an important tool for coastal waterfowl. Although research has explored the effects of season of burn and fire frequency in adjoining upland ecosystems and, under some conditions, has determined advantages of varying fire regimes, these topics remain largely unstudied in coastal marsh areas of the Southeast. Agencies continue to use mostly dormant-season burns in coastal marshes, in part due to concerns about potential negative effects on wildlife, especially seaside sparrows. Due to the lack of research on season and frequency of burn, large gaps still exist in the scientific knowledge required to develop and implement fire management programs in coastal marshes of the southeast United States.

Currently fire effects on marsh habitat structure and function are poorly documented. In a community profile for salt marshes of the northeastern Gulf of Mexico, Stout (1984) suggested that repeated marsh burns would result in community succession but also stated that the details of succession and impacts on marsh functioning are not known. Almost two decades later, the necessary research still has not been done. A few studies have shown that, following dormant-season burns, plant species composition is rarely modified and live biomass rapidly recovers to pre-burn levels, often within a year (reviewed in Mendelssohn et al. 1996). However, other details about the removal of marsh biomass are lacking. Although reduction of invasive shrubs (both natives and exotics) is often listed as a reason for marsh burns, prescribed fire's effectiveness for producing this result is rarely quantified nor are measurements usually made of fuel (biomass) reduction. This is especially true for marshes dominated by *Juncus roemerianus.*

Some studies have described the relationship between fire and changes in plant production (cf. Hackney and de la Cruz, 1981). In general, past studies have indicated that burning increases plant production, but these results were based only on dormant-season burns. It is not known how growing-season burns affect plant production. Vertical accretion (formation of new marsh soil) has been deemed an important process, especially in areas where rising sea level threatens to drown marshes (Roman et al. 1997).

An important result of increasing temperature along the Gulf of Mexico is the observed northward migration of mangroves replacing salt marshes. Mangroves are tropical coastal forests that are freeze-intolerant. Chen and Twilley (1998) developed a model of mangrove response to freeze frequency. They found that when freezes occurred more often than once every 8 years, mangrove forests could not survive. At a freeze frequency of 12 years or longer, mangroves replaced Gulf salt marsh. Along the Louisiana coast, freezes historically occurred about every 4 years. By the spring of 2004, however, a killing freeze had not occurred for 15 years and small mangroves occur over a large area near the coast. As this trend continues, mangroves will probably spread over much of the northern Gulf and part of the southeastern Atlantic coast. Mangroves are already becoming established and more widespread in the northern Gulf of Mexico due to warming (Day et al. 2005).

Known Geomorphic Changes and Events that Have Occurred

Beaches, inlets, and shallow emergent wetlands are regional systems of sediment deposition, erosion, and transport. These processes are profoundly affected by changes in sea level and rates of sea level change, as well as storm events. Scientists and resource managers will be challenged to separate the effects of sea level changes from the effects of storms and the alterations resulting from human beach and inlet management actions, such as dredging, pass hardening, and beach renourishment as well as hydrologic alterations of tributary rivers and streams..

Shoreline retreat due to erosion and overwash is already occurring (Sallenger et al. 2006, FOCC 2009). There has been an increase in the formation of barrier island inlets and in island dissection events, in which islands are eroded by wind and waves (Sallenger et al. 2006; Sallenger et al. 2005). Normal mangrove accretion in stable estuaries occurs at a rate of 7 mm/year (Cahoon et al. 1999) effectively increasing elevations. Under equilibrium conditions, the processes of erosion and deposition balance, and wetlands are not lost. However, even historic sea level rise coupled with local subsidence has upset coastal equilibrium in many parts of the world (Bird 1985; Bruun 1986, Roman et al. 1997).

According to the Florida Department of Environmental Protection (FDEP), beach erosion threatens the very resource that residents and visitors enjoy. In 1989, a first list of erosion areas was developed based upon an abbreviated definition of critical erosion. The list included 217.6 miles of critical erosion and another 114.8 miles of non-critical erosion statewide. Of the state's 825 miles of sandy beaches, the 2006 list includes 385.3 miles of critically eroded beach, 8.6 miles of critically eroded inlet shoreline, 96.8 miles of non-critically eroded beach, and 3.2 miles of non-critically eroded inlet shoreline statewide (FDEP 2006). This data suggests a 20 percent increase in critically eroded beaches within 15 years of records. Over 409 miles, or approximately 50% of the state's beaches, are experiencing erosion. "Critical erosion", is defined as a level of erosion which threatens substantial development, recreational, cultural, or environmental interests.

While some of this erosion is due to natural forces, a significant amount of coastal erosion in Florida is directly attributable to the construction and maintenance of navigation inlets and imprudent coastal development . Florida has over 60 inlets around the state, and many have been artificially deepened to accommodate commercial and recreational vessels and employ jetties to prevent sand from filling in the channels. A by-product of this practice is that the jetties and the inlet channels have interrupted the natural flow of sand along the beach causing an accumulation of sand in the inlet channel and at the jetty on one side of the inlet, and a loss of sand to the beaches on the other side of the inlet (FDEP 2006).

Potential Future Geomorphic Changes Resulting From Climate Changes

Sea level rise will change coastlines in many ways (USEPA CRE 2008; Volk 2008a; Bollman 2007; Feagin et al. 2010, Titus 1998). There will be erosion with landward migration of coastlines, barrier island disintegration, saltwater intrusion into surface and subsurface waters, rising surface and groundwater tables. Where retreat is possible, there will be a migration of mangroves and salt marsh species, altered plant community structural diversity with potential changes in dominant or foundation species, and structural and functional habitat changes. As waters deepen, there will be less sunlight available to submerged aquatic vegetation (SAV) in current locations and light attenuation coefficients will be exceeded (USEPA CRE 2008). The ability of barrier islands to shield coastal areas from higher storm surges and the destructive effects of hurricanes will be reduced by sea level rise (Fiedler et al 2001; Titus 1998; USEPA CRE 2008).

Sea-level change is an important long-term influence on all salt marshes. Depending on the rate and extent of local sea-level change, salt marsh systems will respond differently (Titus 1987, Wanless et al.1994). If rates of sea-level rise are slow, some salt marsh vegetation will migrate upward and inland and grow without much change in composition. If rates are too high, the salt marsh may be overgrown by other species, particularly mangroves, or converted to open bodies of water. If there is no accretion of inorganic sediment or peat, the seaward portions of the salt marsh become flooded so that marsh grass drowns and marsh soils erode; portions of the high marsh become low marsh; and adjacent upland areas are flooded at spring tide, becoming high marsh. Sea-level rise in southwest Florida has been relatively constant for the past 3,200 years at around 0.4 mm/yr,(0.02 in/yr) but is now thought to be rising at rates of 3 to 4 mm/yr (0.12 to 0.16in) based on tide measurements from Key West (Wanless et al.1994). If sea-level rise continues at this present rate, many of the CHNEP salt marshes will be impacted.

Figure 131: Aerial view of Charley Pass, a breach of North Captiva Island created by Hurricane Charley on August 13, 2004

Continued sea level rise will exacerbate erosion (Sallenger et al. 2009), reducing the elevation of barrier islands (Sallenger et al. 2009) and affecting coastal transportation infrastructure. Increased overwash and breaching of coastal islands will occur (Sallenger et al. 2006). Low barrier islands will vanish, exposing salt marshes and estuaries to open-coast; high fetch conditions (Sallenger et al. 2009). The one existing area without coastal barrier island protection opposite Boca Grande Pass on the east wall of Charlotte Harbor is unable to support mangrove or salt marsh shorelines.

A drier climate along the Gulf Coast combined with such activities as dredging, constructing reservoirs, diverting surface water, and pumping groundwater could accelerate local subsidence and sinkhole formation in coastal areas underlain by limestone (Twilley et al. 2001). Carbonate sediment dissolution will accelerate as pH decreases (Orr et al. 2005). There is a potential for ground subsidence with loss of emergent and terrestrial habitat and expansion of open water aquatic habitats (USCCSP 2008; USNOAA 2008; USEPA CRE 2008; SCCP 2008).

Sea level rise will add to the effects of relative surface elevation subsidence caused by changes in sediment transport from watersheds to the estuaries and coast. Dams, diversions, reservoirs, shoreline hardening, dredging of channels and passes with deep water or landward spoil disposal can starve the bed load sediment budget preventing the relative elevation of shallow subtidal and intertidal zones to retain a relative position to sea level to allow wetlands to retreat and re-zone . Some structural adaptations to sea level rise, such as vertical sea walls, tidal barriers, fetch barriers, channelization, etc., will restrict sediment transport and reduce the ability of salt marsh wetlands to migrate inland with sea level rise. The balance between rainfall and evaporation modified by increased human consumption/drawdown of groundwater will reduce supplies for wetlands and estuaries. When wetlands are "squeezed" and can't migrate, they do not create substrate fast enough to avoid drowning (Ebi et al. 2007; Titus 1998).

Specifically for southwest Florida coastal counties, the following erosion report discusses coastal segments mile-by-mile (FDEP 2006). The following are the areas identified by the FDEP as having critical coastal erosion problems as of 2006**.** There are seven designated critically eroded beach areas (23.1 miles), one noncritically eroded beach area (0.4 mile), and two critically eroded inlet shoreline areas (1.1 miles) in Sarasota County. There are three critically eroded areas (5.2 miles) and one noncritically eroded area (0.4 mile) in Charlotte County. There are ten critically eroded beach areas (21.6 miles), four noncritically eroded beach areas (5.3 miles), three critically eroded inlet shoreline areas (0.6 mile), and two noncritically eroded inlet shoreline areas (0.4 mile) in Lee County.

Known Habitat and Species Changes and Events that Have Occurred in the Salt Marshes of the CHNEP

Limited data are available for determining the long-term trends in the extent of salt marshes in Florida. All existing estimates lump the distinct types of Florida salt marsh into a single unified number. It is estimated that Florida contained approximately 163,652 ha (399,152 acres) of salt marsh coverage prior to European colonization (Cox et al. 1994). Since that time, an estimated 45,895 ha (111,940 acres) or 28 percent of salt marsh habitat had been lost by 1993 (Kautz et al. 1993). Of the 117,757 ha (287,212 acres) of salt marsh habitat in Florida in 1993, over 66 percent, or 77,735 ha (189,597 acres), were located in existing conservation areas (Kautz et al.

1993, Cox et al.1994). By 1990, twenty percent of all Florida salt marsh is found in south Florida (Montague and Wiegert 1990), including the CHNEP area.

Salt marshes in Charlotte Harbor Estuary have been destroyed or directly impacted by construction activities for residential and commercial purposes including seawalls, drainage ditches for agriculture and mosquito control, boat facilities, and navigation channels. Man-made hydrological alterations have reduced the amount of freshwater flow from some rivers (e.g., Peace River), while artificially increasing (and decreasing) the flow through others (e.g., Caloosahatchee). Approximately 644 kilometers (400 linear miles) of man-made canals were built from the 1950s to the 1970s, resulting in the loss of salt marsh habitat (Charlotte Harbor SWIM 1993). The interior salt marshes of Sanibel Island were heavily altered from human construction activities, hydrologic changes, and exotic vegetation invasion (Clark 1976).

It has been estimated that over 50 percent of the salt marsh habitat adjoining the Charlotte Harbor system has been destroyed since 1945 (Charlotte Harbor NEP 1995).

Figure 132: Development of the Glovers Bight area of the Caloosahatchee River.,

Predevelopment maps have been developed by the SFWMD, CHNEP and consultants. Within the CHNEP boundary the pre-development map estimates that there were 19,264 acres of salt marsh in the CHNEP. The accuracy of this estimate is unknown. Using these estimates it can be calculated that Lee County has lost 8,739 acres of salt marsh to development and habitat shifts. Assuming that this is an accurate, and then 56.1 % of the pre-development salt marsh extents have been lost in Lee County. The estimates for watersheds in Charlotte, DeSoto and Sarasota Counties are not as clear since the difference between salt marsh and mangrove historic extents is not as clear.

Salt marshes in Charlotte Harbor Estuary were not significantly modified by human activities until the early 20th century when many areas were permanently altered to accommodate the speculative real estate development, and reduce the populations of salt marsh mosquitoes, that led to a rapidly growing human population. The common practice of constructing bulkheads and filling salt marsh areas for residential and commercial development destroyed many salt marshes and also altered the natural hydrology. As a result, many salt marsh communities experienced changes in water and soil salinities, water levels, and tidal flushing regimes.

Contaminants and pollutants have also been introduced into salt marshes. Exotic plant species are conveyed by a variety of means, including water transport, birds, illegal dumping of vegetation and land clearing. Many exotics initially colonize along roadways, on spoil piles crated by ditching or similarly cleared areas. Disturbed or denuded areas are often invaded by exotics including Australian pine and Brazilian pepper and melaleuca before native salt marsh seedlings can establish themselves.

Unregulated dredging and filling occurred in southwest Florida until the early 1970s when Federal and State governmental policies were implemented to minimize impacts on salt marshes. Current Federal and State regulations normally require some degree of mitigation to offset the alterations or losses of wetland habitat; however, salt marsh habitat continues to be destroyed or altered today as coastal development continues.

Natural disturbances on salt marshes include fires, storms and hurricanes, drought, and floods. In a stable natural environment these events usually have a short-term, localized effect on salt marsh habitat and the resilient salt marsh community is generally able to recover. However, when disturbances occur closely together, or are coupled with human-induced impacts, the effects can be catastrophic to the salt marsh community.

Fires usually do not permanently affect salt marshes but may temporarily affect soil composition, species composition and biomass (Schmalzer et al.1991, Schmalzer and Hinkle 1992). Most salt marshes are affected by storm surge more than flooding or strong winds caused by tropical storms. One of the most significant impacts to salt marshes from hurricanes is the potential for rapid invasion of exotic vegetation into disturbed areas. Florida has experienced 426 tropical storms from 18501 to 2010, with 144 of these reaching hurricane strength (Landsea 2011). Forty percent of all U.S. hurricanes hit Florida. Eighty-three percent of category 4 or higher hurricanes strikes have hit either Florida or Texas (Jarrell et al. 2001)

Recent mapping of the CHNEP watershed found approximately 3,963 kilometers (2,463 miles) of coastal shoreline encompassing approximately 90,000 ha (220,000 acres) from the Dona and Roberts Bays in Sarasota County to southern Estero Bay in Lee County. Currently, over 41 percent or 1,642 kilometers (1,020 miles) of coastal wetland shorelines have been lost or significantly altered in the CHNEP watershed. The most significant coastal wetland losses have been on estuarine rivers and creeks and on barrier islands and include substantial losses of salt marsh.

Available digital and hard copy salt marsh mapping GIS data sets were collected from the federal government (U.S Environmental Protection Agency (USEPA), U.S. Army Corps of Engineers (USACOE)); state of Florida (Florida Department of Environmental Protection (FDEP)), Florida Fish and Wildlife Conservation Commission (FWC), South Florida Water Management District, South West FWMD, and the Charlotte Harbor National Estuary Program (CHNEP). National

Wetlands Inventory (NWI); local governments (Charlotte, Lee, and Sarasota Counties, the Cities of Bonita Springs, Cape Coral, Fort Myers, Fort Myers Beach, Punta Gorda, North Port, Sanibel, and Venice and regional (South Florida Water Management District (SFWMD), Southwest Florida Regional Planning Council (SWFRPC), and Southwest Florida Water Management District (SWFWMD)) resource management agencies in southwest Florida. Salt marsh GIS maps have been collected from the SFWMD, SWFWMD, and the Charlotte Harbor National Estuary Program (CHNEP). Other map products from other time periods with a baseline from 1953 are also being collected.

Approximately 400 linear miles of man-made canals were built in the 1950s to 70s, resulting in the loss of salt marsh habitat (Charlotte Harbor SWIM 1993). The interior salt marshes of Sanibel Island were heavily altered from human construction activities, hydrologic changes, and exotic vegetation invasion (Clark 1976).

Prior Maps of Salt Marsh in the CHNEP

In 1995 it was estimated that there were approximately 1,454 ha (3,547 acres) of salt marsh in the Charlotte Harbor Estuary (Charlotte Harbor NEP 1995). This has proved to be a very low estimate.

The distribution of salt marshes in the Charlotte Harbor NEP study area was compiled from delineations completed in 1988 by the SFWMD and in 1990 by the SWFWMD. The wetlands were delineated from color infrared aerial photographs. A series of maps from these data is presented and descriptions given in the following text. Earlier estimates have 3,983.48 hectares (9,843.37 acres) of salt marsh identified by GFC in the SFWMD part of Charlotte Harbor as compared to SFWMD estimates of 1,526.73 hectares (3,772.61 acres) of saltwater marshes/halophytic herbaceous prairie and 402.55 hectares (994.72 acres) of saltwater ponds and 2,673.78 hectares (6,607.03 acres) of saltwater marshes and 246.63 hectares (609.42 acres) of salt flats.

According to the 2004 Land Cover mapping by the FWC there was 6,196.14 hectares (15,310.99 acres) of salt marsh in the CHNEP boundary. This includes 4,325.37 acres of salt marsh in Charlotte Harbor proper; 273.69 acres of salt marsh in the Dona and Roberts Bay; 378.12 acres of salt marsh in the Lemon Bay; 2,181.2 acres of salt marsh in the Myakka River; 3,301.04 acres of salt marsh in the Peace River; 2,402.72 acres of salt marsh in the Pine Island Sound/ Matlacha Pass; 563.17 acres of salt marsh in the Caloosahatchee River; and 1,885.68 acres of salt marsh in the Estero Bay.

According to 2006/2007 Land Use/ Land Cover mapping by the SWFWMD and the SFWMD there was a total of 5,658.32 hectares (13,982.01 acres) of salt marsh in the CHNEP. The 2006 SFWMD Land Use/Land Cover there was 4,405.82 acres of salt marsh in southern part of the CHNEP. This includes 377.88 acres of salt marsh in the Caloosahatchee River; 271.57 acres of salt marsh in southern Charlotte Harbor; 1,409.4 acres of salt marsh in the Pine Island Sound/ Matlacha Pass watershed; 2,347 acres of salt marsh in the Estero Bay watershed. The SWFWMD 2007 Land Use/Land Cover there was 9,575.24 acres of salt marsh in northern CHNEP. This includes 4,923.88 acres of salt marsh in northern Charlotte Harbor; 61.06 acres of salt marsh in Dona and Roberts Bay; 686.92 acres of salt marsh in Lemon Bay; 1,789.65 acres of salt marsh in Myakka River; and 2,113.73 acres of salt marsh in Peace River.

In contrast the CHNEP estimated that there are 3,730.39 hectares (9,218 acres) of salt marsh in the CHNEP boundary in 2008.

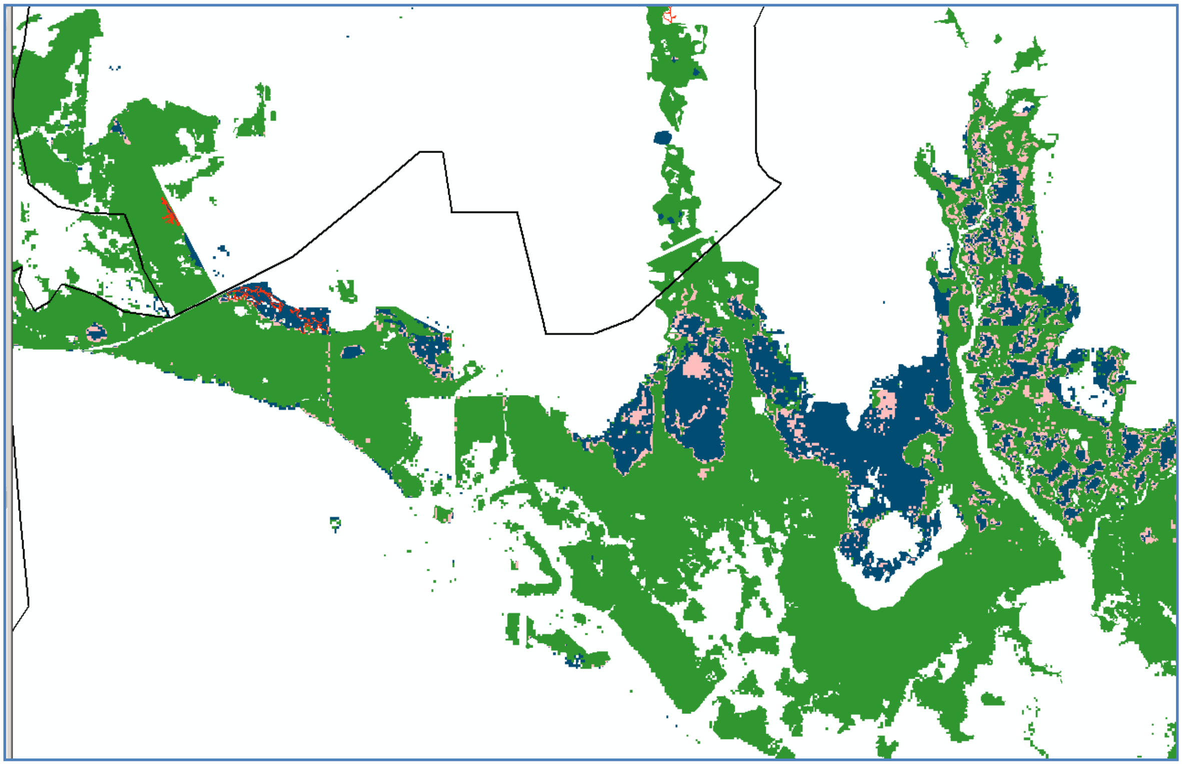


Figure 133: Map of overlay of FWC and SFWMD mangrove and salt marsh mapping showing the differences in how multiple agencies delineate land cover, west Estero Bay Watershed.

The blue and green colors represent no conflict between agencies for the salt marsh and mangrove respectively. This means that they agree (cartographically) about what is on the ground, in this case salt marsh and mangrove coverage. The pink color represents those areas where the two entities do not agree about land cover type.
Most of the discrepancies are on the edges between land cover types. The small red areas are location we found salt marsh where mangroves had been mapped by both agencies.

We believe the apparent differences in salt marsh acreage from earlier mapping by FWC and the WMDs is not the result of an actual increase in salt marsh extents as much as it is a result of the improved mapping methods of this study. Significant areas of salt marsh were mapped as mangrove forest in the earlier mapping efforts and areas of mangrove were designated as salt marsh. In some watersheds areas of freshwater marsh and bare sand upland areas were mapped as salt marsh. In the Lemon Bay watershed areas of the west branch of Coral Creek that are freshwater cattail marsh located upstream of a earth dam across the creek were mapped as salt marsh by the WMD.

Watershed	Our Study 2010-2012	SFWMD 2006	FWC 2004
Caloosahatchee River	389.32	377.88	563.17
Charlotte Harbor	4,222.68	5,195.45	4,325.37
Dona and Roberts Bay	35.70	61.06	273.69
Estero Bay	2,773.92	2,347.00	1,885.68
Lemon Bay	162.18	686.92	378.12
Myakka River	1,291.73	1,789.65	2,181.2
Peace River	2,301.65	2,113.73	3,301.04
Pine Island Sound/ Matlacha Pass	3,678.91	1,409.4	2,402.72
Total	14,856.18	13,981.09	15,310.99

Table 14: A comparison of acres of salt marsh mapped in the CHNEP by this study in 2010-2012, by the SFWMD and SWFWMD in 2007, and the FWC in 2004.

Source: D. Cobb and J. Beever SWFRPC, SFWMD, SWFWMD, and FWC

Potential Future Effects on the Salt Marsh Habitats and Species of the CHNEP Resulting From Climate Changes

Climate-related changes in freshwater runoff to salt marshes, coupled with changes in stratification (or layering) patterns linked to warming and altered salinity, will change the quantity and availability of nutrients in estuarine systems (Boyd and Doney 2002). Changes in the absolute and relative availability of nutrients will lead to changes in microscopic plants (phytoplankton) and microbial activity in the marine food web (Arrigo 2005). Induced changes may result in food webs that are less efficient in transferring energy to higher levels, thus affecting the productivity of economically important fish and other plant and animal life (Arrigo 2005).

Increased runoff in some areas, coupled with human population increases in Florida, will lead to the increased transport of nutrients to coastal waters, contributing to hypoxia (IPPC 2007b) and leading to adverse impacts on bottom-feeding fish and sessile (attached to the bottom) organisms

(IPPC 2007b). Locations that have experienced hypoxia may experience longer hypoxic episodes or more frequent recurrence of hypoxia (Osterman et al. 2007). Increased density stratification within estuaries could also occur with increased precipitation and runoff. New locations with hypoxia may develop in coastal areas where they previously have not appeared (Osterman et al. 2007).

As sea-surface temperatures continue to rise, die-offs of marine fauna incapable of moving to cooler water are likely to become more frequent. Other factors, such as low levels of dissolved oxygen, the addition of nutrients and other land-based sources of pollution, and harmful algal blooms, will exacerbate these die-offs. The conditions that have contributed to fish diseases and various die-offs in the Florida Keys may move to more northern latitudes. As sea-surface temperatures continue to increase, the impacts may begin to affect more northerly coastal and marine environments that have thus far escaped these problems (FOCC 2009).

Marine thermal stratification will change dissolved oxygen levels at different water depths. This will result in changes to zonation for animal and plant life and increase the probability of fish and other marine life kills (Coastal States Organization Climate Change Work Group 2007; Holman 2008; FOCC 2009; USEPA CRE 2008)

The range of potential impacts on species and ecosystems include the following:

Increased atmospheric concentrations of carbon dioxide are expected to contribute to increased acidity (lower pH) of sea water. Marine organisms with calcium carbonate shells or skeletons, such as corals, clams, and plankton at the base of the food chain may be adversely affected by decreases in pH and carbonate saturation state (IPPC 2007b; Bates 2007). A higher carbonate saturation state favors the precipitation of calcium carbonate, a mineral, while a lower state supports its dissolution into the water. Carbonate-depositing organisms will have to expend more energy to maintain shell construction and structural integrity in a lower pH environment (Peterson et al. 2007; SCCP 2008; FOCC 2009; USEPA CRE 2008).

With decreases in the pH of seawater, some marine plants may show increases in production until a particular threshold is met, and then will show a decline (FOCC 2009). Some marine organisms will not be able to tolerate decreases in pH (FOCC 2009). It is probable that the die-offs of sponges, sea grasses, and other important components of coastal and marine ecosystems from increased sea surface temperatures will become more frequent (FOCC 2009; USEPA CRE 2008). Ocean acidification may lead to shifts in marine ecosystem structure and dynamics that can alter the biological production and export from the ocean surface of organic carbon and calcium carbonate (Royal Society 2005). Important fisheries habitats and salt marsh substrates, such as oyster bars, may markedly decline or disappear (Kleypas et al.2006; Ishimatsu et. al. 2005).

The geographic range of marine species will shift northward as sea-surface temperatures continue to rise. The species composition of Florida's native marine and estuarine communities will change, perhaps drastically. With further rises in water and atmospheric temperatures, conditions will probably become more favorable for certain exotic plant and animal species to invade Florida's coastal waters (FOCC 2009). Some native species may be able to survive farther north than in current ranges, but interactions among communities with new species compositions cannot be predicted. Moreover, reproduction in some fishes decreases in warmer temperatures, potentially resulting in population decreases (Straile and Stenseth 2007).

Increased numbers and altered ranges of jellyfish are also expected with some invasion of exotic jellyfish species, and with increased predation on local prey species. Some highly vulnerable prey species may be significantly affected (Perry and Yeager 2006; FOCC 2009; USEPA CRE 2008).

Sea level rise is expected to cause migration of seagrass beds landward with subsequent depletion of existing beds at the deeper waterward edges due to less penetration of sunlight. This coupled with increased turbidity from erosion and breakup of coastlines, increased storm season runoff, and human activities will likely lead to die-off at deeper edges. Where natural shoreline exists, seagrass beds are expected to migrate into appropriate depths. Where opportunities for landward migration of the shallow subtidal zone is blocked by human bulkheads or other barriers, the seagrass beds will be reduced and then disappear if the water depths at the sea wall barriers exceeds the light extinction coefficient for the sea grasses (USCCSP 2008; USEPA CRE 2008).

Harmful blooms are caused by microscopic algae in the water column that can produce biological toxins, such as those generated by red tide in coastal marine waters, blue-green algae in estuarine waters., Larger species of marine and estuarine algae that grow on the bottom can smother corals and other native plants and animals. Environmental factors, including light, temperature, and nutrient availability, set the upper limit to the buildup of biomass in marine algae (Smyda 1997). The algae that cause harmful blooms in coastal marine and estuarine waters are favored over other algal species when water temperature is high and becomes thermally stratified (Paerl and Huisman 2008, Peperzak 2005, Van Dolah 2000; FOCC 2009; Twilley et al.2001; Coastal States Organization Climate Change Work Group 2007; Holman 2008; USEPA Office of Policy, Planning and Evaluation 1997; USEPA CRE 2008). The increased occurrence, intensity, and toxicity of harmful algal blooms may result in the disruption of coastal marine and estuarine food webs, more frequent fish kills, and adverse impacts to people in or near an affected coastal area (Smyda 1997; Paerl and Huisman 2008; Van Dolah 2000). Harmful algal blooms have been reported throughout Florida’s coastal marine and estuarine waters (Carder and Steward 1985).

Figure 134: Caloosahatchee River Algae Bloom resulting from Lake Okeechobee flow management.
Source: J. Cassani 2006

If climate change systematically increases nutrient availability and this alters the amount of available light and the stability of the water column, there may be substantive changes in the productivity, composition, and biomass of marine algae, including harmful species (Smetacek and Cloern 2008).

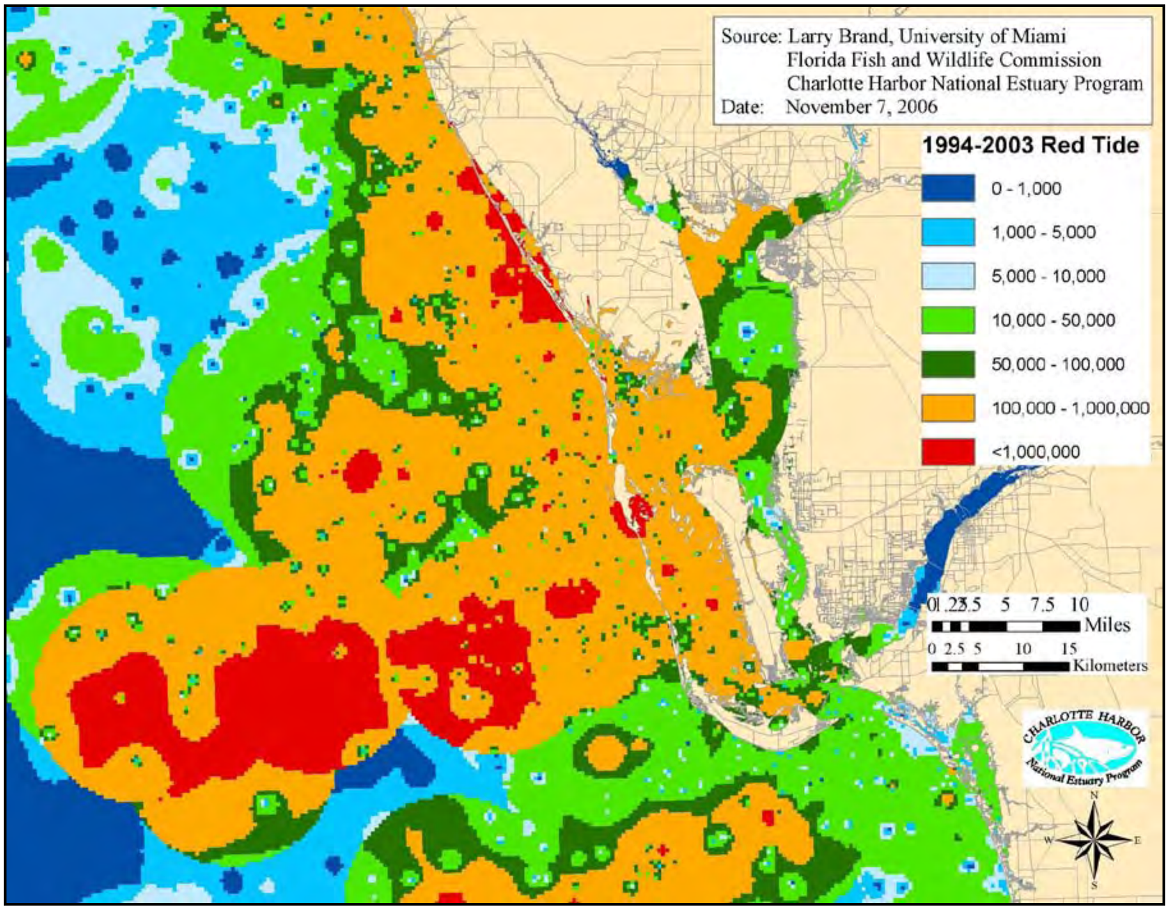


Figure 135: Intensity and location of red tides in Charlotte Harbor and nearshore areas 1994-2003. Source indicated on key.

Although southwest Florida tide ranges are relatively small, tidal effects extend far inland because much of the state is so low in relative elevation and flat in topography. Because sea level change has been relatively constant and slow for a long time, tidal wetlands such as salt marshes have been able to grow into expansive habitats for estuarine and marine life. However, these tidal wetlands are sensitive to the rate of sea level rise and can perish if that rate exceeds their capacity to adapt. With rising sea levels, sandbars and shoals, estuarine beaches, salt flats, and coastal forests will be altered, and changes in freshwater inflow from tidal rivers will affect salinity regimes in estuaries as well as patterns of animal use. Major redistributions of mainland and barrier island sediments may have compensatory or larger benefits for wetland, seagrass, or fish and wildlife communities, but these processes cannot be forecast with existing models.

Sea level change is an important long-term influence on all salt marshes and mangroves (Gilman et al. 2008). Based on available evidence, of all the climate change outcomes, relative sea level rise may be the greatest threat to salt marshes. Most salt marsh sediment surface elevations are not keeping pace with sea level rise, although longer term studies from a larger number of regions are needed. Rising sea level will have the greatest impact on salt marshes experiencing net lowering in sediment elevation, where there is limited area for landward migration.

Depending on the rate and extent of local sea level change, mangrove and salt marsh systems will respond differently (Titus 1987, Wanless et al.1994). If rates of sea level rise are slow, some mangrove salt marsh vegetation will migrate upward and inland and grow without much change in composition. If rates are too high, the salt marsh may be overgrown by other species, particularly mangroves, or converted to open bodies of water. If there is no accretion of inorganic sediment or peat, the seaward portions of the salt marsh become flooded so that marsh grass drowns and marsh soils erode; portions of the high marsh become low marsh; and adjacent upland areas are flooded at spring tide, becoming high marsh.

Don Cahoon of the USGS has stated that if wetland plant communities are unable to keep vertical pace with sea level rise they will likely to also be unable to keep pace with lateral migration upslope. This can occur because on some soil types when saltwater inundates formerly unsubmerged uplands, sulfate reduction reactions can cause the land to sink up to six inches in micro-tidal areas that then shift from nontidal wetlands directly to open subtidal waters. (Titus 2009). This would be mediated by fetch and wave action as well as the emergent vegetation that is present, since both red mangroves and cordgrass can colonize low energy intertidal zones.

Extirpation of cooler water temperate fishes that seasonally visit the Charlotte Harbor estuaries and alteration of reproductive rates and maturation in invertebrate species leading to declining populations can be expected from increases in global surface water temperatures (USEPA CRE 2008; Rubinoff et al. 2008; Holman 2008; USNOAA 2008).

There will be changes associated with inundation of coastal wetlands and marshes including altered tidal ranges, tidal asymmetry leading to changes in tidal mixing, changes in sediment transport, migration of estuarine salinity gradients inland, migration inland of marsh species zonation, altered diversity of foundation dominant plant species, structural and functional habitat changes, and less sunlight available to submerged marsh plants (USEPA CRE 2008;USNOAA 2008; Titus 1998; Bollman 2007; Volk 2008a).

Changes in precipitation will affect different wetlands differently with regional increases or decreases depending on the type and landscape position. Local extirpations of fish, amphibians, or water-dispersed plants are expected due to drought conditions that isolate and dry down tributaries and connected wetlands (USEPA CRE 2008; Holman 2008; FOCC 2009).

As rising sea temperatures causes a 5 to 10% increase in hurricane wind speeds, storm events will result in increased erosion and losses of mangroves and marshes. , (USCCSP 2008; USNOAA 2008; USEPA CRE 2008). With sea level rise there will be an increased inundation of fringing marsh dominated by black needle rush and the few areas with smooth cordgrass. Subsequently there will be a migration up-gradient and inland of mangroves and fringing marsh habitat into the high marsh areas with a resultant expansion of fringing marsh and a depletion of high marsh if high marsh does not have adjacent native upland to migrate into (USCCSP 2008; USEPA CRE 2008). More frequent or longer lasting droughts and reduced freshwater inflows could increase the incidence of extreme salt concentrations in coastal ecosystems, resulting in a decline of valuable habitats that are less salt tolerant (Twilley et al. 2001).

Wetlands elsewhere are perishing as estuarine and coastal forests and swamps are retreating and being replaced by marsh vegetation (Williams et al. 1999; Raabe et al. 2004; Desantis et al.

2007). Open estuarine waters, some brackish marshes, and mangroves in south Florida estuaries are expanding (Glick and Clough 2006; Hine and Belknap 1986). Even at constant rates of sea level rise, some tidal wetlands will eventually be “pinched out” where their upslope migration is prevented by upland defenses such as seawalls (Estevez 1988; Schleupner 2008).

Climate change is predicted to be one of the greatest drivers of ecological change in the coming century. Increases in temperature over the last century have clearly been linked to shifts in species distributions (Parmesan 2006). Given the magnitude of projected future climatic changes, Lawler et al. (2009) expects even larger range shifts over the next 100 years. These changes will, in turn, alter ecological communities and the functioning of ecosystems. Despite the seriousness of predicted climate change, the uncertainty in climate-change projections makes it difficult for conservation managers and planners to proactively respond to climate stresses. To address one aspect of this uncertainty, Lawler et al. (2009) identified predictions of faunal change for which a high level of consensus was exhibited by different climate models. Specifically, they assessed the potential effects of 30 coupled atmosphere-ocean general circulational model (AOGCM) future-climate simulations on the geographic ranges of 2,954 species of birds, mammals and amphibians in the Western Hemisphere. Eighty percent of the climate projections based on a relatively low greenhouse-gas emissions scenario result in the local loss of at least 10% of the vertebrate fauna over much of North America. The largest changes in fauna are not predicted for Florida.

Shifts in behavior phenology of perching birds, seabirds, and farmland birds have been observed and are expected to continue. Perching birds will breed earlier in the calendar year. Seabird populations are expected to decline due to reduction in needed prey items at the right locations at the right time of the year. This disjuncture between the breeding season and vital food or other resources availability is termed “mismatching” (Eaton et al. 2008; USEPA CRE 2008).

