Chapter 3

Big Bend and Springs Coast

Contributors:

Ellen Raabe, U.S. Geological Survey (retired)

Kris Kaufman, NOAA Restoration Center

Chris Anastasiou, Southwest Florida Water Management District

Michelle Moorman, U.S. Fish and Wildlife Service

Jamie Letendre, Big Bend Seagrasses Aquatic Preserve,
Florida Department of Environmental Protection

Kara R. Radabaugh, Florida Fish and Wildlife Conservation Commission

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EDITED BY KARA R. RADABAUGH AND RYAN P. MOYER

Florida Fish and Wildlife Conservation Commission
Fish and Wildlife Research Institute
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St. Petersburg, Florida 33701

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Description of the region

The region of Florida between Tampa Bay and the Panhandle barrier island system is a marsh-dominated coast often referred to as the Big Bend. The region is also frequently split in two, with Wakulla County to northern Levy County referred to as the Big Bend and southern Levy County to Pasco County called the Springs Coast (Figure 3.1). The latter naming convention of the Big Bend and the Springs Coast is used throughout this chapter. This extensive region is divided among three water management districts: Northwest Florida, Suwannee River, and Southwest Florida (NWFWMD, SRWMD, and SWFWMD, respectively; Figure 3.1). The gentle topography, low wave energy, and broad, shallow West Florida Shelf provide ideal conditions for the extensive salt marshes along the Big Bend and Springs Coast region (Rupert and Arthur 1997, FDEP 2015). The shallow shelf and low energy also allow the region to support many oyster reefs and the second-largest expanse of seagrass habitat in the eastern Gulf of Mexico (Hale et al. 2004).

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

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

Salt marshes in the Big Bend and Springs Coast region include tidal creeks and some natural levees created by sediment deposited during high tides and storms (Leonard et al. 1995, Wright et al. 2005). Salt barrens are common in the marsh interior, particularly in counties north of the Suwannee River (Raabe et al. 1996, Hoffman and Dawes 1997). These sparsely vegetated salt barrens occur between the marsh and coastal forest at elevations only centimeters above mean high water (Raabe et al. 1996).

Freshwater flow from tidal creeks and rivers is dark-colored due to mineral particulates and dissolved and particulate organic matter, which limit light

Figure 3.1. Salt marsh and mangrove extent in the Big Bend and Springs Coast region. Data sources: NWFWMD 2015–2016, SRWMD 2016–2017, and SWFWMD 2017 land-use/land-cover data, based on FLUCCS classifications (FDOT 1999, NWFWMD 2018, SRWMD 2020, SWFWMD 2020).

availability and aquatic primary production (Bledsoe and Phlips 2000, Hilliard 2010). Extensive seagrass beds are found offshore of salt marshes in areas of sufficient water clarity, interspersed with unvegetated intertidal flats (Mattson et al. 2007, Carlson et al. 2010). Oyster reefs are found near river mouths, tidal creeks, and offshore, particularly in areas of lower salinity as a result of freshwater input (Seavey et al. 2011).

Mangroves can be found fringing salt marsh on the Springs Coast along the coastal mainland and barrier islands, particularly at Cedar Key (Figure 3.2), in the Ozello archipelago in Citrus County, and in Pasco County. Freezing temperatures limit the northern range of mangroves, although the trees, especially black mangroves (*Avicennia germinans*), have been able to expand northward due to reduced frequency of extreme-cold events (Lugo and Patterson-Zucca 1977, Kangas and Lugo 1990, Stevens et al. 2006, Cavanaugh et al. 2014). After several hard freezes in the 1980s killed black mangroves along Cedar Key and the Springs Coast, salt marshes, primarily smooth cordgrass, recolonized the area (Clewell et al. 2002). Subsequent mild winters allowed black mangroves to reclaim the area and expand northward. This increase in mangrove swamps, often at the expense of salt marsh habitat, is evident in mangrove acreage data from SRWMD and SWFWMD land-cover maps (Figure 3.3, Table 3.1).

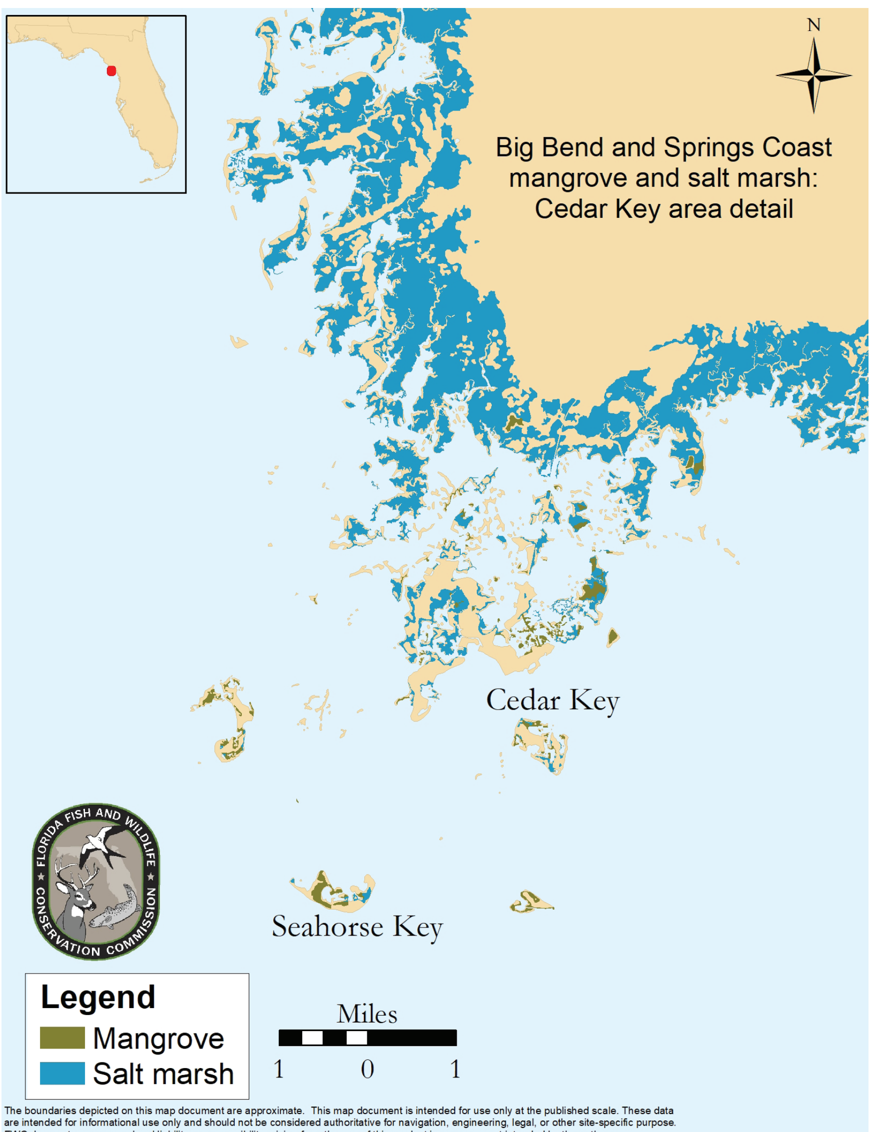

Figure 3.2. Salt marsh and mangrove extent around Cedar Key. Data source: SRWMD 2016–2017 land-use/land-cover data, based on FLUCCS classifications (FDOT 1999, SRWMD 2020).

