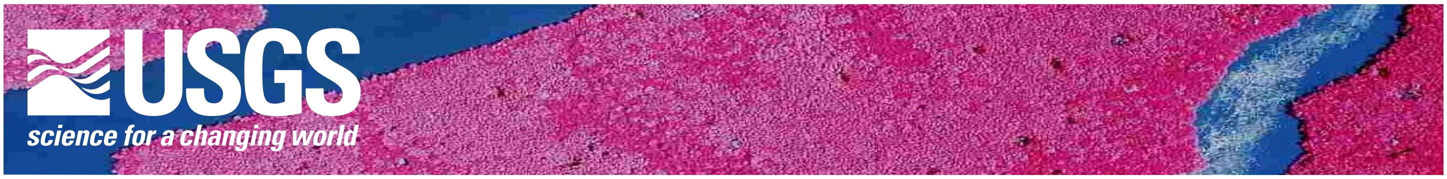

Development of a Long-term Sampling Network to Monitor Restoration Success in the Southwest Coastal Everglades: Vegetation, Hydrology, and Sediments

INTRODUCTION AND HISTORY

Hurricane Andrew, a Category 5 storm, crossed the southern Florida peninsula on the morning of August 24, 1992 (Fig. 1). Following the storm, the National Park Service conducted an environmental damage assessment to gauge the storm's impacts on the natural resources of south Florida Park Service holdings (Pimm et al., 1994). Although hurricanes have impacted Park Service lands such as the Everglades in the past (Houston and Powell, 2003), no systematic, permanent sampling scheme has been established to monitor long-term recovery (or lack thereof) following disturbance.

Figure 1. What is left of a mangrove forest that was crossed by the eye wall of Hurricane Andrew. The photo was taken in Biscayne National Park in September 1992, three weeks after the storm.

In October 1992, vegetation monitoring plots were established in heavily damaged areas of mangrove forest on the southwest coast of the Everlgades, along the Lostmans and Broad Rivers (Smith et al., 1994, see Fig. 2). As the permanent plot network was being established, funding was awarded for the South Florida Global Climate Change project (SOFL-GCC). This led to the establishment of a network of hydrological monitoring stations (Anderson and Smith, 2004). Finally, sediment elevation tables (SETs) were installed at many locations. SETs provide the means to measure very small changes (2 mm) in the sediment surface elevation accurately over time (Cahoon et al., 2002). We also set up marker horizons to measure accretion of sediment at each site (Smith and Cahoon, 2003). Sampling sites were located along three transects extending from upstream freshwater wetlands to downstream saltwater wetlands along the Shark, Lostmans and Chatham Rivers in Everglades National Park (Fig. 2).

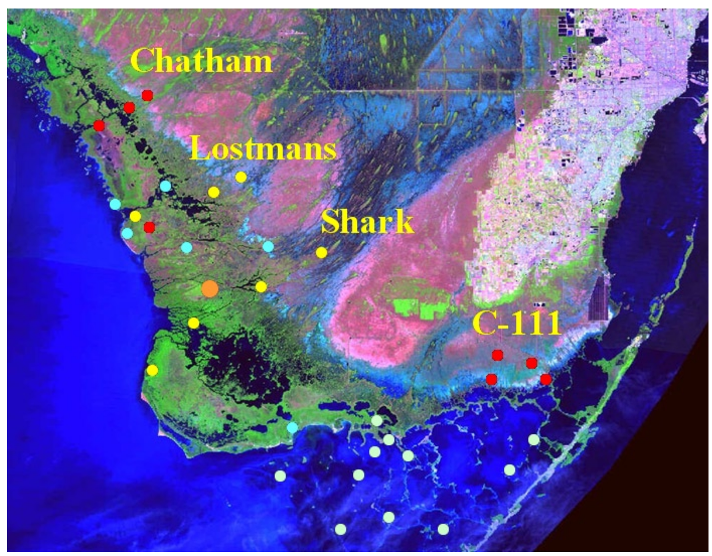

Figure 2. Location of sampling sites in Everglades National Park. RED dots = surface and groundwater stage and conductivity; YELLOW dots = surface and groundwater stage and conductivity, permanent vegetation plots, and sediment elevation sampling; light GREEN dots = sediment porewater piezometers and permanent vegetation plots; light BLUE dots = permanent vegetation plots; large TAN dot = location of the mangrove marsh ecotone boardwalk, with surface and groundwater wells, sediment porewater piezometers, and permanent vegetation plots.

