Chapter 10

Biscayne Bay

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Description of the region

Biscayne Bay was formed between 5,000 and 2,400 years ago, when a rising sea flooded a limestone depression on the Miami Ridge, creating a shallow estuarine lagoon (FDEP 2013). The bay is partly sheltered from the Atlantic Ocean by the Florida Keys along its southern margin and by barrier islands off Miami along its northern margin (Figure 10.1). The Atlantic Coastal Ridge, an oolitic limestone feature that reaches a maximum elevation of 6 m (20 ft), runs along part of Biscayne Bay's western shore and separates the Everglades from the Atlantic Ocean. Biscayne Bay once had a strong hydrological connection to the Everglades via rivers and creeks that ran through and around the Atlantic Coastal Ridge. As observed in 1892, there was sufficient hydraulic head and connectivity that the Miami River had small waterfalls, which dropped 3 m over a distance of 275 m (10 ft over 300 yd) (Ingraham 1923). Freshwater also entered the bay as a diffuse sheet of surface water from the surrounding wetlands and through groundwater springs (Browder et al. 2005).

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

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

Freshwater also enters Biscayne Bay from the Biscayne Aquifer. The aquifer is a subterranean wedge of water-bearing, highly permeable limestone bedrock that extends across Miami-Dade County; it reaches its maximum thickness of 73 m (240 ft) at the eastern edge of the bay (CERP 2011). Since the aquifer is highly permeable, at shallow depths it is susceptible to groundwater contamination. The Biscayne Aquifer is one of the most important natural resources in the area, supplying drinking water for Miami-Dade, Broward, and southern Palm Beach counties. Flow from freshwater springs into Biscayne Bay declined in the early 1900s, when altered Everglades hydrology lowered the water table (FDEP 2013). A few of these rare springs still exist (e.g., 75 m offshore of Deering Estate, due north of the northern tip of the boat basin; K. Whelan, personal observation in fall of 2020). Groundwater levels have continued to decline due to increasing urban and agricultural demand for freshwater.

Biscayne Bay is adjacent to the most heavily populated region in Florida. In 2019, the population of Miami-Dade County was estimated at 2.7 million and had grown 8.8% since 2010 (U.S. Census 2020). The Port of Miami is Florida's fifth-largest port, receiving both cruise and cargo ships (FDEP 2013). The northern portion of Biscayne Bay has been the most severely impacted, with six fill

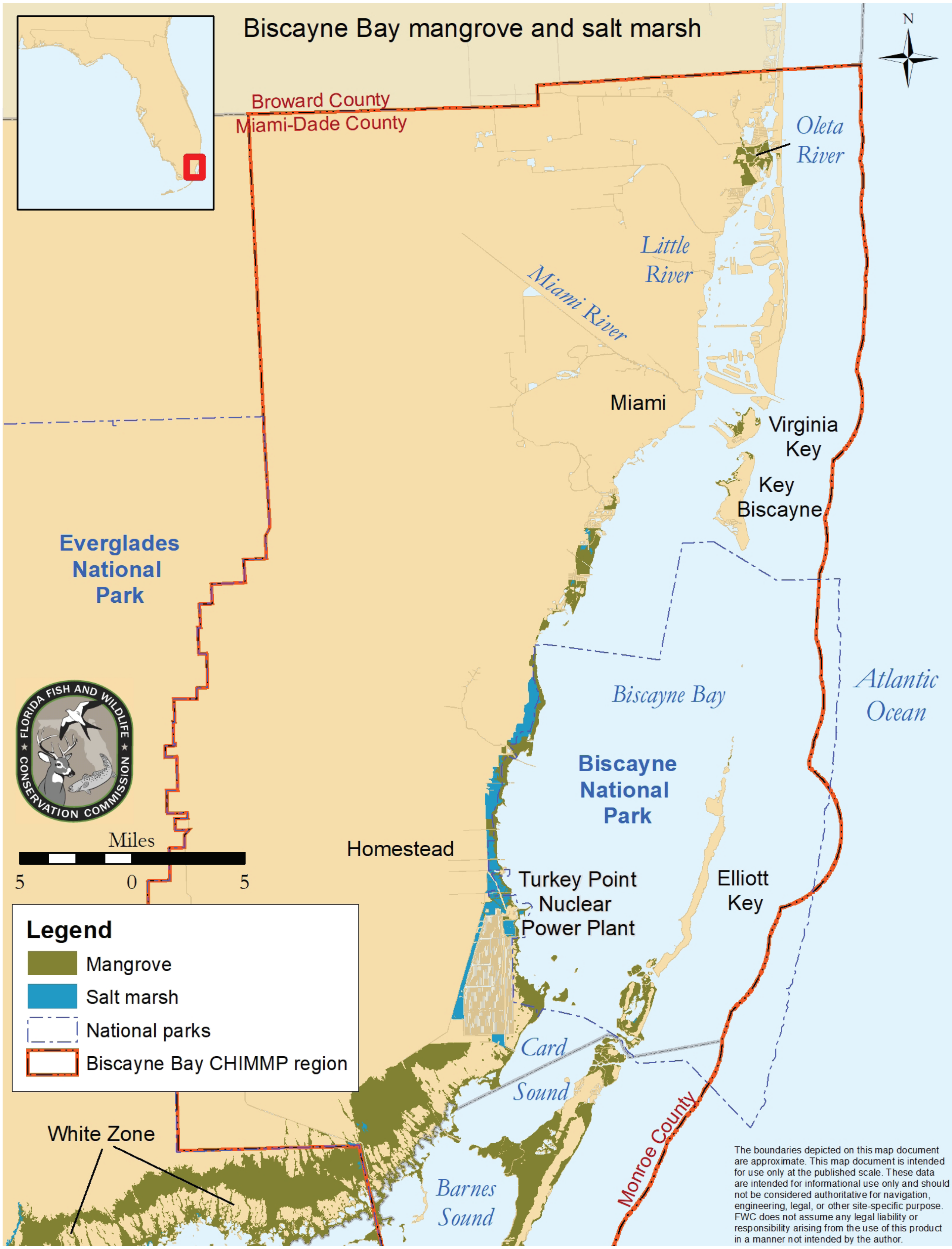

Figure 10.1. Mangrove and salt marsh coverage in the Biscayne Bay area. Data source: SFWMD 2014–2016 land-use/land-cover data, based upon FLUCCS classifications (FDOT 1999, SFWMD 2018).

