Chapter 8
Everglades

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Description of the region

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

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

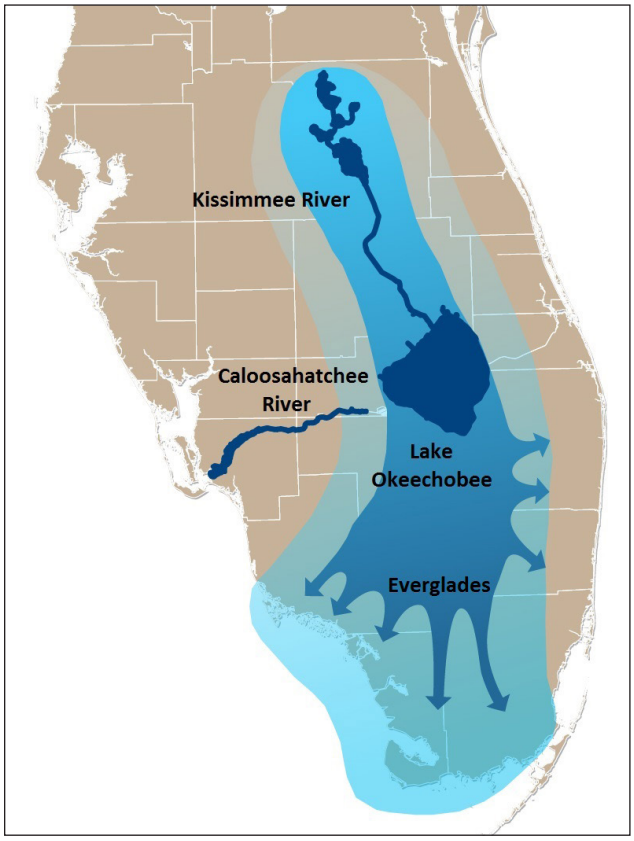

Figure 8.1. Historical flow of surface water in the South Florida watershed. Figure credit: Chris Anderson, based on CERP 2014.

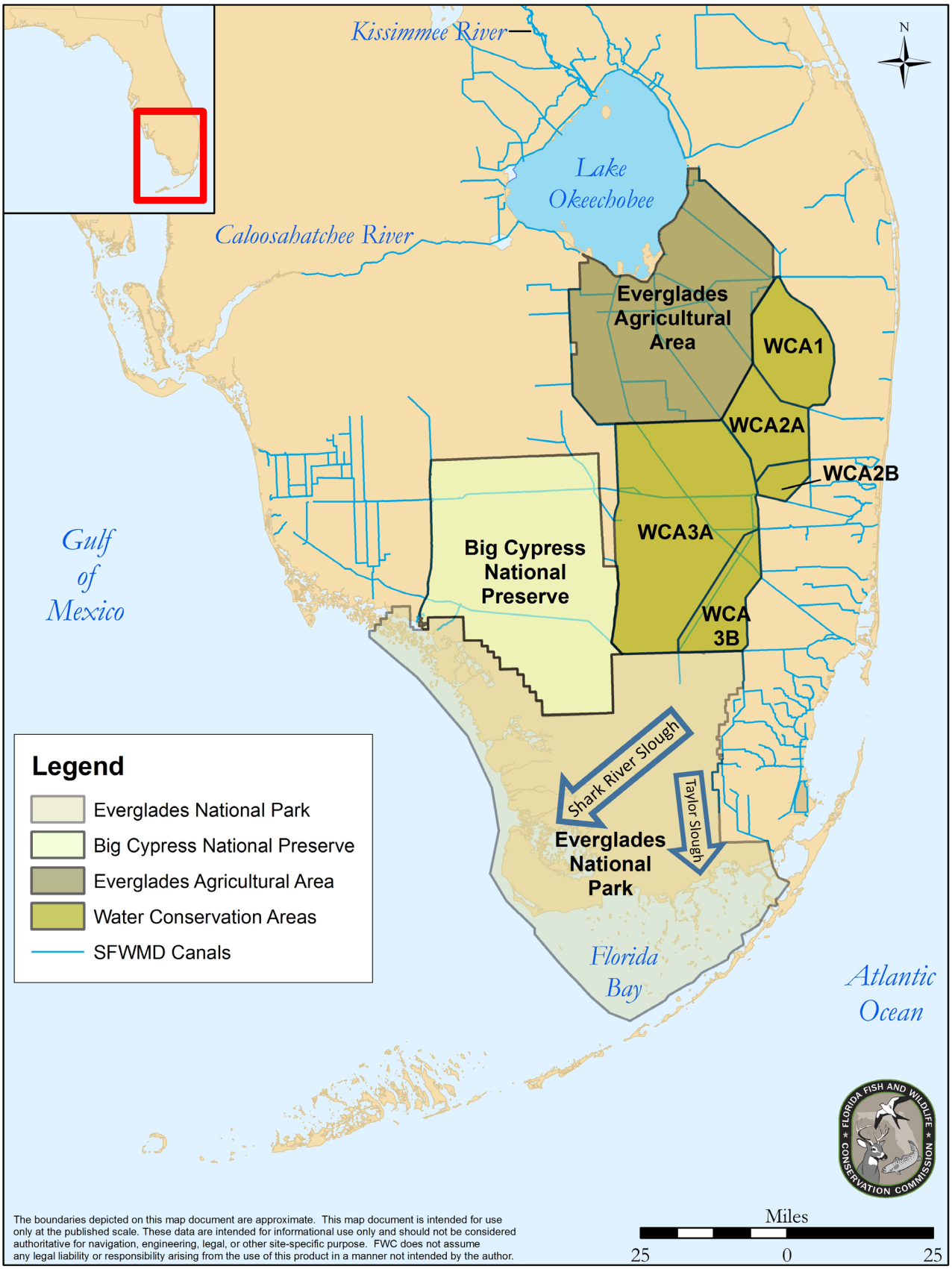

Figure 8.2. Major features of the current South Florida watershed.