Climate change will affect the phenology of pest and beneficial insects by altering reproductive cycles, feeding and predation, and mismatching with host plants and pollinators (Backlund et al. 2008). For example, moth phenology will be shifted to earlier dates. This will affect birds and other animals that depend upon the moths for food, the host plant vegetation that moth larvae feed on, and the plants that depend upon the moths for pollination (Eaton et al. 2008; USEPA CRE 2008). There will be both positive and negative outcomes depending upon the phenological sequence and nature of the participants. In any case significant change could be expected.

Air temperature increases will affect soil temperatures in uplands and other areas where reptiles nest. The increased soil temperatures may affect nesting lizards, changing hatchling gender determination, fitness, and hatch date, which may expose hatchlings to different prey availability and predation potentials (Telemeco 2009). Amphibian populations' ranges, health, and phenology will also be affected (Backlund et al. 2008; FOCC 2009; USEPA CRE 2008). Increased air temperatures will also affect animal health, resulting in reduced feeding; reduced reproduction; reduced milk production (in mammals) for offspring; and increased pathogens and parasites (Backlund et al. 2008).

The altered timing of seasonal temperature changes is expected to disrupt predator/prey availability, food and reproductive cycles, patterns of upstream faunal migration, disruption of temperature-driven behavior including breeding and hibernation, and disruption of biological ocean-estuary exchanges of fishes and invertebrates (Peterson et al. 2007). Events occurring in spring or summer may occur later or have a longer "window". Events occurring in fall or winter may occur later or have a smaller "window". Events dependent on seasonal rainfall may occur differently with changes in rainfall patterns. Some animal and plant populations may migrate northward or inland to conditions supporting their required limiting life/reproductive cycles. There may be local extirpation of some plant and animal populations with replacement by exotic species tolerant of/or advantaged by the new climate conditions.

Increases in precipitation of five to 10% over levels of the 20th century, including more heavy and extreme precipitation events will result in increased flash flooding, affecting ground-dwelling and ground nesting species of the high marsh (UWCES 2007; USNOAA 2008; SECCP SDRT LCCP 2005, FOCC 2009, USEPA CRE 2008).

All of the listed species inhabiting southwest Florida can be expected to be impacted by potential climate change effects including habitat losses and translocations of habitat, water quality effects, and decreases in forage vegetation and forage fishes.

Relative to other marine systems, salt marshes and estuaries are highly susceptible to invasion, and impacts by exotic species in these systems seem particularly pronounced. These impacts range from purely trophic and competitive effects that can lead to replacement of native species by exotics, to physical transformation by exotic species that engineer habitat and alter large-scale abiotic and hydrographic properties of the marsh environment. Byar (2009) discusses several examples of each of these, as well as three mechanisms that promote high establishment rates and strong competitive effects of nonnative species in marshes. Although the problem of exotic species in marsh systems is substantial, marshes 'tractable, discrete boundaries make intervention more successful than in other marine systems, such as the open coast. However, protocols and policies (ideally standardized at a national or international level) need to be in place for eradication or containment of incipient invasions, which often require fast action to be effective. Protocols and monitoring efforts should aim not only to detect newly introduced species but also to quantify the dynamics and impacts of established invaders to enable prioritization of intervention efforts. Estuaries and associated marshes are a heavily invaded habitat that must be well managed to mitigate the increasing ecological impacts of exotic species on native species and the valuable ecosystems services they provide.

Known Sea Level Changes and Events

Florida’s geologic history has consisted of cycles of sediment deposition and erosion in response to sea level changes over the last 65 million years (Figure 136) (Florida’s Geological History and Geological Resources (FGHGS) 1994). The most “recent” geologic history (1.8 million years ago to present) has been a time of worldwide glaciations, widely fluctuating sea level and the emergence of humankind (FGHGS 1994). This geologic period is called the Quaternary Period and is made of two geologic epochs, the Pleistocene Epoch (1.8 million to 10,000 years ago) and the Holocene (Recent) Epoch (10,000 years ago to the present).

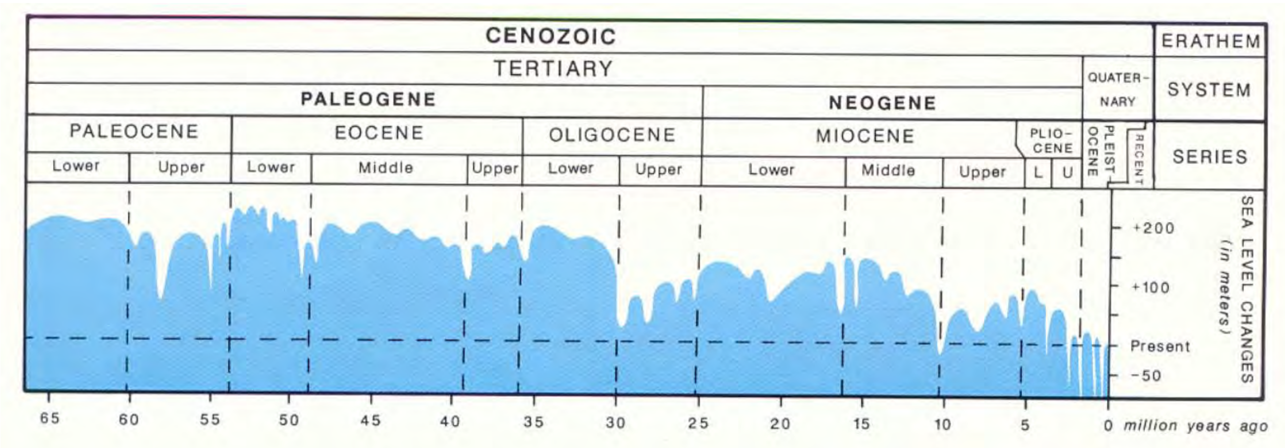


Figure 136: Sea level changes during the last 65 million years

The Pleistocene Epoch is known as the "Ice Age" and includes at least four great glacial periods. During each period huge ice sheets covered much of the northern United States. Seawater was the primary water source for the expanding glaciers, causing sea level to drop as much as 300 feet below present level. Between glaciations the Florida shoreline attained heights 150 feet above present sea level (Figure 137).

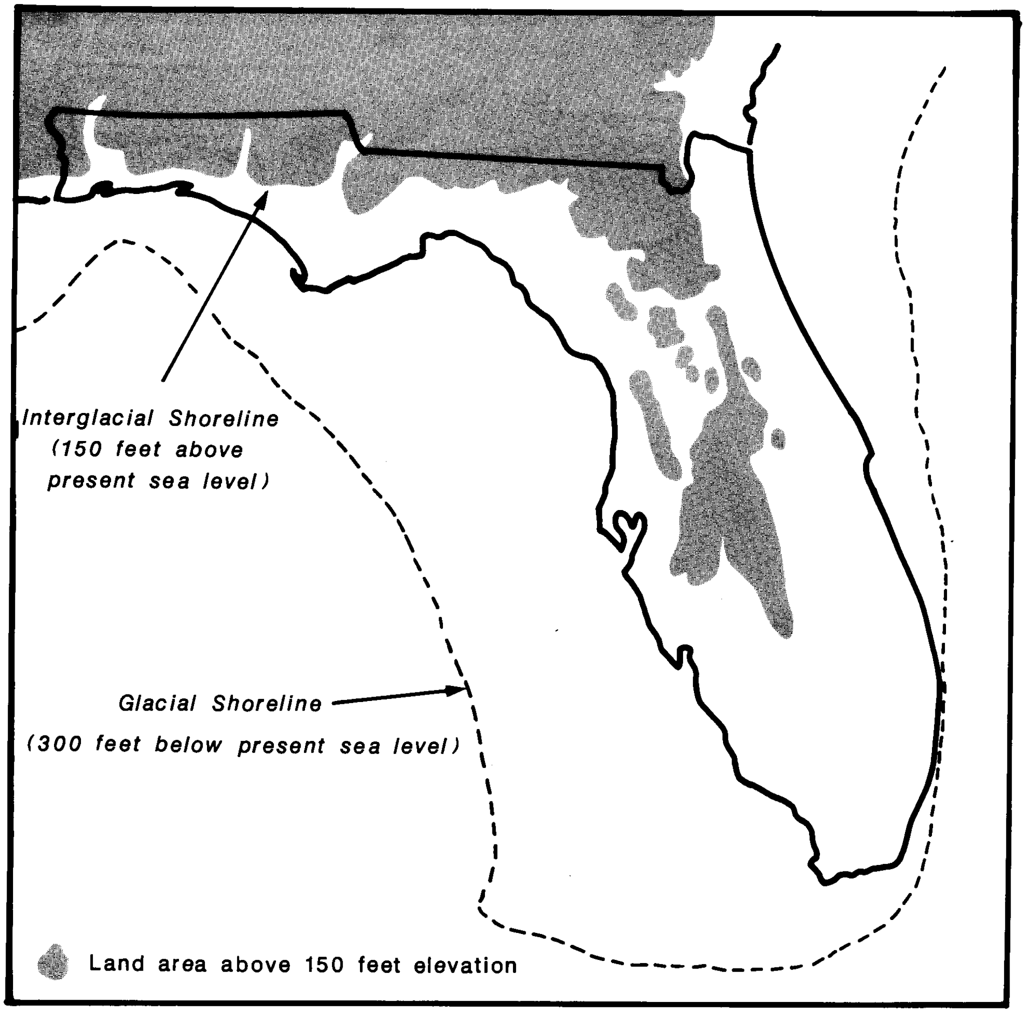


Figure 137: Shoreline of Florida between 1.8 million to 10,000 years ago

The large drop in sea level during the most recent ice age increased the land area of Florida dramatically, by as much as 100 miles west of current position (Figure 137) (FGHGR 1994). Considerably warmer interglacial intervals melted the glaciers, raising sea level and flooding the Florida peninsula as least 100 to 150 feet above the present level and creating islands.

The Holocene Epoch began 10,000 years ago during a slow warming of the Earth's climate. From a glacial low about 18,000 years ago, sea level climbed intermittently to its present level (FGHGR 1994). Beginning roughly 6,000 years ago, as two of the major ice sheets melted, sea level rose to two meters higher than its present level; evidence for this "high" stand can been seen in many parts of the state's coast (Atlas of Florida 1992).

Over the past 6000 years, as 57 15 indicates, the sea has been rising. Throughout South Florida, during the first half of this period, the rate of rise was about 23 centimeters per century, then the rate slowed to about 4 centimeters per century. During the last one hundred years, the rate of rise has been at a rapid pace of 30-40 centimeters (Wanless et al. 1994).

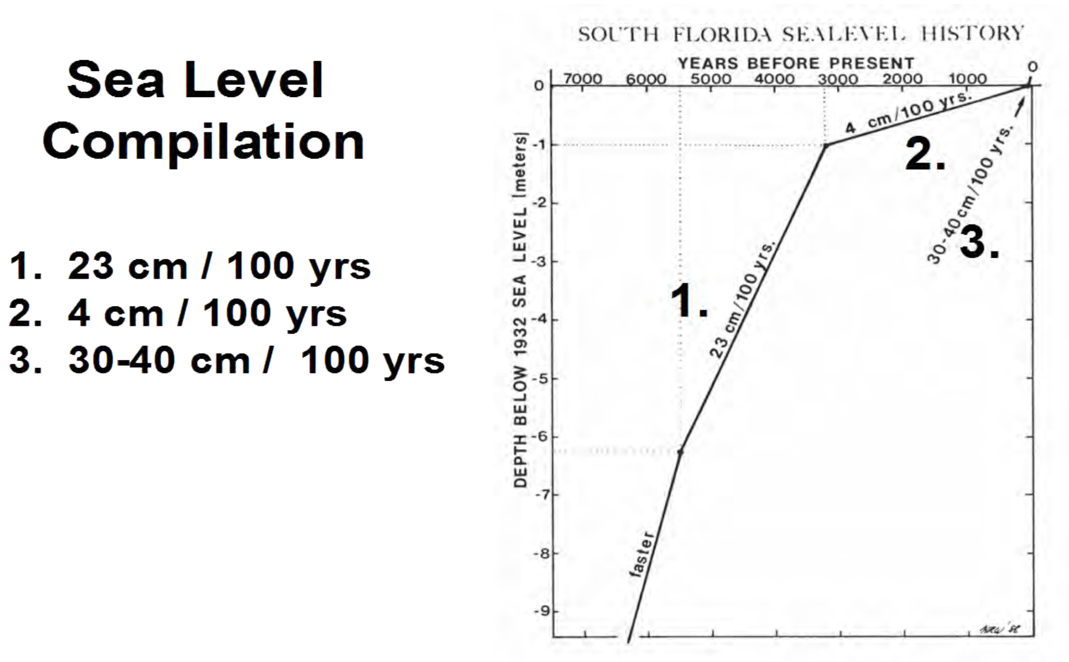


Figure 138: Sea level rise rates compiled by Wanless et al. (1994)

For the past few thousand years, the sea level around Florida has been rising very slowly, although a persistent upturn in the rate of relative sea level rise may have begun recently (IPCC 2007b). Geological studies show that, in the past, the sea level of Florida, as well as the rest of the globe, changed much more rapidly than it has in more recent times. Distinguishing Florida-specific sea level trends from future global trends is a critical research need.

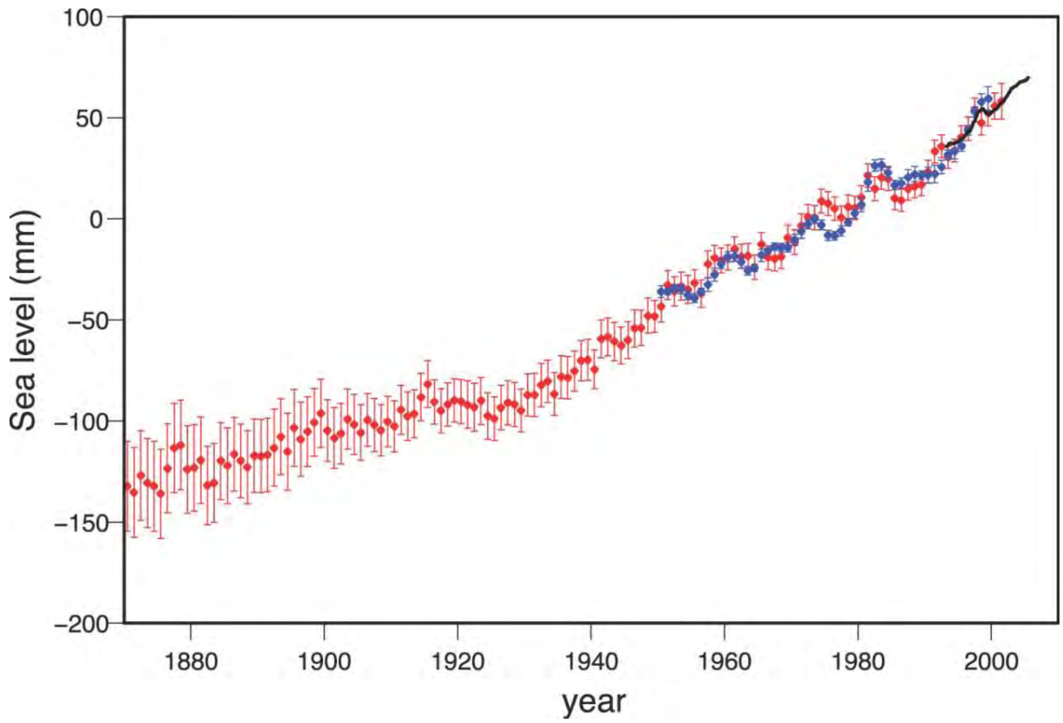


Figure 139: Annual averages of global mean sea level in millimeters

The red curve shows reconstructed sea level fields since 1870 (updated from Church and White, 2006); the blue curve shows coastal tide gauge measurements since 1950 (from Holgate and Woodworth, 2004) and the black curve is based on satellite altimetry (Leuliette et al., 2004). The red and blue curves are deviations from their averages for 1961 to 1990, and the black curve is the deviation from the average of the red curve for the period 1993 to 2001. Error bars show 90% confidence intervals.

Source: *Intergovernmental Panel on Climate Change (2007) fig-5-13*

The *rate* at which sea level rises is equally as important to coastal resources as how much it rises. The rate of global sea level rise increased from the 19th to the 20th century (IPCC 2007b) and has increased further since 1993 (FOCC 2009). Sea level has been rising at a rate of 0.08-0.12 inches per year (2.0-3.0 mm per year) along most of the U.S. Atlantic and Gulf coasts. The rate of sea level rise varies from about 0.36 inches per year (10 mm per year) along the Louisiana Coast (due to land sinking), to a *drop* of a few inches per decade in parts of Alaska (because land is rising). See Figure 140 for sea level trends in selected cities.

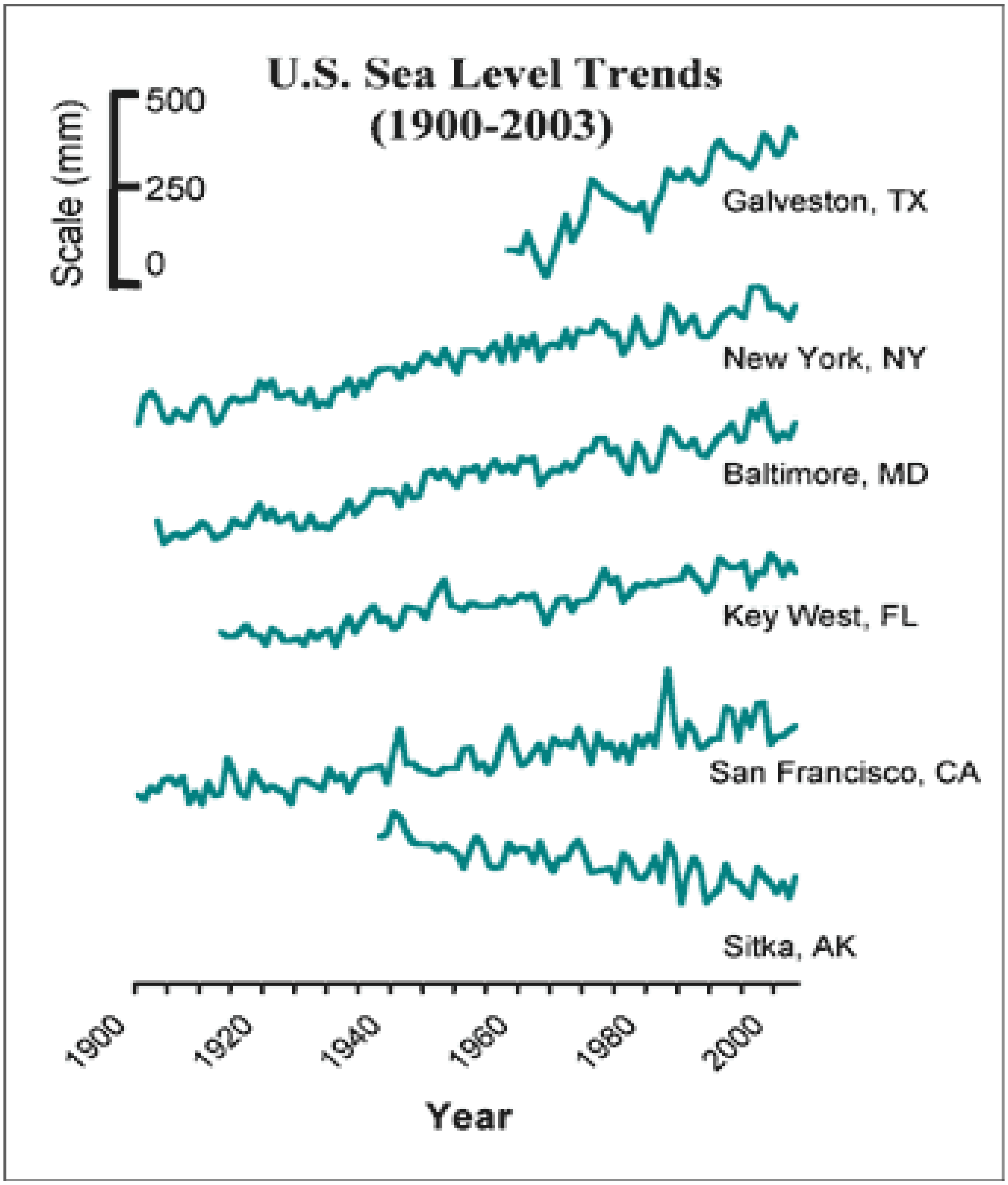


Figure 140: U.S. Sea Level Trends

Source: Monthly and Annual Mean Sea Level Station Files from the Permanent Service for Mean Sea Level (PSMSL) at the Proudman Oceanographic Laboratory

Around Florida, relative sea level has been rising at a slow but constant rate, about an inch or less per decade (Maul and Martin 1993; FOCC 2009). The historic (1947-2009) sea level rise in southwest Florida measured at St. Petersburg is 2.3 mm/yr (Walton 2007, FOCC 2009). Figure 141 provides further evidence specific to southwest Florida, measured at Key West, that sea level has been rising at an estimated rate of 3 mm/yr (Maul and Martin 1993; Savarese et al. 2002).

Since 1933, the Permanent Service for Mean Sea Level (PSMSL) has been responsible for the collection, publication, analysis and interpretation of sea level data from the global network of tide gauges. It is based in Liverpool at the Proudman Oceanographic Laboratory (POL) which is a component of the UK Natural Environment Research Council (NERC). The PSMSL is a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) established by the International Council for Science (ICSU). It is supported by FAGS, the Intergovernmental Oceanographic Commission (IOC) and NERC.

As of December 2006, the database of the PSMSL contained over 55,000 station-years of monthly and annual mean values of sea level from almost 2,000 tide gauge stations around the world received from almost 200 national authorities. On average, approximately 2,000 station-years of data are entered into the database each year (Woodworth and Player 2003). Local sea level information from PSMSL is found below.

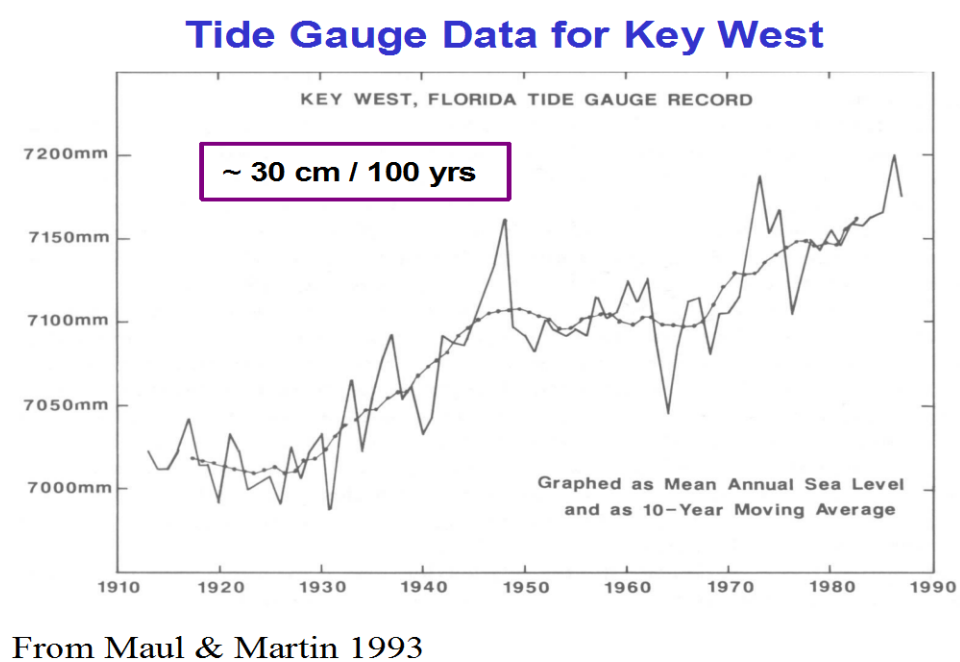


Figure 141: Mean annual sea level at Key West, Florida 1910-1990Key: 7000 mm is 275.6 inches, 7200 mm is 283.5 inches, and 30 cm is 11.8 inches in 100 years of record

The only National Oceanic and Atmospheric Administration (NOAA) tide gauge operating in the Charlotte Harbor Region is in Fort Myers. The period of record for this station begins in 1965. The next closest tide stations with longer periods of record are St. Petersburg, Florida beginning its record in 1947 and Key West, Florida beginning in 1913. NOAA analysis suggests that sea level has increased at Fort Myers 4 inches (plus or minus 1 inch) over the past 43 years, the equivalent of an inch every decade. For the Key West period of record, sea level has risen the equivalent of 8 inches(plus or minus 1/2 inch) in the 95 year period. Theist. Petersburg station in between the Fort Myers and Key West stations for period of record, sea level rise per year, and level of error.

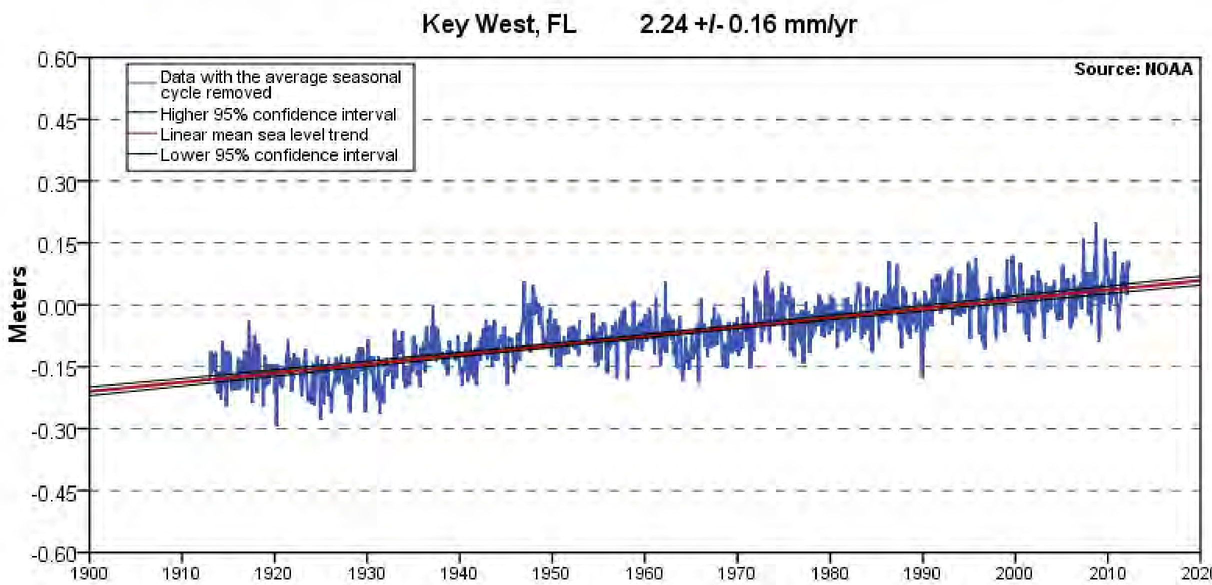


Figure 142: Mean rate of annual sea level at Key West, Florida 1910-2012 This is 1 inch every 11.3 years.

Source : USGS 2012

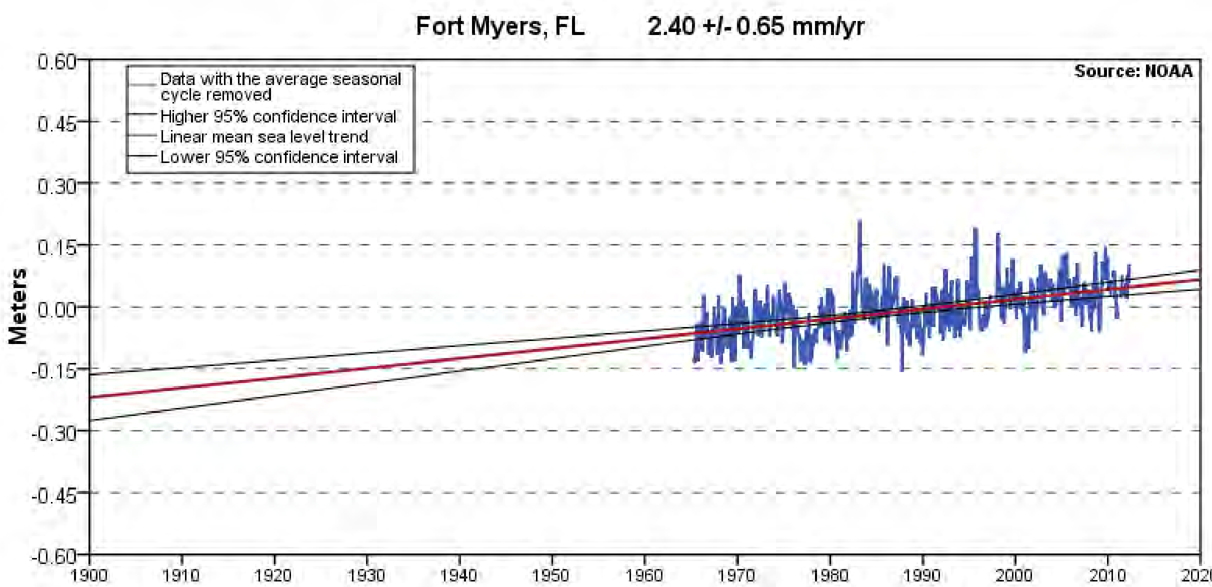


Figure 143: Mean rate of annual sea level at Fort Myers, Florida 1965-2012 This is 1 inch every 10.6 years.

Source : USGS 2012

Potential Future Climate Effects on the Salt Marshes of the CHNEP from Sea Level Rise

We have examined five sea level rise "severity" scenarios shown on Table 15:

Probability (%)	2025		2050		2075		2100		2150		2200	
	cm	inches	cm	inches	cm	inches	cm	inches	cm	inches	cm	inches
Rapid Stabilization Case	41	1.8	9	3.5	13	5.3	18	7.1	22	8.8	27	10.5
90 (least)	7	2.8	13	5.0	20	7.7	26	10.4	40	15.7	53	21.0
80	9	3.6	17	6.6	26	10.1	35	13.9	53	20.8	71	28.1
70	11	4.4	20	7.8	30	11.6	41	16.3	63	24.7	85	33.6
60	12	4.7	22	8.6	34	13.2	45	17.8	72	28.3	99	39.1
50 (moderate)	13	5.1	24	9.4	37	14.4	50	19.8	80	31.4	112	44.2
40	14	5.5	27	10.6	41	16.0	55	21.8	90	35.4	126	49.7
30	16	6.3	29	11.3	44	17.1	61	24.1	102	40.1	146	57.6
20	17	6.7	32	12.5	49	19.1	69	27.3	117	46.0	173	68.2
10	20	7.9	37	14.5	57	22.3	80	31.6	143	56.2	222	87.5
5 (worst)	22	8.7	41	16.1	63	24.6	91	35.9	171	67.2	279	110.0
2.5	25	9.9	45	17.6	70	27.4	103	40.7	204	80.2	344	135.6
1	27	10.6	49	19.2	77	30.1	117	46.2	247	97.2	450	177.3
Business as Usual	29	11.3	57	22.6	86	34	115	45.3	247	97	450	177

***The results of this table are based on using Tables 9-1 and 9-2 of the USEPA Report "The Probability of Sea Level Rise". Basically, the formula is multiplying the historic sea level rise (2.3 mm/yr) in Southwest Florida (closest point used is St. Petersburg, Fl., Table 9-2) by the future number of years from 1990 plus the Normalized Sea Level Projections in Table 9-1 and Table ES-2. Two Future Climate Scenarios for Florida Stanton and Ackerman 2007**

Table 15: Combined Sea Level Projections by Year for Southwest Florida
Source: IPCC 2007b

One cause of sea level rise is increased temperature and the subsequent expansion of the warmer water volume (Titus 1998; USEPA CRE 2008). The rate of global average sea level rise has increased during the late 20th century (Church and White 2006) and may accelerate further because of ocean warming and contributions from land-based ice melt from glaciers and the ice sheets of Greenland and Antarctica (IPCC 2007b). Sea level rise will continue well after 2100 even if greenhouse gas concentrations are stabilized by then (IPCC 2007b). Major inputs of water from the melting of high latitude and high altitude ice reservoirs could cause several meters of sea level rise over the centuries to come (Hansen 2007).

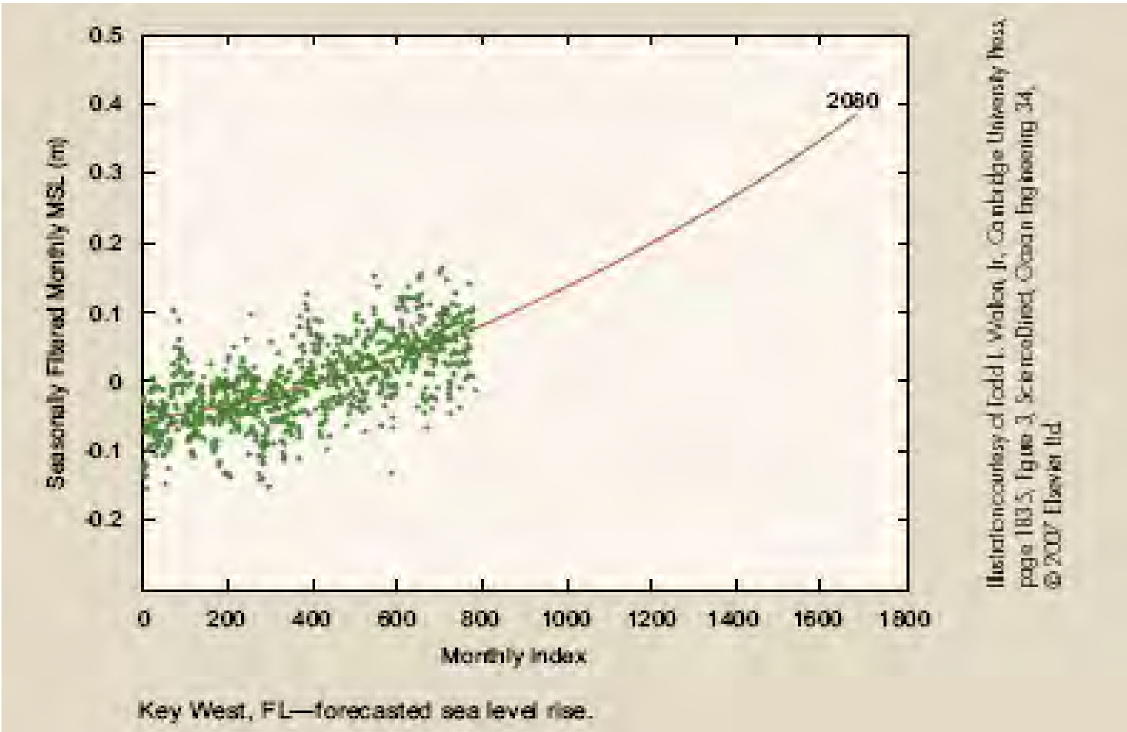
As a result of these increasing sea levels, Florida will become more vulnerable to coastal flooding and storm surges (FOCC 2009). Sea levels around the state will probably continue to rise at historical or accelerated rates in upcoming decades (FOCC 2009).

Increases in sea level will probably increase shoreline erosion. Barrier islands will likely continue to erode and migrate towards the mainland or along prevailing lateral pathways (FOCC 2009), which could eventually threaten the ecological integrity of natural communities in estuaries, tidal wetlands, and tidal rivers (FOCC 2009). As sea levels rise, shallow coastal aquifers and associated public drinking water supplies are at risk from saltwater intrusion (FOCC 2009).

Sea level rise will also exacerbate many other effects of climate change. For example, coastal shorelines, beaches, mangroves, low marsh, river and creek shorelines will experience higher tides including higher high tides, higher normal tides, and higher low tides (Titus 1998; USEPA CRE 2008; Folland and Karl 2001; IPCC 2001c).

The danger is that when the rate of sea-level rise is too high, the marsh will not be able to maintain a suitable elevation and will simply drown. An increase in elevation in response to sea-level rise also causes a landward migration of the marsh, but not all species will be able to migrate inland, or they will not migrate fast enough, and species diversity can be expected to decline. Further, as mentioned before, landward migration can occur only so far as there is available land. High-marsh habitats are lost when migrating marshes come upon human-dominated shorelines. Developed and paved areas are common just landward of a salt marsh, and they prevent the marsh from moving onto the main roads of coastal towns. The marsh cannot compete for territory with highways, causeways, residences, and golf courses. Landward movement is also prevented where seawalls, lawns, and other structures exist at the edge of the wetland. Hardened shorelines with rip-rap (rocks) or seawalls separate urban or residential development from flooding, but they damage coastal marshes by directing the energy of waves downward, eroding away plants, animals, sediments, and seed banks, and reducing the possibility of recovery.

As sea levels rise, salt marshes may disappear completely from some parts of the CHNEP. The extent of this problem will inevitably increase unless action is taken. In order for marshes to survive, a broad buffer of undeveloped land needs to be preserved to allow them to migrate inland.



Key West, FL—forecasted sea level rise.

