Application of Paleoecologic Methods to Coastal Resource Management: An Example from Biscayne National Park

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Introduction

THE NATION'S COASTAL ECOSYSTEMS HAVE CHANGED PROFOUNDLY during the last century due to human activities. The Estuary Restoration Act was passed by Congress in 2000 and a component of the act was to develop a *National Strategy to Restore Coastal and Estuarine Habitat* (NOAA 2002). The national strategy identifies the importance of establishing historical or baseline conditions within estuarine ecosystems "to determine rates of loss, evaluate threats and predict future trends for various habitat types and areas within the system" (NOAA 2002:2). The report continues: "The availability of historical information varies greatly from place to place. For some estuarine systems, historical maps … along with anecdotal information on previous centuries may be available. For other systems, only limited anecdotal information may be available."

Understanding natural patterns and cycles of change that have occurred in a system prior to significant human disturbance is a critical component of restoration; however, land managers do not have to rely on historical maps or anecdotal information, as the above report suggests. Changes in ecosystems take place at many time scales, from diurnal to millennial, and it is not practical or even possible to directly observe change at these longer time scales. Basic paleoecologic methods have been successfully used in ecosystems around the country to determine short- and long-term patterns of change in the physical and biological components of ecosystems. In South Florida, these methods have been utilized to establish the ecosystem history of the Everglades, and those of the downstream estuaries of Biscayne Bay and Florida Bay.

Approach

An integrated approach to interpreting ecosystem history provides significant benefits. Data from different groups of plants and animals enhance the reliability of the results and provide an averaging effect to smooth out species-level responses. Data from different scientific disciplines allow researchers to derive information on many aspects of an ecosystem and to determine if synchronous changes have occurred in different components of the system. For example, if sediment geochemistry analyses detect an increase in nitrogen, paleoecologic assemblage analyses of the same sample will indicate if a corresponding change occurred in the fauna. While these data do not prove cause-and-effect relationships, they point to areas where observation or experimentation in the living system might be worthwhile.

The process begins by locating areas that have sufficient sedimentary cover and as little bioturbation, storm disruption, and erosion as possible, within the area being evaluated. Once sites are identified, cores are collected using methods that minimize sediment disruption. Cores are x-rayed and described, then cut into samples 1 to 5 cm thick.

An age model for each core is derived using three methods, where possible. Lead-210 analysis establishes the chronology of the upper portions of the cores (see Holmes et al. 2001 for explanation of the methodology). Radiocarbon ages on shells or wood fragments provide data points for the lower portion of the cores. Additional confirmation of the age model comes from pollen of exotic flora with documented dates of introduction into the system. For South Florida, the first occurrence of *Casuarina* (Australian pine) pollen, an exotic introduced around the beginning of the 20th century (Langeland 1990), provides an excellent stratigraphic marker for the early 1900s.

The basic principles of paleoecology are utilized to interpret the faunal and floral assemblages in the core samples. Modern sites are established within the ecosystem for routine observation and sampling. Environmental parameters such as temperature, salinity, and pH of the water and the nature of the substrate are recorded along with information on the faunal and floral species living at each site. These data are entered into a database that is utilized for downcore interpretations. Comparison of the living biota to the core assemblage data allows us to develop a general picture of the environment at the time of deposition, including the range of salinities that existed, substrates, and availability of freshwater. (See Brewster-Wingard et al. 2001; Cronin et al. 2001; Ishman et al. 1998; Willard, Holmes, and Weimer 2001; and Willard, Weimer, and Riegel 2001 for examples of paleoecologic studies in South Florida.)

Biogeochemical analyses of the calcium carbonate tests of ostracodes, mollusks, or forams provide another method for deriving numerical salinity values for each segment of a core. A combination of ostracode and mollusk shell analyses can provide a powerful tool to reconstruct seasonal and annual salinity variations. Ostracode adult tests represent essentially instantaneous secretions recording the salinity and temperature at that point in time. Mollusks provide a nearly continuous record throughout the span of the individual's life. Experiments to calibrate molluscan shell chemistry to water chemistry are currently ongoing; however, calibration curves for the ostracodes have been successfully developed and utilized for South Florida (Dwyer and Cronin 2001; Dwyer et al. 2002).

