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Estuaries of the Greater Everglades Ecosystem: Laboratories of Long-term Change

Introduction

Restoring the greater Everglades ecosystem of south Florida is arguably the largest ecosystem restoration effort to date and is guided by the Comprehensive Everglades Restoration Plan (CERP) (U.S. Army Corps of Engineers, 1999), which was authorized by Congress in the Water Resources Development Act of 2000. A critical goal of the restoration plan is to return more natural patterns of flow through south Florida wetlands and into the estuaries. Resource managers are developing performance measures and targets for various components of the system to assess the progress of restoration—an effort that will continue for the next few decades.

Development of realistic targets requires acknowledgement that ecosystems are constantly evolving and changing in response to a variety of natural and human-driven stressors. What did the ecosystem look like prior to substantial water management and land-use changes introduced in the 20th century? How did the system respond to different modes of climate variability? How accurately can we predict responses to natural climate variability, changes in resource management, and anticipated changes in sea level and temperature over the coming decades? The answers to these questions rely on examination of the longer term history of the ecosystem over decadal and centennial scales to understand the historical responses to past climatic and environmental change.

The Greater Everglades Ecosystem as a Laboratory of Change

Ecosystem changes operate on time scales ranging from instantaneous to thousands of years or longer. Humans can study and monitor these changes over minutes, days, weeks, and months, and, if persistent, over years and decades. Over these short periods of record, the ecosystem acts as a living laboratory to study the dynamic interaction of the physical, chemical, and biological components of the system.

Examination of ecosystems over longer periods of time requires analysis of sedimentary records, such as those deposited in wetlands and estuaries of south Florida. As sediment accumulates, it preserves information about the animals and plants that lived in the environment and the physical, chemical, and climatic conditions present. One of the methods used to interpret this information is paleoecology—the study of the ecology of previously living organisms. A key to paleoecology is to first understand the ecology of the living organisms. How does a snail species live today? At what water depths does it live? At what salinity does it survive? Where do you find a particular plant species? Do you find it in freshwater wetlands or the mangrove fringe environment? Such types of information help scientists interpret the longer term history of the ecosystem when we find the same species preserved in sediment cores collected throughout a region.

Significance of the Estuaries

The southern estuaries of the greater Everglades ecosystem include Biscayne Bay on the east, Florida Bay to the south, and the channeled mangrove environment of the southwest coast (fig. 1). These areas are transition zones between the freshwater flows from the wetlands of south Florida and the marine environments of the Gulf of Mexico, the Florida Keys reef tract, and the Atlantic Ocean. They provide critical habitat for many commercially important species, such as pink shrimp (*Farfantepenaeus duorarum*), Caribbean spiny lobsters (*Panulirus argus*), and stone crabs (*Menippe mercenaria*).

The die-off of vast amounts of seagrass in Florida Bay in the late 1980s served as one of the initial motivations for

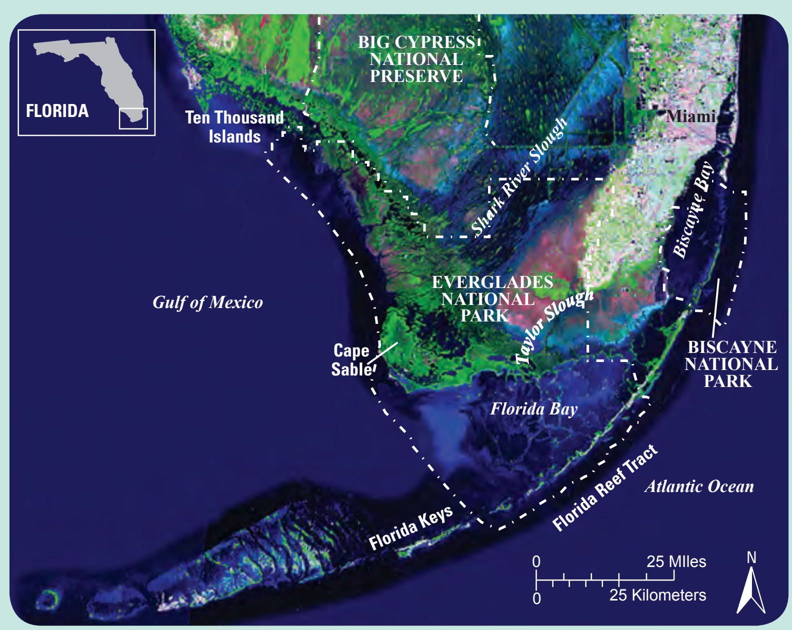

Figure 1. Satellite image of south Florida showing the key features of the greater Everglades ecosystem. The southern estuaries of the ecosystem include (1) Biscayne Bay on the east coast, including Biscayne National Park, (2) Florida Bay, which is part of Everglades National Park, and (3) the southwestern mangrove coastal margin between Ten Thousand Islands and Cape Sable, which falls within Everglades National Park. The image is modified (cropped) with permission from Jones and others (2001).

