Sea-level rise: Observations, impacts, and proactive measures in Everglades National Park

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Abstract

Everglades National Park, because of its flat landscape, is particularly vulnerable to the impacts of sea-level rise. The goal of the Comprehensive Everglades Restoration Plan is to improve the quantity, quality, timing, and distribution of freshwater to the greater Everglades region, primarily for habitat restoration purposes, yet this program may also provide reprieve from an adverse impact of sea-level rise: saltwater intrusion. We present here evidence that sea-level rise and saltwater intrusion are affecting the park with changes evident in the composition of coastal forest communities. Controlled experiments reveal species-based differences in the salinity tolerance of plants in the coastal community and suggest that climate change may alter the coastal ecology of the park. Furthermore, in some regions a common response to saltwater intrusion, upland migration, is not likely because of a lack of suitable habitat and, as a result, local ecological changes are probable. Park management is developing prioritized protection options for species and habitats at risk in light of climate change.

Key words: climate change, restoration, saltwater intrusion, sea-level rise, water management

THE FLAT EXPANSE OF SAWGRASS marsh and mangrove coastline in Everglades National Park, Florida, serves as valuable habitat for a number of unique, rare, or endangered species. Unfortunately, this same expanse, with only about a 5 cm (2 in) increase in elevation per linear kilometer (0.6 mi) inland, makes the region exceptionally vulnerable to the effects of sea-level rise. Slight increases in sea level are expected to lead to disproportionate increases in inundation periods for broad areas in the park, and have already influenced both surface and subsurface saltwater intrusion. Saltwater intrusion has also likely been influenced by reductions in freshwater discharge that have accompanied upstream development over the past century. These hydrologic changes put pressure on the ecosystem, causing a variety of impacts, such as inland migration of plants, variation in species composition, and disruptions of predator-prey relationships (Pearlstine et al. 2010). Salt-tolerant mangrove species have already migrated approximately 3 km (2 mi) inland since the 1940s in parts of the national park, presumably in response to rising sea level (Ross et al. 2000). Understanding these impacts and protecting park resources are critical when one considers that only 10% of all coastal areas that are below 1 m (3 ft) elevation in the eastern United States have been set aside for conservation (Titus et al. 2009). Many coastal resources in Everglades National Park are not protected elsewhere in the United States. Faced with these challenges, our group is examining the factors that regulate variability in the long-term record of sea level maintained at Key West, Florida, located less than 100 km (62 mi) south of the park's southernmost landward extent. We are also investigating how freshwater management strategies and rainfall fluctuations interact with rising sea level to influence water and salinity levels and plant community composition in the park's coastal wetlands. This information should eventually assist in determining the potential ecological consequences of rising sea levels in the park's most vulnerable habitats.

Sea-level rise and water management

Surface water stage (elevation relative to a fixed datum) in the coastal wetlands of the park is determined by the interaction between tidal influences and the quantity of freshwater released through water management structures across the park's upstream boundaries. Freshwater flows through Shark and Taylor sloughs, two wide, shallow, slow-moving expanses of surface water that are the primary drainage features of the park. An extensive set of hydrologic monitoring stations in these sloughs provides continuous data on rain, temperature, salinity, and surface water stage. Initially we used this data set to determine the rate of change in stage for the stations in the freshwater-to-marine transition zones of Shark and Taylor sloughs (fig. 1). The results from station P35 are provided as an example of this work (fig. 2). For this station we calculate, using least-squares regression, an increasing linear trend in water levels of 2.61 mm/yr (0.1 in/yr) from 1952 through 2010. This rate is higher than the average global rate of sea-level rise of 1.7 mm/yr (0.07 in/yr) from 1961 to 2003, but not significantly different from the recent satellite-based estimate of 3.1 ± 0.7 mm/yr (0.12 ± 0.03 in/yr) for 1993–2003 (Bindoff et al. 2007). It is also in agreement with the rate of 2.36 mm/yr (0.09 in/yr) observed at Key West, Florida, over the past 110 years, which totaled 0.26 m (10.2 in).