Geochemical analyses of sediments are conducted to examine historical changes in nutrients, primarily carbon, nitrogen, phosphorous, and sulfur. Information on historical changes in nutrient elements in sediments reflects changes in nutrient load to the watershed from both natural and anthropogenic sources (Orem et al., 1999; Zielinski et al. 2000).

Biscayne Bay

Setting. Biscayne National Park is a unique subtropical preserve, sitting on the edge of the metropolis of Miami and containing part of the only living barrier reef in North America and the third-longest barrier reef in the world. The majority (95%) of the park's 172,924 acres is underwater, making Biscayne the largest underwater park in the national park system. The park itself contains four distinct environments: the mangrove coastline, the shallow waters of Biscayne Bay, the northernmost islands of the Florida Keys, and the reef tract.

The Greater Everglades Ecosystem encompasses most of southern Florida from the Kissimmee River southward, through Lake Okeechobee, into the freshwater marshes of Everglades National Park, and eventually into the estuaries of Biscayne Bay, Florida Bay, and the southwest coast.

Since the beginning of the twentieth century, Biscayne Bay and the Greater Everglades Ecosystem have undergone dramatic changes as the population of Miami-Dade County has grown from 4,955 residents in 1900 to 2,253,362 in 2000 (U.S. Census Bureau). As the population increased, so too did demands for protection from seasonal flooding and for potable water for the residents and for the growing agricultural area. A complex series of canals and water control structures, built throughout the 20th century, have altered the natural flow of freshwater through the wetlands and into Biscayne Bay. Along the shores of Biscayne Bay, power plants, water treatment plants, solid waste sites, and large-scale developments have stressed the ecosystem.

During the 1980s and 1990s, momentum began to build for restoration of a more natural freshwater flow throughout South Florida (National Research Council 2003), which led to the development of the Comprehensive Everglades Restoration Plan (CERP; USACE 1999). The primary goal of the CERP is to restore the timing, quantity, quality, and distribution of freshwater to the ecosystem so that it approximates the predevelopment conditions as closely as possible. The role of the U.S. Geological Survey (USGS) ecosystem history projects is to provide information on the pre-development conditions of the Everglades.

Ecosystem history results and discussion. Nine sites within Biscayne Bay, Card Sound, and Barnes Sound have been cored. Four of the locations are within the park boundaries; the other five are located at sites selected to examine changes in freshwater flow into the estuary (Figure 1). Paleoecologic, biochemical, and geochemical analyses on these cores provide information on historical changes in salinity and nutrient influx into the bay. Details of the core analyses are available in Wingard et al. (2003; 2004), but a brief summary is provided here.

Faunal and floral assemblages from cores at Middle Key and Manatee Bay (Figure 1) indicate that the southern end of the Biscayne system (Card Sound and Barnes Sound), had significantly more freshwater influx prior to 1900 than in the later half of the 20th century. Figure 2 illustrates changes in percent abundance of key indicator species throughout the core and over time. The fauna in the lower portion of Middle Key core, deposited prior to 1900, are predominantly freshwater gastropods (Figure 2, #1), but the environment begins to shift around 40 cm and increasing numbers of species typical of an upper estuarine environment appear (Figure 2, #2–4). Between 30 and 20 cm (approximately 1900), freshwater species begin to decline (Figure 2, #5), and concurrent increases occur in all estuarine species: mesohaline (upper estuary; 5–18 parts per thousand (ppt) dissolved salts), polyhaline (middle to lower estuary; 18–30 ppt), and euryhaline