Local geology and hydrology

The prominent coastal marshes of the Big Bend and Springs Coast region are underlain by an Eocene–Oligocene limestone shelf that crops out close to the land surface, resulting in a relatively stable shoreline compared to other regions in Florida (Rupert and Arthur 1997, Raabe et al. 2004). This area is also distinct from other coastal regions in Florida in that it has limited quantities of mineral sediment and is entirely dominated by coastal marshes. The karst limestone is occasionally exposed on land and along stream beds, supporting tree islands and providing high banks in which tidal creeks form (Wolfe 1990, FDEP 2015, Hine 2019). Offshore, these bedrock outcrops are the underlying substrate for modern oyster reefs (Hine 2019). While sandy features are rare, sediment is maintained in the system because of relatively low wave energy (Rupert and Arthur 1997) with occasional redistribution during wind and storm events (Leonard et al. 1995, Wright et al. 2005). A few natural sandy beaches occur on Seahorse and Cedar keys, remnants of ancient sand dunes (Wright et al. 2005).

The area is not a traditional estuary, since it is not partly enclosed by land. It is, however, bounded by a broad, shallow limestone shelf

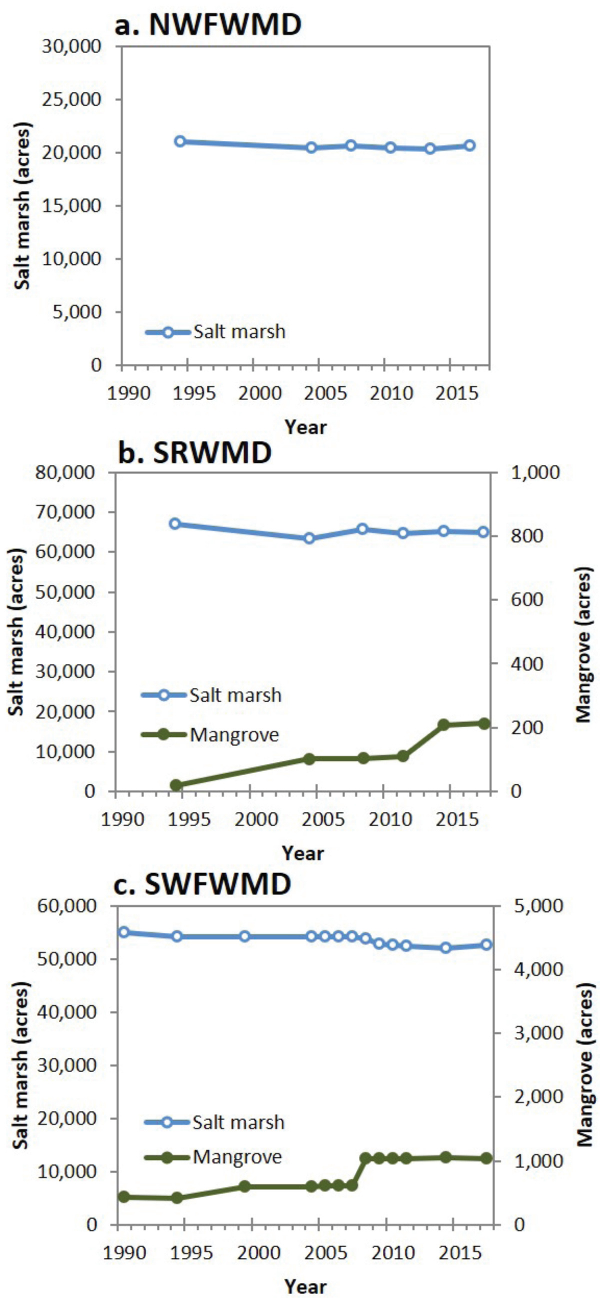

Figure 3.3. Extent of salt marsh and mangrove swamp in land-use/land-cover maps from the three water management districts in the Big Bend and Springs Coast region (NWFWMD 2018, SRWMD 2020, SWFWMD 2020).

and offshore oyster reefs that reduce wave energy and slow freshwater flow, resulting in a low-energy, brackish estuarine environment (Rupert and Arthur 1997, Kaplan et al. 2016). Year-round the coastal waters are typically less saline than seawater due to freshwater input (Orlando et al. 1993). The Floridan aquifer lies close to the surface here, and freshwater springs feed several rivers and contribute directly to coastal waters (Coultas and Hsieh 1997, Raabe et al. 2011). Flow from the springs is more consistent than in surface-fed streams, since groundwater responds more slowly to changes in rainfall (Wolfe 1990). The springwater is very clear, and the temperature is consistent year-round. The mean water temperature is approximately 22 °C (72 °F), roughly the same as the mean air temperature (Hornsby and Ceryak 2000), making the region a natural haven for manatees in colder weather and a popular tourist destination.

Human impacts

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

The populations in Citrus, Hernando, and Pasco counties on the Springs Coast, however, increased by 6–19% from 2010 to 2019 (U.S. Census 2019). In places like Hernando Beach in Hernando County, coastal wetland habitat was dredged and filled during construction of subdivisions (Wolfe 1990). Although the Big Bend is predominantly undeveloped and much of the population is rural, human impact is growing as the region becomes increasingly popular for ecotourism and marine activities (FDEP 2015). Other economically important industries in the region include pit mining for lime rock, cattle ranging, hog ranging, fishing, and shellfish harvesting (Wolfe 1990, FWC 2004, FDEP 2015).