The long-term, linear trends in average water levels observed at Key West and P35

Figure 1. Map of Everglades National Park showing the location of hydrologic monitoring stations, water control structures, and other key features. The buttonwood embankment along the southeastern edge of the mainland portion of the park, isolated between Florida Bay and inland lakes, is highlighted in purple and shown with arrows.

(see map) represent only one aspect of how changing water levels along the coast may affect park resources. Significant interannual to (multi)decadal-scale variability in the rate and magnitude of change in water levels is also observed in these two records. Wavelet analysis, a technique that reveals the time period of cyclical events in a data time-series, was used to evaluate relationships between changes in water levels in or near the park and global cyclical climate features. This analysis revealed that sea level at Key West and marsh water levels at station P35 both vary on frequencies that correlate with shifts in the North Atlantic Oscillation (NAO) and the El Niño Southern Oscillation (ENSO). These oscillations are indicators of changes in global circulation patterns, contain both atmospheric and oceanic components, and are related to ocean temperatures and variations in ocean currents. Results of the wavelet analysis suggest that sea levels around southern Florida and precipitation on the Florida peninsula are influenced by large-scale climatic processes, and that any changes in sea level because of these factors may in turn affect coastal marsh water levels and salinity values through direct hydrologic connections. The physical basis of the relationships among NAO, ENSO, and Key West water levels is uncertain at this point, but it is thought to be related to changes in the rate of flow in the Florida Current or to temperature-related changes, where thermal expansion or contraction of surface water causes changes in sea-level in the Caribbean Sea (DiNezio et al. 2009). The NAO and ENSO may also affect marsh water levels directly by influencing precipitation timing and amounts (Kwon et al. 2006; Abtew and Trimble 2010). Because of the independent and cyclical nature of these climate features, there are periods during which their influences combine to cause short-term increases in water levels that are significantly faster than the long-term trend (Engel et al. 2010). For example, the periods 1965–1971 and 1988–1995 were marked by an accelerated rise in both sea and marsh water levels compared with long-term trends.

Water released through the hydrologic control structures along the northern boundary of Everglades National Park discharges through the coastal marshes into Florida Bay and the Gulf of Mexico. Upstream water management practices