Figure 144: Forecasted Sea Level Rise at Key West, Florida

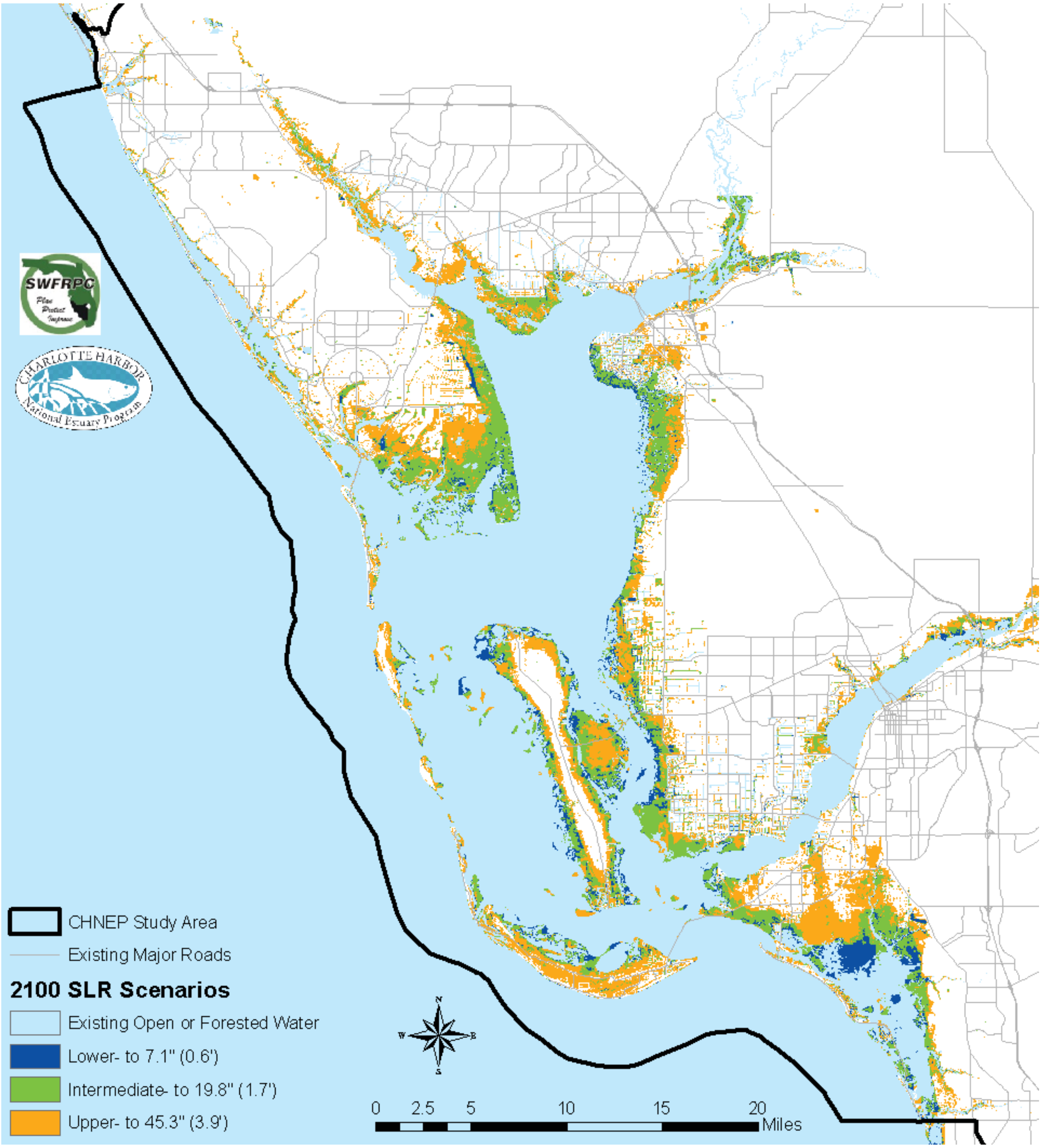


Figure 145: Projected 2100 Charlotte Harbor Regional Sea Level Rise

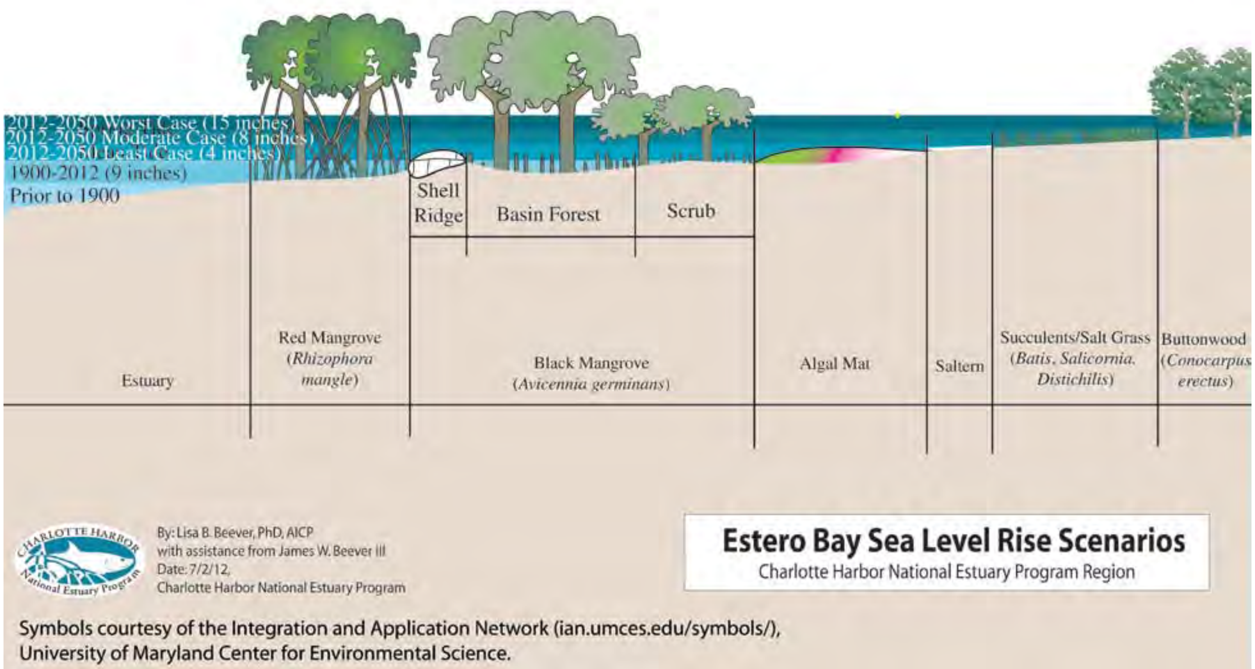


Figure 146: Sea level rise in three different probabilities in the year 2050 for Estero Bay at Bunche Beach. Least case (90% probable), moderate case (50% probable) and worst case (5% probable)
Source: IPCC 2007a

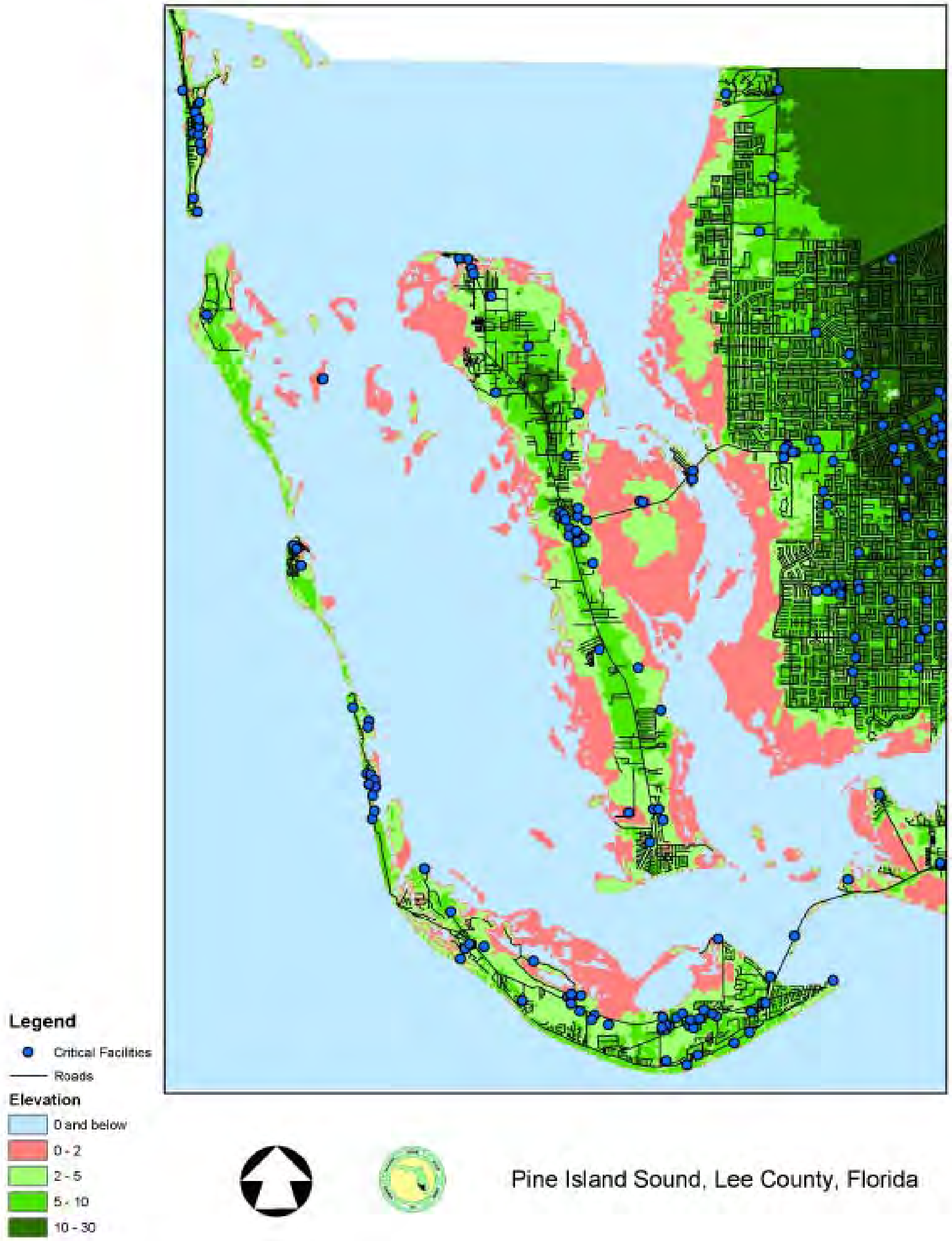


Figure 147: Two-foot contour sea level rise for the Pine Island Sound, Matlacha Pass, and San Carlos Bay Area. This is the prediction of Karl et al. (2007) for the year 2100; approximately equivalent to a 90% probability 2200 prediction (IPCC 2007a); a 5% Probability 2075 prediction (IPCC 2007a); or the 2050 Business as Usual Worst Case scenario (Stanton and Ackerman 2007).

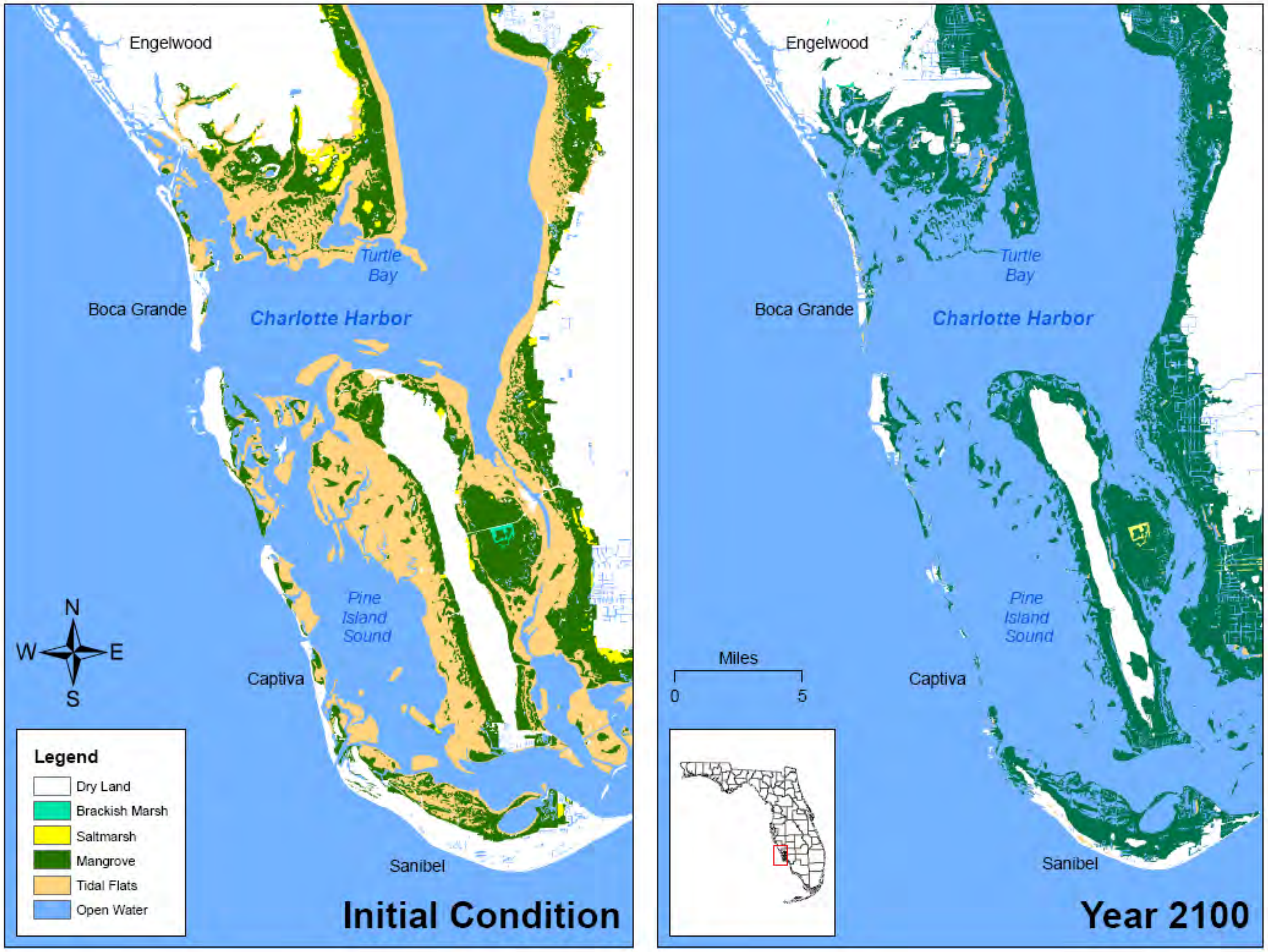


Figure 148: Three-foot contour sea level rise Sea Level Rise in Lower Charlotte Harbor Estuary Year 2100.
This is the 5% probability worst case IPCC (2007a) scenario.

Some scientists expect more rapid sea level rise than previously predicted by IPCC 2007 (USEPA CRE 2008, Rahmstorf 2007). One team of researchers has suggested that global sea level could rise far higher than previously forecast because of changes in the polar ice sheets, a meter or more by 2100. They assert that the IPCC projections did not include the potential impact of polar melting and ice breaking off (Rahmstorf 2007). The IPCC, in its 2007 Fourth Assessment Report, had said that the maximum rise in sea level would be about 59 centimeters. Professor Konrad Steffen from the University of Colorado, speaking at a press conference, highlighted new studies into ice loss in Greenland, showing that it has accelerated over the last decade. Professor Steffen, who has studied the Arctic ice for the past 35 years, has said, "I would predict sea level rise by 2100 in the order of one meter; it could be 1.2 meters or 0.9 meters. But it is one meter or more seeing the current change, which is up to three times more than the average predicted by the IPCC. It is a major change and it actually calls for action." Dr John Church of the Centre for Australian Weather and Climate Research added, "The most recent research showed that sea level is rising by 3 mm a year since 1993, a rate well above the 20th century average." Professor Eric Rignot, a senior research scientist at NASA's Jet Propulsion Laboratory, said that results gathered since the IPCC report showed that melting and ice loss could not be overlooked. "As a result of the acceleration of outlet glaciers over large regions, the ice sheets in Greenland and Antarctica are already contributing more and faster to sea level rise than anticipated," he observed. Professor Stefan Ramstorf of the Potsdam Institute for Climate Impact Research said, "Based on past experience, I expect that sea level rise will accelerate as the planet gets hotter" (Shukman 2009).

Local topography and land use will greatly affect the scope and reach of whatever sea level rise occurs in Florida. The area included in this study is divided into uplands (433 square miles/277,050 acres) and wetlands (915 square miles/585,766 acres) below 10 feet in elevation, which only exist in the four coastal counties (1,348 total square miles/862,816 acres). The areas below 10 feet in elevation, (equivalent to 9.2 feet above mean sea level or subject to daily tidal inundation with 8.2 feet of sea level rise), which are subject to sea level rise impacts, comprise 22.4 percent of the region's total land area. A current population of approximately 607,000 people lives in 357,000 dwelling units (SWFRPC 2001). Millions of square feet of commercial, office and other uses exist within the study area. This area is expected to be essentially built-out in the next 50 years with a population of more than one million people.

Utilizing the most recent available land cover data from the Florida Fish and Wildlife Conservation Commission (FWC2004) and currently available Lidar elevations, it is possible to project the amount of habitat that would be subject to future inundation from various levels of sea level rise. The following tables and graphs display the results for Lee and Collier Counties, which are the two counties with complete Lidar data at this time. There are currently gaps in the Lidar data for Charlotte and Sarasota Counties.

The elevations analyzed (0.5, 1.0, 1.5, 2.0, 3.0, 4.0, and 9.0 feet NGVD) correspond to the following climate change scenarios:

Elevation in NGVD	Rapid Stabilization Case	90% (least)	50% (moderate)	5% (worst)	Business as Usual
Half Foot	2084	2059	2030	2014	2011
One Foot	2222	2107	2063	2036	2027
Two Feet	2398	2214	2109	2075	2053
Three Feet	2575	2270	2158	2100	2079
Four Feet	2751	2327	2208	2109	2101
Nine Feet	3633	2610	2338	2174	2153

Table 16: Predicted year of different elevation levels (NGVD) of sea level rise for different future scenarios. Source: Beever et al. 2009a.

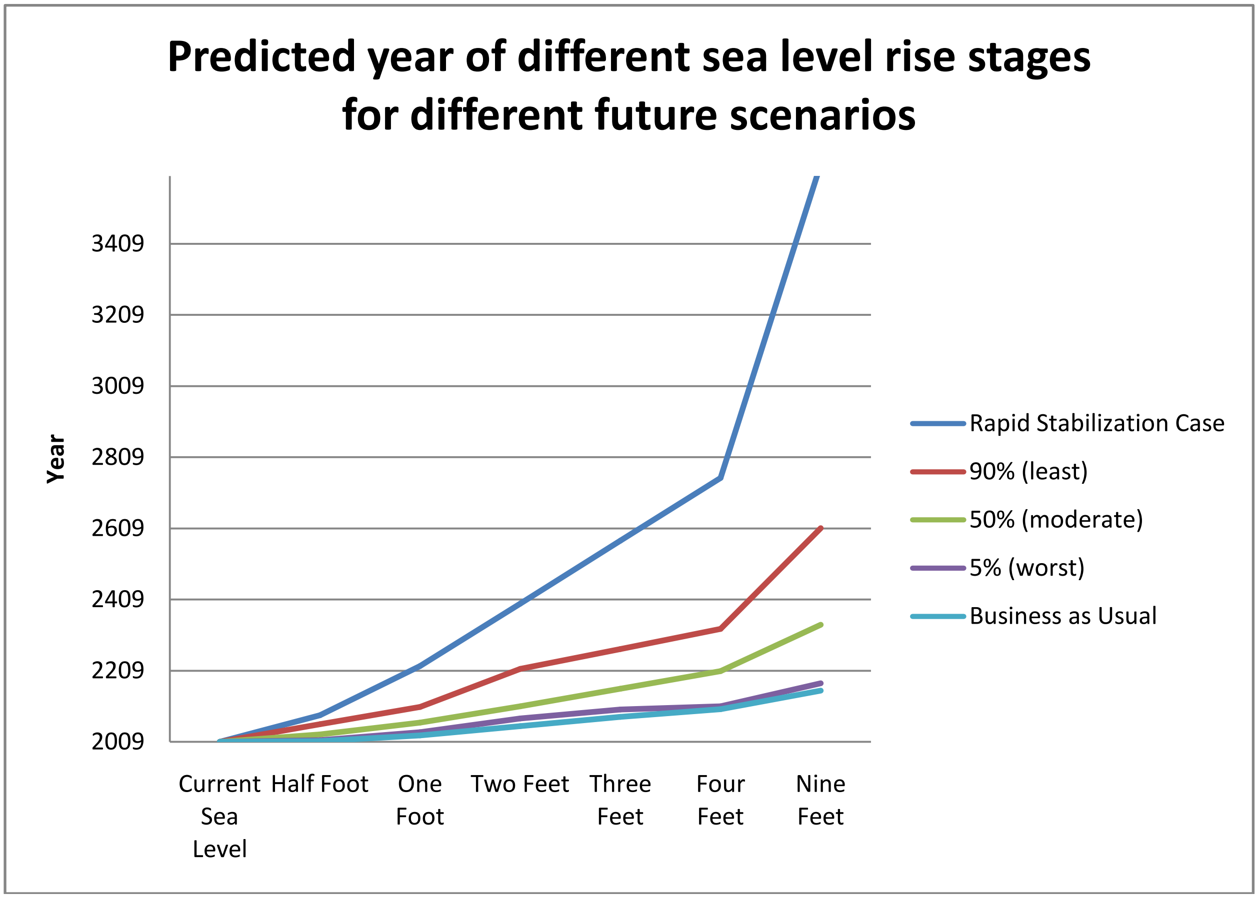


Figure 149: Approximate predicted year of different elevation levels (NGVD) of sea level rise for different future scenarios

Wetland Types	Lee	Charlotte	Sarasota	Total	Sq. Miles
Mangrove Swamps	42,341	18,162	777	661,280	225.1
Saltwater Marshes	3,785	7,378	1,011	12,174	46.2
Tidal Flats	1,179	0	0	1,179	3.0
Tidal Flats/Submerged Shallow Platform	0	1,207	396	1,603	2.5
Total Acreage	47,305	26,747	2,184	177,192	276.8

Table 17: SLAMM Results Southwest Florida Region Coastal Wetland Acreage Subject to 10 Feet NGVD Sea Level Rise (Glick 2006)
(equivalent to 9.2 feet above mean sea level) or subject to daily tidal inundation with 8.2 feet of sea level rise)

In the course of this study we examined the amount of the mapped salt marshes that would be inundated at different levels of sea level rise up to 3 feet sea level rise. A series of watershed and sub watershed maps were created that indicate the area of salt marsh that would be under different water levels. This map does not project marsh extents if marshes are able to move landward it the absence of barriers and the presence of public or other lands that could accommodate their establishment. The maps indicate a one foot inundation in red, a two foot inundation in orange, a three foot inundation in yellow. Salt marsh Areas currently above three feet elevation are indicated in green.

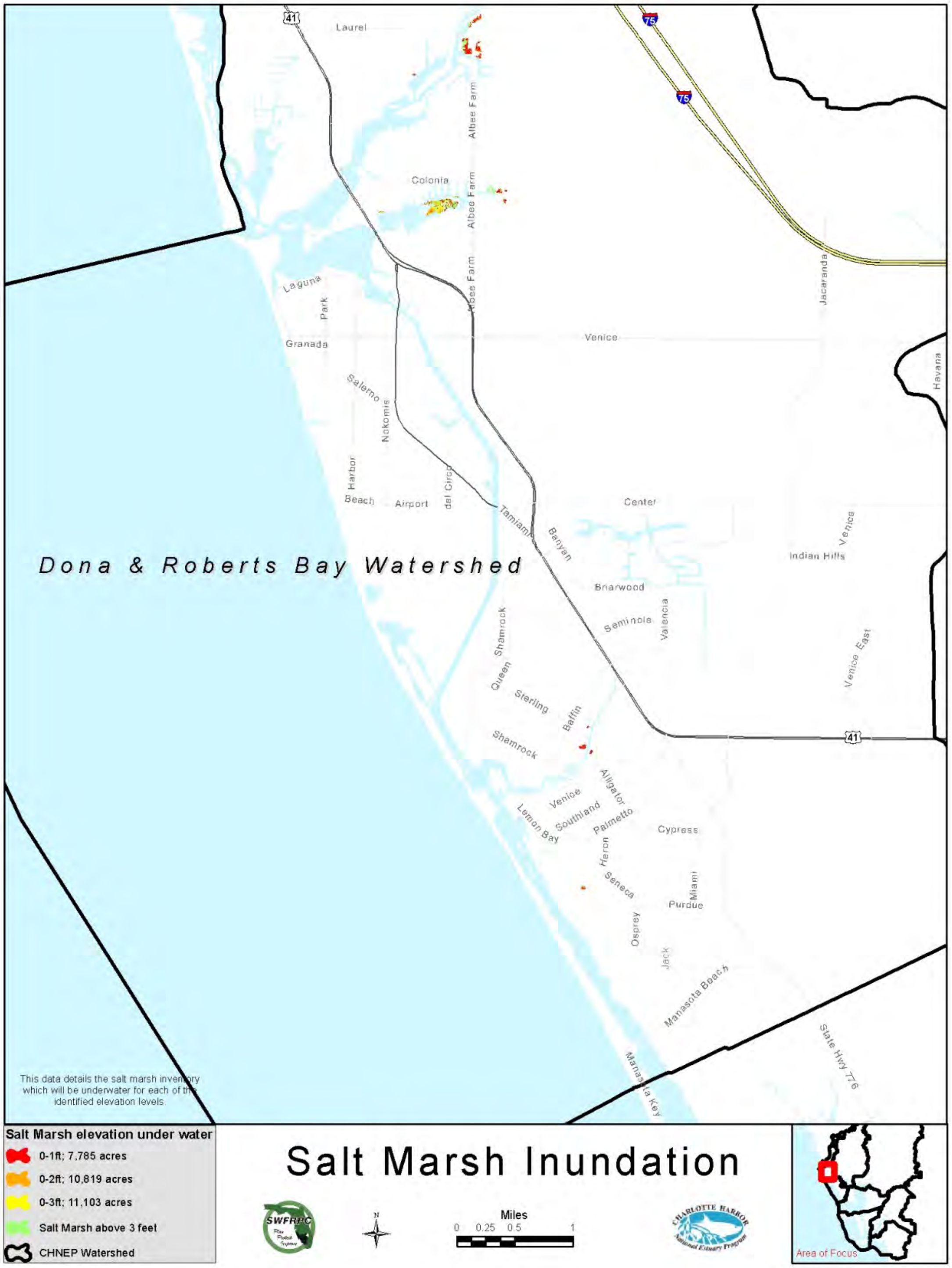


Figure 150: Inundation of existing salt marsh extents by 1, 2, and 3 feet of sea level rise. Dona and Roberts Bay Watershed.
Source: SWFRPC 2012

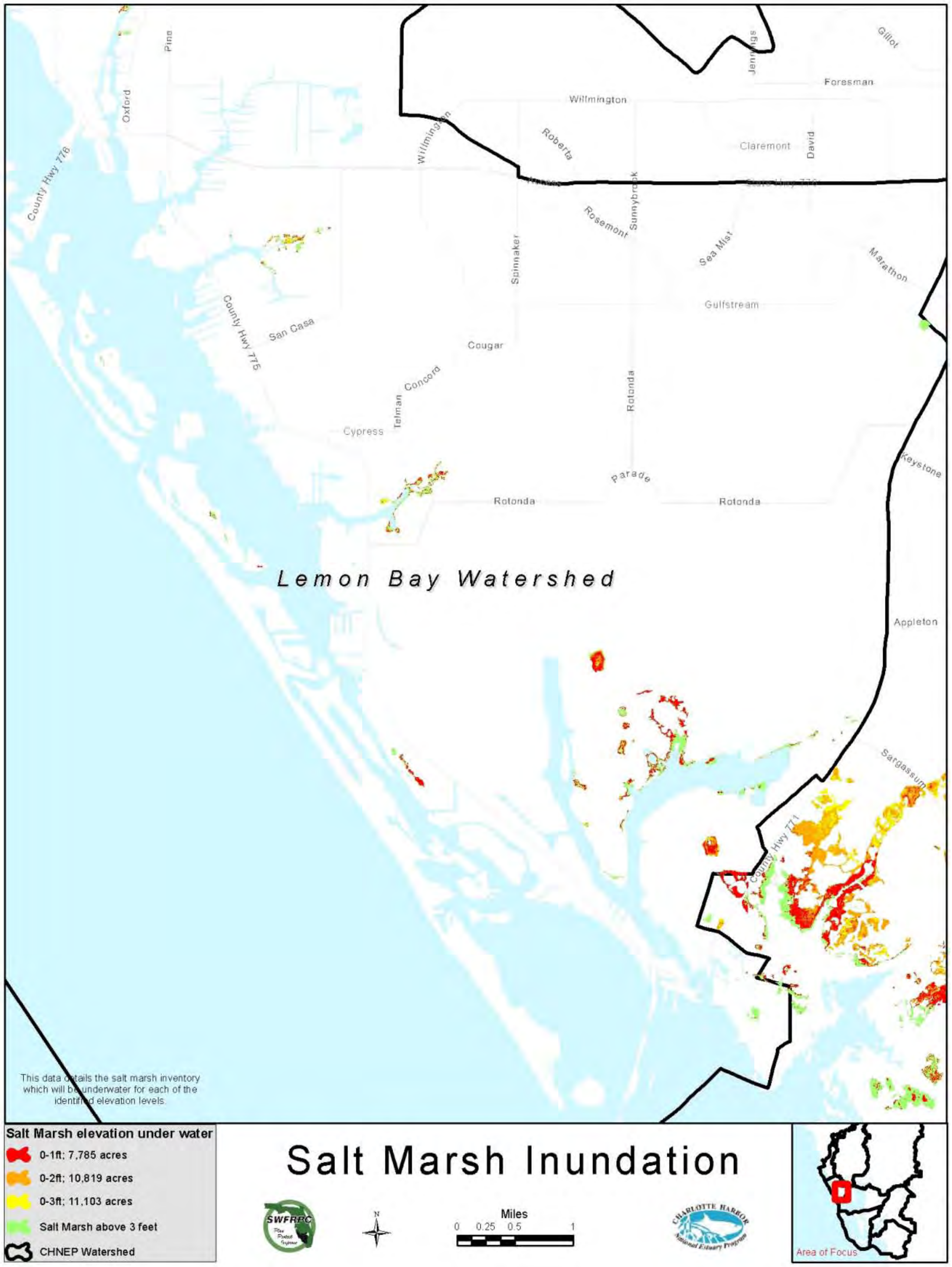


Figure 151: Inundation of existing salt marsh extents by 1, 2, and 3 feet of sea level rise. Lemon Bay Watershed

Source: SWFRPC 2012

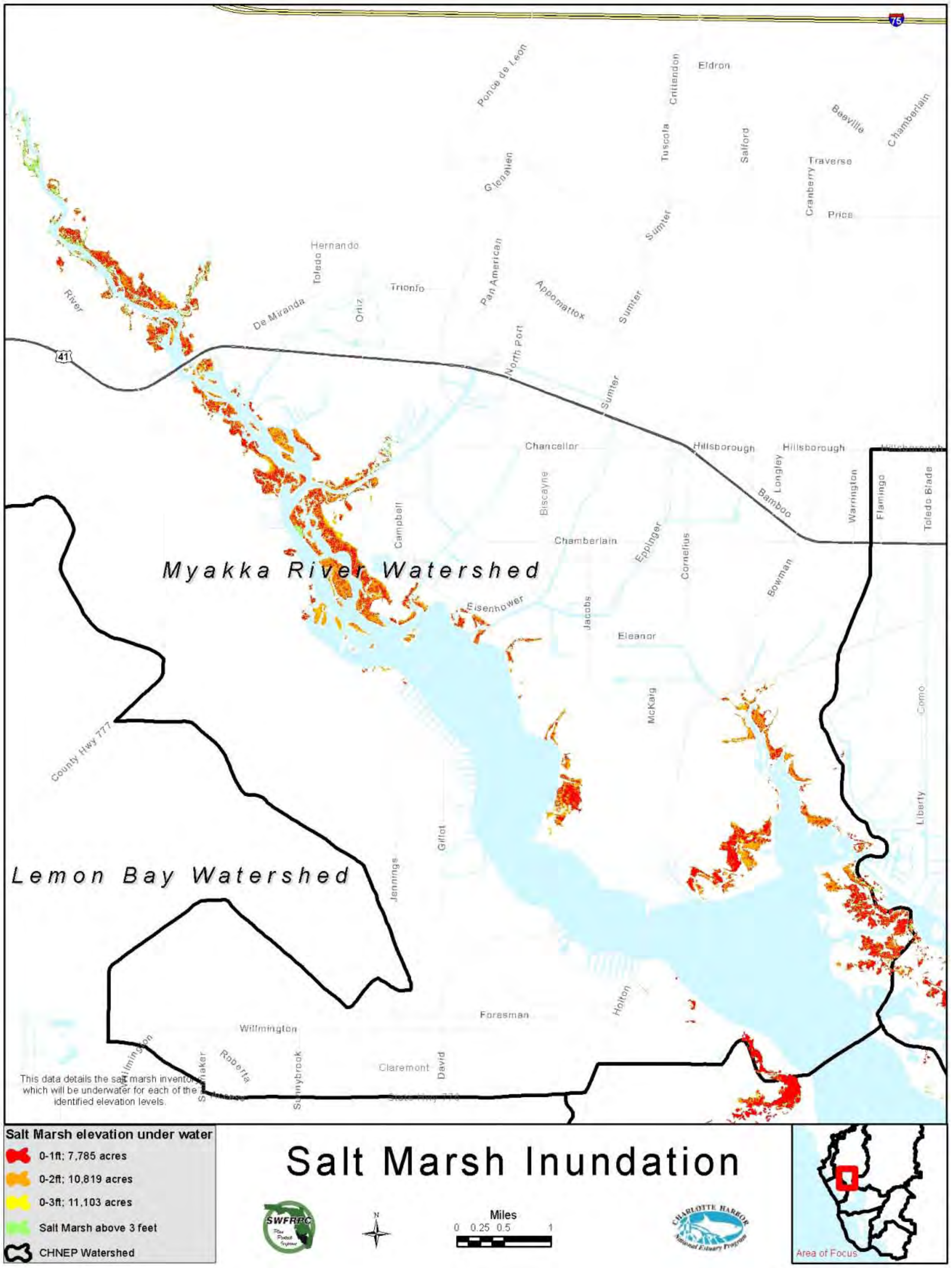


Figure 152: Inundation of existing salt marsh extents by 1, 2, and 3 feet of sea level rise. Myakka River Watershed

Source: SWFRPC 2012

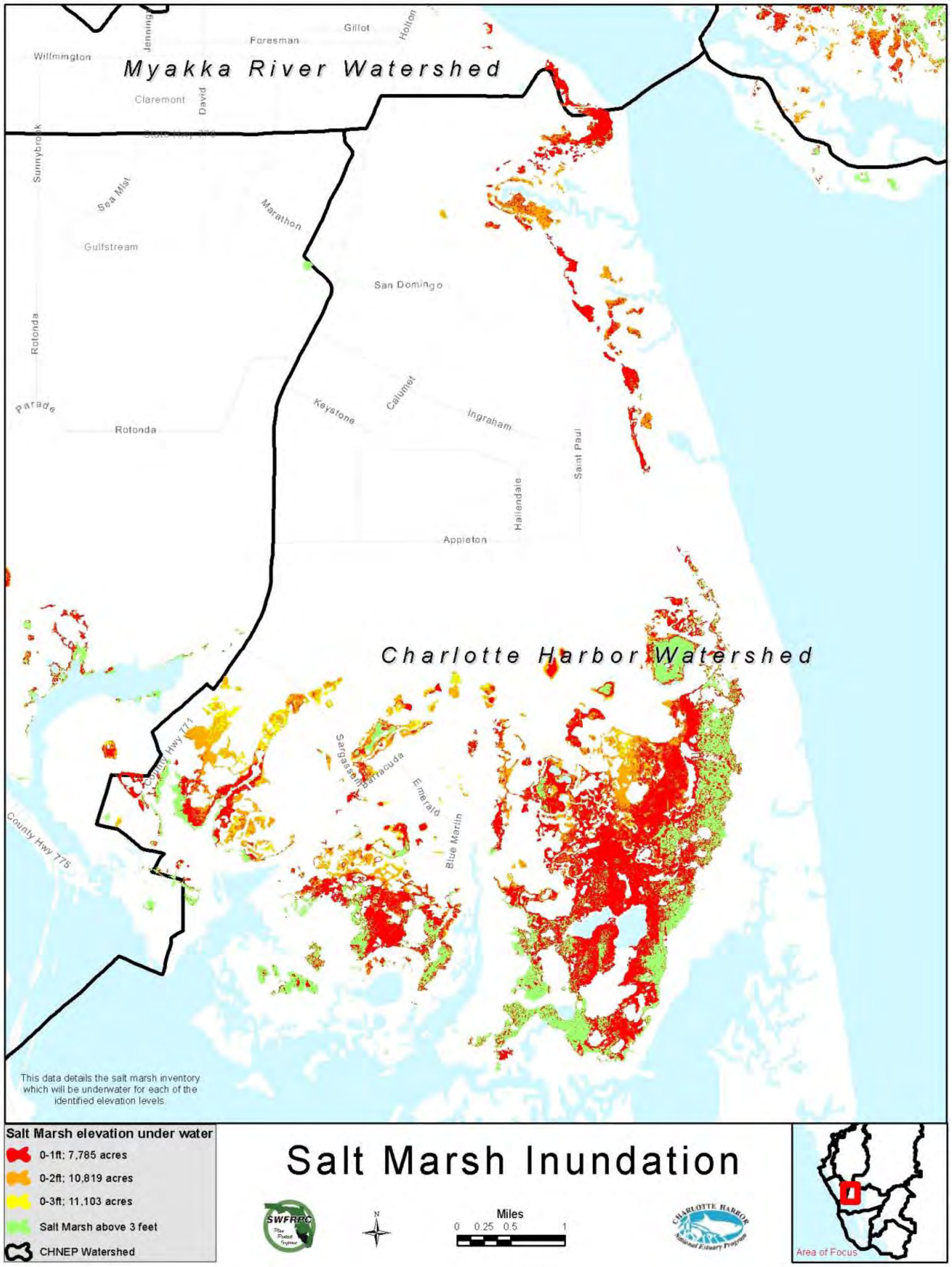


Figure 153: Inundation of existing salt marsh extents by 1, 2, and 3 feet of sea level rise.
West Charlotte Harbor Watershed
Source: SWFRPC 2012