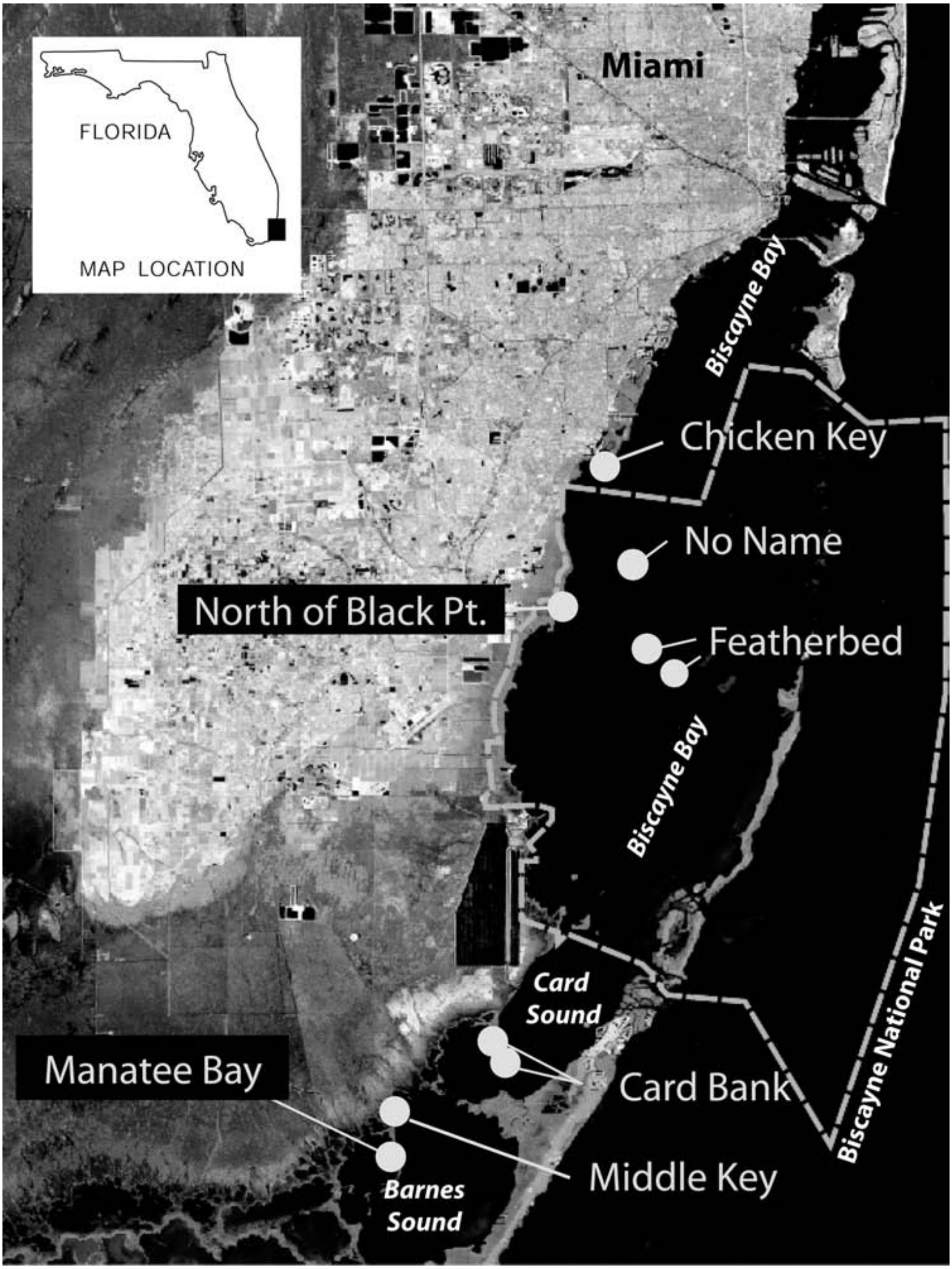
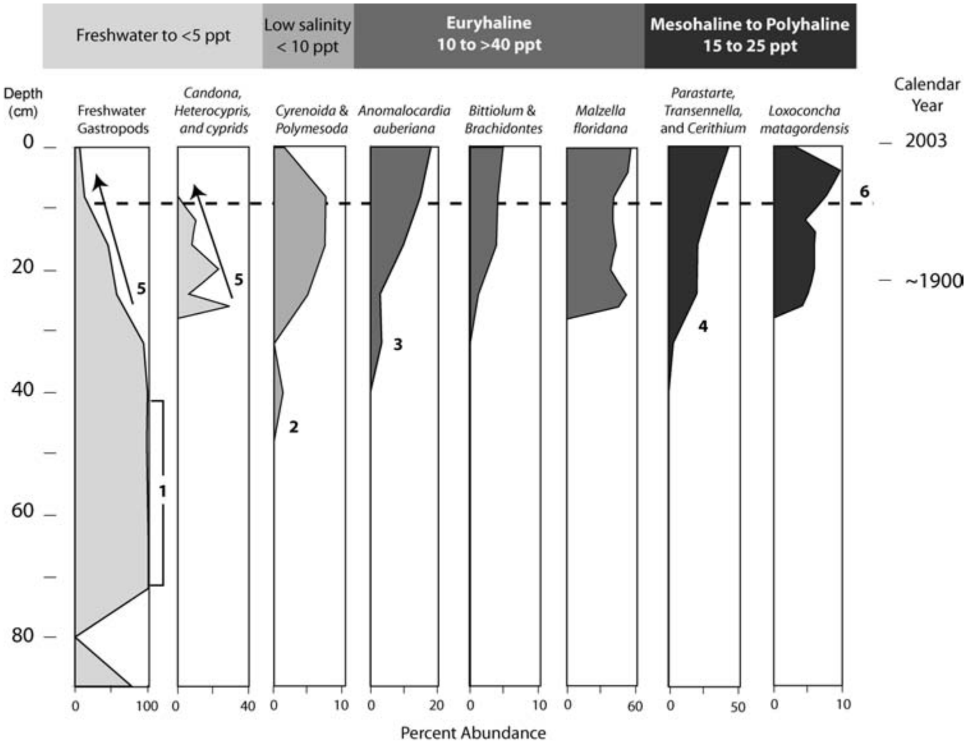