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restoration of The Everglades. Resource managers were concerned that the changes in Florida Bay resulted from a reduction in freshwater flow through Everglades National Park to the southern estuaries. The two systems—the wetlands and the estuaries—are interdependent, and estuarine salinity depends largely on the volume of freshwater delivered from the wetlands to the estuary. One way to estimate past hydrologic conditions in The Everglades wetlands is by reconstructing past salinity in the estuaries.

Methods of Reconstructing Past Salinity Patterns

The abundance and composition of estuarine animal communities is dependent on salinity, nutrient content, temperature, and other environmental conditions. Figure 2 shows the changes in mollusk assemblages that occurred during a 1,600-year period, as recorded in a sediment core collected near the mouth of Taylor Slough, one of the two principal flow-ways through The Everglades (fig. 1). Our studies of the living mollusks in south Florida indicate that salinity is an important control on composition of mollusk communities, and we can interpret past salinity patterns from changes we see in the abundance of different species in the sediment cores. We integrate data from multiple locations to reconstruct changes in salinity patterns over time (fig. 3) and space (fig. 4).

Descriptive assessments of salinity patterns are useful for a qualitative examination of the changes that have occurred, but hydrologic models that link freshwater flow from the wetlands to the estuaries require quantitative salinity data. We used data on salinity preferences of living mollusks from south Florida to calculate an average salinity value for each species. A weighted averaging technique that integrates salinity requirements of all species in an assemblage (see page 4) provides a single estimated salinity value for each sample in a core.

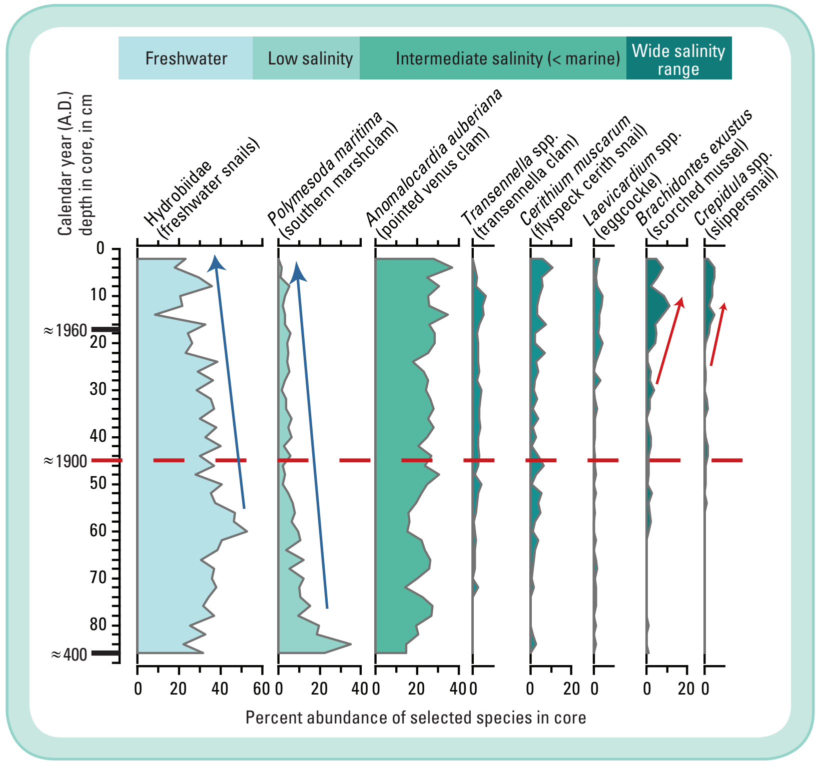

Figure 2. Changes in abundance of mollusk groups in a sediment core collected near the mouth of Taylor Slough (fig. 1) reflect changes in estuarine salinity through time. Calendar year dates are based on radiocarbon dating, pollen biostratigraphy, and short-lived radioisotopes. Blue arrows show declines in species preferring freshwater and low salinities during the last 1,500 years. Red arrows highlight increased abundance of species that tolerate broad and rapid fluctuations in salinity. The red dashed line indicates the approximate depth of sediments deposited A.D. ≈1900.