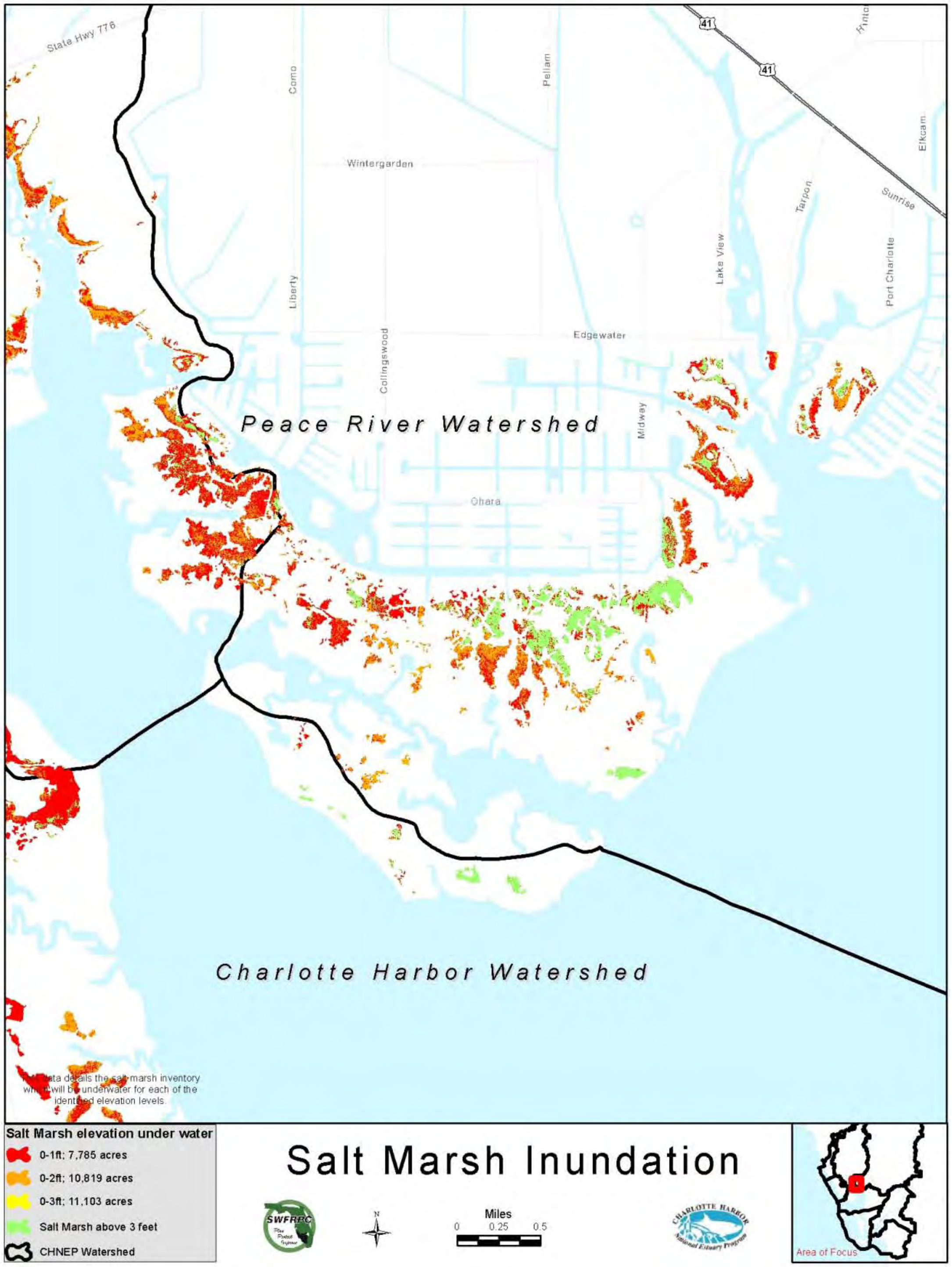


Figure 154: Inundation of existing salt marsh extents by 1, 2, and 3 feet of sea level rise. West Peace River Watershed

Source: SWFRPC 2012

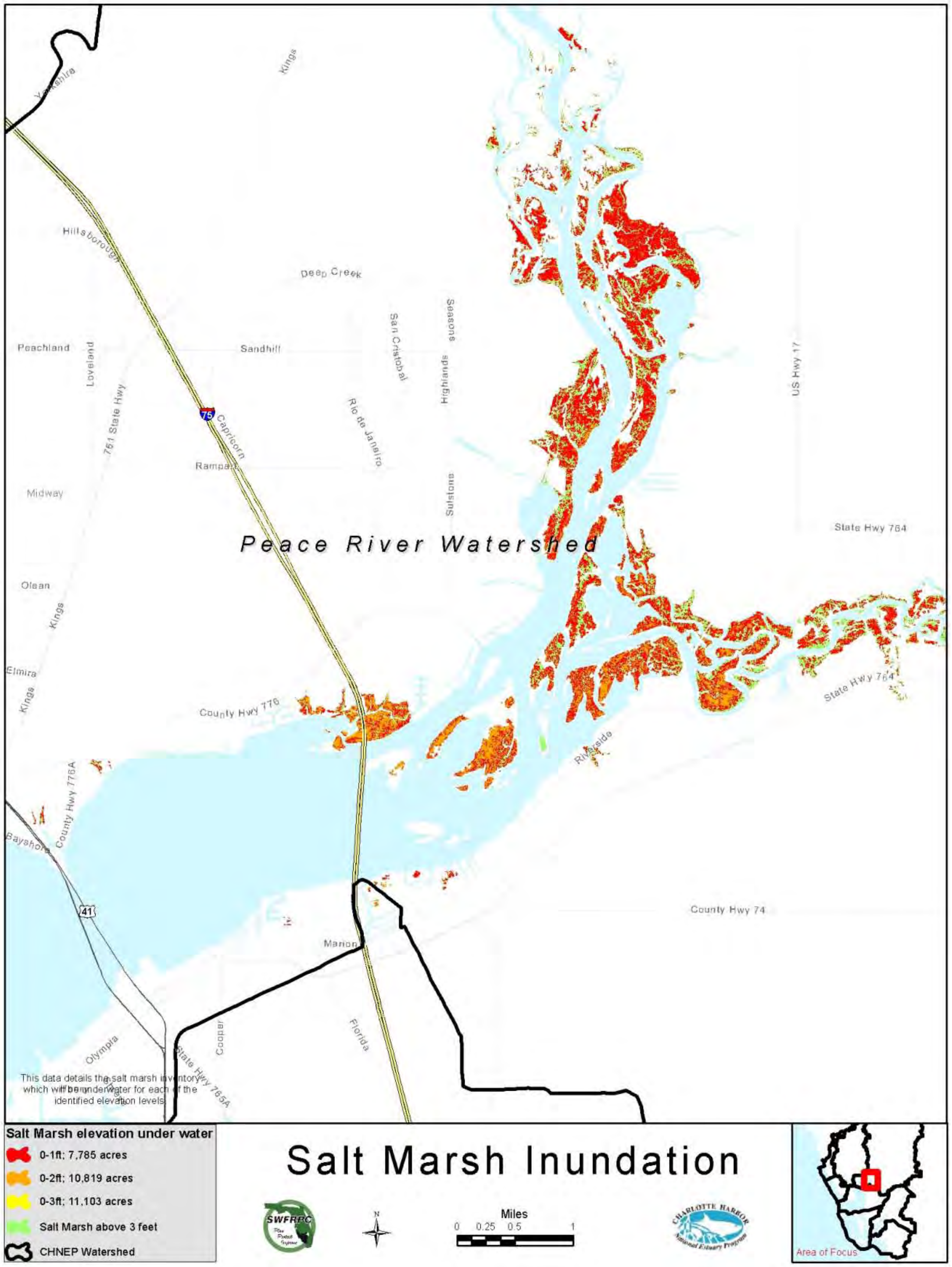


Figure 155: Inundation of existing salt marsh extents by 1, 2, and 3 feet of sea level rise. East Peace River Watershed

Source: SWFRPC 2012

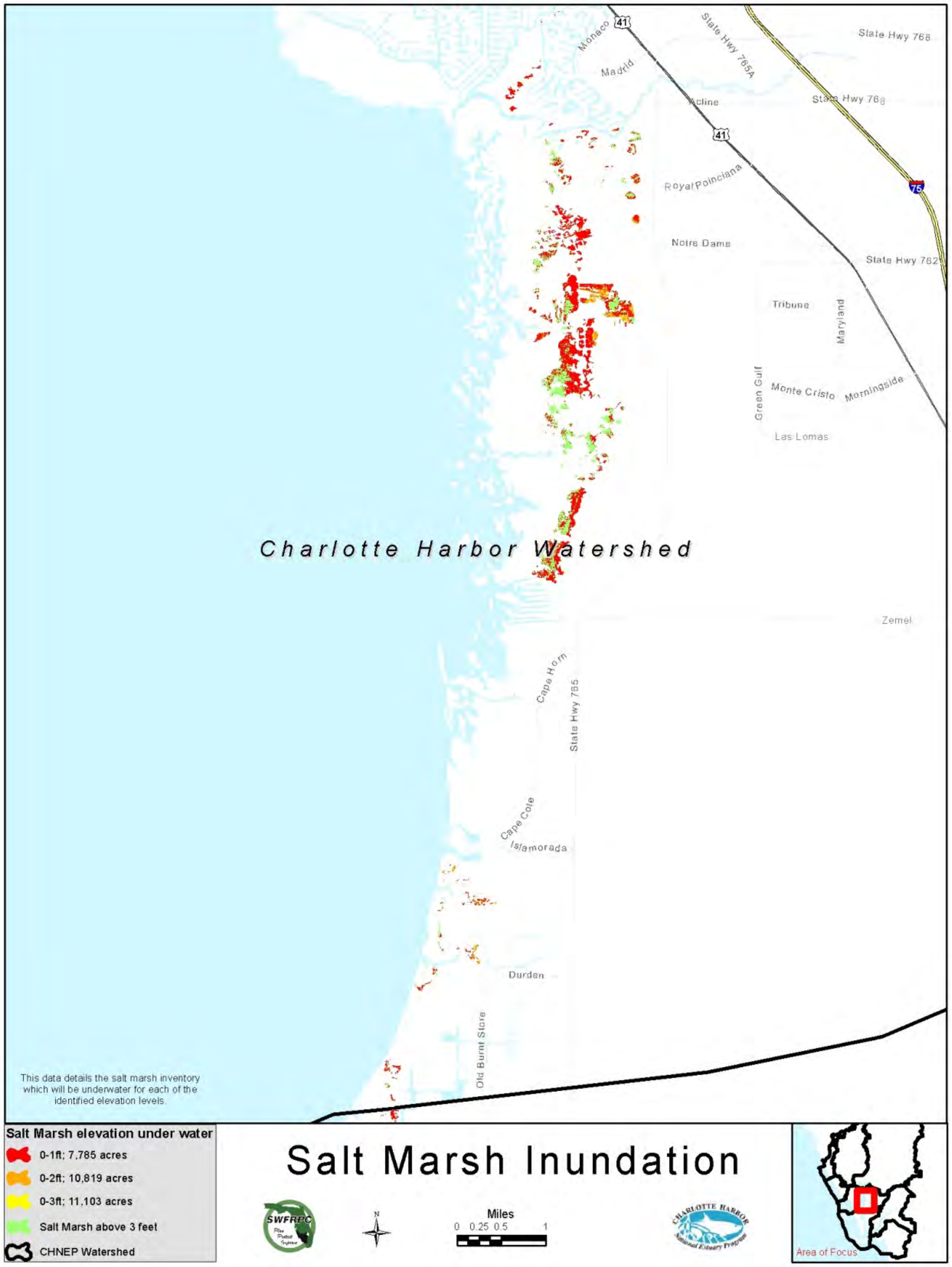


Figure 156: Inundation of existing salt marsh extents by 1, 2, and 3 feet of sea level rise. East Charlotte Harbor Watershed

Source: SWFRPC 2012

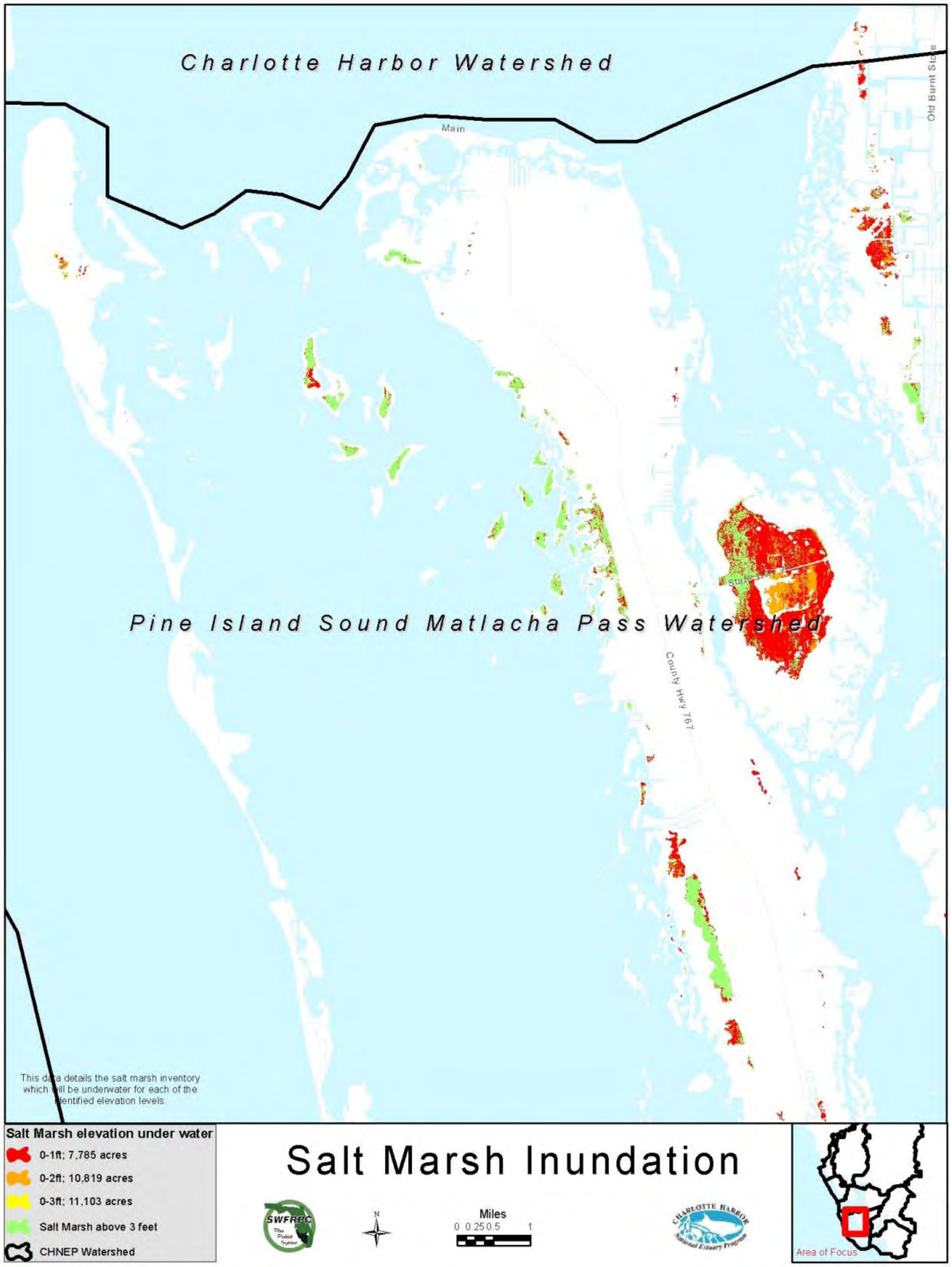


Figure 157: Inundation of existing salt marsh extents by 1, 2, and 3 feet of sea level rise.
North Pine Island Sound Watershed
Source: SWFRPC 2012

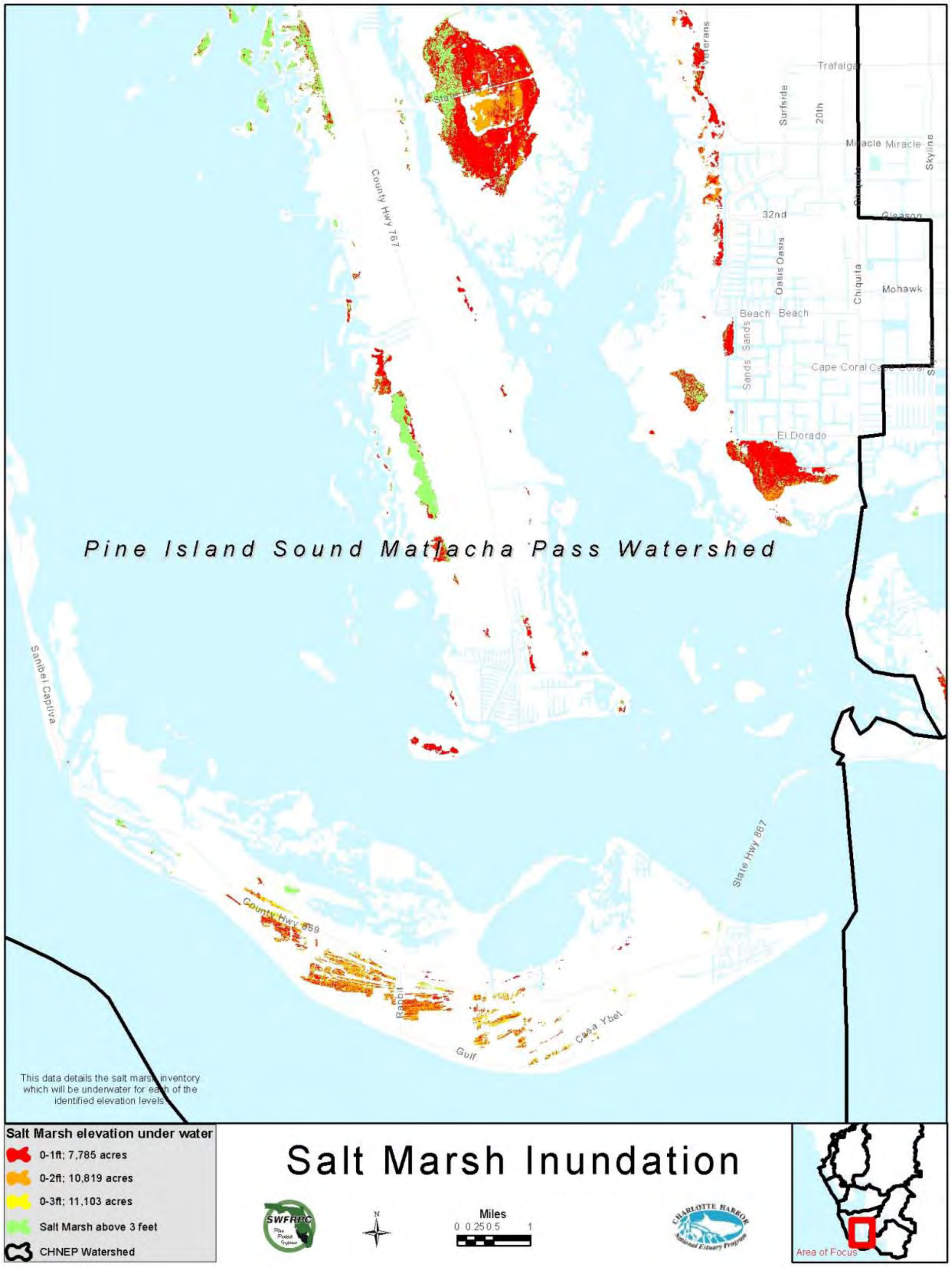


Figure 158: Inundation of existing salt marsh extents by 1, 2, and 3 feet of sea level rise. South Pine Island Sound Watershed

Source: SWFRPC 2012

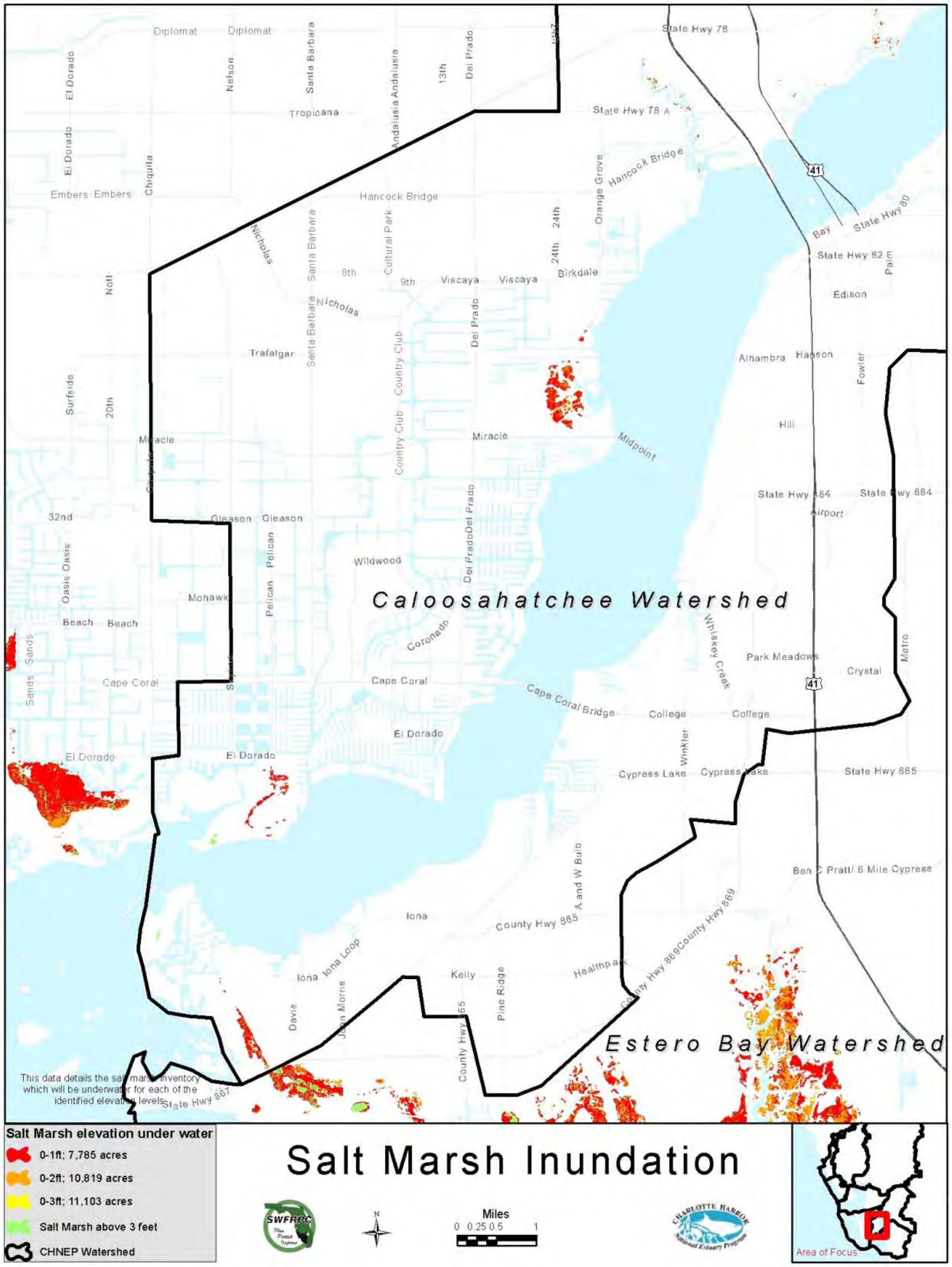


Figure 159: Inundation of existing salt marsh extents by 1, 2, and 3 feet of sea level rise. South Caloosahatchee River Watershed

Source: SWFRPC 2012

Figure 160: Inundation of existing salt marsh extents by 1, 2, and 3 feet of sea level rise. North Caloosahatchee River Watershed

Source: SWFRPC 2012

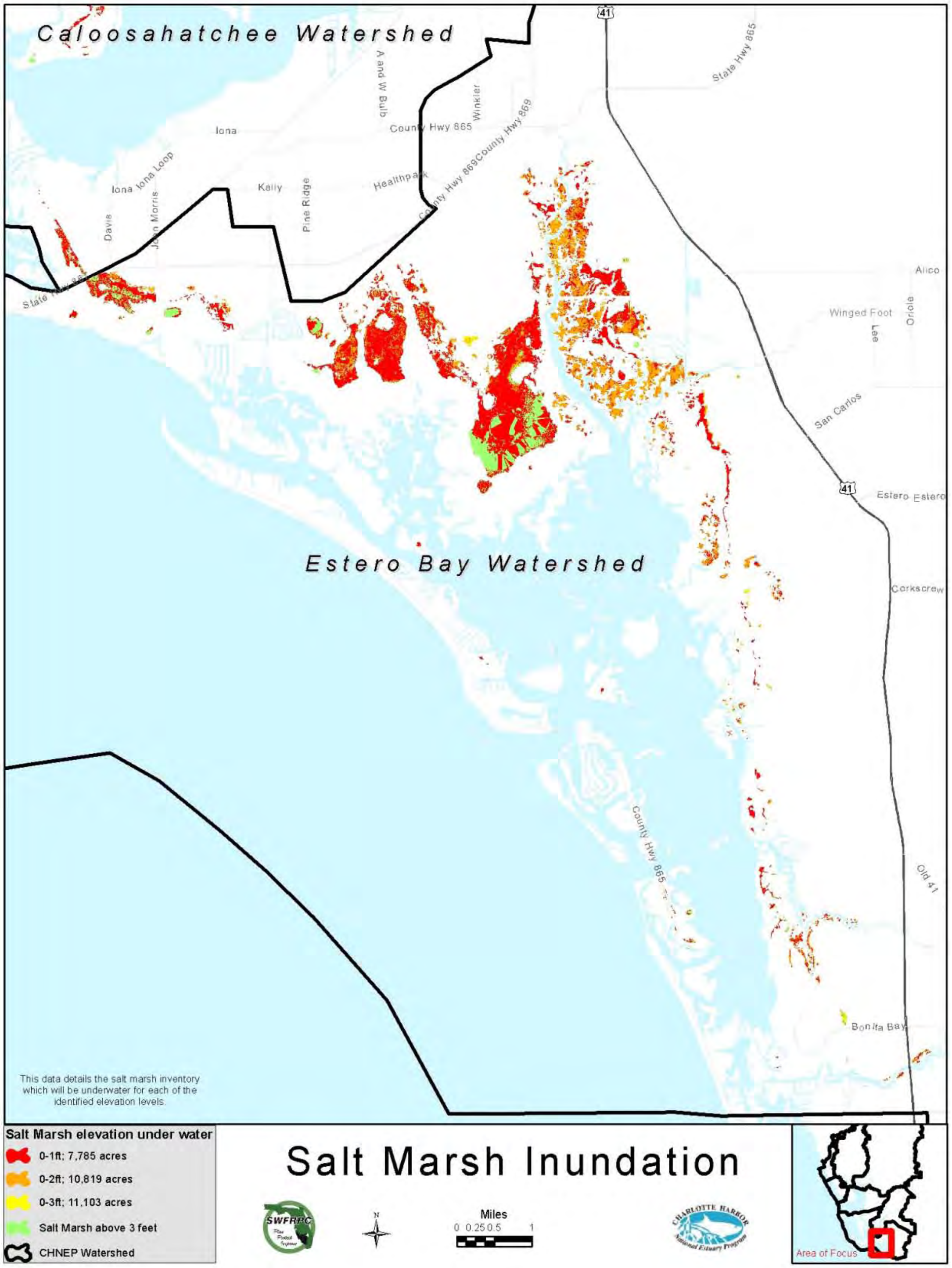


Figure 161: Inundation of existing salt marsh extents by 1, 2, and 3 feet of sea level rise. Estero Bay Watershed

Source: SWFRPC 2012

Amount of Inundation in Feet from 2012 Baseline	% Area of Salt Marsh Inundated	Cumulative Area of Salt Marsh in Acres Inundated	Scenario Level Prediction
1 Foot	52%	7,785	Current Measure 2150 Best case 2114 Moderate case 2075 Worst Case 2021
2 Feet	73%	10,819	Current Measure 2150 Best Case 2228 Moderate Case 2108 Worst Case 2044
3 Feet	75%	11,103	Best Case 2342 Moderate Case 2162 Worst Case 2065

Table 18: Area of CHNEP Salt Marsh Inundated as Sea Level Rises

Development of Sea Level Response Maps

Current trends and policies regarding land use, conservation and shoreline protection provided a starting point for developing maps of the region's likely land use response to sea level rise. Nevertheless, because those policies do not precisely correspond to existing land use categories, and because those categories can change over time, some analysis and judgment is necessary to develop the maps. The procedures used to create the maps are described in Beever et al. 2009a, Titus et al. 1991 and SWFRPC 2005.

Seven colors are used to define the map in each county. First, all water areas in the Gulf of Mexico, bays, rivers, canals or lakes are shown in the color light blue. Second and third, all wetlands either fresh or saltwater are shown in the color dark green with the tidal wetlands shown as purple. Fourth, uplands where no shore protection from sea level rise is assumed are shown in the color light green. Fifth, uplands where shore protection from sea level rise is assumed unlikely are shown in the color blue. Sixth, uplands where shore protection is assumed to be likely are shown in the color red. The seventh color is brown where shore protection is almost certain. Finally, the non-color white is everything above 10' in elevation and is outside the study area.

Assumptions regarding the protection scenarios were made according to elevation and generalized land uses and are defined as follows. The counties agreed with SWFRPC staff that agriculture, mining and upland preserves would not protect their property from sea level rise and therefore would be colored light green. Commercial, estate, industrial, military, multi-family and single family would "almost certainly" protect their property from sea level rise and therefore would be colored brown. Dark blue areas would be land uses between zero and five feet in elevation that is not likely to be protected from sea level rise and might be areas such as unbridged barrier island, low income housing, low value property not on central water and sewer or repetitive flood loss properties. In this phase of the process only critical facilities between the elevation of five and 10 feet were colored brown, but the land itself was colored red. Critical facilities below five feet in elevation were shown as blue and protection was not recommended. Planners from all the counties agreed that we should assume that government owned critical facilities in this area should relocate these facilities to higher ground. Once other regional planning councils started to implement the SWFRPC staff initial methodology, it became clear that other data sources were becoming available, such as the Florida Land Use Cover Classification System for existing and future land uses in GIS format, and that even more up-to-date land use information was needed to better determine how to assign the shore protection colors. The table below was subsequently developed.

State-wide approach for identifying the likelihood of human land use protection from the consequences of 10 feet of sea level rise		
Likelihood of Protection[2]	**Land-Use Category**	**Source Used to Identify Land Area**
Shore Protection Almost Certain (brown)	Existing developed land (FLUCCS Level 1-100 Urban and Built-up) within extensively developed areas and/or designated growth areas.	Developed Lands identified from Water Management Districts (WMD) existing Florida Land Use, Cover and Forms Classification System (FLUCCS) as defined by Florida Department of Transportation Handbook (January 1999); Growth areas identified from planner input and local comprehensive plans.
	Future development within extensively developed areas and/or designated growth areas (residential/office/commercial/industrial).	Generalized Future Land Use Maps from local comprehensive plans, local planner input and Water Management Districts.
	Extensively-used parks operated for purposes other than conservation and have current protection [3] or are surrounded by brown colored land uses.	County-Owned, State-Owned, and Federally-Owned Lands (based on local knowledge) or lands defined as 180 Recreational on the Level 1 FLUCCS, local planner input and Florida Marine Research Info System (FMRIS) for current protection measures.
	Mobile home developments outside of coastal high hazard[4], expected to gentrify, or connected to central sewer and water.	Local planner input and current regional hurricane evacuation studies.
Shore Protection Likely (red)	Existing development within less densely developed areas, outside of growth areas.	Developed Lands identified from WMD existing FLUCCS; Growth areas identified from local planner input, local comprehensive plans and current regional hurricane evacuation studies.
	Mobile home development neither within a coastal high hazard area that is neither anticipated to gentrify nor on central water and sewer.	Local comprehensive plans and current regional hurricane evacuation studies.
	Projected future development outside of growth areas could be estate land use on Future Land Use Map.	Local planner input
	Moderately-used parks operated for purposes other than conservation and have no current protection or are surrounded by red colored land uses.	County-Owned, State-Owned, and Federally-Owned Lands (based on local knowledge) or lands defined as 180 Recreational on the Level 1 FLUCCS, local planner input and FMRIS.
	Coastal areas that are extensively developed but are ineligible for beach nourishment funding due to CoBRA (or possibly private beaches unless case can be made that they will convert to public)	Flood Insurance Rate Maps for CoBRA, local knowledge for beach nourishment.

	Undeveloped areas where most of the land will be developed, but a park or refuge is also planned, and the boundaries have not yet been defined so we are unable to designate which areas are brown and which are green; so red is a compromise between.	Local planner input
	Agricultural areas where development is not expected, but where there is a history of erecting shore protection structures to protect farmland.	Local planner input
	Dredge Spoil Areas likely to continue to receive spoils or be developed, and hence unlikely to convert to tidal wetland as sea level rises	Local planner input
	Military Lands in areas where protection is not certain.	FLUCCS Level 173
Shore Protection Unlikely (blue)	Undeveloped privately-owned that are in areas expected to remain sparsely developed (i.e., not in a designated growth area and not expected to be developed) and there is no history of erecting shore protection structures to protect farms and forests.	Undeveloped Lands identified from WMD existing FLUCCS Level 1- 160 mining, 200 Agriculture, 300 Rangeland, 400 Upland Forest, 700 barren land ; Non-growth areas identified from planner input, local comprehensive plans, Flood Insurance Rate Maps for CoBRA and current regional hurricane evacuation studies.
	Unbridged barrier island and CoBRA areas or within a coastal high hazard area that are not likely to become developed enough to justify private beach nourishment.	Flood Insurance Rate Maps for CoBRA, local knowledge for beach nourishment and local planner input.
	Minimally-used parks operated partly for conservation, have no current protection or are surrounded by blue colored land uses, but for which we can articulate a reason for expecting that the shore might be protected.	County-Owned, State-Owned, and Federally-Owned Lands (based on local knowledge) or lands defined as preserve on Future Land Use Map, local planner input and FMRIS.
	Undeveloped areas where most of the land will be part of a wildlife reserve, but where some of it will probably be developed; and the boundaries have not yet been defined so we are unable to designate which areas are brown and which are green; so blue is a compromise between red and green.	local planner input

	Dredge Spoil Areas unlikely to continue to receive spoils or be developed, and hence likely to convert to tidal wetland as sea level rises	local planner input
	Conservation Easements (unless they preclude shore protection)	local planner input
No Shore Protection (light green)	Private lands owned by conservation groups (when data available)	Private Conservation Lands
	Conservation Easements that preclude shore protection	local planner input
	Wildlife Refuges, Portions of Parks operated for conservation by agencies with a policy preference for allowing natural processes (e.g. National Park Service)	local planner input
	Publicly-owned natural lands or parks with little or no prospect for access for public use.	County-Owned, State-Owned, and Federally-Owned Lands (based on local knowledge) defined as preserve on the Future Land Use Map and local planner input.

Notes:
1. These generalized land use categories describe typical decisions applied in the county studies. County-specific differences in these decisions and site-specific departures from this approach are discussed in the county-specific sections of this report.
2. Colored line file should be used in areas where less than 10 ft. elevations exist within 1,000 feet of the rising sea or color can't be seen on ledger paper map.
3. Current protection may include sea walls, rock revetments, beach renourishment, levees, spreader swales or dikes.
4. Coastal High Hazard Area defined in Rule 9J-5 FAC as the Category 1 hurricane evacuation zone and/or storm surge zone.