Figure 1. Satellite image map of Biscayne Bay, Florida, showing sites where USGS cores were collected (circles) and the boundary of Biscayne National Park (dashed line). Source: Jones et al. 2001.

(tolerant of wide fluctuations in salinity from 10 to >40 ppt). At approximately10 cm, (Figure 2, #6) the freshwater and low-salinity species (<10 ppt) almost disappear at the site, and the euryhaline species, tolerant of wide ranges in salinity from 10 to >40 ppt, become increasingly abundant. Similar changes are seen at the Manatee Bay core site, located 2.8 km (1.7 miles) to the south of the Middle Key core site (Figure 1).

Card Sound Bank is a shallow mud-bank that extends from the mainland just north of Card Sound Bridge, over to the northern portion of Key Largo, effectively separating Card Sound and Barnes Sound (Figure 1). The lower portion of cores from Card Sound Bank indicate that the area has been transitional between a more restricted upper estuarine environment and a more open estuarine environment, fluctuating between these conditions over time (Figure 3, below dashed line). During the later part of the 20th century, however, more marine species and fewer euryhaline species are present (Figure 3, above dashed line). This shift in the faunal assemblage indicates a shift from an estuarine environment subject to frequent salinity fluctuations, to a more

Figure 2. Changes in salinity in Middle Key Basin (see Figure 1 for location), as indicated by percent abundance of key ostracode and mollusk indicators plotted against depth in cm, from Middle Key core (GLW603-MKA). Calendar year is indicated on right. Numbers on plots are referenced in text discussion; ppt is a measure of salinity in parts per thousand dissolved solids. Note different percent abundance scales.



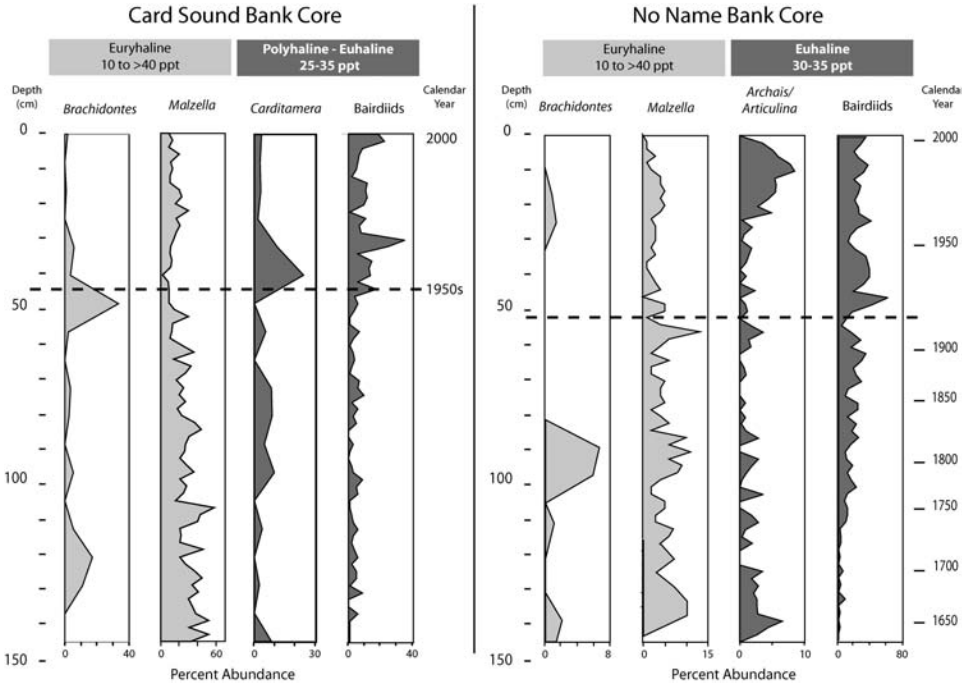
stable marine environment with fewer salinity fluctuations.