causeways, a major seaport facility, and highly urbanized development. Water quality greatly improved in the bay in the 1970s with the development of more wastewater treatment plants and the elimination of direct sewage discharge into the bay. But there are still more than 100,000 homes with septic tanks disposing into the Biscayne Aquifer in Miami-Dade County (Miami-Dade County 2018), and the bay still receives significant amounts of nutrients and other pollutants via stormwater runoff (Browder et al. 2005, FDEP 2013). Nutrient runoff is particularly high south of greater Miami, where urban development is replaced by agriculture (FDEP 2013).

Mangroves dominate coastal wetland vegetation along Biscayne Bay (Figure 10.1), with mangrove canopy highest along the bay's western shoreline and decreasing inland (Ruiz 2007). Red mangrove (*Rhizophora mangle*) is the most abundant species along the coast and in many of the inland forests. Black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), and the closely associated buttonwood (*Conocarpus erectus*) become more prominent further inland (Smith et al. 1994, Ruiz 2007). Much of the area mapped as salt marsh in Figure 10.1 is actually vegetated by sawgrass (*Cladium jamaicense*) and spikerush (*Eleocharis* spp.) interspersed with occasional red mangroves. The small areas of true salt marsh around the bay, which have been reduced by the expansion of mangroves, tend to be dominated by black needlerush (*Juncus roemerianus*) or salt grass (*Distichlis spicata*, Ruiz 2007).

Extensive damage occurred to the mangrove forests of Biscayne Bay after Hurricane Donna in 1960, Hurricane Betsy in 1965, and particularly Hurricane Andrew in 1992. Hurricane Andrew made landfall at Elliot Key, then crossed Biscayne Bay and made a second landfall in Homestead as a Category 5 hurricane. Hurricane Andrew caused catastrophic damage to the tall (10–15 m/33–49 ft) red and black mangrove trees along the coast (Smith et al. 1994), with the red mangroves suffering particularly high mortality (Baldwin et al. 1995). Scrub red mangroves located farther inland, however, suffered little damage (Smith et al. 1994), and red mangroves along the coast were noted to have high seedling recruitment seven months after Hurricane Andrew (Baldwin et al. 1995). More recently, while the storm surge brought by Hurricane Irma in 2017 resulted in 1.2–1.8 m (4–6 ft) of inundation on the coast around Biscayne Bay, the region was generally spared the hurricane-force winds experienced in the Florida Keys and on the southwest coast of Florida (Cangialosi et al. 2018). Salt water was pushed several miles inland into the scrub mangroves in both the Card Sound and Barnes Sound areas (Ecology and Environment Inc. 2018). Some larger mangroves died on the coastal edge of southern Biscayne Bay after Hurricane Irma. The smaller scrub mangroves were inundated at the height of the storm and spared much of the immediate damage, but delayed mortality was observed in some of the scrub mangroves 2–3 years later (S. Ewe, personal observation).

An additional impact of the large urban population is a power plant located along the shoreline of Biscayne Bay. The Turkey Point Clean Energy Center, located in southern Biscayne Bay (Figure 10.1), includes a natural gas power unit and twin nuclear power units. The plant was constructed and began operation in the late 1960s and early 1970s. The warmwater effluent was found to have been detrimental to seagrass and many of the fish and benthic organisms (Zieman and Wood 1975). Consequently, 270 km (168 miles) of cooling canals were built through 2,750 ha (6,800 ac) of mangroves adjacent to the power plant (FDEP 2013; Figure 10.2). These canals are now a productive nursery ground for the American crocodile (*Crocodylus acutus*).

Southeast Saline Everglades "white zone"

The region landward of Card Sound and Barnes Sound (Figure 10.1) is part of a unique ecosystem that has been named the Southeast Saline Everglades (Egler 1952, Ross et al. 2000). From an aerial view, this region of sparse vegetation appears white due to the highly reflective nature of the marl substrate (Figure 10.2) and so it is also called the white zone (Ross et al. 2000, Browder et al. 2005, Briceño et al. 2011). The vegetation is composed of scrub mangroves along the coastline, which transition to sparse mangrove–graminoid mixtures of predominantly red mangrove and spikerush (Ross et al. 2000, 2002). The vegetation transitions to sawgrass-dominated freshwater wetlands further inland. Productivity in this coastal ecosystem is restricted by a combination of reduced seasonal freshwater flows, phosphorus limitation, and highly variable soil salinity. The vegetation in the white zone is generally not dense enough to be classified as mangrove forest under most land-cover classification systems.