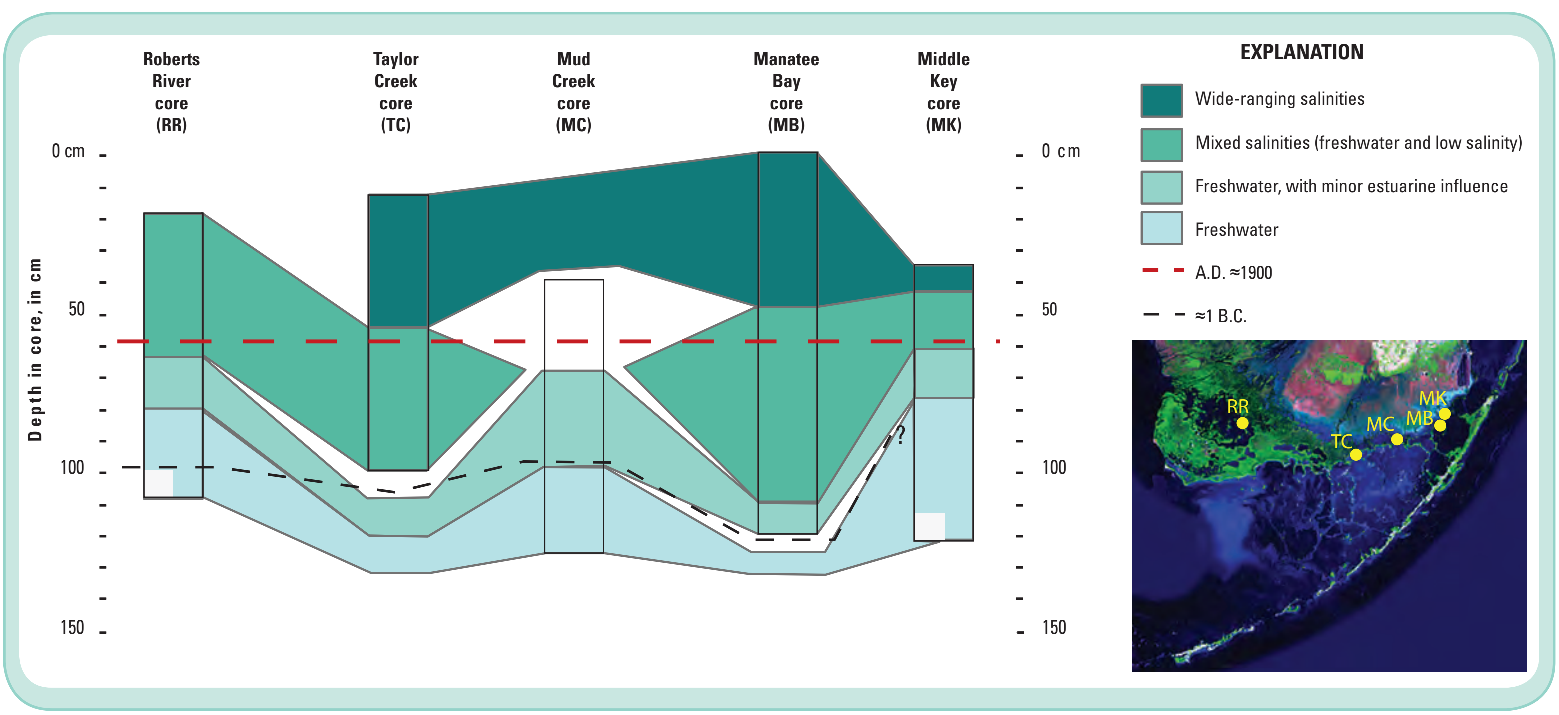

Figure 3. Salinity patterns over time from five sediment cores obtained along the transition zone between the wetlands and the estuaries. Locations of the cores are illustrated in the inset satellite image. Information for this diagram is compiled from individual core analyses such as those portrayed in figure 2 (data for the Taylor Slough core). This figure illustrates the gradual increases in salinity that occur between ≈1 B.C. and A.D. ≈1900 in the transition zone. After A.D. 1900, most of the mollusk assemblages in the cores shift to species that tolerate rapidly and widely fluctuating salinities.