A large array of protected lands and coastal waters is found along the Big Bend and Springs Coast region. Aquatic preserves include the extensive Big Bend Seagrasses Aquatic Preserve, which covers 364,000 ha (900,000 ac), along with the smaller Alligator Harbor and St. Martins Marsh Aquatic Preserves (FDEP 2015). In 2020, the Nature Coast Aquatic Preserve was established as the 42nd aquatic preserve in Florida, protecting an additional 160,000 ha (400,000 ac) of submerged land. The region includes five national wildlife refuges (NWRs): St. Marks, Lower Suwannee, Cedar Keys, Crystal River, and Chassahowitzka, totaling more than 62,700 ha (155,000 acres). In addition to public land owned by water management districts, State-managed lands along the coast include Econfina River State Park, Waccasassa Bay Preserve State

Table 3.1. Mangrove and salt marsh extent in land-use/land-cover maps from the three water management districts in the Big Bend and Springs Coast region (NWFWMD 2018, SRWMD 2020, SWFWMD 2020).

District/year of LULC map	Salt marsh (ha)	Salt marsh (ac)	Mangrove (ha)	Mangrove (ac)
NWFWMD				
1994–1995	8,477	20,946	0	0
2004	8,260	20,410	0	0
2006–2007	8,344	20,619	0	0
2009–2010	8,278	20,455	0	0
2012–2013	8,219	20,310	0	0
2015–2016	8,356	20,648	0	0
SRWMD				
1994–1995	27,156	67,104	8	19
2004	25,640	63,357	41	101
2006–2008	26,617	65,772	42	103
2010–2011	26,172	64,672	45	110
2013–2014	26,336	65,078	84	208
2016–2017	26,266	64,904	86	212
SWFWMD				
1990	22,206	54,871	176	435
1994	21,889	54,090	169	418
1999	21,892	54,097	241	596
2004	21,908	54,135	243	600
2005	21,900	54,116	244	604
2006	21,897	54,109	244	604
2007	21,890	54,092	244	604
2008	21,751	53,749	419	1,035
2009	21,373	52,815	419	1,035
2010	21,295	52,620	418	1,034
2011	21,223	52,442	418	1,033
2014	21,006	51,906	422	1,043
2017	21,273	52,566	417	1,030

Park, Crystal River Preserve State Park, the Marjorie Harris Carr Cross Florida Greenway, Werner-Boyce Salt Springs State Park, Withlacoochee Gulf Preserve, Cedar Key Scrub State Reserve, and numerous Florida Fish and Wildlife Conservation Commission (FWC) wildlife management areas.

Threats to coastal wetlands

- **Climate change and sea-level rise:** Sea-level rise impacts coastal wetlands in this region through greater tidal inundation, saltwater intrusion, and heightened wave erosion. At Cedar Key, sea level rose an average of 2.23 mm (0.09 in.) per year (22.3 cm/8.76 in. per 100 years) from 1914 to 2020 (NOAA 2021). The Big Bend and Springs Coast region is particularly susceptible to sea-level rise and storm surge due to the gentle slope of the topography. In regions with just 1.5 m of elevation gain over 5 km (5 ft over 3 mi), 5 cm (2 in.) of increased sea level can affect land 150 m (500 ft) inland, with drastic impacts on coastal forests adjoining the tidal marsh system (Stumpf and Haines 1998). As a result of increased tidal flooding and saltwater intrusion, freshwater and upland ecosystems are in decline, and salt-tolerant vegetation is moving farther inland (Figure 3.4; Raabe and Stumpf 2016, Langston et al. 2017, McCarthy et al. 2018).
- **Erosion:** Despite the relative stability afforded by the shallow limestone shelf, the shoreline along the Big Bend has been eroding at 1.2 m (3.9 ft) per year over the past 120 years (Raabe et al. 2004, Raabe and Stumpf 2016). Mapping efforts comparing historical and modern shorelines show both the loss and gain of marsh habitat along the Big Bend and Springs Coast region. In several locations, including those just north of Weeki Wachee and east of Cedar Key, salt marshes have been disproportionately replaced by unvegetated mud flats or open water (Raabe et al. 2004). Landward expansion of salt marshes has compensated for this loss of salt marsh habitat, but at the expense of upland forest communities that cannot tolerate the increased salinity (Kurz and Wagner 1957, Williams et al. 1999, Raabe et al. 2004, Raabe and Stumpf 2016, Langston et al. 2017). The rate of landward expansion of the salt marsh has been documented to occur at 2–3 times the rate of loss of the shoreward margin (Raabe and Stumpf 2016).
- **Altered hydrology:** Although the population in this region is relatively small, humans have impacted both surface and groundwater hydrology. Ditches, dams, and flood-protection structures alter surface water flow, rates of drainage, and water-retention times (Wolfe 1990). The Hickory Mound impoundment in Taylor County altered salinity regimes when it was built in 1968 to create a brackish marsh and augment waterfowl habitat (FDEP 2015). Roads through low-lying lands can function as levees, decreasing hydrologic connectivity of the wetlands, fragmenting habitats, and obstructing

Figure 3.4. Dead cabbage palm (*Sabal palmetto*) trunks (top) and bases (bottom) surrounded by salt marsh at high tide near the Homosassa River show evidence of sea-level rise as salt-tolerant vegetation overtakes regions previously dominated by upland species. Photo credit: Kara Radabaugh.

water flow (Warren Pinnacle 2011). Boating channels have also been dredged in parts of the region, the most prominent of which is the remnant western edge of the attempted Cross Florida Barge Canal, which ends in Withlacoochee Bay.

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

- **High nutrient concentrations:** Increased nutrient concentrations are an important water-quality concern in natural springs and the Suwannee River (Thom et al. 2015, ESA et al. 2017, Hilliard 2010). Fertilizers, atmospheric deposition, septic tanks, and manure contribute nitrogen to surface water and groundwater, which later comes to the surface at springs (Katz et al. 1999, Harrington et al. 2010). By the late 1990s, nitrogen concentrations in the Chassahowitzka River and other nearby springs were already 50 times those found in pristine waters (Dixon and Estevez 1998). Nitrate levels are particularly high in the Suwannee River during periods of low flow, when water flow is dominated by Floridan aquifer spring flow rather than by water from the Okeefenokee Swamp (Pittman et al. 1997, Katz et al. 1999, FDEP 2003, Hilliard 2010). Nitrate levels in spring boils along the Springs Coast range from 0.185 to 0.575 mg/L, frequently exceeding the Florida Department of Environmental Protection's nitrate threshold of 0.35 mg/L for clear-water streams (Harrington et al. 2010). Isotope studies indicate that the primary contributors of nitrogen to these springs are inorganic fertilizer, most likely from lawn and golf course applications, and septic tanks (Harrington et al. 2010). Wastewater retained in percolation ponds or discharged via land application (wastewater sprayed on land for nutrient reduction via microbial processes and plant growth) may also contribute nutrients to groundwater (Harrington et al. 2010). Surface water naturally percolates down to the aquifer, but this process is accelerated by drainage wells and sinkholes (Wolfe 1990).