While this unique ecosystem was present to a reduced extent before hydrologic alterations in South Florida, the reduction in sheet flow following channelization led to the landward expansion of the white zone of about 1.4 km (0.9 mi) from the 1940s through the 1990s (Ross et al. 2000). Sea-level rise is the primary cause of saltwater encroachment into the white zone (Meeder et al. 2017), but freshwater flow can mitigate saltwater intrusion, as seen in the reduced landward expansion of the white zone in

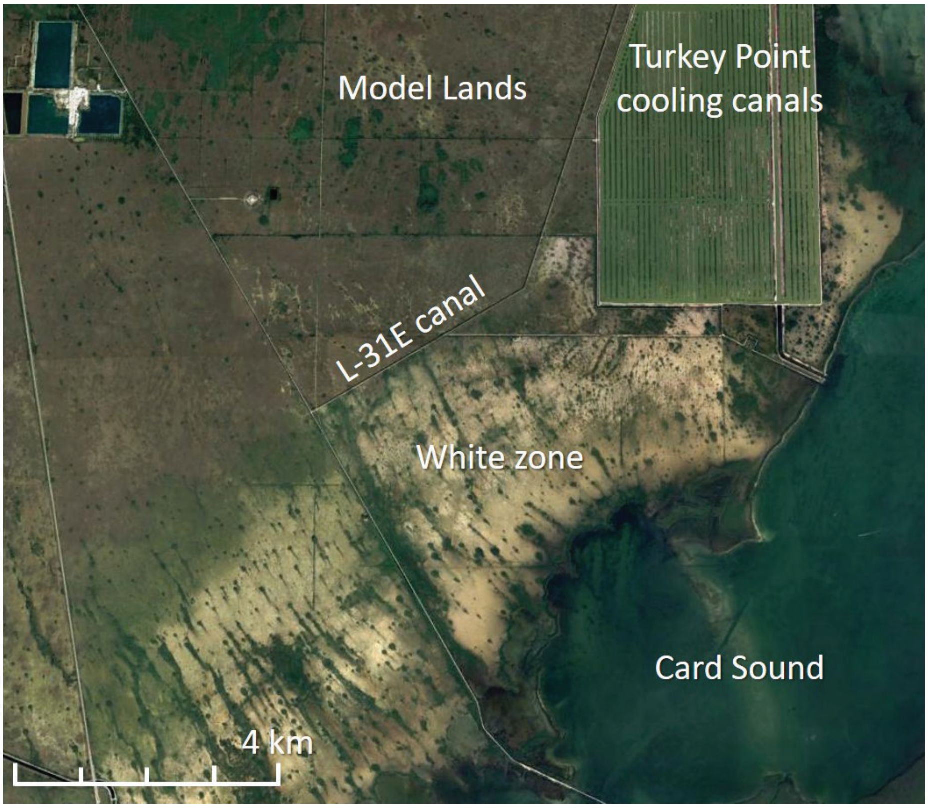

Figure 10.2. Aerial image of the white zone adjacent to Card Sound. Image credit: Google Earth 2017.

areas where surface freshwater flow was not restricted by roads or levees (Ross et al. 2000). Landward expansion of the white zone has been slowed due to restoration of sheet flow from a series of culverts connecting the Model Lands to the north with the white zone southeast of the L-31E canal (Figure 10.2).

Biscayne Bay management

Managed regions in the bay include Biscayne Bay Aquatic Preserve (established in 1974), Biscayne Bay–Cape Florida to Monroe County Line Aquatic Preserve (established in 1975), and Biscayne National Park (established in 1980) (FDEP 2013). Biscayne Bay Aquatic Preserve boundaries are restricted to submerged lands in the bay itself, so most of the mapping and monitoring conducted by the preserve has focused on parameters such as seagrass extent and water quality (FDEP 2013). Several parks and preserves also are located on the bay's shoreline, and all regions of the bay are used extensively for recreation. More than 500,000 people visit every year, and 54% of local residents report using the bay annually (CERP 2011, FDEP 2013).

In an effort to restore the wetlands in this region to a more natural state, the Comprehensive Everglades Restoration Plan (CERP) includes the Biscayne Bay Coastal Wetlands Project that aims to redirect freshwater from canals into coastal wetlands adjacent to the bay (CERP 2011, 2019, USACE and SFWMD 2020). The three regions of focus for this restoration program are the Deering Estate, the Cutler wetlands, and the L-31 East Flow-way wetlands near Military Canal. This surface flow of freshwater will help restore the coastal wetlands by re-establishing lower salinities, although invasive vegetation that has taken hold in some parts of the region may also need to be addressed (Browder et al. 2005, Briceño et al. 2011, FDEP 2013). Miami-Dade County restoration efforts in the area include habitat enhancement of spoil islands, shoreline stabilization, removal of invasive vegetation, planting of native vegetation, and the creation of flushing channels (Milano 2000, FDEP 2013).

Threats to coastal wetlands

- **Climate change and sea-level rise:** Sea-level rise is a threat to coastal ecosystems due to saltwater intrusion and longer hydroperiod from increased tidal flooding and slower freshwater runoff, which often results in coastal vegetation migrating further inland (CERP 2011). Coastal wetland extent is expected to decline in regions where extensive agriculture and urban development have replaced natural buffer zones. Additionally, saline intrusion into aquifers further diminishes freshwater availability from groundwater sources, which are already under stress due to water demand and surface water management (Browder et al. 2005).
- **Altered hydrology:** As mentioned, the canalization and reduction in sheet flow has led to freshwater depletion in many wetlands along the bay. This alteration has caused freshwater wetlands to shift to salt-tolerant vegetation. Increasing saltwater intrusion and the high salinity of water in the coastal wetlands decreases their productivity and ecosystem utility (Gaiser and

Ross 2003, SFNRC 2006). The South Florida Natural Resources Center outlined salinity targets optimal for the coastal mangrove zone along Biscayne Bay (SFNRC 2006). They include a maximum salinity of 30 on the practical salinity scale, which is difficult to maintain during the dry season, and oligohaline conditions with a salinity of 0–5 are recommended in the coastal mangrove zone during the summer rainy season.