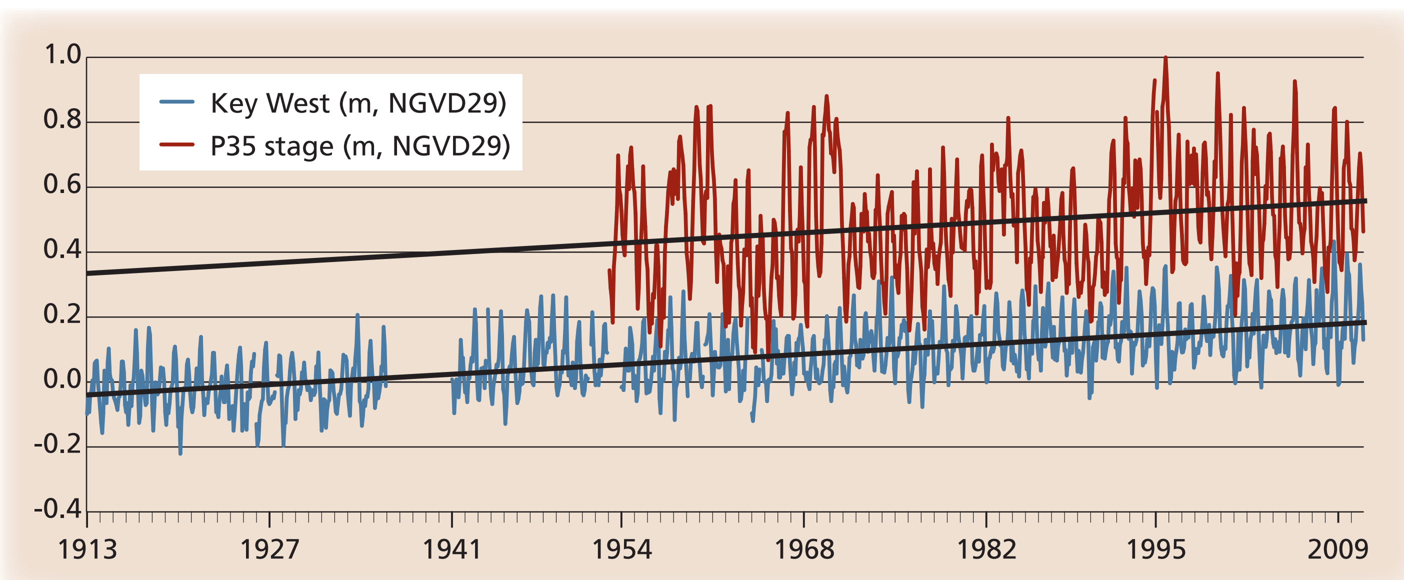

Figure 2. Station P35 water-level time series (red) with linear trend (black) showing that the rate of marsh water-level rise is similar to the rate of sea-level rise observed at the Key West tide monitoring station (blue).

may affect coastal marsh water levels, the location of the freshwater-saltwater interface, and estuarine salinity values. The amount of water released to the park is generally dependent on prevailing rainfall amounts and the resultant water levels in the water conservation areas adjacent to the northern boundary of the park, but is also regulated by other factors, including concerns over impacts on endangered species (Lockwood et al. 2001). The U.S. Army Corps of Engineers and the South Florida Water Management District regulate the water releases to the park based on recommendations from the region's stakeholders, including the National Park Service and other federal (e.g., U.S. Fish and Wildlife Service), state, local, and tribal organizations.

In the future the Comprehensive Everglades Restoration Plan, which guides the multiagency restoration effort for the greater Everglades ecosystem, is intended to restore the historical quantity, quality, timing, and distribution of freshwater flows. It is not yet known how enactment of this plan will affect current trends in coastal wetland water levels and the rate of saltwater intrusion into Everglades National Park. Sea level has already increased substantially since drainage activities on the mainland began in the late 1800s. The restoration of freshwater flows toward predrainage conditions will likely increase marsh water levels and reduce the extent of saltwater intrusion caused by changing sea levels and past management practices. However, the combined impacts of higher freshwater inflows and further increases in sea level on the park's coastal ecosystems are unknown. Both the magnitude and the rates of change in hydrologic conditions as influenced by climate factors will determine ecological outcomes in this region.

Determining the ecological tolerances of tree species is essential to understanding how community changes will occur, given the expected changes in sea-level rise.

Ecological consequences for imperiled habitats

Expansive freshwater wetlands gradually intergrade or mix with saline marshes and mangrove forests at the southern tip of Florida in Everglades National Park. A slightly elevated embankment, 65–100 cm (26–39 in) above current mean sea level, lies just north of the open saline waters of Florida Bay, between Cape Sable and Joe Bay (fig. 3). This narrow ridge is bordered on the north and south by tidally influenced salt marsh and mangrove forest. The elevation prevents tidal and seasonal flooding and the soils of this formation hold a freshwater lens generated by rainfall (Olmsted and Loope n.d.). Buttonwood (*Conocarpus erectus*) trees form a relatively open-canopy forest along the lower slopes of the embankment (65–85 cm [26–33 in]) while tropical hardwood trees, including mahogany (*Swietenia mahogany*), Jamaica dogwood (*Piscidia piscipula*), and Spanish stopper (*Eugenia foetida*), form closed-canopy forests at the highest elevations (85–100 cm [33–39 in]). A number of rare plant species not found elsewhere in the United States, including orchids, cacti, herbs, and shrubs, live in these forest communities. Because of its restricted size, low elevation, proximity to the coast, and lack of similar geologic features nearby, these plant communities are considered to be particularly vulnerable to the effects of sea-level rise. The distribution of other plant community types in relation to salinity suggests that an increase in mean sea level of as little as 20 cm (8 in) will result in a transformation of the buttonwood forest to a herbaceous salt marsh or mangrove forest. With this change, buttonwood trees will move upslope to replace the tropical hardwood hammock. These community changes will be coupled with impacts on already imperiled subcanopy species. For example, Cape Sable thoroughwort (*Chromolaena frustrata*) is an endemic terrestrial herb that lives in the ecotone between buttonwood and tropical hardwood forests. Its tolerance to soil salinity will determine its ability to persist in this changing environment. In addition, Cape Sable thoroughwort appears to rely on the shady conditions created by the overstory of buttonwood and tropical hardwood trees. Thus its survival is linked to the persistence of this forest complex.