The response of coastal wetlands to eutrophication is variable and poorly understood (Kirwan and Megonigal 2013). Deegan et al. (2012) found that high nutrient levels increased above-ground *Spartina* spp. biomass at the expense of root systems and subsequently decreased marsh soil stability. High nitrogen concentrations can also increase mangrove growth, which may facilitate mangrove encroachment into salt marsh ecosystems (Simpson et al. 2013, Dangremond et al. 2019). Interactions among the many related factors and the tendency of tidal marsh ecosystems to resist disturbances (up to a threshold) make it difficult to predict the impacts of increasing nutrients in coastal wetland environments (Kirwan and Megonigal 2013).

- **Mangrove encroachment:** Mangroves are becoming increasingly abundant fringing salt marshes along the Springs Coast and the southern Big Bend due to the lack of recent cold events (Stevens et al. 2006, Raabe and Stumpf 2016). Mangroves at the northern end of their range tend to establish on the seaward margin of salt marshes and on islands (Figure 3.2). As the mangroves increase in size and canopy coverage, they shade and eventually replace marsh vegetation (Stevens et al. 2006, Cavanaugh et al. 2014). Mangroves provide many of the same ecosystem services as salt marshes, but mangrove encroachment will alter habitat availability for obligate salt marsh species.
- **Invasive vegetation:** As in much of the rest of Florida, invasive plant species threaten coastal wetlands in the Big Bend and Springs Coast region. More than 60 nonnative invasive plant species have been identified in Big Bend Seagrasses Aquatic Preserve, including water hyacinth (*Eichornia crassipes*), Brazilian pepper (*Schinus terebinthifolia*), and Australian pine (*Casuarina* spp.) (FDEP 2015). Increased nutrient levels may also make freshwater sawgrass (*Cladium jamaicense*) marshes vulnerable to invasion by native cattails (*Typha* spp.) in a manner similar to that in South Florida marshes (Newman et al. 1998).
- **Industrial pollutants:** Before 1998, the Fenholloway River was classified as a Class V body of water (designated for industrial use), as it received point-source pollutants from the Buckeye Foley pulp mill, mining companies, and the City of Perry's wastewater-treatment plant (FWC 2004). Fishing and shellfish harvest were banned there, and more than 2,300 ha (5,700 ac) of seagrass beds were lost offshore of the Fenholloway River (Mattson et al. 2007). Water quality in the river has improved somewhat in recent decades. The river was upgraded to a Class III body of water in 1998, indicating it is now a water body with limited recreation, fish consumption, and aquatic life due to human impacts (FDEP 2020).

Mapping and monitoring efforts

Coastal wetland elevation monitoring

The U.S. Fish and Wildlife Service Southeast Region Inventory and Monitoring Branch has implemented coastal wetland elevation monitoring in 18 NWRs in the southeastern United States since 2012. Participating refuges follow standard protocols for collecting data on surface elevation, accretion, pore-water salinity, and vegetation at permanent monitoring sites in selected priority wetland habitats (Lynch et al. 2015, Boyle 2018, Moorman and Rankin 2020). Data are entered into a national database and analyzed using standard methods (Ladin and Moorman 2020). The objectives of this monitoring program are to quantify rates of change in wetland elevation relative to sea-level rise in order to forecast longevity of these priority habitats. The rod surface elevation table (SET) method is used to monitor sediment height and calculate vertical changes in wetland surface elevation (Cahoon et al. 2002, 2003). Vegetation assessments (Boyle et al. 2015, Cook et al. 2016), benchmark elevations (Moorman et al. 2019), and surface elevation trends have been published for each participating site in the network (Ladin and Moorman 2020).

Monitoring locations along the Big Bend include black needlerush salt marshes in Lower Suwannee NWR and St. Marks NWR and a sawgrass marsh in Lower Suwannee NWR. The sawgrass monitoring site was abandoned in 2014 because it was so difficult to reach (Ladin and Moorman 2020). While it is recommended that data be collected for at least 5 years before trend analysis is conducted, preliminary analyses show both slightly positive and slightly negative trends in elevation (Ladin and Moorman 2020). Surface elevation changed −0.99 ± 0.58 mm/year (mean ± standard error) from 2012 to 2018 at three SETs in St. Marks NWR. At three SETs in the Lower Suwannee NWR, surface elevation increased by 1.06 ± 0.67 mm/year from 2012 to 2016.

Gulf of Mexico and Southeast Tidal Wetlands Project

The U.S. Geological Survey (USGS) collaborated with the University of Florida and the Florida Geological Survey to conduct the Gulf of Mexico and Southeast Tidal Wetlands Project, which used satellite imagery to evaluate changes in Big Bend marshes (Raabe and Stumpf 1997). Temporal variation in water level, vegetation land cover, and the normalized difference vegetation index (NDVI) were assessed using a time series of satellite images and classified by observed types of disturbance (fire, drought, flooding, storm surge). Several SETs were used to monitor marsh height and rates of sedimentation (Ladner et al. 2001, Cahoon et al. 2002, 2003). Thermal infrared mapping enabled the identification of coastal seeps and springs (Raabe et al. 2011), and terrain was mapped using an airborne laser swath mapping system (Raabe et al. 2008). Nineteenth-century topographic sheets were used to compare historical and modern features along the coastline (Raabe et al. 2004). The study found that salt marsh has been migrating landward along much of the Big Bend, overtaking upland habitat. Meanwhile, the edge of the marsh has been lost to open water at a rate of 1.2 m (3.9 ft) per year (Raabe and Stumpf 2016).

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

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

SWFWMD tidal river monitoring

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

FWC coastal wetland monitoring

The Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute recently established coastal wetland transects for long-term vegetation monitoring following the methods of Tampa Bay's Critical Coastal Habitat Assessment (Radabaugh et al. 2017). This monitoring is designed to assess the status and trends of different vegetation strata of coastal wetlands, from the water's edge to upland forest. Repeat monitoring is intended to occur every 3–5 years to evaluate changes in vegetation extent, abiotic characteristics such as soil organic content and pore-water salinity, and inland migration of vegetation over time as a result of sea-level rise or climate change. Two long-term monitoring transects were established near the Homosassa and Weeki Wachee rivers in the fall of 2020.