Moving north in Biscayne to the more open waters of the mid-bay, the faunal assemblages in cores from Featherbed Bank and No Name Bank (Figure 1) also show shifts from more fluctuating estuarine environments in the lower portions of the core (Figure 3, below dashed line) to more stable marine environments in the 20th century (Figure 3, above dashed line). Figure 3 compares indicator species at Card Sound Bank and at No Name Bank. The trends are very similar at the two sites, but based on our current age models, the environment at No Name began to shift towards more marine sooner than the environment at Card Sound Bank.

Implications and importance to managers

All nine cores demonstrate a common trend—an increase in salinity in the Biscayne Bay ecosystem in the 20th century. The timing of the onset of increased salinity varies at different core sites, and the indicator species differ, but there are no exceptions to this trend. Our preliminary age models indicate that a combination of factors is at work. The earlier onset of increased salinity in the more open portion of the bay at No Name and Featherbed

Figure 3. Comparison of changes in salinity from Card Sound Bank core (SEI297-CB1) and No Name Bank Core (GLW402-NNB)(see Figure 1 for locations) as indicated by percent abundance of key ostracode, mollusk, and foram indicators plotted against depth in cm. Calendar year is indicated on right for No Name Bank core; age model for Card Sound Bank has not been completed. Dashed lines are referenced in text discussion; ppt is a measure of salinity in parts per thousand dissolved solids. Note different percent abundance scales.



Banks, compared with Card Sound Bank and the southern portion of the ecosystem, implies a rise in sea level. The more rapid and dramatic shifts seen in nearshore cores (for example at the top of the Middle Key core) indicate other factors are involved. A number of potential factors could explain the increase in salinity in Biscayne Bay: decreases in runoff entering the bay due to canal construction and water management practices, decreases in rainfall, decreases in groundwater upwelling, increases in evaporation, and a rising sea level. We are currently working on refining our age models and correlating results to known events affecting the bay.

The trend of increasing salinity has immediate and long-term implications for resource managers at Biscayne National Park. In the park's science overview document (NPS 2000), it is stated that "science aids in stewardship of resources" by answering questions such as "How does the condition of our resources change over time?" As Biscayne Bay becomes increasingly marine, the biodiversity and, ultimately, the distribution of the environments within the park will shift.

From the restoration perspective, it is important to understand what component of the increased salinity is due to natural patterns (sea level rise, climate change), and what is anthropogenically induced. Although the goal of restoration is to return to a predisturbance state, this may not always be possible. If a system has undergone significant natural change, such as sea level rise, the effects cannot be reversed within the scope of restoration; however, the component of change due to anthropogenic factors, such as changes in freshwater influx, may be corrected. The results of this research can be used by the restoration managers to set realistic targets and performance measures for restoration. In setting target salinity values, the immediate implications of our findings are the following: (1) significant spatial and temporal variations occur within the system, so separate target values need to be established for different habitats; (2) targets must incorporate the natural range of variation (minimums and maximums) that has existed in the past, and not focus on mean values; and (3) nearshore sites are dramatically different from the mid-bay mudbanks and have been for hundreds of years, so changes in freshwater influx during restoration will have little effect on the central portions of the bay.

Natural systems are not static—they evolve and change over time. So as society attempts to manage and restore these systems, it is important to look at natural patterns of change. Examining decadal to centennial trends in a variety of habitats within an ecosystem using basic paleoecologic methods provides resource managers with the information necessary to make informed decisions and to enlighten the public on what the natural system of the bay looked like prior to significant human alteration of the environment.

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