Table 19: State-wide approach for identifying the likelihood of human land use protection from the consequences of 10 feet of sea level rise

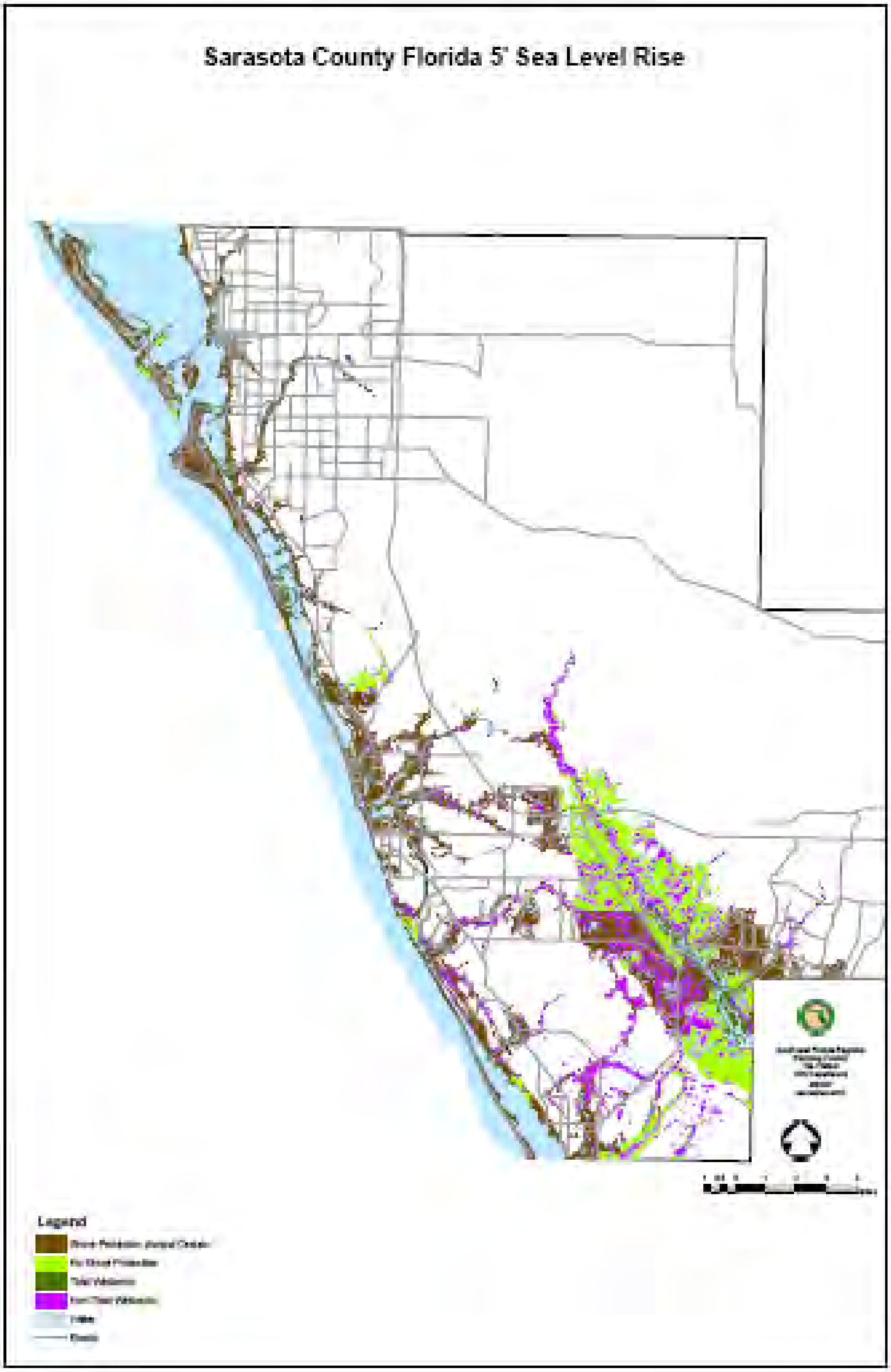


Figure 162: Sea level rise response land use projection map of Sarasota County at 5 foot sea level rise

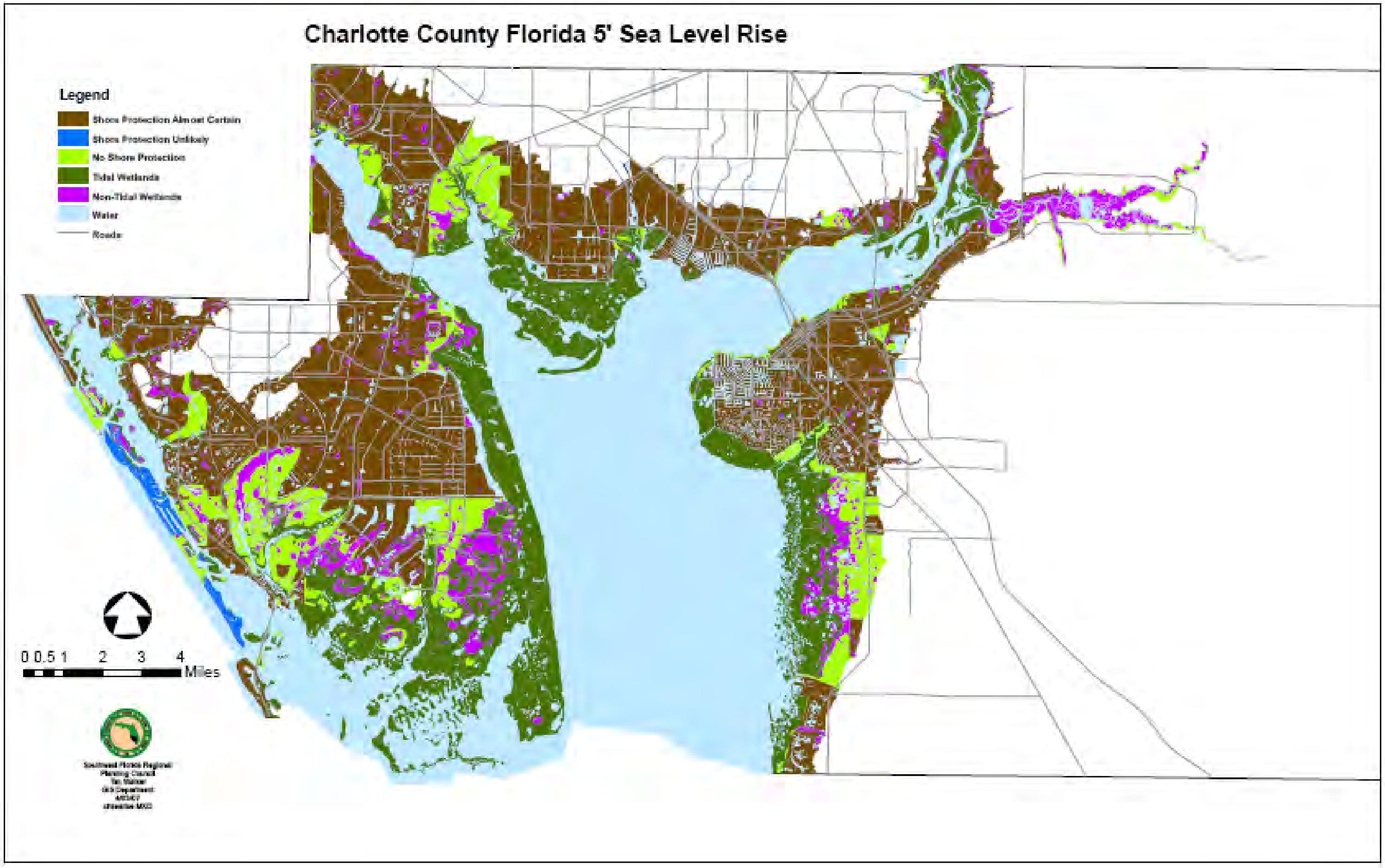


Figure 163: Sea level rise response land use projection map of Charlotte County at 5 foot sea level rise

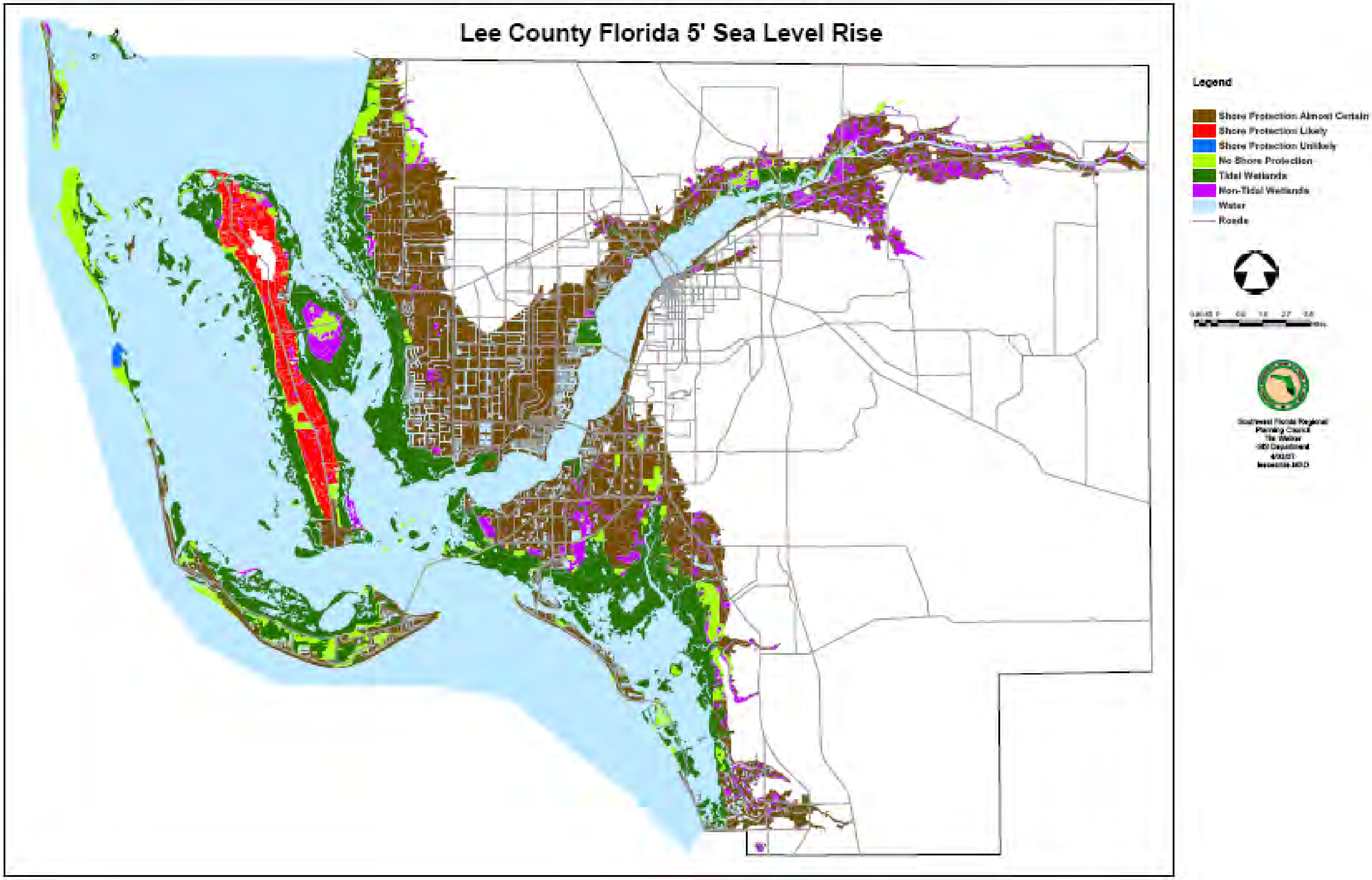


Figure 164: Sea level rise response land use projection map of Lee County at 5 foot sea level rise

The Observed Effects of Climate Change on the Salt Marshes of the CHNEP

Salt Marsh Movement Landward

Depending on the rate and extent of local sea level change, mangrove and salt marsh systems will respond differently (Titus and Richman 2005; Wanless et al. 1994). If rates of sea level rise are slow, some mangrove and salt marsh vegetation will migrate landward, up-gradient and inland. Zonation may remain the same or differ with soil conditions If sea level rise rates are too high, the salt marsh may be overgrown, overshadowed and replaced by mangroves, or drowned and converted to open bodies of water. If there is no accretion of inorganic sediment and/or organic peat, the salt marsh will become flooded so that marsh grasses and herbs drown and marsh soils erode. Portions of the high marsh will become low marsh and adjacent upland areas that are flooded at spring and fall high-high tides, will becoming high marsh, unless insurmountable physical barriers are encountered.

Although Charlotte Harbor region tide ranges are relatively small, tidal effects extend far inland because much coastal land is low in real and relative elevation. Because sea level change has been relatively constant and relatively slow for a long time, mangrove forests and salt marshes have been able to grow into expansive habitats for estuarine and marine life. With rising sea levels, sandbars and shoals, estuarine beaches, salt flats, and coastal forests will be altered, and changes in freshwater in flow from tidal rivers will affect salinity regimes in estuaries as well as patterns of animal use. Major redistributions of mainland and barrier island sediments may have compensatory or larger benefits for wetland, seagrass, or fish and wildlife communities, but these processes cannot be forecast with existing models. Estuarine circulation, salinity, and faunal use patterns are already changing with changes in climate and sea level (Peterson et al.2008). Many tidal wetlands are keeping pace with sea level changes (Estevez 1988). Some are accreting vertically, migrating up-slope, or both (Williams et al. 1999; Raabe et al. 2004; Desantis et al. 2007).

The rate of sea level rise will be critical for tidal wetlands. SLAMM modeling performed for the central part of the CHNEP (Glick and Clough 2006) (not including Estero Bay, Lemon Bay, Dona and Roberts Bay, upper Myakka River and upper Peace River) suggests a 89-98% loss of salt marshes in that subsection of the CHNEP by 2100 if the rate of sea level rise accelerates. Past filling and drainage practices have left salt marshes in the Charlotte Harbor region more vulnerable to these sea level rise effects of climate change.

In the course of this study we were surprised to find that some marsh plant species had a very wide range of elevational occurrence depending upon the relative geography and setting in the marsh profile. However, if migration space is not available through time all high marsh plant species are being replaced by black and red mangroves. Where water is deep enough the vascular plants are replaced by algaes and open water.

Salterns are formed by a hypersaline condition developed slightly above the mean high water (MHW) level. The formation of a coastal salt barren is a sequential event that starts with a formation of salinity maximum above the MHW. If the salinity maximum in pore water reaches 40-50 ppt, thinning of vegetation begins. Vegetation thinning then increases soil temperature and evaporation and salinity. The increased salinity induces more vegetation thinning and these mutually reinforced factors create a hypersaline unvegetated belt slightly above the MHW in which pore water salinity could reach saturation. The location of a saltern is dictated by the mean sea level (MSL). As the MSL rises, falls or stays stationary, the location of the saltern moves landward, seaward or stationary accordingly. The sediment profile property of a saltern registers the recent history of sea level changes (Hsieh and Gone 2001).

Our measurements of the waterward edge of saltern marshes based on historical 1953 aerials and current geo-referenced locations established in the field with the GIS/GPS unit indicate an average movement of 101 meters inland over the 57 year time period from 1953 to 2010. Lateral distances changed relate to relative slope profiles, the presence of mosquito control ditching, the presence of barriers to movement, and changes in upland hydrologic delivery. So far we have been able to observe this inland movement effect on large marshes located between stream and river courses on San Carlos Bay, Matlacha Pass, and Cape Haze and on Little Pine Island.

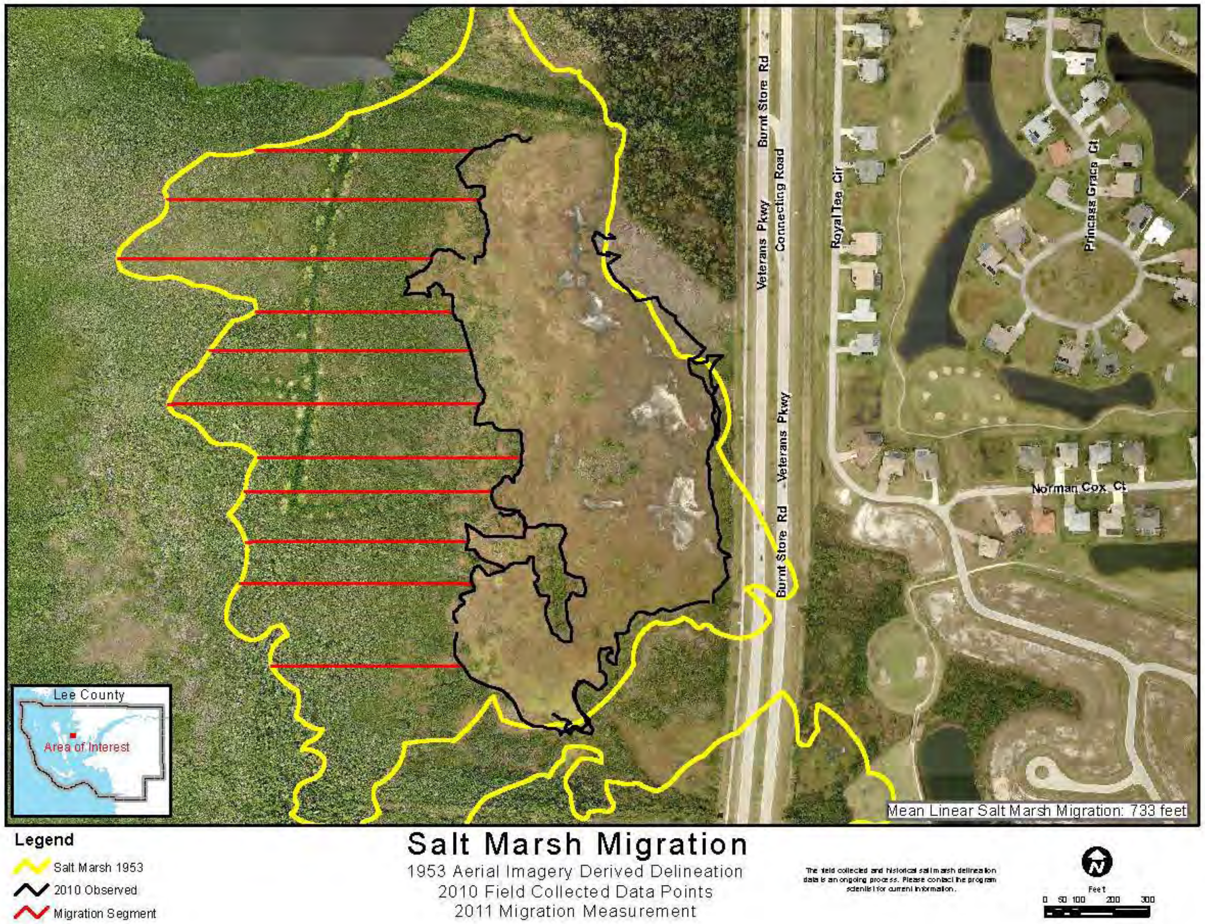
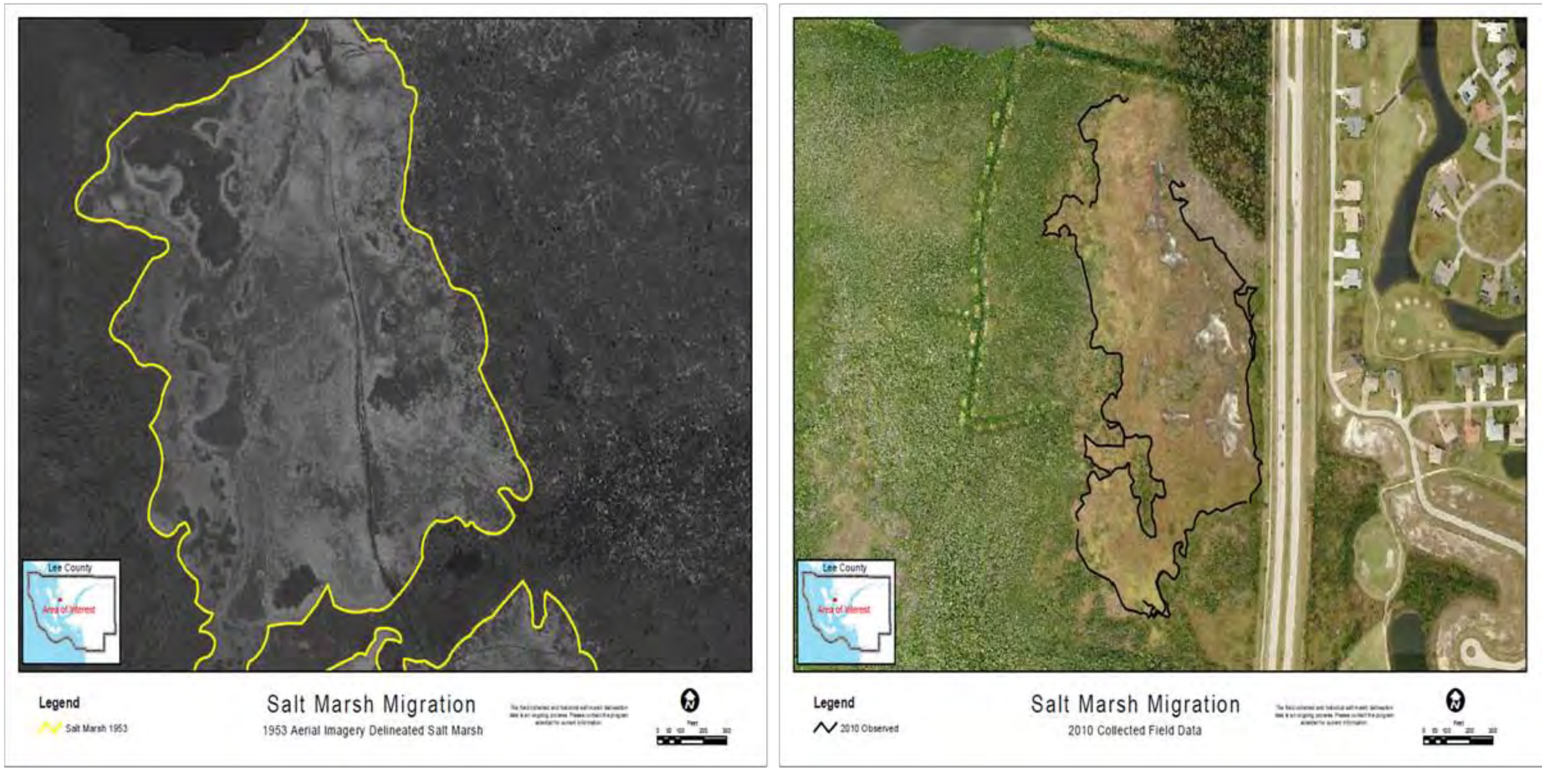


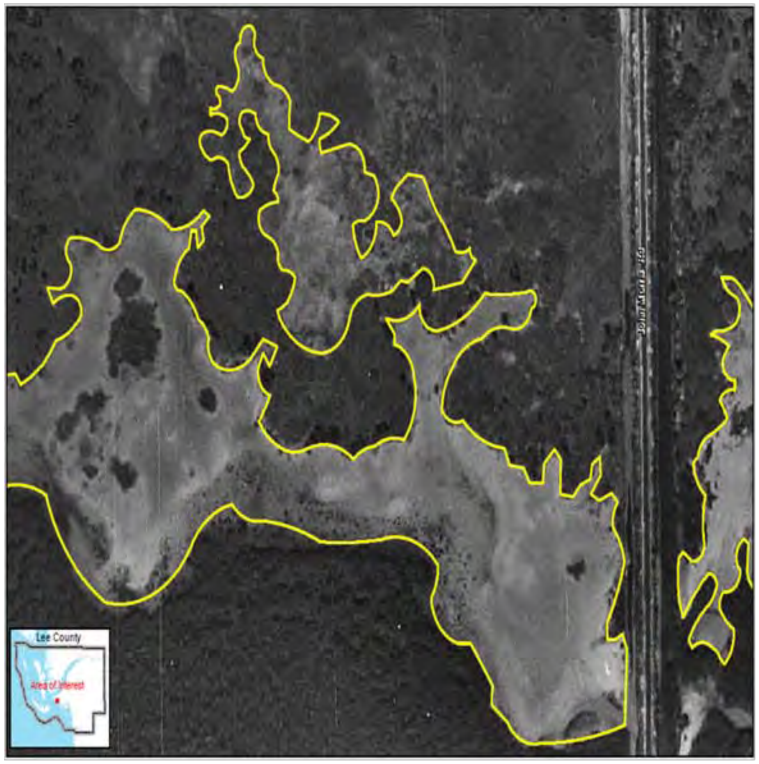
Figure 165: Comparison of marsh areas in 1953 (yellow line) and 2010 (black line), with movement distance indicated in red lines. Veterans Parkway Salt Marsh, Charlotte Harbor Preserve State Park, Matlacha Pass Watershed



1953

2010

Figure 166: Side by side comparison of marsh areas in 1953 (yellow line) and 2010 (black line), on the same scale and georectified location. Veterans Parkway Salt Marsh, Charlotte Harbor Preserve State Park, Matlacha Pass Watershed



1953

2010

Figure 167: Side by side comparison of marsh areas in 1953 (yellow line) and 2010 (black line), on the same scale and georectified location. Bunche Beach High Salt Marsh, Estero Bay Watershed

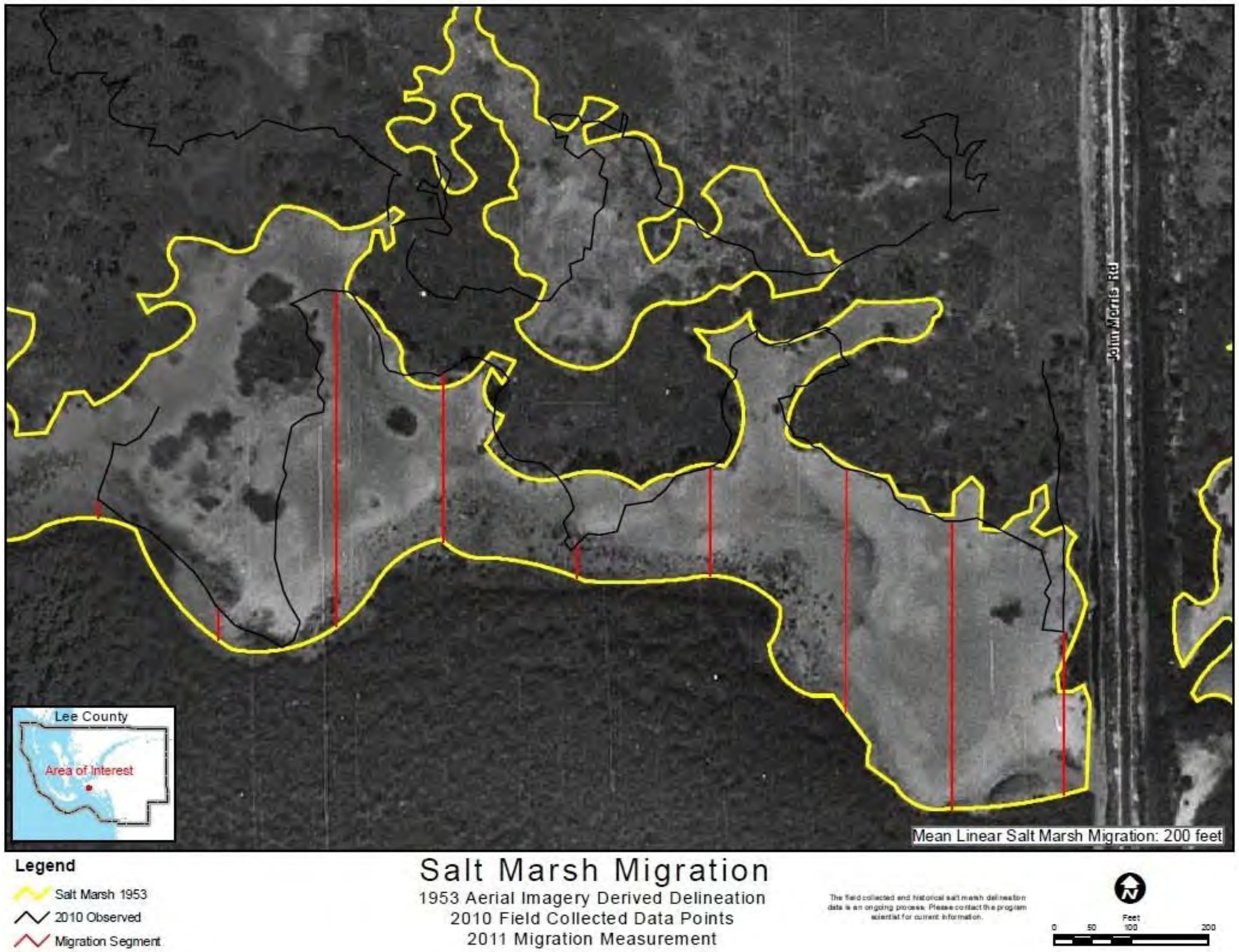
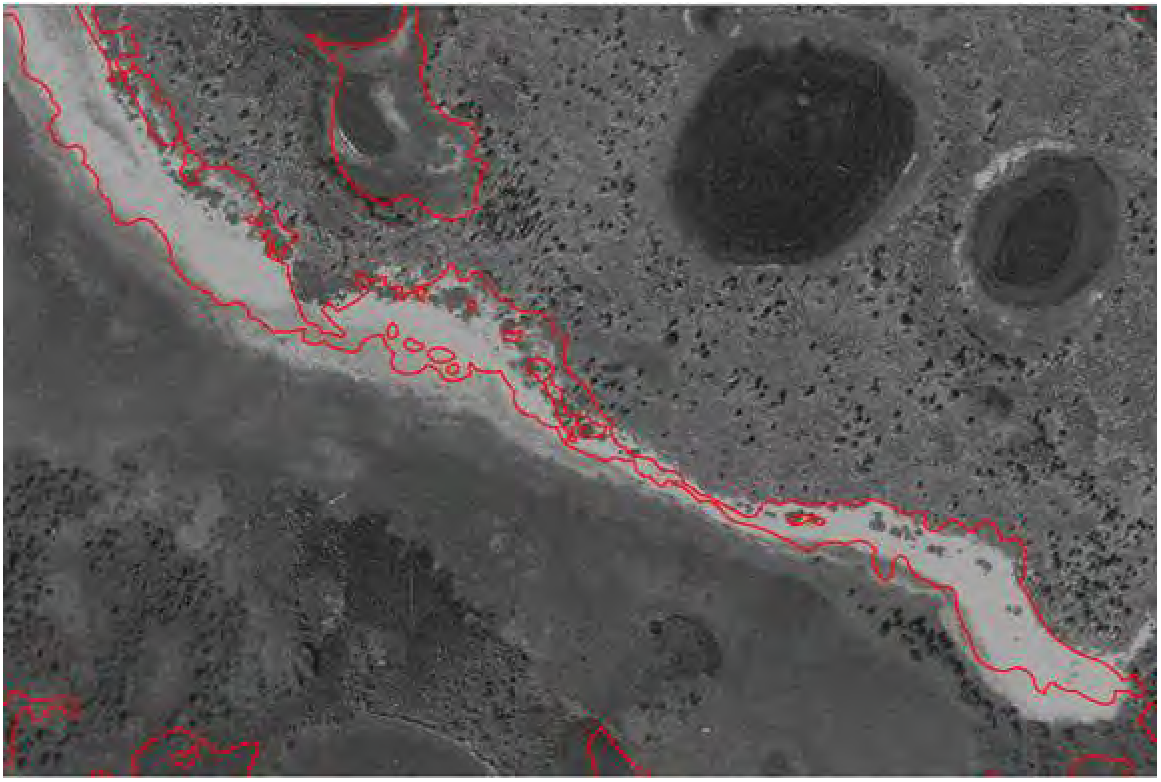


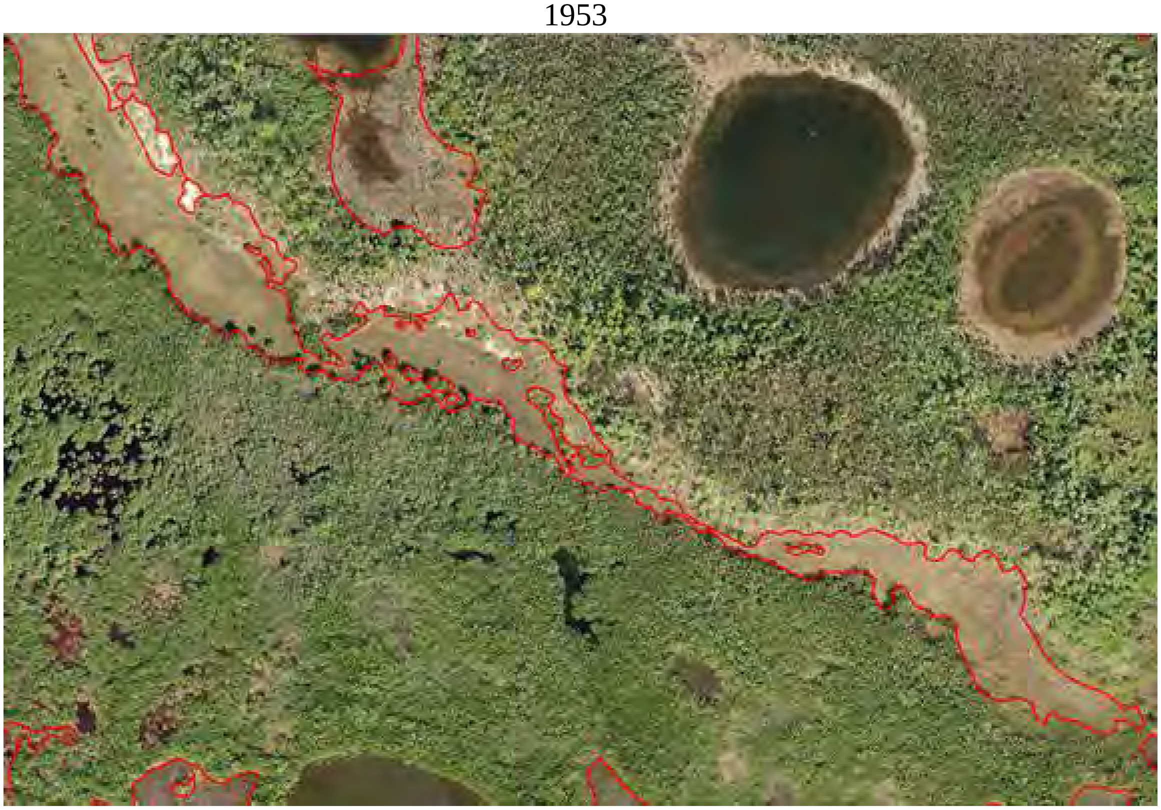
Figure 168: Comparison of marsh areas in 1953 (yellow line) and 2010 (black line), with movement distance indicated in red lines. Bunche Beach High Salt Marsh, Estero Bay Watershed

In other areas, such as the south end of the large salt marsh located west of Hendry Creek the location of saltern in 1953 has been replaced by a deeper water algal marsh. Areas of saltern have changed to algal marsh and then to scrub mangrove marsh and then to full mangrove forest. The interior black mangrove basins of islands in Pine Island Sound have been flooded as the shell ridge edges were breeched and the pneumatophores of the black mangroves were covered with tidal waters eliminating effective oxygen exchange. Subsequently the black mangroves have expired. The lower elevation interiors filled with water and depending upon the frequency of inundation changed to herbaceous high marsh patches, were colonized by smooth cordgrass or went to algal marsh.

Figure 169: West Hendry Creek Algal Marsh
Source: Google Earth 2010



1953



2010

Figure 170: Area of saltern converted to algal marsh and algal marsh converted to mangrove forest. East of Hendry Creek, Estero Bay Watershed

Source: Google Earth 2010

2002

2007

2010

Figure 171: Sequence of years at the same location on the west end of the Bunche Beach High Marsh on the approach to the Sanibel Bridge. Note saltern converts to algal marsh and mangroves dies providing a gray register. Source: Google Earth 2010

White mangroves are often the first mangrove to move into areas above the mean time line since their propagules are small and more easily carried past vegetative and topographic barriers. Man-made restoration areas are often colonized by the young white mangroves that form a uniform coverage that grows over the bared soils. Subsequently the mangroves grow densely through the early period until selective tree death begins to provide differential in age classes.

On northern areas of Hendry Creek areas of open mixed high marsh in the 1953 have been replaced by shrub white mangroves that subsequently were killed by freezes in the winter of 2010-2011. These mangroves were in an age class of 5-10 years and sitting on a higher plateau sediment shelf than living red and white mangroves lining the adjacent tributary creek. When the freeze occurred during a low-low tide these mangroves were not protected by the underlying warmer water and the freeze killed the tops of these mangroves. In the autumn of 2011 the trees are resprounting as coppices form the base of the trunk and lower branches.

The movement of salt marshes in response to sea level rise has been measured at other locations in the United States. The coastal salt barren (salterns) in the North Florida has moved inland 3-8 m horizontally from 1951 to 1997, which was translated to a 37 mm increase in MHW, or 0.82 mm/y increase in sea level. Corrected for the post-glacial continental rebound factor, the rate of sea-level rise since 1951 is estimated at 1 mm/y (Hsieh and Gone 2001). Low marsh has moved into and replaced high marsh in New England salt marshes (Donnelly and Bertness 2001) without a subsequent movement of high marsh landward.

Faculty and students from the University of Florida have documented coastal forest decline and replacement by saltmarsh in the Yankeetown area since the mid-1990s (Williams et al. 1999, Castaneda and Putz 2007, DeSantis et al. 2007). These studies revealed that the die-off of cabbage palm and red cedar uplands is mostly a consequence of chronic stresses of sea level rise coupled with the punctuated disturbances of storms and droughts.

Barriers to Salt Marsh Movement in Response to Sea Level Rise that have Resulted in the Loss of Salt Marshes in the CHNEP

Borrow Pits

The clear white sands of the saltern areas were once a preferred location for excavation of sand for use in road beds and fill pads for construction. The utility of this highly salinated material as a base for foundations seems questionable but be-that-as-it-may there are borrow pits located in the high salt marsh of San Carlos Bay, Hurricane Bay, east Hendry Creek, Glover Bight, the east and west sides of Pine Island, and Cape Haze,.

Salt marsh is not able to move landward when blocked by these deep water features. The high salt marsh east of John Morris Road is disappearing as mangroves move into the former marsh and the marsh cannot move into the location where the borrow pit and associated berm are located. This Yakubik borrow pit was excavated in salt marsh and is now utilized as a lake amenity for a high rise development known as Mastique. It is interesting to note that a site review of the pit in the late 1980s observed a shark, mullet, and other estuarine life in the pit which was still connected to tidal waters during high-high tide. Today it is surrounded by a perimeter berm. Examination of successive aerial photography indicates that the high marshes are disappearing in the area waterward of the borrow pit and berm through time. It appears that 57% of the high marsh present in 1994 is now replaced by mangrove.

Figure 172: Yakubik Borrow Pit, now a lake feature at a high rise development, excavated in salt marsh.

Spreader Waterways

Southwest Florida has been an area developed with the most significant spreader waterways in Florida. The initial concept of spreader waterways was that these manmade waterbodies would intercept freshwater run-off from developed urban and suburban landscapes and then spread the stormwater run-off across the salt marshes and mangroves located waterward of them. The natural marshes would then serve as a filter remove pollutants prior to their entry into open state 3waters. The design concept was that the spreader water ways would be built in the uplands located immediately adjacent to the landward edges of the salt marshes and mangroves. However this was not what occurred. Instead spreader waterways were constructed by excavation of high marshes paralleling the mangrove forests of Matlacha Pass, Cape haze and Hog Island. The waterward edges of these linear manmade features were at or within the basin black mangrove forests of these large fringe mangrove forests. Subsequently significant areas of salt marsh were immediately eliminated and other areas were buried under the spoil piles cast on the waterward side of the spreaders. The systems did not function as hypothesized. Significant environmental damage was initially done and subsequently exotic plants colonized the spoil piles. Where the surface elevation of the spreader was lower than the adjacent waterward salt marsh or mangrove land surface the wetlands were back drained into the spreader dry out the wetlands and allowing further expansion of exotic plants and animals into the former estuarine wetlands. It is unsurprising that the Nile monitor lizard and the mahoe have become established in association with the landscape created by spreader canals.

These system are large and extend for 7 miles along southern Matlacha Pass and 8 miles north of Pine Island Road along northern Matlacha Pass. The spreader associated with Port Charlotte known as the Manchester Water way is 7. 5 miles long. The spreader on the east side of the developments on Cape Haze is 7 miles long. The South Spreader averages 200 feet in width. The North Spreader averages 150 feet. The Manchester Waterway is highly variable in width that ranges from 75 to 250 feet in width. The Cape Haze waterway ranges from 140 to 1,000 feet in width. A rough calculation yields an estimate of 946 acres (383 hectares) of mangroves and salt marsh eliminated by the construction of these four spreader waterways.

Figure 173: View of the North Spreader Waterway, Cape Coral.

Area in green is State Lands of the Charlotte Harbor Preserve State Park. Spreader is locat4ed to the east of the Park. Source: Google Earth 2010

Figure 174: A section of the North Spreader Waterway, Cape Coral.
Spreader is on the right, high salt marsh is central, smaller canal and mangrove forest on Matlacha Pass on left.
Source Google Earth 2010

Navigation Canals

Approximately 400 linear miles of man-made canals were built in the 1950s to 70s on and around the CHNEP, resulting in the loss of salt marsh, mangrove, sea grass, and other shallow bottom habitats (Charlotte Harbor SWIM 1993). Estimation of the amount of acreage of different habitats eliminated would require another study.

Figure 175: Navigation Canal System, Punta Gorda Isles, Charlotte Harbor and Peace River Watersheds.

Note gray color register is damaged mangrove forest form Hurricane Charley. No salt marshes are present.

Drainage Canals and Mosquito Control Ditches

Drainage canals have been constructed in a number of different contexts in the CHNEP typically to deliver freshwater runoff from uplands and wetlands at a faster rate to tidal waters and lower water tables to allow conversion of shorter hydroperiod wetlands into marginal uplands. In salt marshes this can have the joint deleterious effects of short circuiting sheetflow delivery of freshwaters across the high marsh landscape zonation, draining the salt marsh zones directly into a lower elevation feature, and allowing access of deeper waters to deliver mangrove propagules, larger marine predators, and sea level rise higher into the landward gradient than would naturally occur. All such ditches line with mangroves, being colonized first by white mangrove then black and/or red depending on ditch salinities. The canal frequently have associated spoil piles form the cast off excavant that become a focus for exotic plant and animal occupation. The ditches fragment the marsh cross connections, break zonation, and reduce effect habitat space for the native salt marsh plants and animals. The fractalization of the once continuous salt marsh introduces negative edge effects throughout the community. Sediments erode into the ditches lowering marsh substrate surface. Drained organic sediments ablate on exposure to long periods of air drying further reducing marsh platform elevations. All this aids in loss of marsh surface and extents to sea level rise and mangrove colonization.