Monitoring loss of upland forest

Recent studies have focused on the mortality and thinning of upland forests and the increasing prevalence of salt-tolerant vegetation near coastal rivers and tidal creeks in the Big Bend. Langston et al. (2017) studied pockets of cabbage palm and red cedar growing on elevated limestone forest islands surrounded by salt marsh. The study documented a decline in cabbage palm and red cedar trees and increase in salt marsh vegetation on forest islands with more frequent tidal flooding. McCarthy et al. (2018) documented loss of upland forests near the Chassahowitzka River by identifying areas of decline in NDVI, and concluded that tree loss was attributable to both saltwater intrusion and a cold snap exceeding the cold tolerance of cabbage palms. The loss of these coastal islands along the Big Bend has caused habitat loss for dependent species such as the American Oystercatcher (*Haematopus palliatus*; Vitale et al. 2020).

Water management district mapping

The three water management districts in this region (NWFWMD, SRWMD, and SWFWMD) conduct periodic land-use/land-cover (LULC) mapping every 1–4 years (Figure 3.1). The features delineated in LULC maps are categorized into saltwater marsh or mangrove swamp classifications according to the Florida Land Use and Cover Classification System (FLUCCS) (FDOT 1999). Some of the variability between sampling years (Figure 3.3, Table 3.1) is likely due to refinement of sampling methods and variation in resolution of aerial photography. SRWMD did create LULC maps in 1988, but they are not included in Figure 3.3 because different methods and classification systems were used. The most recently published LULC maps available at the time of chapter publication are shown in Figure 3.1.

Sea Level Affecting Marshes Model

The Sea Level Affecting Marshes Model (SLAMM) developed by The Nature Conservancy modeled the spatial extent of coastal ecosystems as a function of current extent, rates of accretion, and multiple rates of sea-level rise (Geselbracht et al. 2011, 2015, Warren Pinnacle 2011). The model predicted a continued loss of coastal forest, tidal swamp, inland freshwater marsh, and tidal freshwater marsh with a concurrent increase in tidal flats, beaches, brackish marsh, and salt marsh (Geselbracht et al. 2015).

National Wetlands Inventory mapping

A note of caution should be made regarding the National Wetlands Inventory (NWI) mapping and all uses of NWI maps for mapping, analysis, and models in this region. The boundary between salt marshes and upland forest communities in the Big Bend and Springs Coast region is frequently classified as the Cowardin et al. (1979) category of E2FO3 (estuarine intertidal forested broad-leaved evergreen wetland) or E2SS3 (estuarine intertidal scrub–shrub broad-leaved evergreen) (NWI 2020), categories often interpreted by users as mangrove. While in much of Florida these categories are indeed used to identify mangrove swamps, in the Big Bend and Springs Coast Region fully formed mangrove swamps do not appear along the landward boundary of the salt marsh. The vegetation composition of this boundary, commonly referred to as a transition, includes salt-tolerant scrub and marsh, cabbage palms, pine, wetland forested mix, and mixed scrub/shrub wetland (Williams et al. 1999, Raabe et al. 2004, SRWMD 2011). The erroneous interpretation of a marsh-to-forest transition zones as mangrove produces misleading results in subsequent applications (e.g. SLAMM models), where expansion of intertidal habitat into coastal forest is interpreted as expansion of mangroves (Warren Pinnacle 2011, Geselbracht et al. 2015). This type of error propagation must be searched for and corrected.

Recommendations for protection, management, and monitoring

- Mangroves continue to expand their range and encroach upon salt marsh habitat in the Big Bend and Springs Coast region. This expansion and proliferation may start as individual trees or a mangrove fringe along salt marsh, yet current land classification schemes have categories for either mangrove swamp or salt marsh and do not distinguish ecosystems that may include a mixture of the two vegetation types (FDOT 1999). This gap necessitates monitoring with the use of presence/absence techniques or biomass change rather than traditional vegetation classification categories to accurately track mangroves in this region.
- The rate of landward migration of salt marshes often compensates for the rate of loss and erosion along the shore (Raabe and Stumpf 2016). Land purchases for conservation should be aimed at linking habitats and providing room for landward migration, requiring coordination between state, federal, and local conservation managers.
- Protection and management of coastal wetlands must incorporate watershed and groundwater management, including the monitoring of water quantity and quality. Sufficient freshwater flow is necessary to maintain salinity gradients along the coast and to moderate saltwater inundation. Although the ultimate impacts of eutrophication on salt marsh vegetation are difficult to predict (Kirwan and Megonigal 2013), efforts to reduce nutrients are recommended to prevent ecosystem-level alterations to the stability and biomass allocation of salt marsh plants.
- Prevent the introduction and spread of invasive species through active monitoring, early detection, and removal of exotic vegetation.
- Due to the large area and relatively wild status of the region, monitoring based upon vegetation and wetness indices derived from remote sensing data such as the Landsat Thematic Mapper may be more efficient than traditional land-cover classifications. This process eliminates errors associated with classification and enables rapid identification of regions with unusual changes that can be further investigated with high-resolution data. The use of high-resolution digital elevation model maps derived from light detection and ranging (LiDAR) data may also be useful when assessing impacts or predicting responses to vegetation changes associated with sea-level rise.

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Works cited

Bledsoe EL, Phlips EJ. 2000. Relationships between phytoplankton standing crop and physical, chemical, and biological gradients in the Suwannee River and plume region, USA. Estuaries. 23(4):458–473.

Boyle MF, Cook CE, Rankin NM. 2018. Regional protocol framework for vegetation monitoring on coastal wetland elevation monitoring (CWEM) sites in the southeastern U.S. (Region 4). Atlanta, GA: U.S. Fish and Wildlife Service, Southeast Region. https://ecos.fws.gov/ServCat/Reference/Profile/105164, accessed November 2020.

Boyle, MF, Rankin NM, Stanton, WD. 2015. Vegetation of coastal wetland elevation monitoring sites on national wildlife refuges in the South Atlantic geography: baseline inventory report. Atlanta, GA: U.S. Fish and Wildlife Service, Southeast Region. Available from https://www.fws.gov/southeast/pdf/report/vegetation-of-coastal-wetland-elevation-monitoring-sites-on-nwrs-in-the-south-atlantic-geography-baseline-inventory.pdf.

Cahoon DR, Lynch JC, Hensel P. 2003. Surface elevation table website. Laurel, MD: Patuxent Wildlife Research Center. https://www.usgs.gov/states/maryland/science/surface-elevation-table?qt-science_center_objects=0#qt-science_center_objects, accessed November 2020.

Cahoon DR, Lynch JC, Perez BC, Segura B, et al. 2002. High-precision measurements of wetland sediment elevation: II. The rod surface elevation table. J Sediment Res. 72:734–739.

Carlson PR, Yarbro LA, Kaufman KA, Mattson RA. 2010. Vulnerability and resilience of seagrasses to hurricane and runoff impacts along Florida's west coast. Hydrobiologia 649(1):39–53.