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

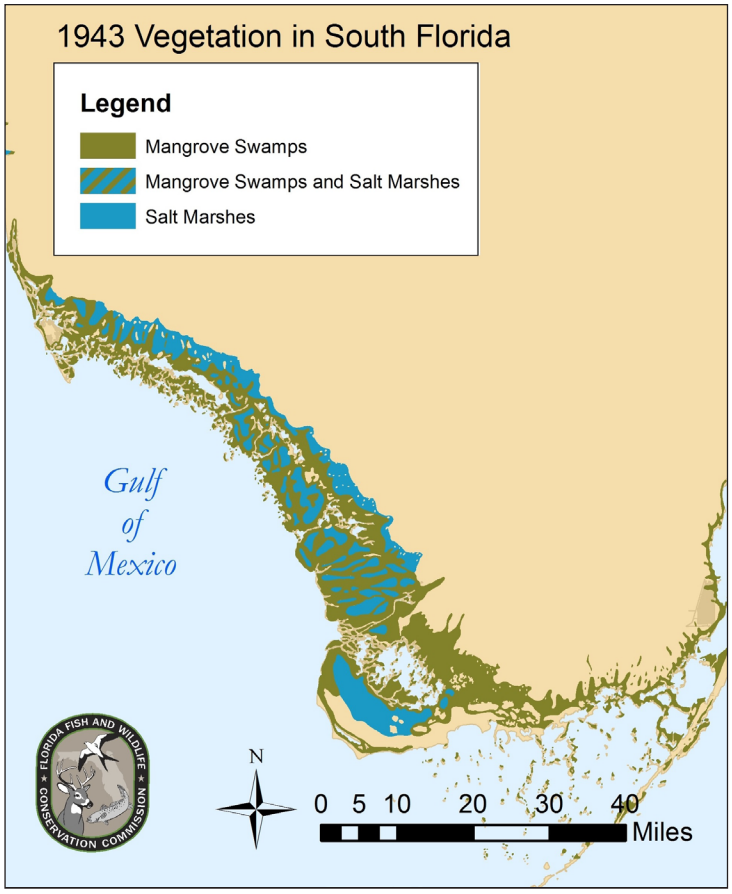

Figure 8.4. Extent of mangrove swamps and salt marshes in 1943, before the hydrologic changes of the Central and South Florida Project. Data source: Davis 1943.

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

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

Hydrologic alterations

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

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

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

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

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

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

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

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

Impact of tropical storms and hurricanes

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

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

tion and substrate changes (Armentano et al. 2002). The abundance of palms and hardwoods in the coastal Everglades has also declined due to transition into mangrove swamps and salt flats.

Threats to coastal wetlands

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

  Additionally, many tidal creeks along the lower Everglades have been filled in by vegetation and sediment as a result of low freshwater flow and nutrients provided by rising sea levels (Davis et al. 2005). Choked waterways and reduced flushing are detrimental to wetlands as flushing by salt water or freshwater is important for the resiliency and long-term viability of wetlands (Davis et al. 2005, Wanless and Vlaswinkel 2005).

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

  If peat accumulation cannot keep pace with sea-level rise, mangroves will move inland and the shoreline will erode (Davis et al. 2005). Increased wave activity would increase erosion and exposure of mangrove peat, making the organic matter vulnerable to oxidation. Oxidation may be avoided if organic carbon is transported inland and reburied as storm-surge deposits (Smoak et al. 2013).

- **Invasive vegetation:** As in much of Florida, invasive plants, such as *Schinus terebinthifolius* (Brazilian pepper), *Colubrina asiatica* (latherleaf), *Lygodium microphyllum* (Old World climbing fern), and *Melaleuca quinquenervia* (melaleuca) continue to expand their acreage and outcompete native plants on the edges of coastal wetlands in southern Florida (USFWS 1999a, Davis et al. 2005, Wingard and Lorenz 2013). Invasive vegetation is particularly threatening after a disturbance, as it can outpace the regrowth of native vegetation.

Mapping and monitoring efforts

Water management district mapping

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

Comprehensive Everglades Restoration Plan monitoring

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

Long-term Ecological Research mapping and monitoring

The National Science Foundation's Long-term Ecological Research (LTER) network includes a section in the Florida Coastal Everglades. This program, based at Florida International University, was established in 2000 and involves the collaboration of many governmental, academic, and

independent organizations. Interactive vegetation maps of the Everglades, created by the University of Georgia, the National Park Service, and SFWMD, are available at the Florida Coastal Everglades LTER website (fcelter.fiu.edu).

National Park Service's South Florida/ Caribbean Network mapping

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

Everglades vegetation model

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

Mangrove height mapping

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

Mangrove expansion mapping

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

G-LiHT mapping

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

Recommendations for protection, management, and monitoring

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

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

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

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