While we were developing our sampling network for basic scientific research needs, concern mounted over the health of the Greater Everglades Ecosystem and in particular over the influence of decreased freshwater flows (Smith et al., 1989). Ecosystem restoration planning was begun, resulting in the multi-agency, $8 billion Comprehensive Everglades Restoration Plan (CERP). Our co-located sampling networks (Fig. 3) allow us to track the interaction of hydrology, sediment, and vegetation over time, and will provide the opportunity to monitor the progress of the Everglades restoration and to gauge its success. Our earlier research questions have been modified over time to place a major emphasis on CERP needs, while still recognizing the importance of other processes, including disturbance and sea-level rise.

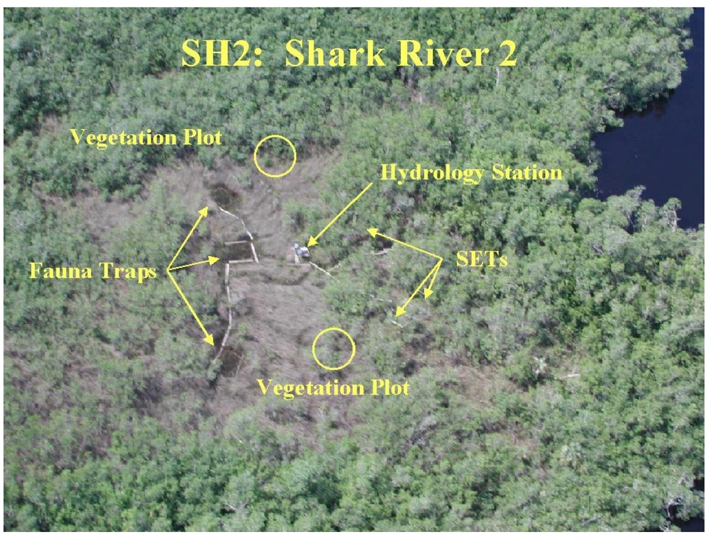

Figure 3. Oblique aerial photograph of a representative study site layout with vegetation plots, hydrology station, and sediment elevation tables (SETs). The greenish color is mangrove forest and the grayish color is black needle-rush marsh. Estuarine fauna is also sampled at this site.

Our research addresses processes relevant to the following restoration and related questions:

* How will increasing freshwater flow affect wetland primary production?

* Will increasing freshwater inflow alter nutrient availability?

* Does recovery following disturbance in mangroves depend on freshwater inflow?

* Will the position of vegetation ecotones change in response to upstream water management?

* What will be the influence of global climate change, such as sea-level rise, on the Everglades restoration?

* Will processes of wetlands soil formation be altered by sea-level rise and changed freshwater inflow?

ILLUSTRATIVE RESULTS

The trajectory of vegetation change, growth, mortality, and recruitment has been highly variable among plots. Indeed, most plots have followed unique patterns. The only overall pattern was the increase in stem density observed in all plots (Fig. 4). The species that dominated recruitment varied, sometimes being *Rhizophora mangle* (red mangrove), often *Laguncularia racemosa* (white mangrove), but never *Avicennia germinans* (black mangrove). The rate of stem-density increase has varied among plots by over two orders of magnitude. Individuals are continuing to recruit into the population at many sites.