Cavanaugh KC, Kellner JR, Forde AJ, Gruner DS, et al. 2014. Poleward expansion of mangroves is a threshold response to decreased frequency of extreme cold events. Proc Natl Acad Sci USA. 111:723–727.

Clewell AF, Flannery MS, Janicki SS, Eisenwerth RD, Montgomery RT. 2002. An analysis of vegetation–salinity relationships in seven tidal rivers on the coast of west-central Florida. Technical report [draft]. Brooksville, FL: Southwest Florida Water Management District.

Cook CE, Boyle MF, Rankin NM. 2016. Vegetation of coastal wetland elevation monitoring sites on National Wildlife Refuges in the South Atlantic geography: 1st status assessment report. Atlanta, GA: U.S. Fish and Wildlife Service, Southeast Region Inventory & Monitoring Branch. Available from https://ecos.fws.gov/ServCat/DownloadFile/138965?Reference=91821.

Coultas CL, Hsieh YP. 1997. Ecology and management of tidal marshes: a model from the Gulf of Mexico. Delray Beach, FL: St. Lucie Press.

Cowardin LM, Carter V, Golet FC, Laroe ET. 1979. Classification of wetlands and deepwater habitats of the United States. Jamestown, ND: U.S. Fish and Wildlife Service. FWS/OBS-79/31. Available from https://www.fws.gov/wetlands/Documents/Classification-of-Wetlands-and-Deepwater-Habitats-of-the-United-States.pdf.

Dangremond EM, Simpson LT, Osborne TZ, Feller IC. 2020. Nitrogen enrichment accelerates mangrove range expansion in the temperate–tropical ecotone. Ecosystems. 23(4):703–714.

Deegan LA, Johnson DS, Warren RS, Peterson BJ, et al. 2012. Coastal eutrophication as a driver of salt marsh loss. Nature. 490:388–392.

Dixon LK, Estevez ED. 1998. Chassahowitzka National Wildlife Refuge status and trends. Denver, CO: U.S. Fish and Wildlife Service. Mote Marine Laboratory technical report no. 579. Available from http://isurus.mote.org/techreps/579/579.pdf.

ESA et al. (Environmental Science Associates, Janicki Environmental Inc., RPI, and TLSC). 2017. Suwannee River basin surface water improvement and management (SWIM) plan. Live Oak, FL: Suwannee River Water Management District. Available from https://www.mysuwanneeriver.com/DocumentCenter/View/12027/Suwannee-River-Basin-SWIM-Plan?bidId=.

FDEP (Florida Department of Environmental Protection). 2003. Water quality assessment report: Suwannee (including Aucilla, Coastal, Suwannee and Waccasassa basins in Florida). Tallahassee, FL: Florida Department of Environmental Protection.

FDEP (Florida Department of Environmental Protection). 2015. Big Bend Seagrasses Aquatic

Preserve management plan. Crystal River, FL: Big Bend Seagrasses Aquatic Preserve. Available from http://publicfiles.dep.state.fl.us/cama/plans/aquatic/Big-Bend-Seagrasses-AP-Management-Plan.pdf.

FDEP (Florida Department of Environmental Protection). 2020. Surface water quality standards: classes, uses, criteria. Tallahassee, FL: Florida Department of Environmental Protection. https://floridadep.gov/dear/water-quality-standards/content/surface-water-quality-standards-classes-uses-criteria, accessed August 2020.

FDOT (Florida Department of Transportation). 1999. Florida land use, cover and forms classification system, 3rd edition. State Topographic Bureau, Thematic Mapping Section. Available from https://www.nwfwater.com/content/download/4688/32122/fluccmanual.pdf.

FWC (Florida Fish and Wildlife Conservation Commission). 2004. A conceptual management plan for Big Bend Wildlife Management Area 2004–2014, Taylor and Dixie counties, Florida. Tallahassee, FL: Florida Fish and Wildlife Conservation Commission.

Geselbracht LL, Freeman K, Birch AP, Brenner J, Gordon DR. 2015. Modeled sea level rise impacts on coastal ecosystems at six major estuaries on Florida's gulf coast: implications for adaptation planning. PLOS ONE. 10(7):e0132079.

Geselbracht L, Freeman K, Kelly E, Gordon DR, Putz FE. 2011. Retrospective and prospective model simulations of sea level rise impacts on Gulf of Mexico coastal marshes and forests in Waccasassa Bay, Florida. Clim Change. 107(1–2):35–57.

Hale J, Frazer T, Tomasko D, Hall M. 2004. Changes in the distribution of seagrass species along Florida's central Gulf coast: Iverson and Bittaker revisited. Estuaries. 27:36–43.

Harrington D, Maddox G, Hicks R. 2010. Florida springs initiative monitoring network report and recognized sources of nitrate. Tallahassee, FL: Florida Department of Environmental Protection, Ground Water Protection Section. Available from https://floridadep.gov/sites/default/files/springs_Monitoring_report_102110.pdf.

Hilliard D. 2010. Attachment B: site-specific information in support of establishing numeric nutrient criteria in Suwannee Estuary/Suwannee Sound/Cedar Keys, Waccasassa Bay, and Withlacoochee Bay. Tallahassee, FL: Florida Department of Environmental Protection. Available from https://www.nrc.gov/docs/ML1032/ML103280530.pdf.

Hine AC. 2019. Geologic history of Florida: major events that formed the Sunshine State. Tallahassee, FL: University of Florida Press.

Hoffman BA, Dawes CJ. 1997. Vegetational and abiotic analysis of the salterns of mangals and salt marshes of the west coast of Florida. J Coast Res. 13:147–154.

Hornsby D, Ceryak R. 2000. Springs of the Aucilla, Coastal, and Waccasassa basins in Florida. Live Oak, FL: Suwannee River Water Management District. Report WR00-03. http://www.srwmd.state.fl.us/DocumentCenter/View/684/Springs-of-the-Aucilla-Coastal-and-Waccasassa?bidId=, accessed July 2020.

Kangas PC, Lugo AE. 1990. The distribution of mangroves and saltmarsh in Florida. J Trop Ecol. 31:32–39.

Kaplan DA, Olabarrieta M, Frederick P, Valle-Levinson A. 2016. Freshwater detention by oyster reefs: quantifying a keystone ecosystem service. PLOS ONE. 11:e0167694

Katz BG, Hornsby HD, Bohlke JF, Mokray MF. 1999. Sources and chronology of nitrate contamination in spring waters, Suwannee River Basin, Florida. Tallahassee, FL: U.S. Geological Survey. Water-Resources Investigations Report 99-4252. Available from https://pdfs.semanticscholar.org/6a57/22d0d988822d74eccb554e4952a656af078f.pdf?_ga=2.254922637.440776022.1596732230-124080275.1586275404.