Increases in groundwater salinity within the buttonwood embankment are expected to precede actual inundation with ocean water as sea level rises. This will likely have differential impacts on plant species that occur in coastal hammocks. Determining the ecological tolerances of tree species is essential to understanding how community changes will occur, given the expected changes in sea-level rise. In addition, monitoring changes in groundwater salinity and changes in the frequency and extent of flooding events will help improve our estimates of the rate of environmental changes. Finally, understanding the impacts of these changes on plant species of management concern will allow us to prioritize management actions. Everglades National Park, in cooperation with the Institute for Regional Conservation, is using greenhouse experiments to determine the salinity tolerance of species integral to hammock structure as well

Figure 3. A coastal hammock and buttonwood forest winds along the north shore of Florida Bay. These higher-elevation communities are flanked by salt marsh, mangrove, and open-water communities, preventing migration of plant species as sea level rises.

as rare plant species that occur among coastal hammock vegetation. We installed a network of groundwater monitoring wells within the communities found on the buttonwood embankment. Using a survey-grade global positioning system, we will obtain precise elevation profiles of habitats and rare plant populations found throughout the buttonwood embankment. Finally, using isotopic analysis of stem and soil water, we will determine where in the soil horizon key plant species are obtaining water.

Our initial results indicate species along the coast have variable tolerances to salinity. Two important structural components of tropical hardwood hammocks, West Indian mahogany and Jamaica dogwood, showed greater reduction in relative growth rates and leaf gas exchange in high-salinity (15 and 30 parts per thousand [ppt]) treatments than did Spanish stopper and buttonwood. In addition, mortality was significantly greater in one-year-old juveniles of Jamaica dogwood than in all other species in high-salinity treatment as opposed to low-salinity (5 ppt) and control treatments. These results may provide clues to the mechanism causing coastal hammock collapse first described in the early 1980s (Olmsted et al. 1981), in which significant losses of Jamaica dogwood trees were reported but the cause was not determined.

According to Intergovernmental Panel on Climate Change estimates, which are considered conservative, the sea-level rise we are already experiencing in southern Florida may exceed 20 cm (8 in) in the next 30–40 years. Under this scenario we might expect catastrophic changes in these important habitats in the next few decades. However, the fate of these plant communities can be altered by both natural processes and human intervention. Soil deposition events from periodic hurricane storm surges have increased the elevation of coastal embankments in the past (Whelan et al. 2009; Davis et al. 2004). While these deposition events are expected to provide a measure of resistance to rising sea level, they are also a source of saltwater inundation. Increases in freshwater flows through restoration efforts may offset increases in soil salinity in the coastal habitats.

Continuing efforts will be focused on quantifying the effects of increased freshwater delivery on the rate of change in saltwater intrusion and the resultant ability of the coastal system to migrate or adapt. In certain cases, where adverse impacts are inevitable and can be clearly identified, proactive measures, such as seed banking or maintenance of ex situ populations of imperiled plant species, may be warranted.

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