- **Urban development:** Biscayne Bay is located in heavily populated Miami-Dade County. With this large human population comes continued development, loss and fragmentation of natural habitats, and increased recreational use of the bay (Briceño et al. 2011). While sewage management has improved, many septic systems remain in the county. Additionally, pollution in stormwater runoff continues to contribute excess hard debris/garbage (mainly in the form of plastics), nutrients, herbicides, pesticides, fertilizers, heavy metals, and hydrocarbons to the bay (Briceño et al. 2011, CERP 2011, FDEP 2013, Miami-Dade County Grand Jury Report 2018). Water, sediment, and fish contamination has generally been higher in the canals than in Biscayne Bay proper and its surrounding wetlands, indicating that canal discharge is a source of pollution for the bay (Bargar et al. 2017).
- **Hurricanes and tropical storms:** The location of Biscayne Bay makes it highly vulnerable to the powerful winds and storm surge of hurricanes and tropical storms, which can cause widespread canopy damage and tree mortality and alter the forest's species composition and dominant tree sizes (Smith et al. 2009). Large mangroves are particularly vulnerable to extensive damage and mortality in hurricanes (Smith et al. 1994). These storms can also cause saltwater intrusion if the wind-driven bay waters are forced inland; strong winds can push salt water several miles inland in the less developed southern shores of Biscayne Bay (Ecology and Environment Inc. 2018).
- **Invasive species:** As in much of Florida, invasive vegetation such as Brazilian pepper (*Schinus terebinthifolia*) and Australian pines (*Casuarina* spp.) compete with native species along Biscayne Bay, particularly in regions recovering from disturbances (FDEP 2013).

Mapping and monitoring efforts

Water management district mapping

The South Florida Water Management District (SFWMD) has updated its land-use/land-cover (LULC) mapping every 3–5 years since 1995. Land-cover classifications are based upon SFWMD's modifications to the Florida Land Use and Cover Classification System (FLUCCS) (FDOT 1999, SFWMD 2009). Figure 10.1 presents data from 2014–2016 surveys, which was the most recent complete SFWMD LULC map of south Florida at the time of publication (SFWMD 2018). Minimum mapping units were 2 ha (5 ac) for uplands and 0.2 ha (0.5 ac) for wetlands. Maps were made by interpreting aerial photography and updating 2008–2009 LULC vector data (SFWMD 2018).

Changes in mangrove and salt marsh area over time are not graphed in this chapter because changes in LULC methodology masked changes in habitat extent. For instance, SFWMD LULC data showed a 10-fold increase in the area of salt marsh around Biscayne Bay from 2004–2005 to 2008–2009. This difference reflects changes in mapping methodology rather than an actual increase in salt marsh extent.

Comprehensive Everglades Restoration Plan monitoring

Monitoring is conducted as part of the CERP Biscayne Bay Coastal Wetlands Project, which assesses impacts of the ongoing effort (CERP 2011, 2019, USACE and SFWMD 2020). Responsibility for monitoring of hydrology, ecology, water quality, and endangered species is shared by the SFWMD and the U.S. Army Corps of Engineers as part of the Biscayne Bay and Southeastern Everglades Ecosystem Restoration (BBSEER) project (USACE and SFWMD 2020). Monitored parameters in Biscayne Bay include salinity, chlorophyll *a* concentration, extent of submerged aquatic vegetation, and the abundance of multiple fish species and the American crocodile (CERP 2019). Salinity monitoring between 2012 and 2017 indicated that the volume and duration of freshwater flow into Biscayne Bay were not sufficient to create the desired mesohaline conditions along the shoreline (CERP 2019).