Katz BG, Raabe EA. 2005. Suwannee River basin and estuary: an integrated watershed science program. Tallahassee, FL: U.S. Geological Survey. Open-File Report 2005-1210. Available from https://pdfs.semanticscholar.org/60dd/ef4eda5ab8191d035fd6de6f3d98f600445d.pdf?_ga=2.248816003.56477468.1597693309-1865432938.1597693309.

Kirwan ML, Megonigal JP. 2013. Tidal wetland stability in the face of human impacts and sea level rise. Nature. 504:53–60.

Kurz H, Wagner K. 1957. Tidal marshes of the Gulf and Atlantic coasts of northern Florida and Charleston, South Carolina. Tallahassee, FL: Florida State University. Florida State University Studies No. 24.

Ladin Z, Moorman M. 2020. USFWS, southeast region SET data analysis. Newark, DE: University of Delaware and U.S. Fish and Wildlife Service Inventory & Monitoring Branch. https://ecos.fws.gov/ServCat/Reference/Profile/118378, accessed September 2020.

Ladner J, Hoenstine RW, Dabous A, Cross B. 2001. Coastal wetlands study 2001: Big Bend–Atlantic coast regions. Florida Geological Survey Department of Environmental Protection 11th annual report.

Langston AK, Kaplan DA, Putz FE. 2017. A casualty of climate change? Loss of freshwater forest islands on Florida's Gulf coast. Glob Chang Biol. 23(12):5383–5397.

Leonard LA, Hine AC, Luther ME, Stumpf RP, Wright EE. 1995. Sediment transport processes in a west-central Florida open marine marsh tidal creek: the role of tides and extra tropical storms. Estuar Coast Shelf Sci. 41:225–248.

Light HM, Darst MR, Lewis LJ, Howell DA. 2002. Hydrology, vegetation, and soils of riverine and tidal floodplain forests of the lower Suwannee River, Florida, and potential impacts of flow reductions. U.S. Geological Survey Professional Paper 1656A. Tallahassee, FL: U.S. Geological Survey. Available from https://pdfs.semanticscholar.org/2ee4/7c1becd1fd1f48c197bfd6e737a16e53b20f.pdf?_ga=2.7414711.440776022.1596732230-124080275.1586275404.

Livingston RJ. 1990. Inshore marine habitats. In: Meyers RJ, Ewel JJ, editors. Ecosystems of Florida. Orlando, FL: University of Central Florida Press. p. 549–573.

Lugo AE, Patterson-Zucca CP. 1977. The impact of low temperature stress on mangrove structure and growth. Trop Ecol. 18:149–161.

Lynch JC, Hensel P, Cahoon DR. 2015. The surface elevation table and marker horizon technique: a protocol for monitoring wetland elevation dynamics. Fort Collins, CO: U.S. National Park Service. Natural Resource Report NPS/NCBN/NRR—2015/1078.

Marella RL. 2014. Water withdrawals, use, and trends in Florida, 2010. Reston, VA: U.S. Geological Survey. Scientific Investigations Report 2014–5088. https://pubs.usgs.gov/sir/2014/5088/, accessed July 2020.

Mattson RA, Frazer TK, Hale J, Blitch S, Ahijevych L. 2007. Florida Big Bend. In: Handley L, Altsman D, Demay R, editors. Seagrass status and trends in the northern Gulf of Mexico: 1940–2002. Reston, VA: U.S. Geological Survey. Scientific Investigations Report 2006-5287. p. 171–188. Available from https://pubs.usgs.gov/sir/2006/5287/pdf/FloridaBigBend.pdf.

McCarthy MJ, Dimmitt B, Muller-Karger FE. 2018. Rapid coastal forest decline in Florida's Big Bend. Remote Sens. 10(11):1721.

Moorman MC, McDonald JM, Rankin NM, Mulligan AS. 2019. Determining elevation of rod surface elevation table benchmarks at coastal wetland elevation monitoring sites: baseline report. Atlanta, GA: U.S. Fish and Wildlife Service, Southeast Region.

Moorman MC, Rankin NM. 2020. South Atlantic-Gulf and Mississippi basin protocol framework for Coastal Wetland Elevation Monitoring (CWEM). Version 1.0. Atlanta, GA: U.S. Fish and Wildlife Service, South Atlantic-Gulf and Mississippi-Basin. Available from https://ecos.fws.gov/ServCat/DownloadFile/178825.

Newman S, Schuette J, Grace JB, Rutchey K, et al. 1998. Factors influencing cattail abundance in the northern Everglades. Aquat Bot. 60:265–280.

NOAA (National Oceanic and Atmospheric Administration). 2021. Mean sea level trend 8727520: Cedar Key, Florida. https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8727520, accessed April 2021.

NWFWMD (Northwest Florida Water Management District). 2018. Northwest Florida Water Management District (NWFWMD) 2015–2016 Land Use. https://geodata.dep.state.fl.us/datasets/northwest-florida-water-management-district-nwfwmd-2015-2016-land-use, accessed August 2020.

NWI (National Wetland Inventory). 2020. National Wetlands Inventory online mapper. U.S. Fish and Wildlife Service. https://www.fws.gov/wetlands/Data/Mapper.html, accessed July 2020.

Orlando SPJ, Rozas LP, Ward GH, Klein CJ. 1993. Salinity characteristics of Gulf of Mexico estuaries. Silver Spring, MD: National Oceanic and Atmospheric Administration, Office of Ocean Resources Conservation and Assessment. Available from https://repository.library.noaa.gov/view/noaa/2909/noaa_2909_DS1.pdf.

Pittman JR, Hatzell HH, Oaksford ET. 1997. Spring contributions to water quantity and nitrate loads in the Suwannee River during base flow in July 1995. Tallahassee, FL: U.S. Geological Survey. Water-Resources Investigations Report 97-4152. Available from https://pubs.usgs.gov/wri/1997/4152/report.pdf.

Raabe E, Stonehouse D, Ebersol K, Holland K, Robbins L. 2011. Detection of coastal and submarine discharge on the Florida Gulf coast with an airborne thermal-infrared mapping system. Professional Geologist. 48:42–49. https://pubs.er.usgs.gov/publication/70039643, accessed July 2020.

Raabe EA, Harris MS, Shrestha RL, Carter WE. 2008. Derivation of ground surface and vegetation in a coastal Florida wetland with airborne laser technology. St. Petersburg, FL: U.S. Geological Survey. Open-File Report 2008-1125. Available from https://pubs.usgs.gov/of/2008/1125/OFR_2008_1125/OFR_2008_1125.pdf.