Mortality is occurring at all sites. Sources of tree mortality include continuing demise from damage initially caused by Hurricane Andrew, trees being killed by falling debris, lightning, wind-throw during winter cold fronts, freeze, fire, and several less intense tropical cyclones since Andrew such as Hurricanes Georges, Harvey, Irene, and Mitch. Trees in the smaller-size classes are beginning to perish due to suppression (that is, being overtopped and heavily shaded by larger neighbors, see Fig. 4).

Observed patterns of growth by trees that survived Andrew or that recruited into the plots are hard to explain. Productivity cannot be explained simply by sediment-porewater nutrient concentrations, which are highly variable. Salinity and hydrologic parameters seem most promising to explain patterns of biomass increase following the catastrophic disturbance from Hurricane Andrew.

In addition to influencing mangrove forest structure, the severe disturbance from Hurricane Andrew has affected the stability and elevation of the sediment

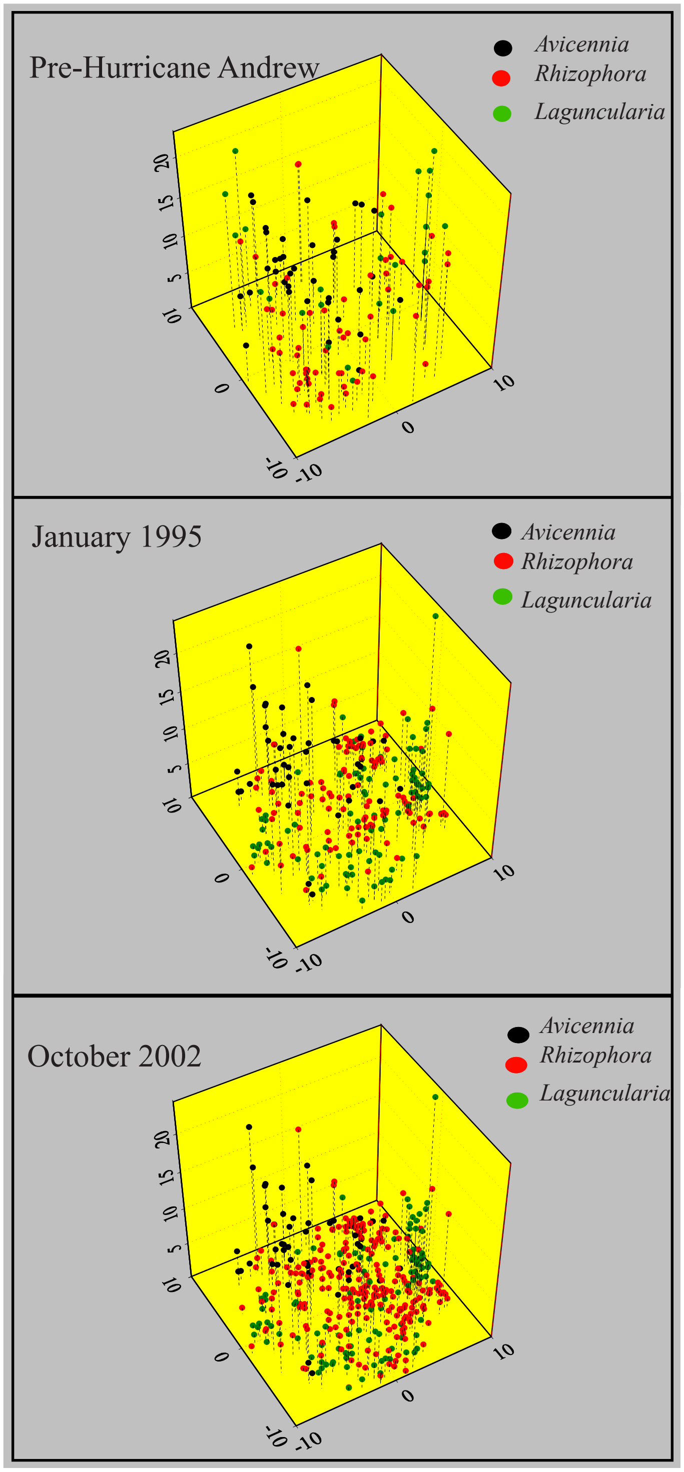

Figure 4. Results from three surveys at the Lostmans Ranger Station plot are shown. The X and Y axes are arbitrary, with 0,0 representing the center of the 10m radius plot. The vertical axis shows stem diameter at breast height, in cm. The top figure depicts the plot as it appeared prior to Hurricane Andrew (based on a "reconstruction" from the initial sampling in October 1992). The middle