Efforts to control mosquitoes in southwest Florida began in the early 1930s with the use of ditching, impoundments, and pesticide spraying (Montague and Wiegert 1990, David 1992). Widespread decreases in wetland habitats were seen with dragline ditching, with the amount of wetland habitat lost varying with the intensity of ditching. Salt marsh plants were killed from the semi-permanent flooding and salinity changes caused by ditching. Mangroves moved up mosquito control ditches. The ditches effectively lowered the marsh's water table by several inches, eliminating ponds and intermittent pools, as well as creating drier soil conditions. Other changes included the elimination of pools containing widgeon grass important to migrating ducks and other waterfowl common in the CHNEP in earlier times. This change in plant species composition led to an overall decrease of values and functions. For example, studies have shown that avifauna species abundance and diversity is greatest on the natural marsh and significantly lower in ditched marsh habitats (Reinert *et al*., 1981 and Clarke *et al*., 1984).

This reduced salt marsh ecological productivity, which in turn reduced the fish and wildlife an area could support. The valuable protection from storms that wetlands provide was also diminished. Juvenile fish habitat was lost. The wetlands lost plants, especially grasses, which are critical for providing food and shelter for fishes, crabs and shrimps. The deep water provided by the ditches allows large fish predators access to what was historically shallow water habitat utilized by small juvenile and resident fish.

Exotic vegetation and upland native plant species moved into drained salt marsh as soil salinities were diluted by precipitation. Spoil areas are substantially higher elevations than the surrounding wetland. Exotic tree species preferentially established on spoil piles left behind form the dredging of the canals. This elevation allows the colonization of upland plant species, including invasive nonnatives, such as Brazilian peppers. The mangroves that remain inhabit a narrow intertidal zone along the edges of spoil piles, but are often out-competed by terrestrial and exotic species on the elevated portion of the pile.

Management efforts to control the population of mosquitoes continue today, although substantial progress had been made to minimize negative impacts on salt marshes and a emphasis on source reduction through larvacides.

Recently there has been renewed resistance to salt marsh restoration by a mosquito-control district that wants to retain deep mosquito control ditches.

Leisnham and Sandoval-Mohapatra (2011) in a study of ditch plugged and control open ditch tidal salt marshes found that the majority of mosquitoes are found in wooded habitats had more total mosquitoes, were also more frequently occupied by mosquitoes and had higher densities of mosquitoes than either salt marsh habitat.

Mosquito Control Impoundments

In the late 1960s the J.N. Ding Darling NWR built a dike through the estuary to create two areas of impounded water in an effort to control mosquito populations. Salt marsh impoundments were constructed as a management technique to decrease mosquito populations by continuously flooding areas during the mosquito-breeding season to prevent mosquitoes from laying their eggs. J. N. Ding Darling NWR manages mosquito impoundments on Sanibel Island. As marshes were impounded, the vegetative community experienced numerous changes. Isolated from regular tidal flushing with adjacent estuarine waters, the water levels in the impoundments often became entrapments for high levels of stagnant or fresh water. Many halophytic species like saltwort and glasswort could not survive the high water levels and were invaded and replaced by mangroves, primarily red. mangrove colonization caused an accumulation of sediments. The, increasing the elevation of the marsh from sediment accumulation significantly reduced the frequency and extent of tidal inundation. The reduction of flushing influenced levels of salinity, dissolved oxygen, temperature, and sulfur compounds and caused the marshes to become stagnant. In areas where the salinity decreased significantly, freshwater vegetation took over, especially cattails (*Typha* sp.). Unfortunately, impoundment degraded the overall health of the habitat in the impoundments and reduced their usefulness for all wildlife.

Impoundment of salt marshes led to a reduction in the number of faunal species present, especially transient species that previously relied on tidal exchange to access the marsh (Harrington and Harrington 1982, David1992). Numerous transient fish species were isolated from their former salt marsh habitat and the changes in water conditions could no longer support many of the estuarine organisms. Although some migratory birds benefited from the availability of habitat in the newly ponded marshes, many others were negatively affected. The most grave and irreversible impact was to the dusky seaside sparrow (*Ammodramus maritimus nigrescens*), which was driven to extinction in 1987(Kale 1996) on the east coast of Florida.

On the short term, impoundment methods were successful in controlling mosquitoes, but the intensive maintenance turned out to be too costly to regularly uphold and many of the impoundments actually turned into mosquito breeding grounds. Recognizing the need to restore some of the natural integrity and function back to the salt marsh ecosystem, new methods were implemented to improve mosquito control while taking natural resource issues into consideration. The current management practice for most impounded marshes uses the rotational impoundment management (RIM) approach (David 1992). The RIM is a method to seasonally control water levels to promote tidal flushing and habitat function while controlling mosquitoes. The RIM includes seasonal management, reduction in pesticide use, tidal range approximation, tidal range estimations, and water quality improvements, restoration of vegetation, customized tide gate aeration and pumping operations, drawdown operations to enhance wading bird use, and block or regional impoundment management (David 1992). This strategy controls the mosquito population while providing essential tidal exchange needed during peak fish recruitment times (spring and fall) (David1992). Management techniques to benefit wading birds focus on lowering water levels to concentrate fish for the wading birds to feed on.

Today the J.N. Ding Darling NWR impoundments have water levels that more closely follow the natural tidal fluctuations. The water levels in the impoundments are artificially lowered only to coincide with the spring and fall shorebird migrations in order to provide optimal feeding habitat for the hundreds of birds that use the refuge as a refueling area.

Review of the these impoundments today finds no salt marsh within them. All emergent vegetation is some form of mangrove forest. All the current salt marshes in the J.N. Ding Darling National Wildlife Refuge are further landward. With the current sea level it is unlikely that salt marshes could be reestablished within the impoundments without significant modifications in elevation on the south sides of the impoundments.

Figure 176: J.N. Ding Darling National Wildlife Refuge Impoundments
Source: Google Earth 2010

Shoreline Hardening: Sea Walls, Bulkheads, Rip-rap, "Living Shorelines" with rip-rap at the landward side

Seawall construction has existed since ancient times. In the 1st century BCE, Romans built a seawall / breakwater at Caesarea Maritima creating an artificial harbor (Sebastos Harbor). The construction used Pozzolana concrete which hardens in contact with sea water. Barges were constructed and filled with the concrete. They were floated into position and sunk. The resulting harbor / breakwater / sea wall is still in existence today - more than 2,000 years later. Some of the first English sea walls were constructed in 1623 in Canvey Island, UK, when great floods of the Thames estuary occurred., Seawall design has become more complex and intricate in response to an improvement in materials, technology and a shift from land protection to wetland conversion to uplands for private property..

For the purposes of this discussion we will use the term coastal bulkheads to refer to seawalls, bulk heading, riprap revetments and other forms of shoreline hardening. These manmade structures are constructed along shorelines with the purpose of controlling coastal erosion and/or retaining a much higher upland elevation in direct juxtaposition to wetland or surface water natural elevations.. Construction materials commonly used include wood pilings, commercially developed vinyl products, large boulders stacked to form a wall, or a seawall built of concrete or another hard substance.

Later bulk heading by United States settlers in Florida tended to be wooden structures. Some of the first stone seawalls and bulkheads in Florida were constructed by the Spanish in St,. Augustine and Pensacola in formalizing the boundaries of the ports established there. Later the U.S. Army extending and expanded seawalls in St. Augustine for Castillo de San Marcos, renamed Fort Marion by the Army, and downtown district of the city. Other port cities (Key West, Pensacola, Jacksonville) were initially sea walled by the U.S. Army Corps of Engineers in cooperation with the U. S. Navy sea-walling expanded in south Florida through the 1920's land boom that created the initial southeast coast waterfronts and then picked up again in the 1960's to 1970's throughout Florida including the CHNEP. Most of the bulkheads around the CHNEP are 40 to 50 years old, though bulkhead construction continues to this day on man0-made canals under general permits and exemptions to ERP rule standards.

For the CHNEP shoreline hardening (seawalls and riprap) is greatest in the Peace River watershed (36.96% of total shoreline).. This is followed by Charlotte Harbor (18.97%), Lemon Bay (12.5%), the Caloosahatchee River (8.37%), Dona and Roberts Bays (5.9%), Myakka River (5.74%), and Pine Island Sound/Matlacha Pass (4.27%).

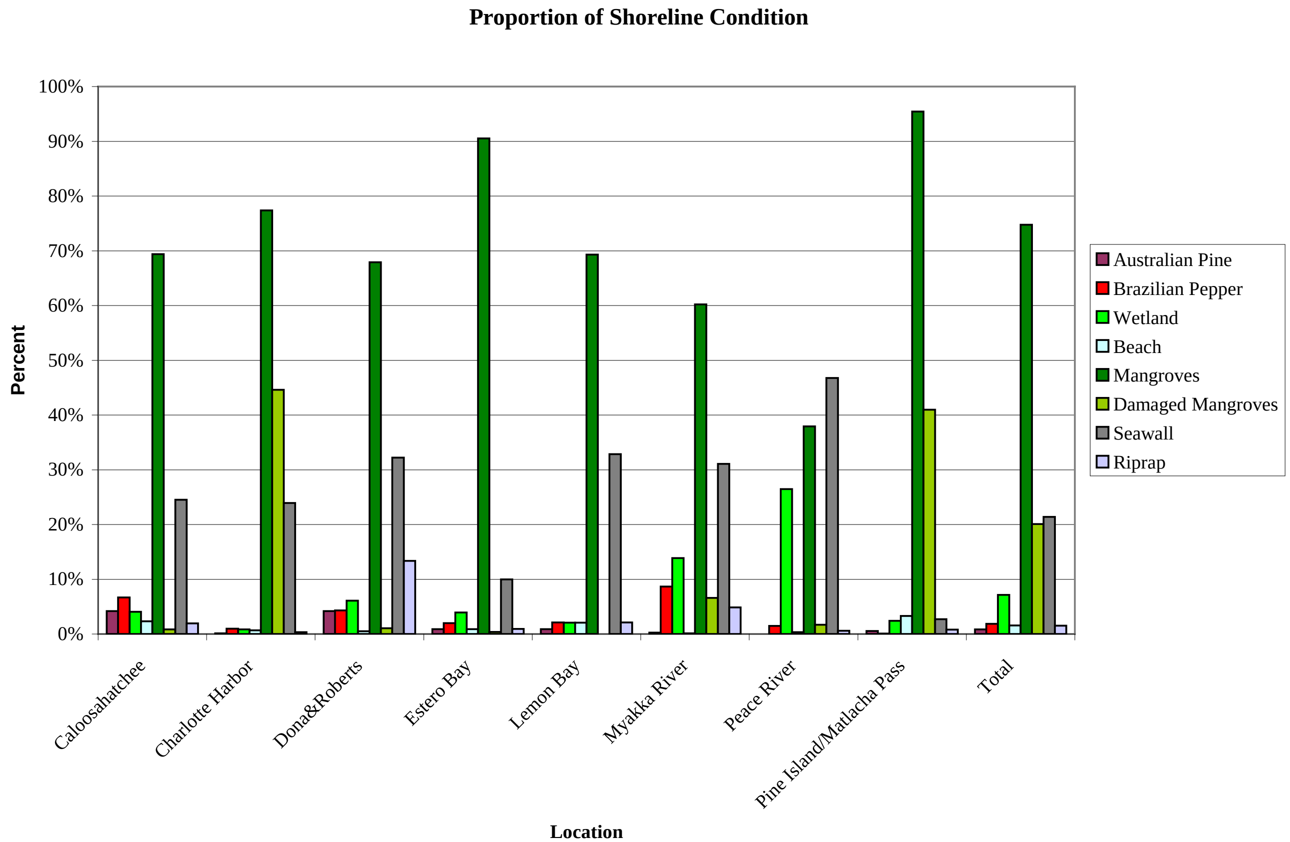


Figure 177: 2007 Shoreline Conditions
Note salt marsh is indicated on the key as wetland. Source: CHNEP 2008

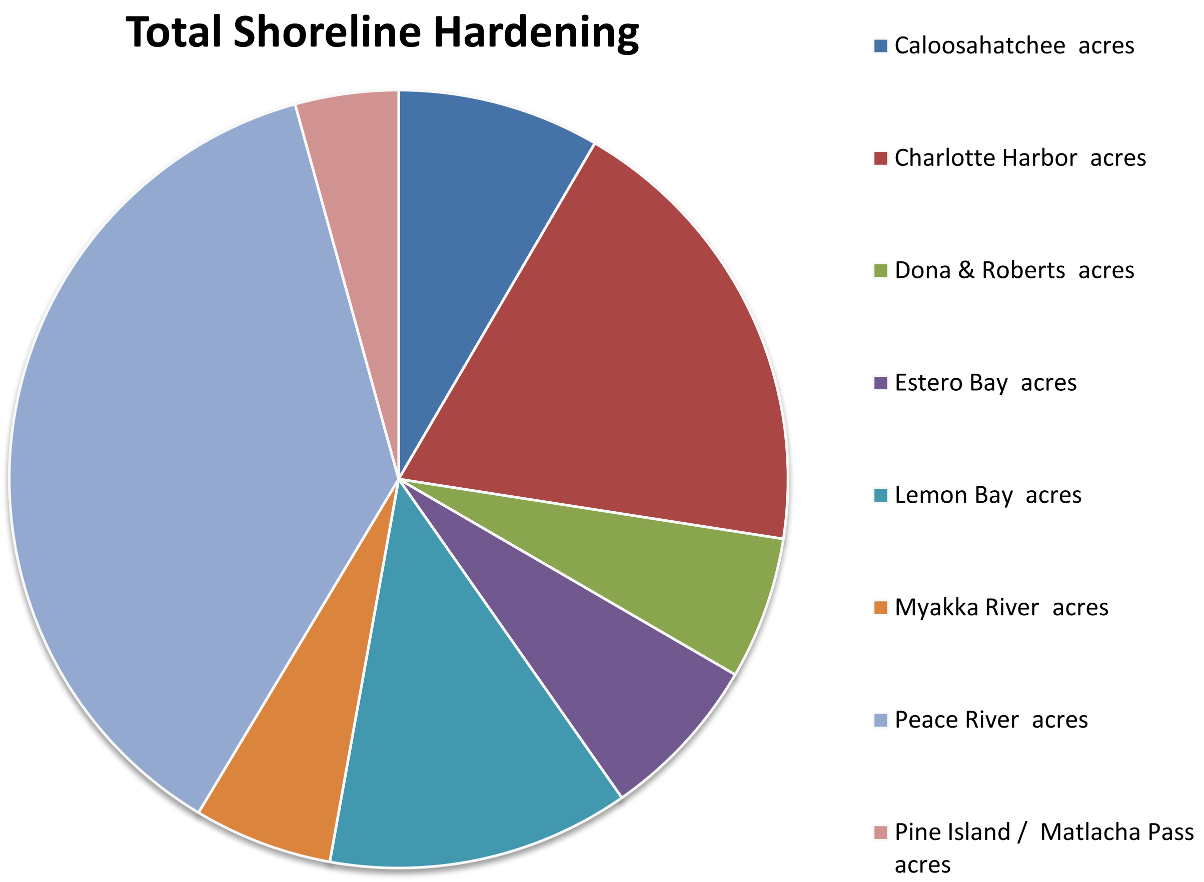


Figure 178: Relative distribution of area of shoreline hardening by watershed

The relative proportion of shoreline hardening is 41% for the Peace River, 29% for Lemon Bay, 5% for both Dona and Roberts Bays and the Myakka River, 22% for the Caloosahatchee River, 16% for Charlotte Harbor, 9% for Estero Bay, and 2% for Pine Island sound/ Matlacha Pass.

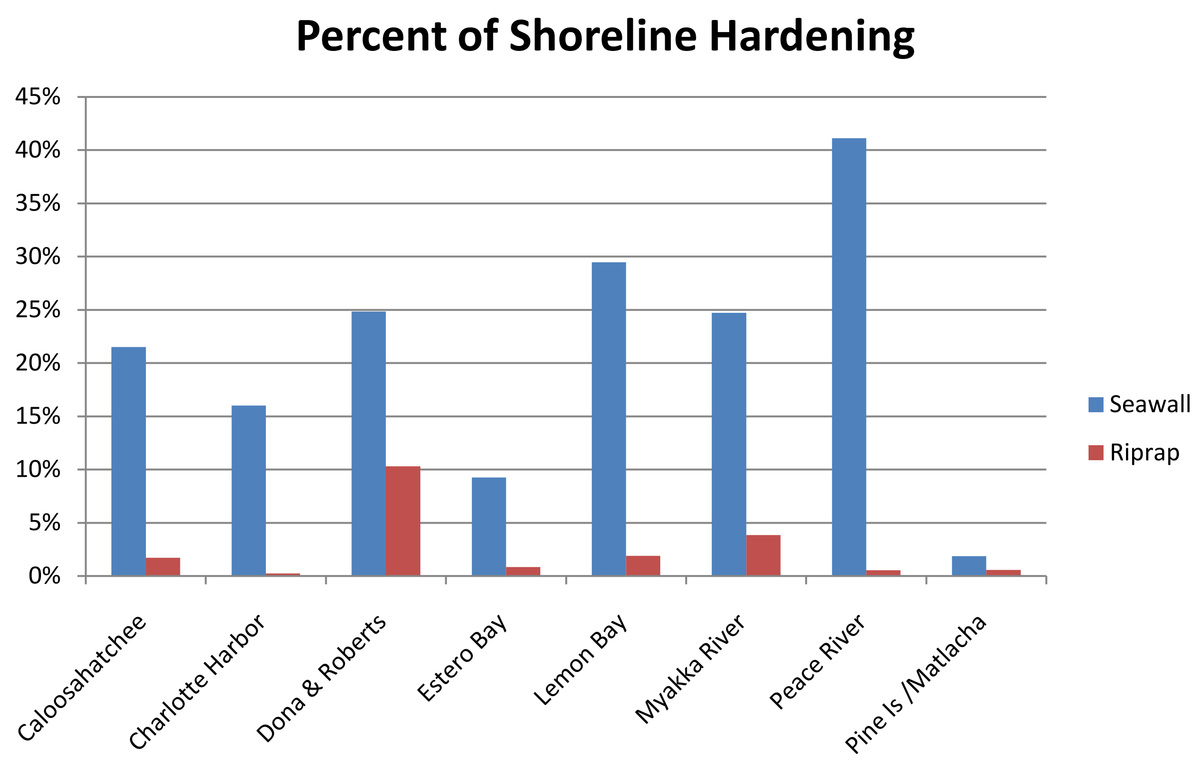


Figure 179: Percentage of shoreline hardening by watershed

Among the disadvantages of coastal bulkheads, is that they are very expensive to construct and maintain; can cause shorelines and other waterward habitats to dissipate rendering them useless for human use, wildlife and vegetation; scars the very landscape that they are purported to protect, providing a scenic 'eyesore.'; reflect the energy of waves leading to scour at the base of the coastal bulkheads disrupting natural shoreline processes and destroy shoreline habitats such as salt marsh wetlands and intertidal beaches; and alter sediment transport processes that disrupt sand movement that can lead to increased erosion down drift from the structure (Short 1999).

While bulkheads may serve their purpose in the short term to slow erosion at a canal or shoreline they commonly cause a domino effect of change to the shore profile. The increased wave reflection caused by their presence can result in an increased re-suspension of sand in the water in front of the bulkhead. This can lead to more sand being distributed in the alongshore direction, away from the shore profile. Due to coastal littoral drift, the sand would then instead be distributed toward the ends of the bulkheads, leaving a deeper trough and other exposed turbid sediments in place of the once sandy bottom. Studies over recent decades have resulted in public awareness as to potential negative effects that bulkheads may bring to beaches and the interconnected habitat areas of fish, plants, and birds.

Berms

In some watersheds the salt marsh landward margins encounter and abut berms constructed for a variety of purposes. Most commonly this is related to surface water management systems designed to retain and treat stormwater prior to discharge over control structures at specific points to the salt marsh or a ditch in the salt marsh. Therese berm features are observed on the waterward side of water control retention lakes and ponds, grassed lawns, golf courses, and agricultural fields. Examples of these berm features are prevalent on the mainland side of Estero Bay and both sides of Pine Island and tributaries of Lemon Bay. The height of these features vary and range from a foot to six feet. Often these features have a associated ditch that parallels the base of the berm form which the berm material was excavated. In some of the agricultural sites ditches are found on both sides of the berm. These ditches can channel water perpendicular to tidal flow patterns when the berm is constitute across the tidal gradient. These berms are designed as barriers to water flow from the upland land use and the adjacent salt marsh wetlands. These berms include the spreader waterway berms on the major spreader waterways that are basically cast off spoil, but do not include the smaller correctly designed spreader swale system at the Bonita Bay development that flanks the central slough between the Imperial River and Spring Creek.

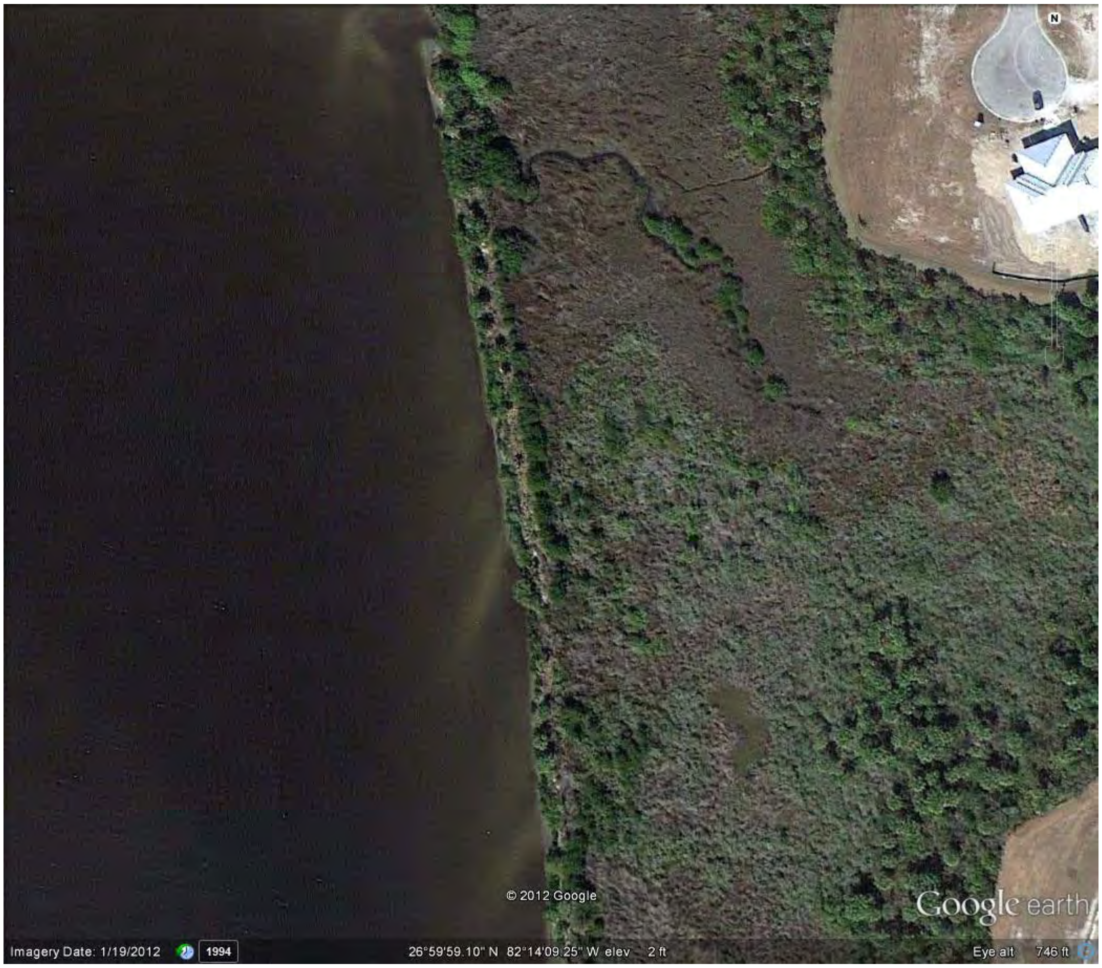


Figure 180: Berm on the Myakka River east bank
Source: Google Earth 2010.

Roadway and Railway Beds that Act as Berms

Roadway and railway construction in southwest Florida and the CHNEP often involves elevating the roadway bed above the natural ground elevation to attain structural integrity, to be above tidal stages and to maintain a level read bed in crossing wetlands and on bridge approaches. This creates significant berms often attaining multiple feet in height above salt marsh elevations. This is particularly common for causeways on major bridges where fill features are constructed across tidal wetlands instead of more expensive bridge decking. Most of these road beds do not have pass-through culverting to allow tidal flow to connect between salt marsh segments.

Major causeways that block tidal flow in the CHNEP include the Summerlin Road approaches to the Sanibel Causeway and Bridges, the north shore of the I-75 Bridge across the Caloosahatchee River, the north shore of the I-75 Bridge across the Peace River, and SR 17 across Shell Creek.

Roadbeds that act as berms in salt marsh wetlands include the section of CR 865 on Big Hickory Island, the west end of Coconut Road, John Morris Road, Shell Pointe Road, Veterans Parkway, Pine Island Road crossing Little Pine Island, SR 775 northeast of Placida, Abee Farm Road south of its intersection with Laurel Road.

Several non-public dirt roads designed to allow access for utilities company inspection and maintenance of power lines cross salt marsh including areas of salt marsh on Estero Bay and Pine Island.

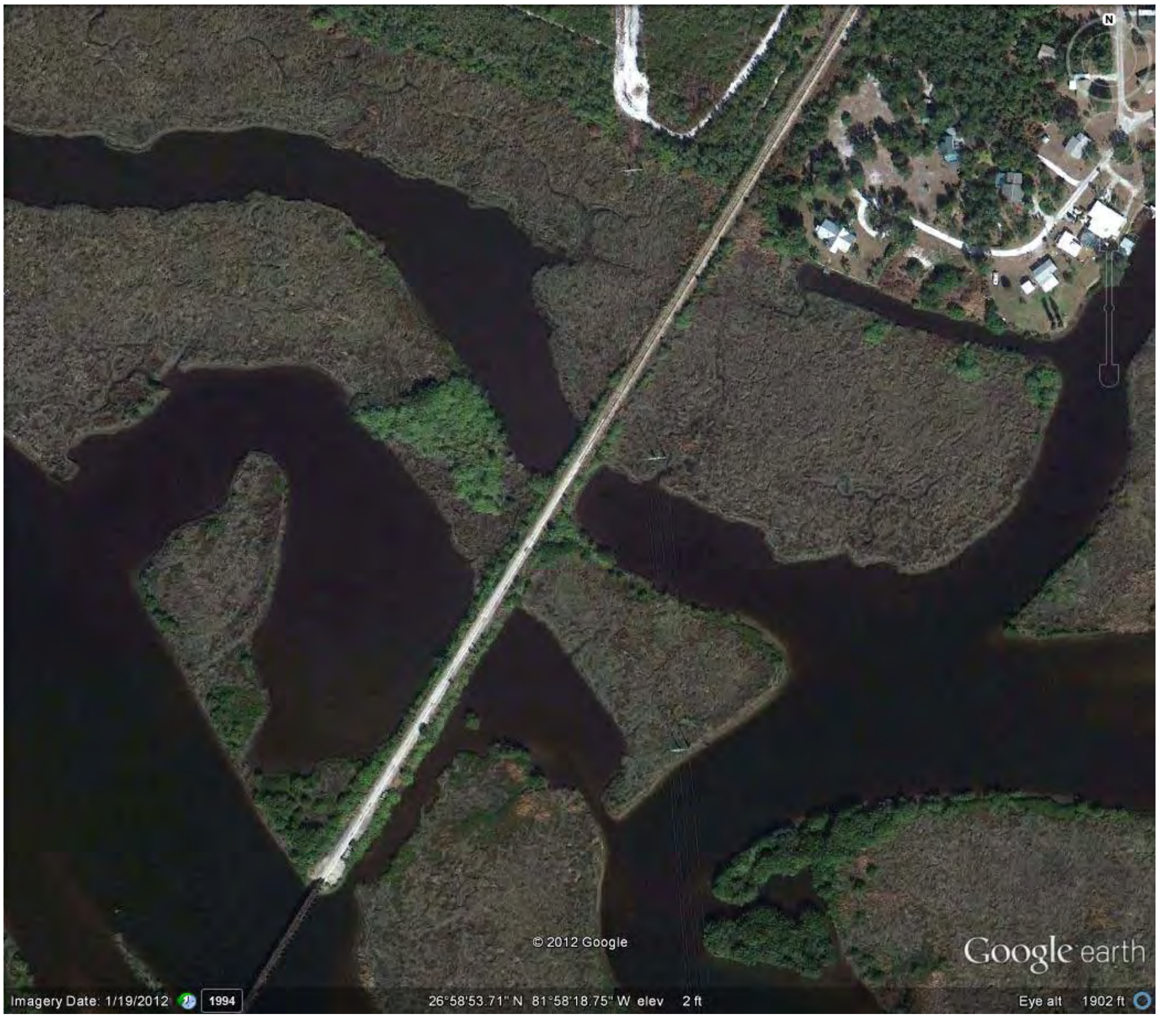


Figure 181: Railway Grade fill across salt marshes of Shell Creek that act as a berm.
Source Google Earth 2010

Ten Opportunities in Critical Areas for Implementation of Avoidance, Minimization, Mitigation and Adaptation (AMMA) Options and Recommended Strategies to Implement the AMMA Options for the Salt Marshes of the CHNEP.

There are several potential adaptations and recommended strategies to implement the AMMA options to maintain salt marshes as a vital and important component of the CHNEP ecosystem. Some of these adaptations have already been undertaken with success because of the foresight and the persistence of vison of citizens and professional conservationists that began protecting the shorelines of the CHNEP stating the 1960's and 1970's.Significnat areas of salt marsh exist today because of these conservation lands acquisitions made at a time when only a few acknowledged the sea level rise that was ongoing and present in Florida. Other adaptations are new for the CHNEP area but have been implemented in different forms in other areas. Other adaptations will be controversial because there are other competing interests that will not desire modifications to the human engineered coastline that have invited sea level and mangrove expansion into salt marshes, that have been made for a verity of reasons. The removal or retrofitting of existing barriers to salt marsh migration including Borrow Pits, Spreader waterways, Mosquito Control ditches, Mosquito Control Impoundments, Bulkheads, Rip-rap, "Living shorelines" with rip-rap at landward side, Berms, Roadway Beds, Drainage Canals, and Navigation Canals will likely prove to be the most difficult set of adaptations for public support.

In considering what adaptations are available in the CHNEP area it is first it is important to recognize the climate change is occurring. Sea level rise has been ongoing and is active today and into the future. Even if the accelerations of the rate of sea-level rise predicted by some do not occur sea-level will continue to rise and the position of salt marshes or existence of salt marshes on a specific shoreline profile within the CHNEP will change over time in response to these changes.

Our examination of historic aerials from 1953 and comparing them to current extents of salt marsh make clear the salt marshes will not stay in place if the opportunity exists for the salt marshes to establish a new land ward position landward of their initial extents. This has occurred in areas where marsh migration corridors were establish by far sighted planning that established public land buffers on the mainland shorelines of significant portions of the CHNEP estuarine waterbodies. We have been able to measure these movements in the Estero Bay Preserve State Park, the Charlotte Harbor Preserve State Park, Little Pine Island and the combination of state, Lee County and federal preserve lands located at and above Bunche Beach.

1) Maintain the existing marsh migration corridors that have been established on Cape Haze, Eastern Charlotte Harbor shoreline, and mainland Estero Bay and Identify the highest priority marsh migration corridors so that they can protect these areas from future development.

Large landscape scale land acquisition has been an ongoing process in southwest Florida and the CHNEP since the early 1970's with acquisition of buffers surrounding the estuaries of the CHNEP , the Big Cypress Swamp and western Everglades. Continued regional habitat planning created corridors for habitat from coastal area inland to interior preserves form Charlotte Harbor to Lake Okeechobee, Estero Bay to the Corkscrew regional Ecosystem, and the Ten-Thousand Islands toward the Caloosahatchee River (Beever et al. 2007). A Coastal Conservation Corridor Plan was developed in coordination with the Nature Conservancy and 54 cooperating governments and public entities to further advance the goal of planned land acquisitions along the Florida Gulf Coast that complemented each other and achieved long term survival in the face of climate change as well as other stressors (Beever and Bryant 2003).

An examination of the mapping performed as part of the study of where humans will likely want to implement coastal armoring against sea level rise demonstrates the location of the highest priority salt marsh migration corridors of the CHNEP. On this maps the areas that have a combination of green, light green and purple colors demonstrate the following locations for priority salt marsh migration corridors

County	Location	Level of Connection to adjacent Public Lands	Path of Connection	Potential extent of migration
Sarasota	Myakka River Riparian Corridor	High	North to Myakka River State park	High
Sarasota	Gottfried Creek	Low	North and East to Myakka River	Low
Sarasota	Rock Creek	Low	North and East to Myakka River	Low
Charlotte	Cape Haze State Preserve	High	North into Cape Haze	High Initially. Can be expanded with acquisitions to remain High
Charlotte	Tippecanoe Bay	High	North into Charlotte County Lands	High then Medium. Could be expanded north of SR 776
Charlotte-DeSoto	Peace River	Low	North up river	High but not extensive as River shoreline elevations become steeper
Charlotte	Shell Creek	Low	East toward headwaters	High then Low when blocked

				by water control structure
Charlotte	Charlotte Harbor State Buffer Preserve	High	East to extensive Public Lands include the Yucca Pens and Cecil Webb Wildlife Management Areas, Babcock Ranch, and Fisheating Creek	High. Perhaps the best in the CHNEP and southwest Florida if roadway barriers can be addressed.
Lee	Burnt Store Creek	Medium	East to extensive Public Lands include the Yucca Pens, Cecil Webb Wildlife Management Areas, Babcock Ranch, and Fisheating Creek	Medium. Connection is narrow and Burnt Store Road is a potential barrier.
Lee	Estero Bay Preserve- North	Medium	Further into preserve	Initially High but block by urban lands uses
Lee	Estero Bay Preserve	Medium	East on State lands and then along Estero River and halfway Creek Corridors	Initially High but narrow with several road barriers until connection to the Corkscrew Regional Ecosystem Watershed

Table 20: Priority salt marsh migration corridors for the CHNEP

2) Acquisition/Protection of inland/landward buffer zones to provide an opportunity for habitats and wildlife to migrate inland.

The following discussion depends significantly on the contributions of and Titus (1998), Trescott and Walker (2009), Volk (2008a), and(Beever et al. 2009b) .

Many adaptation options that maintain sediment transport are reactionary, in that they seek to reverse changes that have already occurred or changes that will continue to occur. Because sediment transport is based on a constant cycle of gains and losses, all of these options require maintenance. However, when combined with other actions, these adaptation options may work to prevent loss of coastal habitats and enable marshes to accrete at a rate consistent with sea level rise (Martinich 2008). Adaptation options to maintain sediment transport include either trapping sediment that would otherwise migrate or reintroducing sediment into systems. Constructing groin structures traps sand and prevents it from traveling down shore. Adding sand to beaches with beach nourishment projects that extend the shoreline or create dunes, and replacing sand in water bodies following storms allows for sediment transport to continue and reverses losses due to erosion (Martinich 2008).

Some possible responses to sea level rise include building walls to hold back the sea, allowing the sea to advance while adapting to it, and raising the land (e.g., by replenishing sand and other substrates). Each of these responses is costly, either in out-of-pocket expenses or in lost land and structures. For example, the cumulative cost of enough beach sand replenishment to protect Florida's coast from a 20-inch rise in sea level by 2100 was estimated at $8.8 billion in 2007 (USEPA 1997). This would be $12.58 billion in 2012.

The three primary options for development responses to sea level rise and storm surge effects discussed in established literature (Titus et al. 1991) are *protection* (armoring, filling, diking), *managed retreat* which is better described as planned relocation, and structural *accommodation* adaptations (such as elevation of substrate). Each method possesses advantages and disadvantages (TCRPC 2005). To date, The major method implemented for some parts of the CHNEP has been planned relocation by habitat migration across a conservation landscape.

One of the major problems in evaluating the different options to address flooding from storm surges, sea level rise and the combination of the two is that the names utilized to describe the activities have psychologically loaded contexts. The term "protection" that can represent expensive and complex engineering solutions has a heroic and active context of man vs. nature, triumph over adversity. In contrast the terms managed retreat and accommodation have passive and negative connotations associated with defeat, particularly for those that seek active, physically tangible solutions to problems (Beever et al. 2009b). In reality the salt marshes of the CHNEP are responding to sea level rise by moving or relocating to a landward location, not by retreating.

It was the determination of the study *Summary of Research on Strategies for Adaptation to Sea Level Rise in Florida* by Michael Volk of the University of Florida, that a variety of strategies will be necessary for adaptation, particularly along protected shorelines. These strategies may be categorized based on the existing and projected land use and on the natural coastal ecology. Volk's (2008b) strategies are broken down based on high or low energy shorelines, and developed or undeveloped land use. The general recommendation from that study was for managed retreat from the shoreline.

Volk's conclusions are that ecologically and financially sustainable shoreline protection is probably not possible, particularly on high energy shorelines. Protection of any shoreline will only be feasible up to a certain amount of sea level rise, after which the financial costs will be too great to justify protection. As an alternative to shoreline protection, managed retreat policies could be implemented and shorelines could generally be allowed to retreat naturally.

Armoring ("Protection")

Protection refers to shoreline stabilizing or hardening techniques, such as seawalls and beach nourishment, that attempt to maintain a static shoreline position. It also includes diking and filling to keep pace with sea level. *Protection* may appear to be financially sustainable in the short term because it does not require relocation or discontinuation of marsh use. If the structural method is a relatively small in proportion to the total infrastructure investment both in terms of effort and costs, including maintenance, then it is more easily selected. However, in the long term *protection* is likely to prove to be financially unsustainable. Recurrent marsh damage will likely increase due to the effects of sea level rise coupled with more severe storms and storm surges, droughts, and changes in seasonal hydrology. Protective structure maintenance and construction costs will increase. The concentration of public resources on protection of shoreline infrastructure will require an unbalanced use of public funding sources repetitively on the same parcels. Armoring, filling and diking all damage the recreational and fisheries values of marshes by causing shoreline ecosystem loss. *Protection* will likely be ecologically unsustainable because it tends to damage coastal ecosystems, alter shoreline processes such as sediment flows, and prohibit ecosystem translocation (Titus et al. 1991).

Strategies for shoreline protection were examined for high and low energy developed shorelines as well as for critical conservation lands by Volk (2008b). It was determined that ecologically and financially sustainable protection of high energy shorelines is not possible, due to the dynamic nature of shoreline processes. Seawalls or other hard stabilizing structures along these shorelines will destroy shoreline ecosystems, require continued maintenance, and will cease to be feasible after some level of rise. Beach nourishment used along shorelines will also have negative ecological effects, and will likely become more financially unsustainable as sea levels rise.
Sustainable protection of low energy developed shorelines was determined to have a higher level of feasibility than protection of high energy shorelines due to decreased wave and erosive energy. It may be possible to maintain functional shoreline ecosystems while still maintaining a 'static' protected shoreline for some limited time period. For this to happen, marsh ecosystems must still be allowed to relocated landward from rising seas. Ecosystem relocation inland from the existing shoreline is likely not possible if the existing shoreline position is expected to be maintained.