Local vegetation mapping and monitoring

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

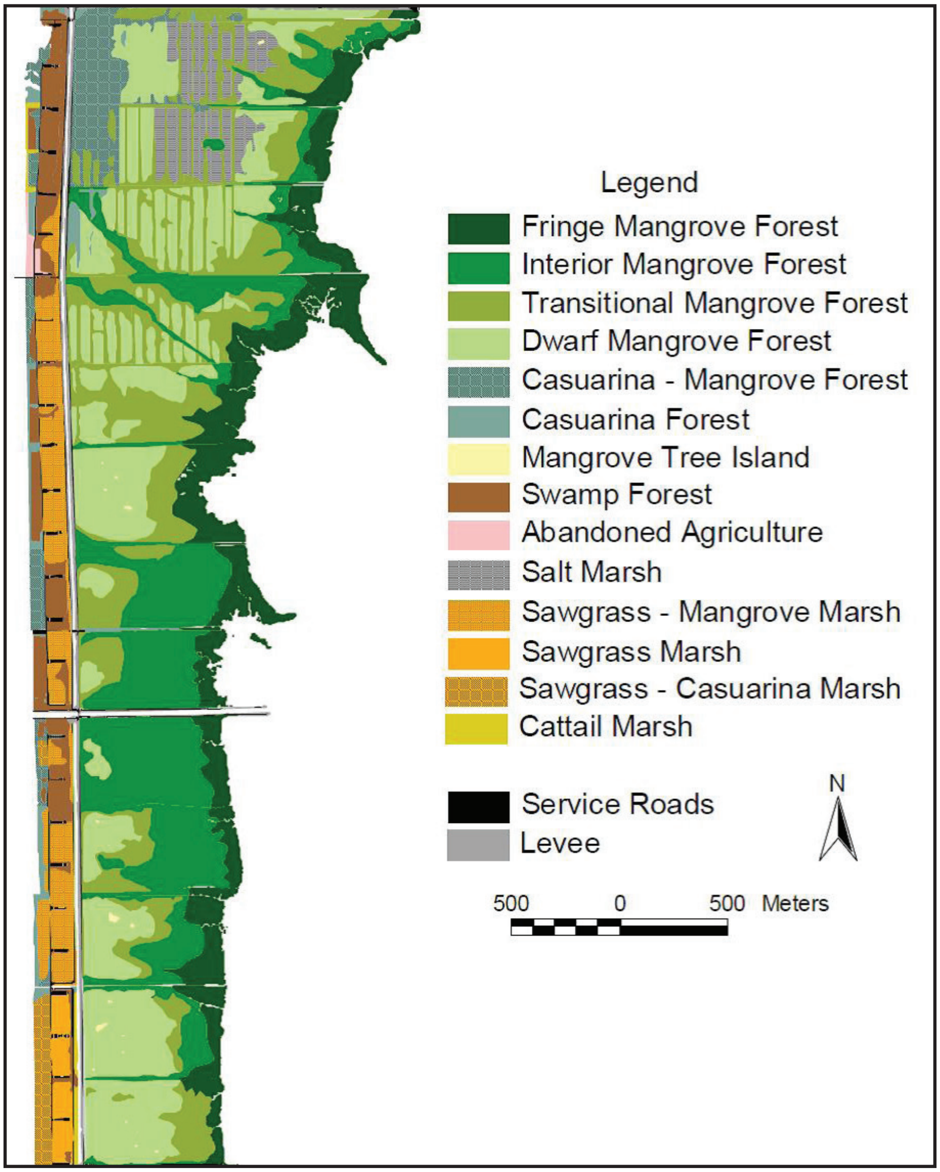

Figure 10.3. Vegetation between Princeton and Mowry canals, as mapped by Ross and Ruiz (2003).

cayne National Park for the National Park Service that included portions of the western shore of the bay between the Deering Estate and Turkey Point (Figure 10.4). The Ruiz et al. (2008) map had an overall accuracy of 83.3% with a Kappa index of 82.6%. Corrections were made to the vegetation map based on the field accuracy assessment (Whelan et al. 2013). Another map of all habitats in Biscayne National Park, including terrestrial and submerged ecosystems, is available from Davis (2017).

Forest monitoring

The National Park Service South Florida/Caribbean Inventory and Monitoring Network (NPS SFCN) has established a forest monitoring program for mangroves and coastal hardwood hammocks, the two dominant forest communities found in Biscayne National Park (Whelan et al. 2020). The SFCN is in the process of establishing eight mangrove and eight coastal hardwood hammock monitoring plots. These plots will be surveyed on a five-year return cycle. The goals for the monitoring of mangrove and coastal hardwood hammocks are to detect changes in species composition and vegetative structure and to determine whether these changes are associated with key stressors such as hurricanes, fires, droughts, altered hydrology, and sea-level rise (Whelan et al. 2020).

Invasive plant monitoring

The NPS SFCN has established a monitoring program for detecting new, possibly invasive nonnative plant species while their populations are small and controllable (Shamblin et al. 2013). This nonnative plant monitoring occurs at "corridors of invasiveness," locations considered most likely to experience plant introductions, such as boat ramps, trails, and campgrounds. Monitoring is done on a five-year rotation in Biscayne National Park. The last survey was carried out in 2016, when a total of 25 km was surveyed, and 45 nonnative species were encountered. Of those 45 nonnatives, 6 were documented for the first time in the park (Shamblin and Cuni 2016).

Soil elevation monitoring

The NPS SFCN has established two soil elevation monitoring sites with surface elevation tables (SETs) in Biscayne National Park for the purpose of measur-