Raabe EA, Streck AE, Stumpf RP. 2004. Historic topographic sheets to satellite imagery: a methodology for evaluating coastal change in

Florida's Big Bend tidal marsh. St. Petersburg, FL: U.S. Geological Survey. Open File Report 02-211. Available from https://pubs.usgs.gov/of/2002/of02-211/pdf/OFR_02-211.pdf.

Raabe EA, Stumpf RP. 1997. Assessment of acreage and vegetation change in Florida's Big Bend tidal wetlands using satellite imagery. In: Proceedings of the 4th International Conference on Remote Sensing for Marine and Coastal Environments: Technology and Applications, 17–19 March 1997, Orlando, Florida, USA, Volume 2. Ann Arbor, MI: Environmental Research Institute of Michigan. p. I84–I93. Available from https://pubs.usgs.gov/unnumbered/70114013/report.pdf.

Raabe EA, Stumpf RP. 2016. Expansion of tidal marsh in response to sea level rise: Gulf coast of Florida, USA. Estuaries Coast. 39:145–157.

Raabe EA, Stumpf RP, Marth NJ, Shrestha RL. 1996. A precise vertical network: establishing new orthometric heights with static surveys in Florida tidal marshes. Surveying and Land Information Systems. 56:200–211.

Radabaugh KR, Moyer RP, Raulerson GE, Sherwood ET. 2017. Critical coastal habitat assessment training manual: a guide for long-term monitoring of coastal wetland habitats. St. Petersburg, FL: Tampa Bay Estuary Program. TBEP Technical Report #06-17. Available from https://drive.google.com/file/d/1cBFAyVheC-z4RyCnRImeAoO_fPibohN-/view.

Rupert FR, Arthur JD. 1997. Geology and geomorphology. In: Coultas CL, Hsieh YP, editors. Ecology and management of tidal marshes: a model from the Gulf of Mexico. Delray Beach, FL: St. Lucie Press. p. 35–52.

Seavey JR, Pine WE III, Frederick P, Sturmer L, Berrigan M. 2011. Decadal changes in oyster reefs in the Big Bend of Florida's Gulf coast. Ecosphere. 2:1–14.

Simpson LT, Feller IC, Chapman SK. 2013. Effects of competition and nutrient enrichment on *Avicennia germinans* in the salt marsh–mangrove ecotone. Aquat Bot. 104:55–59.

Smith C. 2012. Drought has Cedar Key scrambling to provide fresh water. Gainesville, FL: Gainesville Sun. June 20, 2012. https://www.gainesville.com/news/20120620/drought-has-cedar-key-scrambling-to-provide-fresh-water, accessed August 2020.

SRWMD (Suwannee River Water Management District). 2020. Suwannee River Water Management District (SRWMD) 2016–2017 Land Use. https://geodata.dep.state.fl.us/datasets/da31d3d7a1af431d9eb6bc3960ea4463_1, accessed August 2020.

Stevens PW, Fox SL, Montague CL. 2006. The interplay between mangroves and salt marshes at the transition between temperate and subtropical climate in Florida. Wetl Ecol Manag. 14:435–444.

Stout JP. 1984. The ecology of irregularly flooded salt marshes of the northeastern Gulf of Mexico: a community profile. Dauphin Island, AL: Dauphin Island Sea Lab. U.S. Fish and Wildlife Service Biological Report 85(7.1). Available from https://babel.hathitrust.org/cgi/pt?id=mdp.39015086473538&view=1up&seq=7.

Stumpf RP, Haines JW. 1998. Variations in tidal level in the Gulf of Mexico and implications for tidal wetlands. Estuar Coast Mar Sci. 46:165–173.

SWFWMD (Southwest Florida Water Management District). 2001. The hydrology and water quality of select springs in the Southwest Florida Water Management District. Available from http://polk.wateratlas.usf.edu/upload/documents/Hydrology_Water_Quality_Select_Springs.pdf.

SWFWMD (Southwest Florida Water Management District). 2020. Southwest Florida Water Management District Land Use Land Cover 2017. https://data-swfwmd.opendata.arcgis.com/datasets/2017-land-use-land-cover, accessed August 2020.

Thom TA, Hunt KJ, Faustini J. 2015. Water Resource Inventory and Assessment (WRIA): Lower Suwannee National Wildlife Refuge, Dixie and Levy counties, Florida. Atlanta, GA: U.S. Fish and Wildlife Service Southeast Region. https://ecos.fws.gov/ServCat/DownloadFile/44772?Reference=44065, accessed July 2020.

U.S. Census. 2019. United States Census Bureau state & county quick facts. https://www.census.gov/quickfacts/ accessed August 2020.

USGS (U.S. Geological Survey). 2013. National water information system: web interface. https://waterdata.usgs.gov/nwis, accessed July 2020.

Vitale N, Brush J. Powell A. 2020. Loss of coastal islands along Florida's Big Bend region: implications for breeding American Oystercatchers. Estuaries Coast. https://doi.org/10.1007/s12237-020-00811-3.

Warren Pinnacle Consulting Inc. 2011. Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Lower Suwannee NWR. Corpus Christi, TX: Gulf of Mexico Alliance. Available from http://warrenpinnacle.com/prof/SLAMM/USFWS/SLAMM_Lower_Suwannee.pdf.

Williams K, Ewel KC, Stumpf RP, Putz FE, Workman TW. 1999. Sea level rise and coastal forest retreat on the west coast of Florida, USA. Ecology. 80:2045–2063.

Wolfe SH (editor). 1990. An ecological characterization of the Florida Springs Coast: Pithlachascotee to Waccasassa rivers. U.S. Fish and Wildlife Service Biological Report 90(21). https://ufdc.ufl.edu/UF00000130/00001/1j, accessed August 2020.

Wright EE, Hine AC, Goodbred SL Jr, Locker SD. 2005. The effect of sea-level and climate change on the development of a mixed siliciclastic-carbonate, deltaic coastline: Suwannee River, Florida, USA. J Sed Res. 75:621–635.

General references and additional regional information

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

Gulf of Mexico and Southeast Tidal Wetlands Project: https://archive.usgs.gov/archive/sites/coastal.er.usgs.gov/wetlands/

U.S. Fish and Wildlife Inventory and Monitoring Network Southeast Region: https://www.fws.gov/southeast/national-wildlife-refuges/inventory-and-monitoring/

Regional contacts

Kris Kaufman, NOAA Restoration Center, kristen.kaufman@noaa.gov

Kara Radabaugh, Florida Fish and Wildlife Conservation Commission, kara.radabaugh@myfwc.com