An option is to establish marsh ecosystems seaward of the existing shoreline, which can relocate up to the existing shoreline position. With this option, shoreline ecosystems may exist while maintaining an essentially static shoreline. The goals of a strategy such as this would be to maintain the same level of protection as would be gained through construction of a traditional protective structure such as a dike, to reestablish, maintain, and facilitate the adaptation of functional shoreline ecosystems, and to spread shoreline protection costs spread over a long period of time in keeping with rate of sea level rise. Several important issues created by this strategy, which could preclude its use, are sediment sources, takings of sovereign submerged lands, source of funding, and upland drainage.

Planned Relocation ("Managed Retreat")

Planned relocation or m*anaged retreat* refers to providing a moving path for salt marshes out of harm's way in a planned and controlled manner over time using techniques such as long-range landscape scale land conservation acquisition, property abandonment, and hazard avoidance. Planned relocation is ecologically sustainable because it allows natural ecosystem processes and marsh relocation to occur while protecting the public financial and infrastructure investment. It is financially sustainable because it avoids the long-term costs associated with armoring (*protection)*, particularly if it is based on long-range planning. There are however a number of issues related to *planned relocation* including dry land loss, in-migration land use conflicts, the possibility of 'takings' arguments and litigation, the ability to overcome existing external financial incentives for promotion of coastal and near coastal development, potential tax base impacts, and the potential short-term costs.

Protection of conservation lands is not generally recommended (Volk 2008a; Titus et al. 1991; SWFRPC 2005). Rather, facilitation of ecosystem adaptation and migration should occur. However, there may be cases where the criticality of conservation lands is such that it justifies short term protection. Figure 182-185 illustrates conceptually how this could occur. Water flow and disturbance of the existing tidal ecosystems are issues created by this strategy.

The primary elements of a *planned relocation* strategy could be as follows.

The first task: a comprehensive shoreline assessment to determine the unique characteristics of the specific shoreline, suitability analyses to determine which lands should be protected or where shoreline relocation should be allowed, and hazard projections to determine the area first in line to be inundated based on erosion, sea level rise, and storm surge estimates.

Second, fee-simple, non-fee-simple and other forms of acquisition including rolling easements or similar policies that allow shoreline relocation and disallow coastal protection or hardening could be implemented. Rolling easements are a special type of easement purchased from property owners along the shoreline to prevent them from holding back the sea but which allow some other types of use and activity on the land. As the sea advances, the easement automatically moves or "rolls" landward. Because shoreline stabilization structures cannot be erected, sediment transport remains undisturbed and wetlands and other important tidal habitat can migrate naturally. This step does not need to be implemented all at the same time and easements could be acquired in order of priority related to level and timing of exposure to coastal flooding.

Figure 182: Rolling easement step 1 Year 2010. Easement established at current shoreline. Source: CHNEP 2012 Based on Titus 1998.

Unlike setbacks, which prohibit development near the shore and can often result in "takings" claims if a property is deemed undevelopable due to the setback line, rolling easements place no restrictions on development. They allow the landowner to build anywhere on their property with the understanding that they will not be able to prevent shoreline erosion by armoring the shore, or the public from walking along the shore—no matter how close the shoreline gets to their structure. If erosion threatens the structure, the owner will have to relocate the building or allow it to succumb to the encroaching sea.

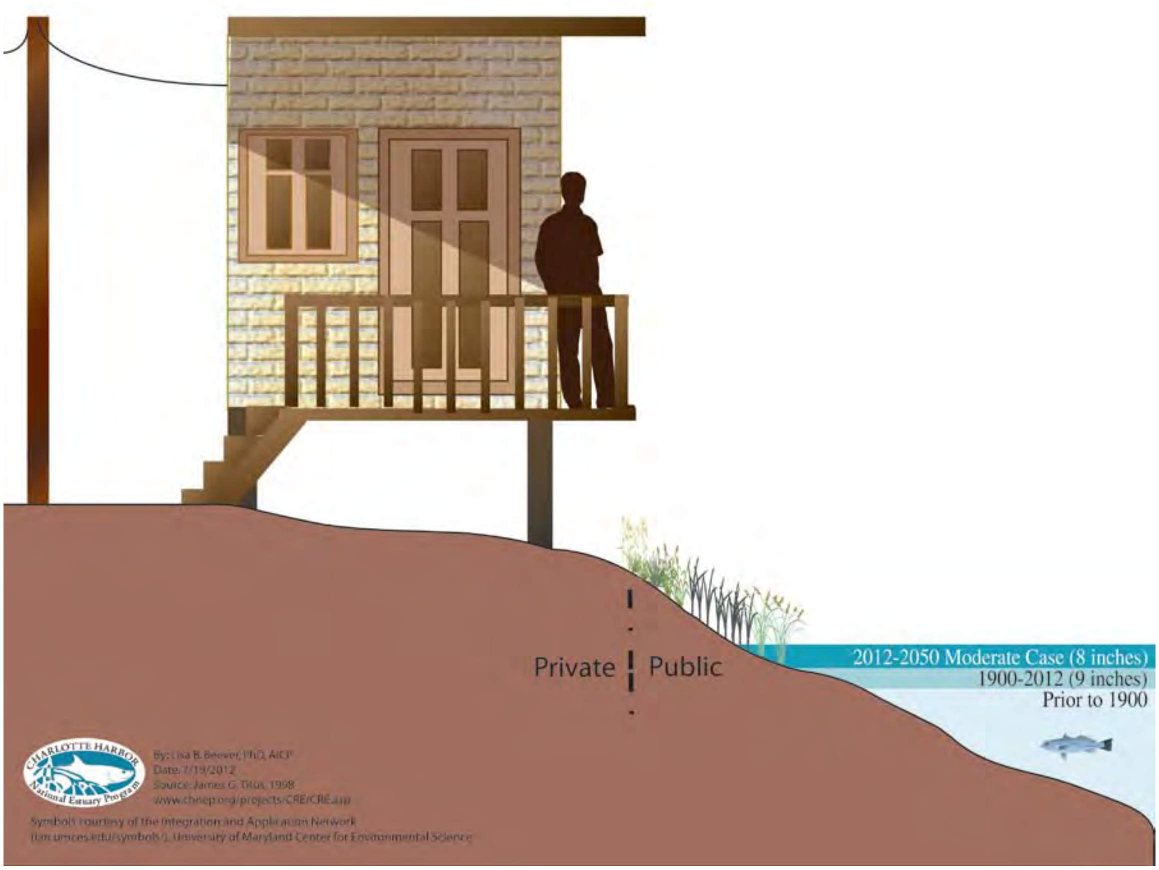


Figure 183: Rolling easement step 2: Year 2050.Moderate case 9 inches sea level rise. Mangroves and marsh move inland. Former mangroves become inundated.
Source: CHNEP 2012 Based on Titus 2000.

Under the Public Trust Doctrine, the public has the right to access tidal lands for fishing and recreation. Therefore, for most states, tidal land is public land. Even for "low-tide" states where private ownership is permitted up to the low-tide line, the public still has the right to access the intertidal zone. For the purposes of a rolling easement, eventually, as the shore continues to erode, the structure that was once on private property, will be sitting on public land. At this point, the private owner could decide to relocate the structure inland. Alternately, the property owner could allow the structure to remain until it becomes unsafe and pay rent to the state for use of public land.

Figure 184: Rolling easement step 3 Year 2100. Moderate case 20 inches sea level rise. Marsh moves inland. Former marsh becomes inundated. Source: CHNEP 2009 Based on Titus 2000.

Because there are no restrictions to land use, rolling easements have minimal impacts on property values, usually reducing property values by one percent or less (Titus 1998). "Takings" claims are also limited because it could be decades or more before erosion impacts are felt. In the meantime, the landowner would have full use of their property. To circumvent any potential "takings" claim, the government could purchase the easement from the property owner. More detailed examples about the cost advantages and disadvantages of rolling easements can be found in Titus (1998).

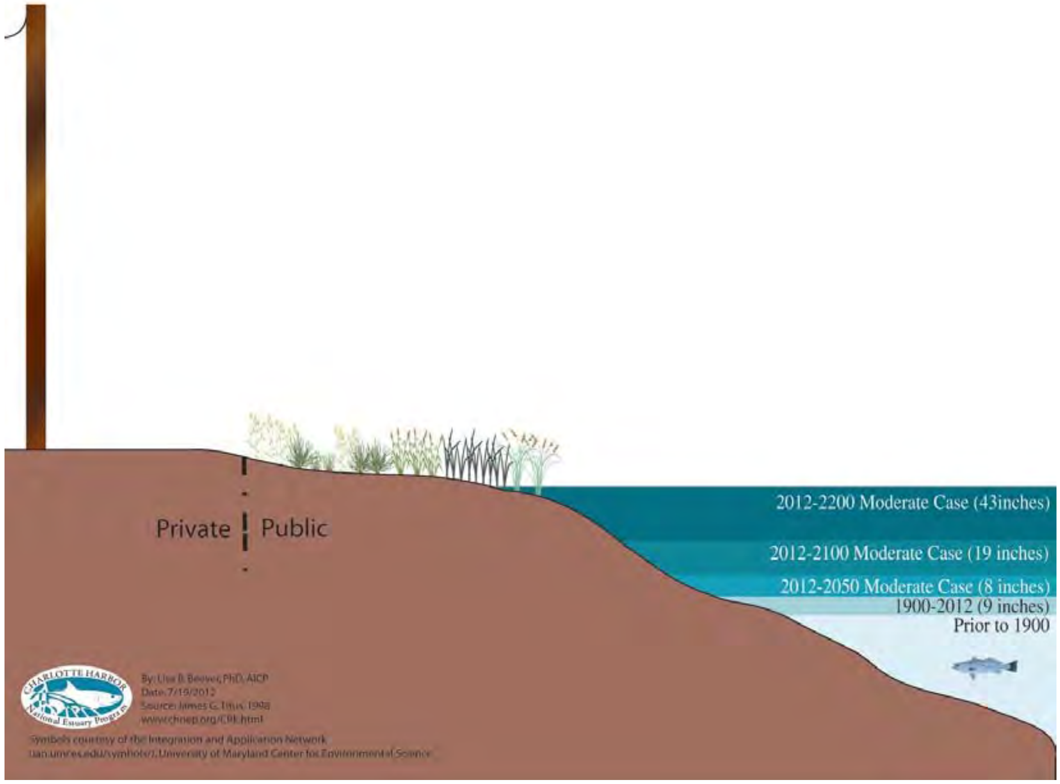


Figure 185: Rolling easement step 4 Year 2200. Moderate case 20 inches sea level rise. Marsh moves inland. Former marsh becomes inundated. Residence moved to new location or abandoned and removed. Source: CHNEP 2012 Based on Titus 2000.

In addition, because landowners are aware that their structure may one day need to be relocated, rolling easements can encourage the building of smaller, and more mobile structures that can be relocated easily.

Although rolling easements, like erosion control easements, can be useful shoreline management tools by themselves, and an effective way to implement managed relocation policies they are typically more effective if used in coordination with other approaches including setbacks and other building restrictions along the shore.

Among the benefits of rolling easements is that they help minimize activities that could enhance erosion problems without prohibiting development altogether. Often property owners can receive tax benefits for placing a conservation easement on their property. Rolling easements can help maintain natural shoreline processes. There are minimal "takings" issues as compared to setbacks. Rolling easements do not require as much scientific data as some other shoreline management approaches such as setbacks. Rolling easements are typically less costly than purchased setbacks as well.

Among the drawbacks of rolling easements is that they are not as effective for shorelines that are already significantly developed. Property owners may be hesitant to place easements on their property because the restrictions may decrease or be perceived to decrease the resale value of their property. Property boundaries typically do not align with drift cell boundaries or other environmentally relevant scales. Therefore, placing an easement along the shoreline to prohibit shoreline armoring or limit development in one area but not for another site in the same drift cell could exacerbate erosion rates down drift from the hardened/developed shoreline, negating any benefits a conservation easement could have. Enforcing rolling easements could be difficult.

Third, a local government may designate a special overlay district in salt marsh areas likely to be inundated based on hazard projections. Unique design guidelines should be implemented in these areas. Public financing in these areas should be minimized, particularly for new infrastructure. Within this area likely to be inundated, the City should create an along-shore buffer or easement for ecosystem retreat, management, and restoration. Property purchases, purchase of development rights, setbacks or deed restrictions, development disincentives, and sale incentives are some ways to create this easement. The City will need to plan for removal of inundated structures, infrastructure, and identify strategies for mitigation of hazards related to inundated structures. Creative reuse will be essential; for example, the reuse of building foundations as marine habitat could be appropriate.

Adaptations ("Accommodation")

Accommodation or in-place adaptation refers to strategies that allow for the use of vulnerable salt marsh lands to continue, but that do not attempt to prevent flooding or inundation with shoreline protection. Examples include relocation friendly restorations, removal or modification of barriers to relocation, and inundation friendly uses. Accommodation adaptations, if not part of a long-range plan for planned relocation, can have the same negative financial and ecological impacts as *protection*.

Accommodation is recommended as part of an overall managed retreat strategy (Volk 2008b), and would occur in areas likely to be inundated where retreat is ultimately planned. It is important to adopt special guidelines for these areas first because suitable land uses within these areas will be better able to respond and adapt to coastal hazards, minimizing financial loss and hazards to coastal populations. These guidelines must be adopted for the use of areas likely to be inundated in order to minimize negative ecological effects and hazards to development, and proactive human action will likely be necessary to facilitate salt marsh ecosystem adaptation to sea level rise. Two of the most important elements to this are discontinuing coastal hardening and providing lands for ecosystem movement.

In the Punta Gorda area for example, the largely undeveloped area west of Burnt Store Road, which forms the east wall of Charlotte Harbor, is a good example of a place where planned relocation is the best strategy. In this area, ecosystem retreat would enable the migration of the extensive mangrove forests and salt marshes, which form an important protective barrier against storm surge and tropical storm-related winds.

3) Support restoration of existing salt marshes by removal of exotic vegetation, backfilling ditches, removal of barriers to tidal connection, and degradation of exotic dominated uplands to make the salt marsh more resilient and capable of self-sustaining substrate building and migration.

One of the goals of building salt marsh resilience to climate change is to significantly reduce non-climate stressors on ecosystems: The reduction of stressors caused by human activities will increase the resiliency of habitats and species to the effects of climate change and variability. In essence, this situation is what good management already seeks to accomplish. However, a changing climate amplifies the need for managers to minimize effects these stressors have on wildlife populations (Erwin 2009).

There are many different ways of examining the overlap between conservation lands geographic mapping information and the occurrence of salt marshes within those categories of conservation land. Many features overlap so it is possible to generate an inflated total if that fact that a land can be a Florida Public Land, a Florida Managed Land, and a conservation easement at the same time. Keeping this in mind here is the extent of salt marshes that are currently in one form of conservation and/or public land status in the CHNEP.

Approximately 73.2% of the salt marshes (10,868 acres) of the CHNEP are in some form of conservation protection. The majority (8,157 acres) are within the boundaries of Florida Forever, Conservation and Recreation Lands Program (CARL), Environmentally Endangered Lands Program (EEL) or Land Acquisition Trust Fund (LATF) or Florida Communities Trust (FCT) properties managed by the State of Florida. Approximately 18.9% of these lands (2,054 acres) are held in water management district conservation easements instead of being fee-simple acquisitions. Approximately 5.5% of the salt marshes in the CHNEP are in conservation easements held by a conservation agency with the underlying land ownership remaining private.

.Approximately 1,156 acres (7.8%) of salt marshes are not under any form of conservation protection in the CHNEP. This include portions of the 2,078 acres of biological corridors designated during the FDEP Greenways Committee program of 1997-1998.

Many Federal agencies have jurisdiction over the management of salt marshes including the FWS, COE, EPA, NOAA, NMFS, NPS, USGS, FEMA, and U.S. Coast Guard (USCG). The scope of their regulatory or management functions varies, but includes dredge and fill activities, maintaining navigable waters of the U.S., fish and wildlife protection, natural resource management, and water quality protection. In the CHNEP, several federally protected areas containing salt marshes have been established, including J. N. Ding Darling, Pine Island Sound, Matlacha Pass, and Caloosahatchee River National Wildlife Refuges. The State of Florida manages and regulates activities that may affect salt marshes, primarily through the DEP and FWC, as well as several other State agencies. Further management and protection of salt marshes is provided through the State's Surface Water Improvement and Management (SWIM) and Aquatic Preserve programs. SWIM plans have been developed for the Charlotte Harbor. Aquatic Preserves include the Charlotte Harbor system, and Estero Bay. Salt marshes are also protected in several of the State's parks and preserves. The issues of habitat acquisition and protection of biodiversity were being addressed by the State's Florida Forever, Preservation-2000, and Conservation-2000 programs.

Every parcel of state-owned conservation and resource-based recreation land must have a manager assigned to it. There are four primary land managers within the state system. The Division of Recreation and Parks within DEP manages the state park system, which includes state parks, state recreation areas and state preserves. The Office of Coastal and Aquatic Managed Areas, also in DEP, manages aquatic preserves, three National Estuarine Research Reserves and the Florida Keys Marine Sanctuary. The Division of Forestry, housed in the Department of Agriculture and Consumer Services, manages the state forest system. Finally, the Fish and Wildlife Conservation Commission (formerly the Game and Fresh Water Fish Commission, but now merged with the former Marine Fisheries Commission) manages Wildlife Management Areas, with an emphasis on hunting, and Wildlife and Environmental Areas, with an emphasis on protecting listed species. The Division of Historical Resources within the Department of State also manages a few historical and archaeological sites around the state, and DEP's Office of Greenways and Trails manages the Cross Florida Greenway State Recreation and Conservation Area.

The purpose for which a project is purchased is identified as part of the project evaluation process, and the managing entity is confirmed by the Governor and Cabinet when the acquisition is approved. After receiving a lease from DEP's Bureau of Public Land Administration, the land manager has one year to develop a management plan for a new management unit or an amendment to the management plan of an existing unit. The management planning process involves holding public meetings in which citizens living near the park, forest, preserve, reserve or wildlife area are given the opportunity to participate in deciding how a parcel will be managed.

The management plans themselves identify in much greater detail the natural resources on the site, outline the management needs of the site and how those needs will be addressed, provide site plans for any proposed development (cabins, camping areas, ranger residences, trails, roads, bathhouses, etc.), and provide an estimate of the amount of funding and personnel that will be needed for optimal management of the site. Upon completion, the management plan must be submitted to and approved by the Acquisition and Restoration Council, who ensure that the sensitive natural resources on the property will be protected.

As part of an ongoing process to provide accountability to the public for proper management of state-owned conservation lands, the 1997 Florida Legislature added a new process to inspect parks, forests, wildlife areas and preserves to ensure that they are being managed appropriately in accordance with their acquisition purposes and management plans. The Department of Environmental Protection is responsible for establishing regional Land Management Review Teams to inspect and evaluate management of units of our state-owned conservation lands inventory. The review teams consist of an individual from the county or local community in which the parcel or project is located and who is selected by the county commission in the county which is most affected by the acquisition; individuals from the Division of Recreation and Parks, the Division of Forestry, and the Fish and Wildlife Conservation Commission; an individual from DEP's district regulatory office in which the parcel is located; a private land manager, a member of the local soil and water conservation district board of supervisors; and a member of a conservation organization.

The review teams are required to visit and report on all management units greater than 1000 acres in size every five years and may also inspect smaller units as time permits. Currently there are approximately 485 State Parks, State Forests, Wildlife Management Areas, State Preserves, and other environmental and cultural management units in Florida (including several jointly owned with local government, water management district, and other partners), of which 148 are greater than 1000 acres in size. All 148 of these have been inspected at least once, and the states is in the process of visiting all of them a second time. The state has also inspected approximately 40 of the smaller units.

The Department of Environmental Protection compiles the results of the site inspections into an annual report for the Governor and Cabinet. Prior to being presented to the Cabinet in October, DEP staff also makes a presentation at a public meeting of the Acquisition and Restoration Council. Members of the general public have an opportunity to comment on Land Management Review Team findings at both the ARC and Cabinet meetings.

Funding for land management prior to Preservation 2000 was historically from a collection of individual trust funds (State Park Trust Fund, Division of Forestry's Incidental Trust Fund, State Game Trust Fund, etc.), unpredictable general revenue appropriations to individual managing agencies, and various other state and federal funds. Management needs exceeded the available funding. It was also difficult for managing agencies to begin to take care of newly-acquired lands and open them to the public because they could not get management money until the next time the legislature was in session.

Management funding became more timely and more stable under Preservation 2000 with a system that continues today. First, with the majority of acquisition funds now coming either from the sale of bonds or directly from general revenue, the old CARL Trust Fund began to be used as a source of funding for land management. Bond funds cannot be used for land management. The old mixture of trust funds and other assorted funds still exists, but there is now a more reliable recurring source of revenue for land management.

The management funds are distributed among managing agencies in accordance with the number of acres they manage, weighted by the intensity of management required by some sites. In particular, the Division of Recreation and Parks receives three times the amount per acre for managing state parks, which typically require more infrastructure and facilities development, more personnel, and more active supervision of visitors. At the beginning of each fiscal year (July 1 of each year), 90 percent of available long-term management funds are distributed among the managing agencies for ongoing management of their lands. Ten percent is held in reserve for managing historical resources and for any special management needs. Any funds from this reserve that are not spent by April 1 of each year are distributed among all managing agencies based on the weighted formula used at the beginning of the fiscal year.

The state has also instituted a procedure for allocating interim management funds to land management agencies as soon as they execute their lease from the Division of State Lands. These interim management funds allow the managing agencies to begin taking care of their lands as soon as they receive them in their system rather than having to wait until the lands are included in the next round of long-term management fund allocation. Immediate needs typically include fencing and various activities necessary to prepare a site to accept visitors.

There are still insufficient management funds for ideal management of all conservation lands, as outlined in the long-term plans for site development and management in individual land management plans. Funding shortages are still the primary reason that parks, forests, wildlife areas and preserves are not managed to their full potential (Farr and Brock 2006).

On the local level, city and county governments also participate in the management of salt marshes by developing and implementing management actions and plans to regulate activities in wetlands. Management issues for salt marshes include dredge and fill activities, mitigation policies, shoreline stabilization projects, and mosquito control practices, alteration of hydrology, exotic plant invasion, waste disposal and nutrient enrichment. All of these issues have had serious effects on the structure and function of salt marshes (Kuhn et al.et al. 1999).

Restoration on a landscape level attempts to re-establish the natural structure, composition, and landscape processes that were historically lost as a result of human actions. To improve the ability to restore some of these processes, it is essential to establish measurable restoration goals and long-term monitoring programs to evaluate the success of the goals.

Salt marsh restoration has generally been aimed at restoring a site to its pre-disturbance condition. It is important to now understand that there will not be a stable environment and climate to allow such restoration to a steady state condition. Instead the management will need to project future conditions and management the restoration toward a range of variable but predictable results with the marsh position moving in response to sea level rise.

Substantial progress in salt marsh restoration techniques has been made over the last four decades because of pioneering efforts in Florida, California, Maryland, and Louisiana. In

South Florida, efforts to restore salt marshes were first initiated in the 1970s when it was recognized that indigenous flora and fauna were decreasing as a result of loss and alteration of habitat. Many restoration efforts have been conducted over the last four. Florida, California, Maryland, Louisiana, Delaware (Weinstein et al. 2001), Washington (Simenstad et al. 2006,Woo et al. 2011,Borde et al. 2010 and Thom et al. 2002).

Kruczynski (1982) discussed salt marsh replanting efforts on the Gulf coast of Florida and Crewz and Lewis (1991) provided one of the first reviews on salt marsh mitigation sites that evaluated the success and failure of restoration efforts. Several compilations of wetland restoration projects in the U.S. are available (**e.g.**, Lewis 1982, Lewis 1989, Kusler and Kentula 1990, Thayer 1992). An accurate estimate of the amount of salt marsh habitat that has been restored in the Florida is not currently available. The process of attempting to re-establish salt marshes in the Florida requires the ability to evaluate the structure, composition and ecological processes of the restored system. Methods on how to develop salt marsh restoration projects have been extensively addressed (Zedler 1984, Kusler and Kentula 1990). Many of these accounts provide suggestions on ways to establish salt marsh vegetation, but very few lend experience on how to re-establish natural ecological processes on a landscape level. Knowledge of creating the structure of a salt marsh is much greater than the knowledge and ability to create a structural marsh capable of supporting abundant and diverse populations and promoting natural habitat processes.

Factors important to the restoration of salt marshes in Florida include: structure (**e.g.**, hydrology, topography), composition (**e.g.**, species diversity, abundance), and ecological processes (**e.g.**, nutrient cycling, primary productivity).

Elevation and Slope

Elevation and slope determine the extent of the intertidal zone, amount of tidal flushing, and zonation of plant species. In a created salt marsh grading is usually necessary to establish appropriate elevations and slopes. Elevation requirements can be determined by observing the upper and lower limits of dominant plant species in a nearby natural marsh. Elevation limits are especially important in areas of small tidal amplitudes where restoration projects may be hindered by low tidal flushing. In their survey of 33 projects in Florida, Crewz and Lewis (1991) found the most common reason for the failure to successfully restore salt marsh habitat was improper elevation and slope requirements. In South Florida some species are more dependent on proper elevation than others and their tolerance for elevation variations will differ (Zedler 1984). Smooth cordgrass can survive at slightly lower elevations, while black needlerush requires slightly higher elevation. Other species that are less tolerant of frequent tidal inundation, like saltmeadow cordgrass and salt grass, require planting at higher elevations. Appropriate planting elevations in South Florida range from +0.2 to+0.6 m (+1.9 ft) National Geodetic Vertical Datum (NGVD) for smooth cordgrass and +0.4 to +0.6 m (+1.3 to +1.9 ft) NGVD for needlerush (Crewz and Lewis 1991). Most salt marsh vegetation does not survive below the 0.0 NGVD (Beever 1986). Juvenile plants tend to be more sensitive to elevation than mature plants. Cordgrass seedlings have been found at +0.03 m (+1.3 ft) NGVD, while older, more established plants were found down to –0.01 m (-0.03 ft) NGVD (Crewz and Lewis 1991).In a Tampa Bay restoration site, Crewz and Lewis (1991) found smooth cordgrass could be out-competed at higher elevations by other species if salinity is too low and favors freshwater species like cattails. Lewis (1983) found elevation played a critical role in the successful establishment and growth of black needlerush; when elevations were too high, he found plants died and the area was colonized by more salt tolerant species; when elevations were too low, white mangroves out competed the black needlerush. Salt marsh plants are also sensitive to the degree of stagnation (anoxia) and salinity extremes that can occur if elevations prevent proper tidal flushing (Zedler1992).

In impounded marshes of St. Lucie County, the number of culverts that need to be installed to increase tidal flushing and prevent stagnation depends on the marsh's elevation (David 1992). Low elevation (+0.09 to 0.24 m [+0.3 to 0.8ft] NGVD) marshes usually require more culverts to promote adequate tidal flushing, whereas those with high elevations (>0.40 m [1.3 ft] NGVD) required fewer. Most marsh plants grow on a wide range of slopes, but gentle slopes reduce wave energy and provide greater area for plants to colonize. Gentle slopes usually between 1 to 3 percent provide the most optimal planting conditions (Seneca and Broome 1992). Slopes that are too flat can cause poor surface drainage resulting in pooling and high salinities. In these areas, high salinities prevent the establishment of seedlings and inhibit plant growth (Zedler 1984, Crewz and Lewis 1991). Slopes that are too steep can promote erosion and the transport of fine-grained sediment from upland to marsh areas. Crewz and Lewis (1991) found this to be the case in several restored sites in Florida where high slopes caused higher turbidity and reduced light penetration. These circumstances led to hypoxic conditions that ultimately inhibited plant growth. Slopes directed towards open water and tidal sources maximize proper tidal flushing, minimizing the likelihood of excess salinity or stagnant waters (Zedler 1984, Seneca and Broome 1992). The stabilization of the slope is as important as its incline. Unstabilized slopes can lead to increased erosion as well as the invasion of exotic plants that often colonize on disturbed soils (Crewz and Lewis 1991).

Sediment and Soil Composition

The goal of obtaining sediments for salt marsh creation and restoration purposes is to provide stable sediment that imitates the natural soil. It is important to ensure the initial soils are stable enough to support plant growth until the roots of marsh plants have the ability to contribute to the stabilization. Unstable and younger soils tend to erode faster than those soils that are stable or more mature (Gallagher 1980).

Dredging channels and harbors to supply sediment for restoration projects often results in a variety of different parent materials low in organic matter (Gallagher 1980, Zedler 1992). In a comparison of natural versus constructed marshes, the soil composition of constructed marshes had less than half the organic matter content of natural marshes (Zedler 1992). These lower organic levels can impair microbial activities and prevent fauna from colonizing in the sediment. Mechanical operations for restoration tend to be easier on sandy soils, but these soils usually have a lower organic matter (Seneca and Broome 1992). Some hard rock and clay substrates are unsuitable for the colonization of planted marsh vegetation. Salt marsh plants were not able to colonize on the hard substrate found in two restoration sites in Key Largo and Stock Island (Crewz and Lewis 1991).

The salinity of the substrate also influences the ability of plants to establish seeds and grow. Fairly high salinities were found to inhibit seed germination in California restored marshes (Zedler et al.1982, Faber 1983, Zedler 1984). Dredged material may also contain contaminants such as pesticides, heavy metals, and petroleum products that can be released into the surrounding environment. Contaminants can be transferred from marsh soils to plants that can then transfer these substances to fish, mammals and birds (COE 1978, Gardner 1980). Obtaining reference soil samples will help determine the suitability and stability of soil for a restoration project and minimize any adverse effects.

Soil Augmentation

Restoration efforts sometimes require the augmentation of marsh soils with nitrogen and different types of organic matter to accelerate plant growth. The response of marsh vegetation to fertilization depends on fertility of soil and the amount of nutrients supplied by tidal inputs, seepage, runoff, prescription, and nitrogen fixation (Seneca and Broome 1992). Soil augmentation efforts have had mixed success and the long-term effects of soil augmentation is not very well understood.

In a North Carolina salt marsh restoration effort, nitrogen applied at the rate of 112 kg/ha and phosphorous at 49 kg/ha was effective in increasing plant growth (Seneca and Broome 1992). Fertilizers may enhance the initial growth of salt marsh vegetation and may improve plants' resistance to wave energy, but the continual application of fertilizers may interfere with the plants' ability to attain natural nutrient equilibrium (Zedler 1984, Seneca and Broome1992). Unnecessary or over fertilization also interferes with plant growth. Over fertilization may alter natural root-to-shoot ratios, resulting in top heavy plants that are more susceptible to uprooting, or increase a plant's susceptibility to fungal infections (Crewz and Lewis 1991). Seneca and Broome (1992) found when nitrogen and phosphorous were added in the same fertilizer, nitrogen could inhibit the availability of phosphorus. Broadcast fertilizers have also been found to be ineffective in enhancing salt marsh plant growth and contribute to higher eutrophication in surrounding water. Zedler (1984) recommends that if fertilizers are used they should be incorporated into the substrate as separate slow time-release fertilizers or should be in a 3:1 N: P ratio if adding directly to a planting hole. The effectiveness of soil augmentation depends on application of nitrogen and phosphorous fertilizers at the time of planting and several years later.

Buffers

.In addition to the site characteristics discussed above, buffer zones and limited human access are important considerations in a restoration plan. Buffer zones provide insulation and protection from both environmental and human influences as well as provide additional habitat and corridors for wetland species (Zedler1984). Natural buffers consisting of native terrestrial or wetland transitional vegetation maximize connection between upland and adjacent estuarine habitats. Intrusion by human activity at a site can interfere with marsh growth (Zedler 1984, Alleman1981). Humans through direct trampling by foot or vehicular traffic and vandalism have damaged several wetland restoration sites in Florida (Crewz and Lewis 1991, Crewz 1992, Alleman 1981). Creating vegetated buffers around a restoration site provides an excellent way to limit human access. In several examples in Florida, restoration sites have restored natural habitat while providing some recreational human use (**e.g.**, Salvesen 1990, Broward County Parks and Recreation 1997, G. Milano, Miami-Dade County DERM, 1998).

Planting Techniques

General salt marsh planting techniques are fairly standard and straightforward, although several considerations specific to the CHNEP are worth mentioning. Normally, the selection of plant species for restoration should be similar to species composition in nearby areas. In the CHNEP, *Spartina alterniflora* is not common along the southwest coast, and S. *spartinae* is not dominant as in the coastal areas of Miami-Dade County and the Keys. Significant genetic variations in *Spartina alterniflora* are evident between Gulf and Atlantic coast populations and between different latitudes (Seliskar 1997).The transportation of species between these regions is strongly discouraged so gene pools are not disrupted or diluted. Seliskar (1997) found the internal function of a salt marsh is significantly altered when different genotypes were mixed together in the same marsh.

The availability of salt marsh seeds and plants for restoration is very limited in south Florida. Seed production of smooth cordgrass is patchier in south Florida populations than other locations and may be related to reproductive response at lower latitudes or susceptibility to predation and fungal infections (Crewz and Lewis 1991). Although smooth cordgrass can be somewhat easier to obtain than many other species, it is necessary to utilize a diversity of plant species in re-vegetating a site. Generally, sites planted with a variety of species over a topographic gradient from intertidal to upland areas are preferred (COE 1978).

For south Florida, the time of year will strongly influence the success of transplanted specimens. For most continental southeast United States salt marshes (Georgia, Carolinas, Virginia), optimal planting dates for smooth cordgrass are between April 1 and June 15 (Broome 1990). But with the unique weather patterns in south Florida, optimal planting times will vary. Crewz and Lewis (1991) recommended planting should occur between June and September to maximize wetter conditions. Extremes in weather that cause exceptionally dry conditions, high tides, or hot or cold temperatures are also not conducive to planting. Many salt marsh species are capable of tolerating high salinities, but greater biomass is usually produced at lower salinities (10 to 20 ppt.) (COE 1978, Crewz and Lewis 1991). Extreme high tides and rainfall have washed away entire plantings (Zedler 1984). Considerations for tides and rainfall will vary between the different geographic zones in South Florida (**e.g.**, west vs. east coast vs. Keys).

Composition

Properly restored salt marshes are not expected to immediately provide the same flora and faunal composition as a natural marsh. Over time, it is expected that the diversity and abundance of organisms should reflect those of natural systems. The vegetation composition determines the suitability of a site for colonization by various fauna. If restoration techniques are able to establish adequate structure, plants and animals should be able to utilize the habitat. The diversity and abundance of species in a restored marsh provide a partial indication of how effective habitat structure is, although they may not provide a true indication of ecological processes.

Several studies have evaluated the “success” of a restoration project by analyzing species composition over time. Benthic invertebrates are good indicators of habitat quality and food chain support (Pacific Estuarine Research Laboratory 1990). In comparisons between natural and restored marshes in San Diego, the abundance of benthic invertebrates (**e.g.**, bivalves, crustaceans, gastropods) in restored marshes was about half that of the natural marsh after 3 years; but after 15 years, composition was fairly similar (Pacific Estuarine Research Laboratory 1990). Since meiofauna and macroinvertebrates are less transient in nature, they rely heavily on established food chains common in stable, undisturbed sediments. Initially, restored marshes tend to lack the developed food chains necessary to support these organisms.

Colonization rates by fish vary depending on site characteristics but appear to be much faster than invertebrates. Although intertidal habitat was established in a restored mitigation marsh in Humboldt Bay, California, fish diversity and density was much lower than nearby natural marshes in initial surveys (Chamberlain and Barnhart 1993). The lack of fish was attributed to missing structural aspects like cover and food. Similar observations were made in North Carolina where an intertidal marsh was created from upland habitat (Broome 1990). After 3 years, nearby natural marshes had greater fish abundance and diversity than the created marsh. Fish composition in the created marsh finally reached levels equivalent to the natural marsh after 12 years.

In 1980 the State of Connecticut began a tidal marsh restoration program targeting systems degraded by tidal restrictions and impoundments with little ecological connection to Long Island Sound (Rozsa and Orson 1993). Warren et al. (2002) studied nine separate sites within six marsh systems along 110 km of Long Island Sound shoreline, with restoration times of 5 to 21 years. Biotic parameters assessed include vegetation, macroinvertebrates, and use by fish and birds. Abiotic factors studied were soil salinity, elevation and tidal flooding, and soil water table depth. Sites fell into two categories of vegetation recovery: slow, ca. 0.5%, or fast, more than 5% of total area per year. Although total cover and frequency of salt marsh angiosperms was positively related to soil salinity, and reed grass stand parameters negatively so, fast versus slow recovery rates could not be attributed to salinity. Instead, rates appear to reflect differences in tidal flooding. Rapid recovery was characterized by lower elevations, greater hydroperiods, and higher soil water tables. Recovery of other biotic attributes and functions does not necessarily parallel those for vegetation. At the longest studied system (rapid vegetation recovery) the high marsh snail *Melampus bidentatus* took two decades to reach densities comparable with a nearby reference marsh, whereas the amphipod *Orchestia grillus* was well established on a slow-recovery marsh, reed grass dominated after 9 years. Typical fish species assemblages were found in restoration site creeks and ditches within 5 years. Gut contents of fish in ditches and on the high marsh suggest that use of restored marsh as foraging areas may require up to 15 years to reach equivalence with reference sites. Bird species that specialize in salt marshes require appropriate vegetation; on the oldest restoration site, breeding populations comparable with reference marshland had become established after 15 years. Use of restoration sites by birds considered marsh generalists was initially high and was still nearly twice that of reference areas even after 20 years. Herons, egrets, and migratory shorebirds used restoration areas extensively. As of 1999 tides have been restored at 57 separate sites along the Connecticut coast

Opposite trends were found in restored Florida marshes. Kurz et al. (1998) found that four restored sites in Tampa Bay provided habitat for equal or greater abundances of fishes than natural marshes. Shortly after construction, fish abundances and diversity in restored marshes were almost equal to natural marshes. Restored marshes tended to provided habitat for nursery or transient fish species, while natural sites offered established habitat for resident species. From these studies, it is evident that different factors like time and habitat type will affect the colonization success of fish. Bird species tend to colonize restored marshes fairly quickly, although this may be due to their transitory nature.

Shortly after restoration of the San Diego marsh, bird colonization was fairly rapid, although species abundance and diversity was about half that of the natural marsh (Pacific Estuarine Research Laboratory 1990). The low number of birds was attributed to the inability of the restored habitat to provide adequate shelter and food. The transitory ability of most birds allows them the flexibility to utilize several marshes without being dependent on just one site.