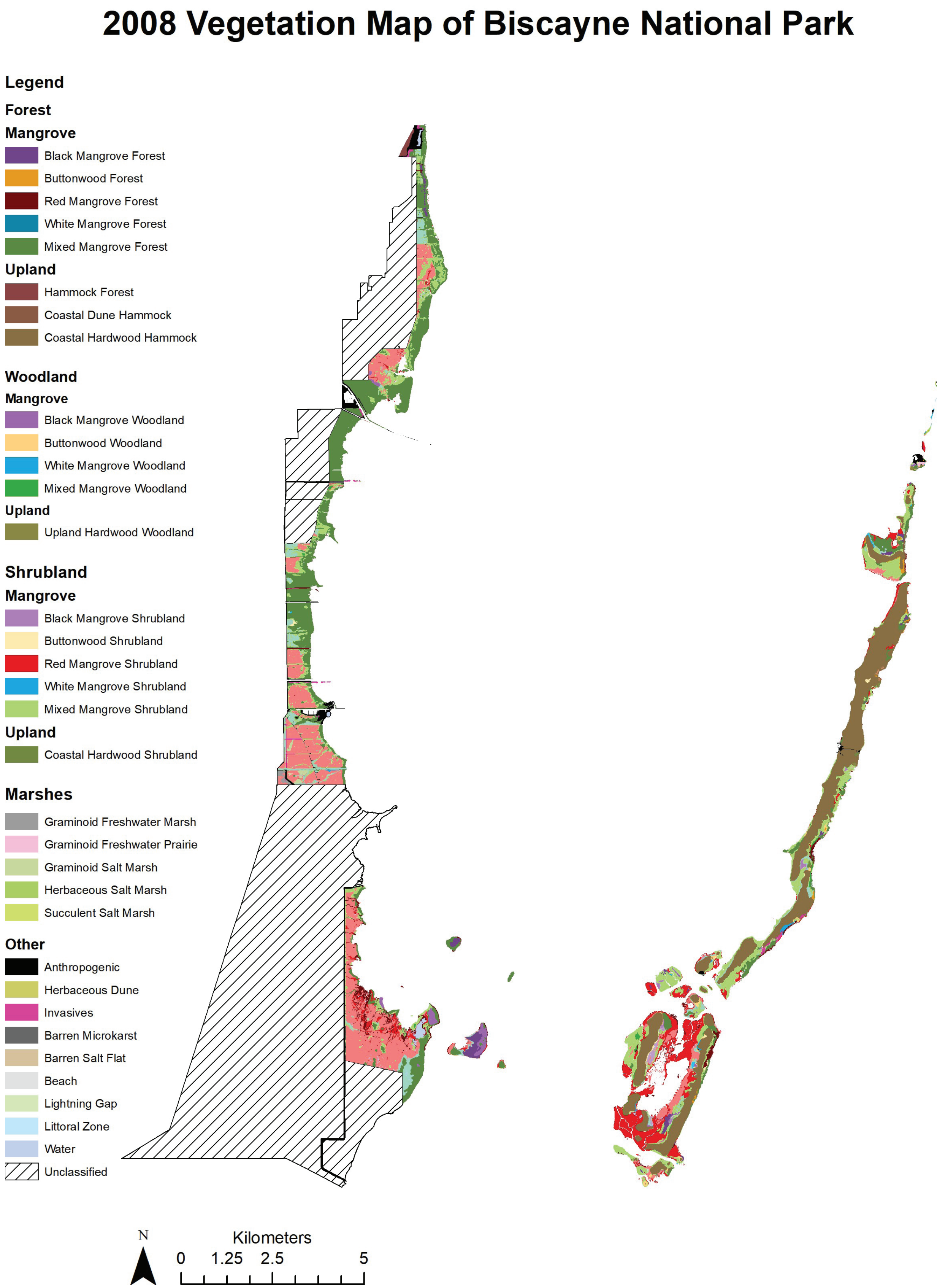

Figure 10.4. Vegetation map of Biscayne National Park (Ruiz et al. 2008).

Figure 10.5. Kevin Whelan, SFCN ecologist, measures soil surface elevation using a surface elevation table (SET). The SET is attached to a permanent benchmark. The height of the pins transcribes the elevation of the soil and standardizes it to a fixed reference point on the horizontal metal arm. Repeated measurements over time are used to monitor the rate of change in soil elevation.

ing mangrove soil elevation and calculating accretion rates over time to determine whether rates of accretion are keeping pace with local sea-level rise (Whelan 2016). Understanding the rate of change in mangrove soil elevation is critical to predicting the long-term viability of mangrove forests (Figure 10.5, SFCN 2019). At one site (established in 2011), the soil surface appeared to be gaining elevation, with increasing rates of accretion. Total soil surface elevation indicated an increase from 2011 to 2016, but surface elevation then decreased after 2016. This suggests that while the overall soil elevation is still accreting at the surface level, belowground processes (e.g., subsidence, compaction) may be causing a decrease in elevation. The second site (established in 2012) seems to have increasing elevation. Both sites are subject to periodic seagrass inputs that cause spikes in accretion, but the seagrass detritus then appears to be incorporated into the soil (SFCN 2019).

Recommendations for protection, management, and monitoring

- Remove mosquito and drainage ditches to improve hydrologic connectivity and freshwater retention and to simplify management of the wetlands. Ditch removal should be performed with caution, however, as it may kill mangroves that have colonized the mosquito ditches, which can facilitate establishment of invasive vegetation such as Brazilian pepper (Ruiz and Ross 2004).
- Continue efforts such as the Biscayne Bay Coastal Wetlands Project to improve hydrologic conditions in coastal wetlands (FDEP 2013).
- Consistently map and monitor coastal land cover and vegetation to monitor impacts of changing climate and altered hydrology (Briceño et al. 2011). Map with consistent methodology to enable comparison of long-term trends in habitat shifts such as mangrove expansion into salt marshes.

- Upgrade sewage systems in the greater Miami area, and address the issues of pollutants, nutrients, and sediment in runoff via stormwater treatment (FDEP 2013).
- Continue to acquire land to make large-scale restoration and water redistribution plans feasible (Briceño et al. 2011). Undeveloped privately owned lands are rare in South Florida and are likely to be developed in the near future (CERP 2011). The urban boundary around much of Biscayne Bay restricts landward migration of coastal wetlands with sea-level rise (FDEP 2013), increasing the importance of protecting existing undeveloped land.

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Works cited

Baldwin AH, Platt WJ, Gathen KL, Lessmann JM, Rauch TJ. 1995. Hurricane damage and regeneration in fringe mangrove forests of southeast Florida, USA. J Coast Res. 1:169–183.

Ball MC. 1980. Patterns of secondary succession in a mangrove forest of southern Florida. Oecologia. 44:226–235.

Bargar TA, Whelan KR, Alvarez D, Echols K, Peterman PH. 2017. Baseline aquatic contamination and endocrine status in a resident fish of Biscayne National Park. Mar Pollut Bull. 115(1–2):525–533.

Briceño HO, Boyer JN, Harlem P. 2011. Ecological impacts on Biscayne Bay and Biscayne National Park from proposed south Miami-Dade County development, and derivation of numeric nutrient criteria for South Florida estuaries and coastal waters. Miami, FL: Florida International University Southeast Environmental Research Center. NPS TA# J5297-08-0085. Available from http://serc.fiu.edu/wqmnetwork/BNP/Final%20Report%20BNP.pdf.