panel shows the situation in January 1995. Recruitment is well underway and consists of an even mix of *Rhizophora* and *Laguncularia*. The bottom figure shows the status in October 2002, 10 years after the hurricane. *Rhizophora* now dominates the pool of recruits.

surface. In the lower Lostmans River, an area highly impacted by the storm, sediment elevation has been decreasing for at least five years (Fig. 5). The forests at the mouth of the Shark River, an area not impacted by Hurricane Andrew, are remaining at constant elevation (Fig. 5). Visual inspection of the data indicates that surface-water dynamics do not seem to be related to sediment-elevation changes.

Sampling of these vegetation plots, hydrology stations, and sediment elevation tables will continue in order to monitor the effect of increasing freshwater inflow that will occur as a major component of the Everglades restoration. We will also use the data currently available to develop performance measures that can be used by CERP.

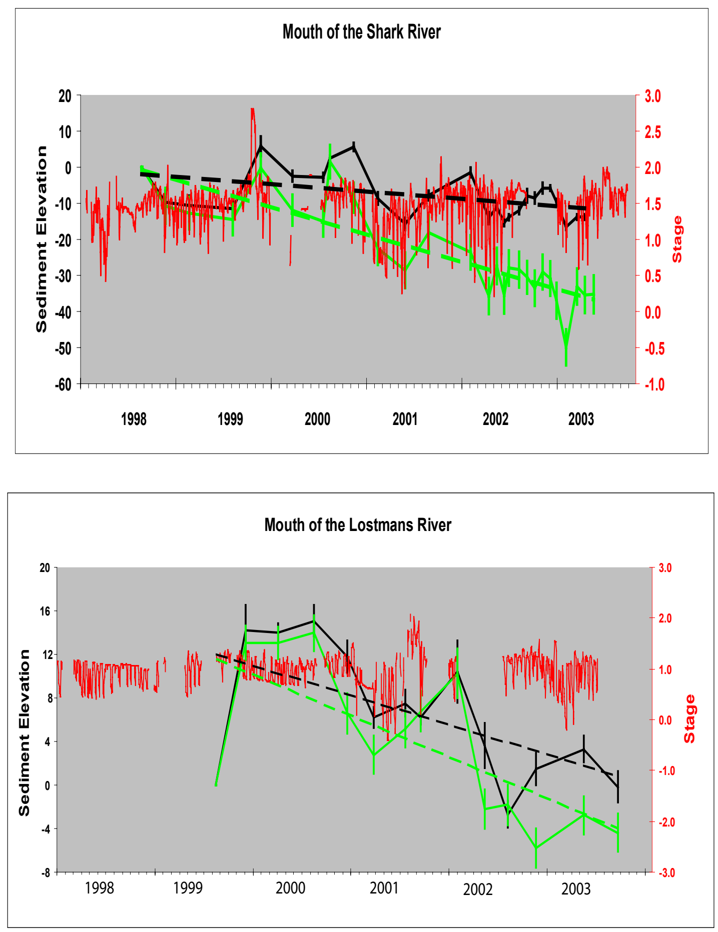

Figure 5. Surface-water hydrology (red) and sediment-elevation dynamics at two river-mouth locations in Everglades National Park. The black lines show sediment surface elevation over time (solid with error bars, ± 1 SE) and the linear trend in elevation (dashed). The green lines show sediment elevation minus accretion (solid with error bars) and the linear trend (dashed).

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