Figure 186: Island Park Filter Marsh after initial grading.

Ecological Processes

Natural salt marsh processes include biotic interactions, primary production, decomposition, organic export, and energy flow. Little information is available to determine if humans are able to create or restore these natural processes. Although it is fairly easy to count the number of organisms in restored marshes, it is much more difficult to determine if restored marshes successfully re-establish ecological processes. It takes time and effective restoration techniques to attain structures and compositions comparable to natural marshes. Even with creation, enhancement, or rehabilitation actions, man may not be able to create marsh systems that support ecological processes.

The Little Pine Island Restoration and Mitigation Bank was created in 1994, when Mariner Properties nominated the property to become its mitigation project. In 1996, Mariner Properties entered a public-private partnership with the state of Florida to restore 633 hectares (1,565 acres) of the island's 1900+ hectares (4,700 acres), of which about 1254 hectares (3,100 acres) are protected mangroves, and 1,4000 acres are salt marsh. The bank was formally established February 1996 by Permit Number 362434779. Mariner Properties Development, Inc., with the guidance of scientists and the oversight of state and federal agencies, began the job of removing the exotic plants. Working with chainsaws and other hand tools, work teams began removing an average of 30 tons of exotic biomass per acre - an amount roughly equal to the full cargo capacity of a tractor-trailer. Although laborious and time-consuming, hand-removal ensures millions of exotic plant seeds are taken away, reducing their regeneration on the island. Birds and animals began returning, and native seeds which had lain buried and dormant for 30 years began sprouting anew. Today, Little Pine Island stands as a good example of what a public-private partnership can accomplish.

Figure 187: Aerial view of Little Pine Island Mitigation Bank, Matlacha Pass, Lee County

The Island Park Mitigation Site includes restoration of high marsh among other habitats in the Estero Bay Watershed on the east side of Hendry Creek. On February 1, 2006 Lee County reached a significant milestone this week when Commissioners approved the first project in a Natural Resources Preservation/Master Mitigation Plan that had been in the works for four years. The Board of Lee County Commissioners approved a contract with Bundschu Kraft to manage the construction of the $923,014 Island Park Regional Mitigation Project (80 acres), with estimated completion in five months. The project includes excavation of a filter marsh and canal bank, FPL easement culvert installation, clearing and grubbing, exotics removal and plantings. This was a meaningful water quality improvement, on a countywide basis, because it is at the headwaters of Mullock Creek in an area that receives runoff from U.S. 41 and filters into Estero Bay. In May 2005, the County Commission endorsed a plan to allow mitigation of public sector projects on Conservation 20/20 parcels. Construction of this project satisfies the mitigation requirements of the South Florida Water Management District (SFWMD) and U.S. Army Corps of Engineers (ACOE) for the Department of Transportation project known as Three Oaks Parkway South, and provides restoration and enhancement on Lee County Conservation 2020 lands known as the Estero Marsh Preserve.

The county began developing its Master Natural Resources Preservation/Mitigation Plan in early 2002 to proactively address potential cumulative impacts to the county's natural resources such as water supply, water quality and wildlife habitat due to existing and future development including both private and public works projects. A proactive and comprehensive approach addresses environmental concerns through implementation of retrofit and restoration-type projects instead of engaging in the continual technical debates and legal challenges, on a case-by-case basis, that had characterized the process. Additionally, many of the mitigation efforts were not coordinated in a comprehensive way, so there were isolated and scattered mitigation projects that weren't as meaningful individually because they did not connect to anything as those that have been identified on a countywide basis as having a countywide impact.

Figure 188: Island Park Mitigation Area prior to restoration.
Note Melaleuca domination of site.
Source Google Earth 2003

Figure 189: Island Park Area After Restoration.

Note return of saltern, mixed high marsh, grassy high marsh, and patches of succulent high marsh.

Source Google Earth 2010

The Charlotte Harbor Estuary NEP has supported several salt marsh restoration efforts and several projects have been initiated. The Venus Lake Habitat Restoration Project on Sanibel Island created 0.6 ha (1.5 acres) of salt marsh and mangrove habitat from spoil uplands, remove exotic plants, and restore natural tidal flow on a 3.5 ha (8.5 acre) parcel. The Punta Gorda Wetland Restoration Project restored a highly disturbed parcel of salt marsh in Punta Gorda. The restoration efforts include the removal of exotics, primarily Brazilian pepper and Australian pine, excavation and grading of the shoreline, and replanting with salt marsh species like *Spartina alterniflora* and S. *patens*. This site was designed to provide compatible recreational use as well.

4) Stop shoreline hardening including seawalls, bulkheads, rip-rap, and "living shorelines" backed by rip-rap. Use natural shoreline vegetation for shoreline stabilization instead.

Coastal marshes are able to dissipate wave energy and accumulate sediment (Knuston 1988). Shorelines with salt marsh vegetation are often more resistant to storm damage than those without, although the amount of protection depends upon the type of salt marsh vegetation and density, salt marsh width, and the amount of wave energy. The greatest protection is usually provided by dense, wide salt marshes. Many of the dredge and fill activities in south Florida have removed shoreline vegetation through direct impacts or alteration of natural hydrological functions. The alteration and destruction of this habitat has, in many cases, resulted in unstable shorelines.

North Carolina State University and COE initiated the first studies on using salt marsh vegetation to stabilize shorelines in 1969 (Woodhouse et al.1974, 1976). Attempts to conduct shoreline stabilization projects have been conducted throughout the U.S., especially in the Chesapeake Bay, Galveston Bay, San Francisco Bay, and Apalachicola Bay in Florida (Woodhouse 1979, Knuston and Innskeep 1982, Knuston and Woodhouse 1983). Knuston ET al. (1981) and Knuston and Innskeep (1982) demonstrated the values of stabilization projects to dissipate wave energy caused by boat wakes and prevent excessive erosion. Early accounts of shoreline stabilization projects in Florida were reported by Courser and Lewis (1981) who planted smooth cordgrass to successfully stabilize 60 m (197 ft) of eroding shoreline along Tampa Bay, and Smith (1992) reported partial success of stabilization using smooth cordgrass along the Indian River Lagoon. Stabilization efforts using salt marsh vegetation continue to be carried out along shorelines and spoil islands in the South Florida Ecosystem.

Living Shorelines use natural shoreline ecosystems to absorb wave energy without causing erosion. Living Shorelines extend from the upper bank of the property to below the water level. They typically include a variety of plants, including salt marsh grasses and/or mangroves as well as structural elements such as oyster shell, or even riprap. The overall concept of Living Shorelines is to provide habitat which will grow and change as water levels change (unlike seawalls which are a fixed height). Having structural elements in the shallow water, and plants which are rooted below water level but grow above the water helps absorb wave energy McGuire 2012).

Many successful Living Shoreline projects have been completed in Florida. In the Pelican Island National Wildlife Refuge, oyster shell was used to create a submerged breakwater, allowing areas to be filled and planted with marsh and mangrove vegetation. These planted areas then naturally expanded, restoring 0.84 acres which had previously eroded from the island in the Indian River Lagoon.

At the Cargill Fertilizer plant in Tampa, an eroding shoreline was re-sloped and planted with marsh grasses in 1990; by 2003 it had become a healthy mangrove/salt marsh ecosystem. At John Lloyd Park, across from Port Everglades in South Florida, limestone boulders were used to create a protected area which naturally vegetated with mangroves over a 20- year period. This mangrove habitat is directly across from the shipping docks. The St. Johns River Water Management District is currently conducting salt marsh restoration projects within Gamble Rogers and North Peninsula State parks (SJRWMD 2012).

5) Re-engineer existing vertical shoreline infrastructure to a sloped soil based shoreline with GeoWeb or other permeable stabilization.

It is possible to re-engineer bulkheads with and without rip rap to have a slope and substrate more favorable to allow salt marsh vegetation to keep pace with existing sea level. While the areal extent of the marsh would be reduced to the area provided on the slope the persistence of that habitat could be maintained until the sea level had attained a height to match the elevation where wider expansion of salt marsh can occur.

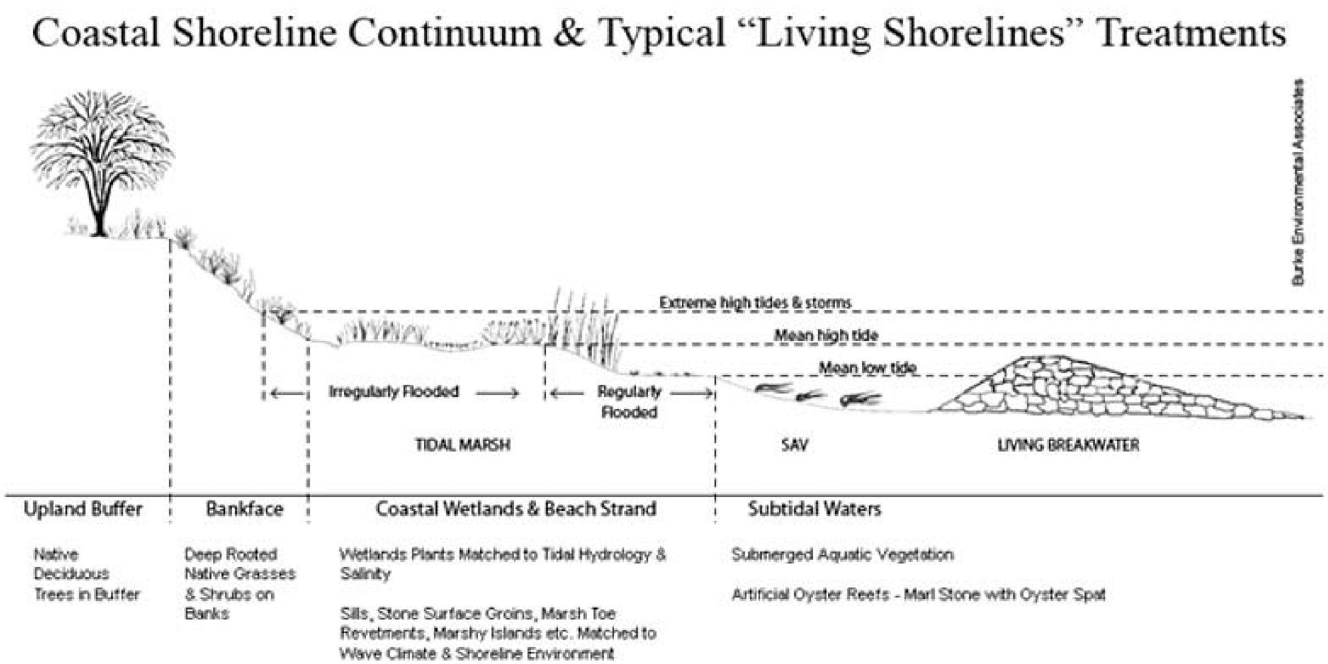


Figure 190 : Sloped and Living Shoreline Diagram
Source: NOAA 2012

Sand fill and clean dredge material is typically used to create a gentle bank slope that dissipates wave energy and provides a surface on which to plant vegetation. Sites without a bulkhead can be regraded, filled, and replanted with native vegetation. Bulkheads can be removed and the shoreline then regraded, filled, and replanted. Another option is to leave the structure in place, add sand fill in front of the bulkhead, and then regrade and replant the shoreline and embankment with native vegetation.

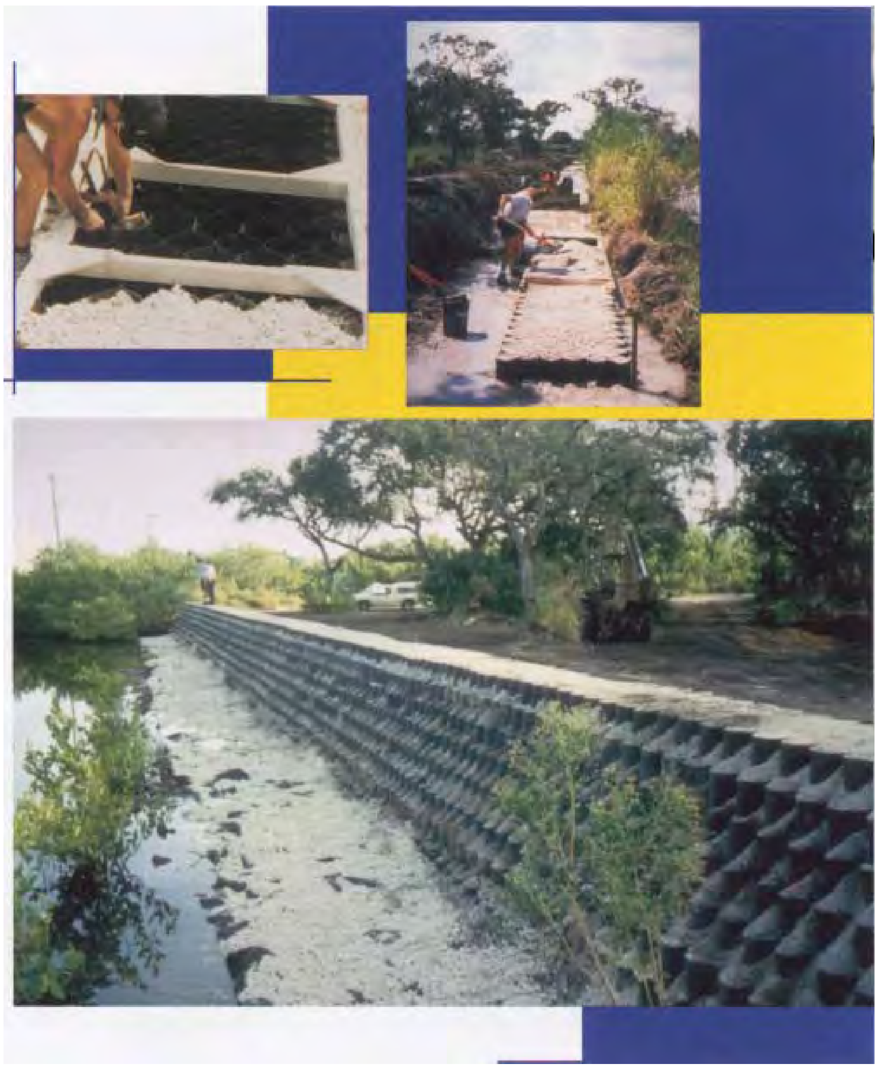


Figure 191: Stepped GeoWeb shoreline, Vero Beach Florida 1994.
Source: R.H. Moore & Associates, Inc.

Tree and grass roots stabilize the riparian zone above high tide by holding on to the soil, which minimizes bank erosion while filtering upland runoff and providing wildlife habitat. Common riparian vegetation used at each site differs depending on the species native to that area, but typically includes a combination of native woody trees, shrubs, and grasses.

Salt marsh grasses dissipate wave energy, filter upland runoff, and improve habitat for fish and wildlife. Native grasses are planted in the water and at the mean high tide mark in the intertidal zone. Marsh grasses may be more successful if they are planted in the spring in areas where there is evidence of existing marsh, where there is less than 3 miles of open water, and where the prevailing winds will not cause destruction of the newly planted grasses.

Natural fiber logs (or bio-logs) made of biodegradable coconut fiber and netting are commonly used to stabilize slopes and minimize bank erosion. These logs are placed at the foot of bank slopes or in the water, molded to fit the bank line, and then anchored in place. They trap and retain sediment, retain moisture for plant growth, and provide bank stability while new vegetation takes root and increases in density.

Natural fiber matting is made of coir fiber, wood, straw, jute, or a combination of organic, biodegradable materials. The matting is laid over eroding steep slopes or coastal areas to minimize the loss of sediment from the land and trap wave-transported sediment. Organic matting can also be planted with marsh grasses or riparian vegetation to enhance shore stabilization.

Rock footers are small amounts of rock or boulder material used to anchor and support bio-logs and stabilize the restored shoreline. The rock footer supports the structural integrity of the bio-log and prevents it from sloughing off into deeper waters of the bank slope.

Low-crested segmented rock sills are freestanding rock structures placed in the water parallel to shore to dissipate wave energy and protect eroding marshes and shorelines.

Sills are generally segmented and stand no more than 6 to 12 inches above mean high water. This allows boats and wind-induced waves to pass over the structure and provides wildlife access to both the water and the shoreline habitat.

Living breakwaters are structures placed parallel to the shore in medium- to high-energy open-water environments for the purpose of dissipating wave energy while providing habitat and erosion control. These breakwaters are constructed rock that is seeded with oyster spat. Living breakwaters create calm areas near the shoreline, which can be replanted with submerged aquatic vegetation and marsh grasses to create intertidal and marsh habitat for aquatic organisms.

Rubble and recycled concrete breakwaters can be used at living shoreline sites as material for offshore breakwaters to reduce wave energy. To provide maximum benefit to the ecosystem, these rubble and concrete breakwaters should be seeded with oyster spat to improve water quality and provide habitat while reducing wave energy.

Sediment-filled geotextile material tubes are placed parallel to shore to dissipate waves in high-energy environments. The tubes, which measure approximately 12 feet in diameter, create new avenues for dredge material disposal, and produce a hard surface on which the eastern oyster can construct reefs.

Filter fabric is a porous layer of geotextile material placed beneath rock sills and breakwaters to prevent sand movement into or through the rock or concrete structure at hybrid living shoreline sites.

6) Restore impaired water flows to enhance sediment supply for marsh deposition. Restoration of natural hydrology could facilitate sediment accretion and building of deltaic salt marsh wetlands

Hydrology is the most important variable in salt marsh restoration and plays a critical role in the establishment and growth of salt marsh vegetation. If proper hydrological conditions are established, the chemical and biological conditions can respond (Mitsch and Gosselink 1993). To ensure proper hydrological conditions, wave energy and tidal inundation considerations need to be met. The initial establishment and long-term stability of plants is affected by the amount of wave activity. Restoration areas in semi-protected areas with little direct wave impact are shielded from the erosional forces of wave action. Usually smooth cordgrass can withstand more dynamic wave environments than mangroves, but excessive wave action can be detrimental to cordgrass as well (Woodhouse et al.1974, 1976; Crewz and Lewis 1991). Knuston et al. (1981) developed four useful factors to characterize wave climate: average fetch, longest fetch, shore configuration, and sediment grain size Tidal flushing is important in maintaining the exchange of saline waters. Closed sites are isolated from regular tidal flushing of adjacent estuarine waters and are more susceptible to becoming entrapments for high levels of stagnant or fresher water. Several restored mitigation sites in Florida suffered from restricted flow exchange which led to oligohaline or hypersaline conditions, decreased water quality, and eutrophic conditions (Crewz and Lewis 1991). Oligotrophic habitats can lead to invasion of cattails, while hypersaline conditions stress plants and inhibit growth or cause death of plants. Proper tidal inundation can met with the creation or maintenance of tidal creeks or channels that provide suitable drainage and tidal exchange. Channels improperly constructed can inhibit water flow and can decrease water quality by causing stagnant water conditions. Channels should be constructed or incorporated to maximize flushing of water, and prevent large areas of standing water while still remaining protected from extreme winds or wave action. Drainage avenues should be deep enough to retain water at low tide but not too much deeper than the access channel. Enclosed areas should be designed to prevent waters from becoming stormwater drainage from upland runoff of fertilizers and toxic compounds.

A number of salt marsh restorations involving removal of spoil material restoring water flow to salt marshes including North Peninsula State Park, Florida; Little Mussachuck Creek, Sachuest Salt Marsh, and the Galilee Bird Sanctuary, Rhode Island.

Areas in the CHNEP where berm removals can improve salt marsh conditions and enhance diversity of marsh type include the waterward sides of the spreader waterways, several navigation access channels with side cast spoil, and areas where smaller drainage ditch spoils block water access.

7) Make roadway berms permeable to marsh migration and hydrology by bridging and culverting or abandon coastal road corridors with associated bermed road beds.

The construction of flow through culverts or bridge spans to restore marsh hydrology is a concept and practice with a long history. The concept of constructing culverts or bridges to allow marsh migration landward is relatively new by comparison.

Some projects that have restored flow through roadway berms include Winsegansett Marsh on Buzzards Bay, Massachusetts and Wormsloe Plantation Salt Marsh, Savannah, Georgia (Rice et al. 2005).

In the western portion of the Big Cypress Swamp Tamiami Trail /US 41 has been improved by the construction of 16 culverts (Figure 192). S-42A has a double pipe culvert and S-46A is a box culvert. These multiple flow-through culverts are designed to enhance sheet flow from the Big Cypress to the Ten Thousand Islands and the western part of Florida Bay. The structures have been operated since June 2006. This project also provides the opportunity for the salt marshes in this part of Collier County to move landward underneath Tamiami Trail/ US 41 when sea level attains the extent for that to occur.

In the eastern Everglades the Tamiami Trail Modifications project had the first concrete pour on the bridge deck completed on July 13, 2012. This is part of a one mile long bridge construction to allow increased water flows into Everglades National Park. Construction of the $81 million Tamiami Trail project, a key component of the Modified Water Deliveries to Everglades Nation Park, began in 2010. The project includes constructing a one-mile bridge and raising and reinforcing an additional 9.7 miles of road, allowing increased water flows that are essential to the health and viability of the Everglades.

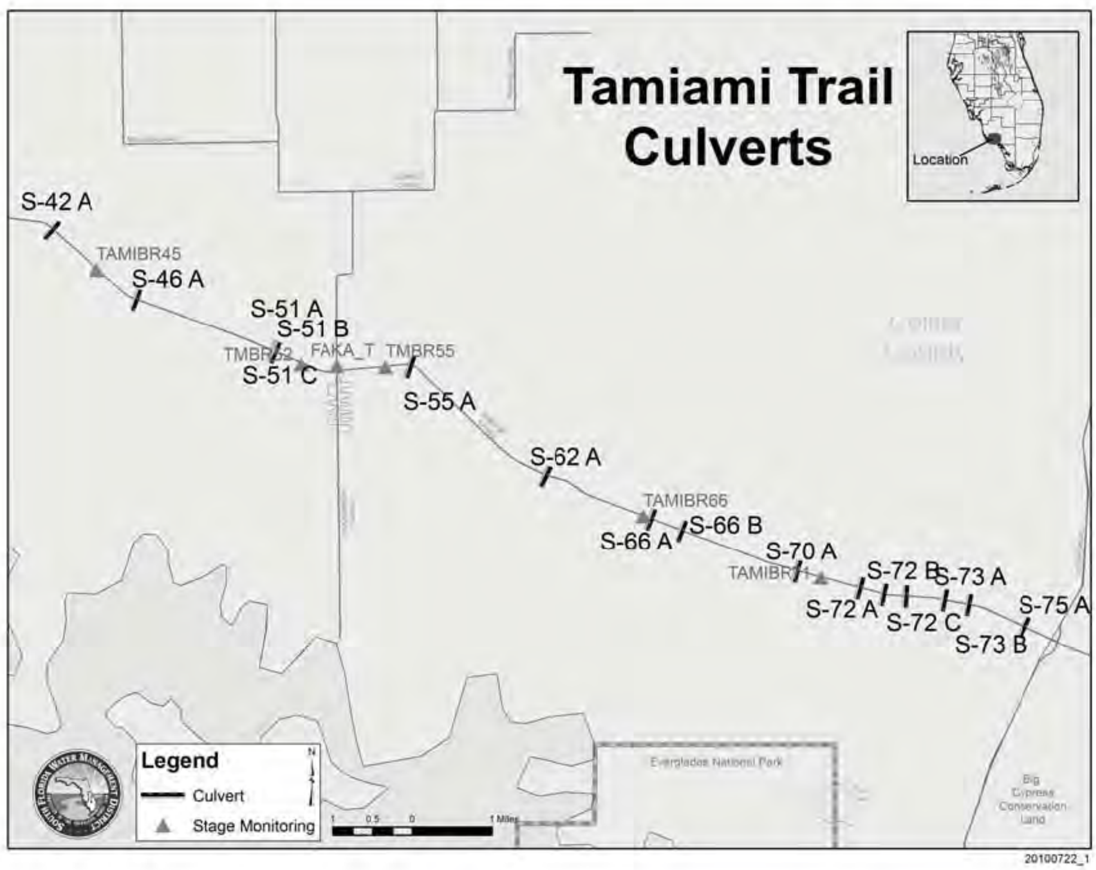


Figure 192: The Tamiami Trail culverts and the six stage monitoring sites.
Source: Abtew and Ciuca 2010

Locations in the CHNEP that would benefit from culverts or bridges to allow salt marsh movement and hydrologic exchange include western Summerlin Road approaches to Sanibel Island causeway and bridges, the north shore of the I-75 Bridge across the Caloosahatchee River, the north shore of the I-75 Bridge across the Peace River; SR 17 across Shell Creek; the section of CR 865 on Big Hickory Island, the west end of Coconut Road, John Morris Road, Shell Pointe Road, Veterans Parkway north of the bend and south of Pine Island Road, Pine Island Road crossing Little Pine Island, SR 775 northeast of Placida, Abee Farm Road south of its intersection with Laurel Road and several non-public dirt roads designed to allow access for utilities company inspection and maintenance of power lines crossing salt marsh areas of Estero Bay and Pine Island.

8) Back-fill mosquito control ditches to reduce depth and sediment loss.

A number of successful restoration projects have been implemented to restore salt marsh elevations by backfilling, at least partially mosquito control ditches in the CHNEP, elsewhere in the United States, and in other parts of the world.

Ditch filling and/or blocking have been completed successfully at Tampa Bay on Feather Sound (TBEP); Mosquito Lagoon, Florida (SJRWMD 2012); Wekeag Marsh in the Ralph Waldo Tyler Wildlife Management Area, South Thomaston, Maine (Coastal America 2001); Scarborough Marsh, Maine (Coastal America 2001, Normandaeu Associates, Inc. 2002) ; William Floyd Estate Marsh, Long Island, New York (Ducks Unlimited 2012) ; Pikering Brook Marsh, Greenland, New Hampshire (NHDES) (2005); and San Francisco Bay (Liu 2005).

Significant backfilling, plugging and restoration of marsh from mosquito control and other ditches has occurred in the CHNEP including high marsh restoration at Charlotte Harbor State Park by the Florida Department of Environmental Protection Charlotte Harbor Aquatic Preserves and State Buffer Park and CHNEP starting in 2001; the Lemon Bay Preserve by Sarasota County, Southwest Florida Water Management District, Fish America Foundation, Inc. and CHNEP; Smokehouse Bay Preserve, Pine Island by Lee County Parks and Recreation Conservation 20/20 and CHNEP; and the Little Pine Island Mitigation Bank has backfilled ditches of various sizes and purposes on state lands restoring high marsh hydrology and habitats.

Figure 193: Restored backfilled mosquito control ditches on the Charlotte Harbor Preserve State Park.
Source: Google Earth 2010

There are locations where mosquito control ditch removal and marsh restoration could occur in all the watersheds of CHNEP.

9) Backfill or reslope shores of borrow pits, agricultural pits, and spreader waterways to allow salt marsh establishment and establishment of marsh migration corridors

There are at least 59 miles of shoreline and 946 acres of potential salt marsh restoration opportunities in the borrow pits, agricultural pits and spreader waterways of the CHNEP adjacent to salt marshes and mangroves of the CHNEP. It is extremely unlikely that backfilling of these features would be possible since these features no longer have sufficient backfill in adjacent locations. The fill excavated from these pits haves been utilized to build up elevations on adjunct lands converting former wetlands and low elevation uplands to residential, agricultural, and commercial areas.

Nature provides the template for how borrow pits, agricultural pits and spreader waterway shorelines should be restored to allow salt marsh colonization and persistence as sea level rises. The shorelines of these features should be restructured to be shallow, irregular, non-Euclidian (no straight lines). The design would include shallow depths to prevent anoxia (lack of oxygen), establish wide irregular shaped and irregular width littoral shelves, curved variable shaped shorelines with high edge to width ratios, irregular bottom topography including submerged shelves and emergent islands, varied substrates (sand, mud/clay, wood). Examples of these designs can be found in freshwater borrow pits constructed as part of the road building for I-75 that crossed conservation areas including Webb Lake at the Fred C. Babcock/ Cecil M. Webb Wildlife Management Area, Tuckers Grade, Charlotte County and Fakahatchee Lake, Fakahatchee Strand State Preserve, S.R. 29, Collier County

10) Sediment-slurry addition to assist in marsh sediment building processes

A potential method of rehabilitating these salt marsh systems is the addition of sediment-slurries to increase marsh surface elevation, ameliorating effects of excessive inundation (Ford et al 1999). Although this technique is growing in popularity, the restoration of ecological function after sediment addition has received little attention. To determine if sediment subsidized salt marshes are functionally equivalent to natural marshes, Stagg and Mendelssohn (2010), examined above- and belowground primary production in replicated restored marshes receiving four levels of sediment addition (29–42 cm North American Vertical Datum of 1988 [NAVD 88]) and in degraded and natural ambient marshes (4–22 cm NAVD 88). To ameliorate the effects of excessive inundation, hydraulically dredged sediments were added to a die-back-affected marsh, with the notion that an increase in elevation would improve soil drainage and ultimately vegetative growth (Mendelssohn and Seneca 1980). The study site was located in the Terrebonne Basin on the west bank of Bayou LaFourche

Moderate intensities of sediment-slurry addition, resulting in elevations at the mid to high intertidal zone (29–36 cm NAVD 88), restored ecological function to degraded salt marshes. Sediment additions significantly decreased flood duration and frequency and increased bulk density, resulting in greater soil drainage and redox potential and significantly lower phytotoxic sulfide concentrations. However, ecological function in the restored salt marsh showed a sediment addition threshold that was characterized by a decline in primary productivity in areas of excessive sediment addition and high elevation (>36 cm NAVD 88). Hence, the addition of intermediate levels of sediment to submerging salt marshes increased marsh surface elevation, ameliorated impacts of prolonged inundation, and increased primary productivity. However, too much sediment resulted in diminished ecological function that was equivalent to the submerged or degraded system (Wilsey, et al 1992).

The use of hydraulically dredged, fine-grain sediments can decrease flood duration (Schrift et al. 2008) and increase bulk density and soil nutrient concentrations (Mendelssohn and Kuhn 2003), resulting in greater aboveground biomass, plant density, and cover (Mendelssohn and Kuhn 2003; Slocum et al. 2005; Schrift et al. 2008). However, the effect of sediment-slurry addition in coastal marshes on ecological function has received little attention(but see Edwards and Mills 2005).The goals of restoration are to return a degraded system to pre-degradation conditions based on ecological services, which depend not only on ecological structure, but also on ecosystem function. Quality ecological functions and resulting services have not always been present after restoration of structural characteristics (Zedler and Callaway 1999; Rozas and Minello2001). Therefore, this study was designed to enhance our knowledge of the effects of sediment addition on an important ecological function, primary production. As the principal contributor of organic matter to salt marsh trophic systems, primary production plays a pivotal role in the overall productivity of the salt marsh (Teal 1962; Houghton and Woodwell 1980). Additionally, primary production significantly influences organic matter accumulation in salt marshes and is a critical factor controlling elevation change (McCaffrey and Thompson 1980; Hatton et al. 1983; Nyman et al. 1993; DeLaune and Pezeshki 2003). As such, the restoration of primary production is of paramount importance in the restitution of ecosystem function and sustainability. However, Edwards and Mills (2005) examined the functional trajectories of above and below ground production in sediment subsidized marshes and found that the restored marshes were not functionally equivalent to natural marshes 19 years after sediment addition.

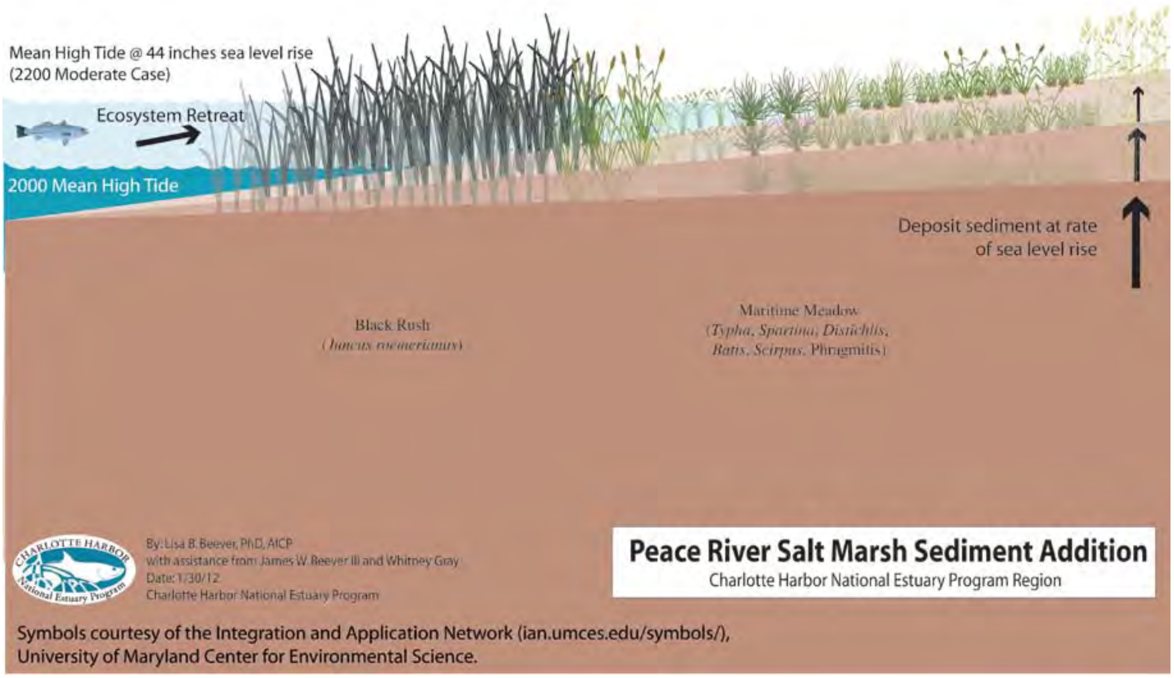


Figure 194: A method of gradual filling of areas in front of shoreline protection to keep pace with sea level rise.

The need for refinements to salt marsh environmental indicators and targets related to quantity and quality as appropriate.

The current CHNEP CCMP targets for salt marsh as defined in FW-J and FW-K for salt marshes of the CHNEP study area are:

- No long-term net declines in intertidal saltwater marsh coverage by basin except as a result of natural variation or restoration.
- No long-term net declines in high saltwater marsh coverage by basin except as a result of natural variation or restoration.
- Achievement of controllable levels of Florida Exotic Pest Plant Council-defined nuisance, invasive exotic plant species on saltwater marsh habitat on public lands by 2020.

While sea level rise is a natural phenomenon the rate of rise is influenced by non-natural variation form human cased drivers. Similarly other climate change effects on salt marshes have a non-natural components related to human environmental degradation. The ability of salt marshes to adapt and move in response to climate change in order to maintain their extents within their watersheds of CHENP will depend upon human action and inaction. At the landward areas of current salt marsh extents there are substantial human created barriers to continued salt marsh existence. With only a few locations for habitat movement it is vital to protect the remaining conservation landscape that can support salt marshes in the CHNEP into the future. Elsewhere it is predicted that a long term decline in salt marsh extents will occur in watersheds without these landscape scale conservation lands features. It is likely necessary to refine the CHNEP salt marsh environmental indicators and targets related to quantities and qualities as appropriate. to the future distribution of salt marshes in a world with higher sea levels and a changed climate. It is possible utilizing the tools developed in this study to do so provide the CHNEP conference proceeds to this decision.

Major Conclusions

This is the first salt marsh mapping in the CHNEP that includes a mapping of the salt marshes by type. There are 12 different types of salt marsh in the CHNEP.

Seventy percent of the salt marshes of the CHNEP are high marsh and 30% of the salt marshes are fringing marsh. The fringing marsh is found on major rivers and tributaries.

The salt marshes are moving landward where there is opportunity to do so. The current pace of sea level rise appears to be at pace that allows marsh migration on mainland shores.

In contrast, in other locations salt marshes are drowning where there is no location to move to such as the center of islands in Pine Island Sound.

Elsewhere areas of former salt marsh have been replaced by: deeper water salt marsh types, mangrove forest, or open water.

Leather fern marshes have been significantly impacted by freeze events associated with recent extremes in winter climate. Recovery appears to be occurring very slowly.

Barriers to the movement of salt marshes have already contributed to the disappearance of salt marshes from areas of former shoreline extents. These barriers include the standard model example of sea walls, and bulkheads, but also include spreader canals, road beds, rip rap revetments, borrow pits, stormwater treatment beam barriers, and even golf course bunkers.

The best solution to maintain salt marsh habitats in the CHNEP is planned relocation and adaptations allowing the salt marshes to maintain themselves at the elevations of sea level that occur through time.

There are adaptations that can be undertaken to assist in salt marsh migration and in some locations this has been occurring. These adaptations include;

1) Maintaining the existing marsh migration corridors that have been established on Cape Haze, the Eastern Charlotte Harbor shoreline, and Estero Bay Preserve State park and identify the highest priority marsh migration corridors so that they can protect these areas from future development.

2) Acquisition/Protection of inland/landward buffer zones to provide an opportunity for salt marsh habitats and wildlife to migrate inland.

3) Support the restoration of existing salt marshes by removal of exotic vegetation, backfilling ditches, removal of barriers to tidal connection, and degradation of exotic

dominated uplands to make the salt marsh more resilient and capable of self-sustaining substrate building and migration.

4) Stop shoreline hardening including seawalls, bulkheads, rip-rap, and "living shorelines" backed by rip-rap. Use natural shoreline vegetation for shoreline stabilization instead

5) Re-engineer existing vertical shoreline infrastructure to a sloped soil based shoreline with GeoWeb or other permeable stabilization.

6) Restore impaired water flows to enhance sediment supply for salt marsh deposition. Restoration of natural hydrology could facilitate sediment accretion and building of deltaic salt marsh wetlands

7) Make roadway berms permeable to marsh migration and hydrology by bridging and culverting or abandon coastal road corridors with associated bermed road beds.

8) Back-fill mosquito control ditches to reduce depth and sediment loss.

9) Backfill or reslope shores of borrow pits, agricultural pits, and spreader waterways to allow salt marsh establishment and establishment of marsh migration corridors

10) Sediment-slurry addition to assist in marsh sediment building processes

For some watersheds of the CHNEP it is unlikely these adaptations will be employed because there is no physical space remaining for salt marshes to move into and because of competing human interests for maintaining higher elevation uplands in direct proximity to open waters and wetlands and navigation channels to access deeper waters.

It is necessary to refine the CHNEP salt marsh environmental indicators and targets related to quantities and qualities, as appropriate, to the future distribution of salt marshes in a world with higher sea levels and a changed climate. It is possible utilizing the tools developed in this study to do so provide the CHNEP conference proceeds to this decision.

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