Browder JA, Alleman R, Markely S, Ortner P, Pitts PA. 2005. Biscayne Bay conceptual ecological model. Wetlands. 25:854–869.

Cangialosi JP, Latto AS, Berg R. 2018. National Hurricane Center tropical cyclone report. Hurricane Irma (AL 112017) 30 August–12 September 2017. Tropical Cyclone Report. Miami, FL: National Hurricane Center. Available from https://www.nhc.noaa.gov/data/tcr/AL112017_Irma.pdf.

CERP (Comprehensive Everglades Restoration Plan). 2011. Central and southern Florida project Comprehensive Everglades Restoration Plan Biscayne Bay coastal wetlands phase 1: final integrated project implementation report and environmental impact statement. Jacksonville, FL: U.S. Army Corps of Engineers Jacksonville District and South Florida Water Management District. Available from https://www.nrc.gov/docs/ML1227/ML12270A058.pdf.

CERP (Comprehensive Everglades Restoration Program). 2019. 2019 system status report. South Florida Water Management District and U.S. Army Corps of Engineers. https://www.saj.usace.army.mil/Missions/Environmental/Ecosystem-Restoration/RECOVER/2019-System-Status-Report/, accessed October 2020.

Davis AD. 2017. Biscayne National Park merged habitat map. Palmetto Bay, FL: National Park Service South Florida/Caribbean Network. https://irma.nps.gov/DataStore/Reference/Profile/2244557, accessed October 2020.

Egler FE. 1952. Southeast Saline Everglades vegetation, Florida, and its management. Vegetatio. 3:213–265.

FDEP (Florida Department of Environmental Protection). 2013. Biscayne Bay Aquatic Preserves management plan. Tallahassee, FL: Florida Department of Environmental Protection Coastal and Aquatic Managed Areas. Available from https://floridadep.gov/sites/default/files/Biscayne_Bay_Aquatic_Preserves_Management_Plan_2012_508.pdf.

FDOT (Florida Department of Transportation). 1999. Florida land use, cover and forms classification system, 3rd edition. Tallahassee, FL: FDOT, State Topographic Bureau, Thematic Mapping Section. Available from https://www.fdot.gov/docs/default-source/geospatial/documentsandpubs/fluccmanual1999.pdf.

Ecology and Environment Inc. 2018. Florida Power & Light Company annual monitoring report for the Turkey Point monitoring project. Ecology and

Environment, Inc., submitted to Miami, FL: Florida Power & Light Company. Available from https://www.nrc.gov/docs/ML1920/ML19205A068.pdf.

Gaiser EE, Ross MS. 2003. Water flow through coastal Everglades. Report to Everglades National Park CESI Contract 1443CA5280-01-019. Miami, FL: Florida International University Southeast Environmental Research Center.

Ingraham J. 1923. Trip of Mr. J.E. Ingraham and party through the Everglades in 1892. Report for the Florida East Coast Railway Company from the Model Land Company. St. Augustine, FL. https://www.uflib.ufl.edu/spec/ingraham/expedition/frontmatter.htm, accessed December 2020.

Meeder JF, Parkinson RW, Ruiz PL, Ross MS. 2017. Saltwater encroachment and prediction of future ecosystem response to the Anthropocene Marine Transgression, Southeast Saline Everglades, Florida. Hydrobiologia. 803:29–48.

Miami-Dade County. 2018. Septic systems vulnerable to sea level rise. Miami, FL: Miami-Dade County and Florida Department of Health in Miami-Dade County. Final Report in support of Miami-Dade County resolution no. R-9I1-I6. Available from https://www.miamidade.gov/green/library/vulnerability-septic-systems-sea-level-rise.pdf.

Miami-Dade Grand Jury Report 2018. The health of Biscayne Bay: water flows and water woes. Miami, FL: Circuit Court of the Eleventh Judicial Circuit of Florida in and for the County of Miami-Dade. Available from https://miamisao.com/wp-content/uploads/2021/02/GJ2018F-1.pdf.

Milano GR. 2000. Island restoration and enhancement in Biscayne Bay, Florida. In: Cannizzarro PJ, editor. Proceedings of the 26th annual conference on ecosystem restoration and creation. Tampa, FL: Hillsborough Community College. p. 1–17. Available from http://www.miamidade.gov/environment/library/reports/island-restoration.pdf.

Ross M, Meeder JF, Sah JP, Ruiz PL, Telesnicki GJ. 2000. The Southeast Saline Everglades revisited: 50 years of coastal vegetation change. J Veg Sci. 11:101–112.

Ross MS, Gaiser EE, Meeder JF, Lewin MT. 2002. Multi-taxon analysis of the "white zone," a common ecotonal feature of South Florida coastal wetlands. In: Porter JW, Porter KG, editors. The Everglades, Florida Bay, and coral reefs of the Florida Keys: an ecosystem sourcebook. Boca Raton, FL: CRC Press. p. 205–238.

Ross MS, Ruiz PL. 2003. Vegetation. In: Gaiser EE, Ross MS, editors. Water flow through coastal wetlands. Report to Everglades National Park CESI Contract 1443CA5280-01-019. Miami, FL: Florida International University Southeast Environmental Research Center. p. 8–16.

Ruiz PL. 2007. A GIS analysis of the Biscayne Bay coastal wetlands vegetation between the Mowry and Princeton canals. Miami, FL: Florida International University.

Ruiz PL, Houle PA, Ross MS. 2008. The 2008 terrestrial vegetation of Biscayne National Park, FL, USA derived from aerial photography, NDVI, and LiDAR. Miami, FL: Florida International University Southeast Environmental Research Center. SERC Research Report 86. Available from https://digitalcommons.fiu.edu/cgi/viewcontent.cgi?article=1092&context=sercrp.

Ruiz PL, Ross MS. 2004. Hydrologic restoration of the Biscayne Bay coastal wetlands: mosquito and drainage ditch inventory and recommendations. Miami, FL: Florida International University Southeast Environmental Research Center. SERC Research Report 82. Available from https://digitalcommons.fiu.edu/cgi/viewcontent.cgi?article=1097&context=sercrp.

SFCN (South Florida/Caribbean Network). 2019. Coastal geomorphology: monitoring mangrove soil surface elevation tables in Biscayne National Park 2019. Palmetto Bay, FL: South Florida/Caribbean Network, U.S. National Park Service. https://irma.nps.gov/DataStore/Reference/Profile/2272013, accessed November 2020.

SFNRC (South Florida Natural Resources Center). 2006. Ecological targets for western Biscayne National Park. U.S. Department of the Interior, National Park Service and Everglades National Park, South Florida Natural Resources Center. SFNRC Technical Series 2006:2. Available from https://www.nps.gov/ever/learn/nature/upload/BISCEcolTargetsHiResSecure.pdf.

SFWMD (South Florida Water Management District). 2009. 2009 SFWMD photointerpretation key. Version 1.5. Available from https://www.sfwmd.gov/sites/default/files/documents/2009_pi-key.pdf.

SFWMD (South Florida Water Management District). 2018. Land cover land use 2014–2016. https://sfwmd.maps.arcgis.com/home/item.html?id=266a64a897514090842e283311c12d30, accessed March 2020.

Shamblin RB, Cuni LM. 2016. SFCN corridors of invasiveness data summary report: Biscayne National Park, 2016. Fort Collins, CO: National Park Service.

Natural Resource Data Series. NPS/SFCN/NRDS—2016/1064. Available from https://irma.nps.gov/DataStore/DownloadFile/563570.

Shamblin RB, Whelan KRT, Vargas RM. 2013. South Florida/Caribbean Network early detection protocol for invasive exotic plants: corridors of invasiveness. Fort Collins, CO: National Park Service. Natural Resource Report NPS/SFCN/NRR—2013/675. Available from https://irma.nps.gov/DataStore/DownloadFile/472357.

Smith TJ III, Anderson GH, Balentine K, Tiling G, et al. 2009. Cumulative impacts of hurricanes on Florida mangrove ecosystems: sediment deposition, storm surges and vegetation. Wetlands. 29:24–34.

Smith TJ III, Robblee MB, Wanless HR, Doyle TW. 1994. Mangroves, hurricanes, and lightning strikes: assessment of Hurricane Andrew suggests an interaction across two differing scales of disturbance. BioScience. 44:256–262.

USACE and SFWMD (U.S. Army Corps of Engineers and South Florida Water Management District). 2020. Biscayne Bay and Southeastern Everglades ecosystem restoration project management plan. Central and Southern Florida Project Comprehensive Everglades Restoration Plan. Available from https://usace.contentdm.oclc.org/utils/getfile/collection/p16021coll7/id/15573.

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

Whelan KRT. 2016. Protocol implementation plan for monitoring mangrove soil surface elevation tables in South Florida/Caribbean Network parks. Fort Collins, CO: National Park Service. Natural Resource Report NPS/SFCN/NRR— 2016/1249. Available from https://irma.nps.gov/DataStore/DownloadFile/554569.

Whelan KRT, Ruiz PL, Shamblin RB, Houle PA, et al. 2013. Biscayne National Park vegetation map project report [and associated files]. Fort Collins, CO: National Park Service. Natural Resource Technical Report NPS/SFCN/NRTR—2013/774. https://irma.nps.gov/DataStore/Reference/Profile/2196852, accessed October 2020.

Whelan KRT, Shamblin RB, Prats M, Patterson JM, et al. 2020. South Florida/Caribbean Network forest vegetation monitoring: protocol implementation plan. Fort Collins, CO: National Park Service. Natural Resource Report NPS/SFCN/NRR—2020/2064. Available from https://irma.nps.gov/DataStore/DownloadFile/636316.

Zieman JC, Wood EJ. 1975. Effects of thermal pollution on tropical-type estuaries, with emphasis on Biscayne Bay, Florida. In: Johannes RE, Wood EJF, editors. Tropical marine pollution. Amsterdam, Netherlands: Elsevier Oceanography Series. p. 75–98.

General references and additional regional information

Miami-Dade County Natural Areas Management Plan 2004. Miami-Dade County Natural Areas Management Working Group. Department of Environmental Resources Management Technical Report Number 2004–1. Available from http://www.miamidade.gov/environment/library/reports/natural-areas-mgmt-plan.pdf.

Nuttle WK, Fletcher PJ, editors. 2013. Integrated conceptual ecosystem model development for the southeast Florida coastal marine ecosystem. Miami, FL: NOAA Technical Memorandum, OAR-AOML-103 and NOS-NCCOS-163. Available from https://www.aoml.noaa.gov/general/lib/TM/TM_OAR_AOML_103.pdf.

Biscayne National Park https://www.nps.gov/bisc/index.htm

Biscayne Bay Aquatic Preserves https://floridadep.gov/rcp/aquatic-preserve/locations/biscayne-bay-aquatic-preserves

South Florida multi-species recovery plan https://www.fws.gov/verobeach/listedspeciesMSRP.html

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

CERP Biscayne Bay coastal wetlands https://www.evergladesrestoration.gov/content/bbrrct/minutes/2015_meetings/071515/BBCW_Project_Status.pdf

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