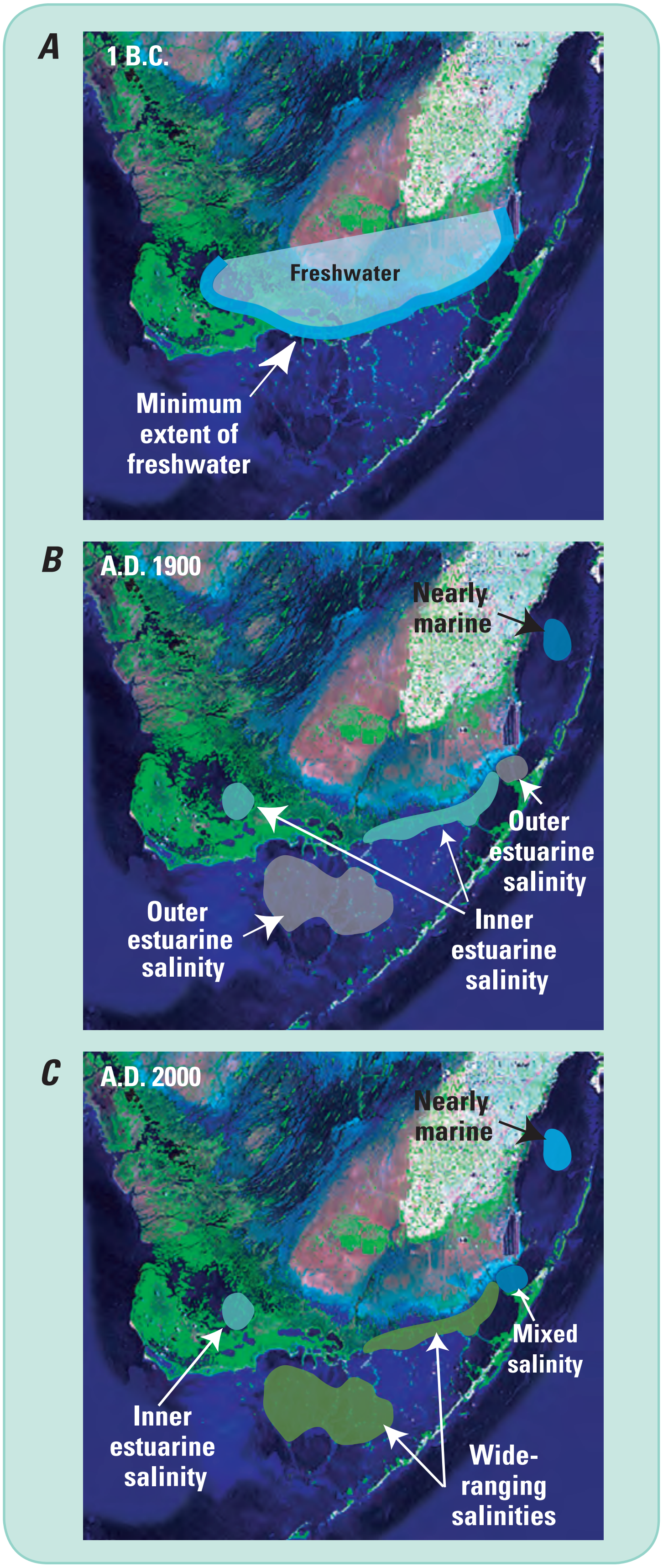

Figure 4. Satellite images of Florida and Biscayne Bays with superimposed salinity patterns for three time intervals. Salinity patterns were derived from paleoecological data on mollusks from multiple sites in the estuaries. *A*, Reconstructed scenario for minimum extent of freshwater environments indicates freshwater habitats extending into northern Florida Bay ≈2000 years ago. *B*, Typical estuarine salinity patterns characterized Florida Bay A.D. ≈1900. *C*, Present-day mollusk assemblages indicate loss of typical estuarine salinity zones and a shift to species that tolerate rapid and widely ranging salinity changes.

Estimates of past salinity provide the input to statistical models that reconstruct past freshwater stage and flow in the natural Everglades wetlands. The first step in the process (described in Marshall and others, 2009) derives salinity estimates from the sediment cores based on the species present, as described above. In the second step, equations are developed that relate stage and flow of freshwater in the wetlands of The Everglades to salinity in the estuaries; these equations are based on instrumental measurements from water monitoring stations and gages in Everglades National Park. The third step links the first two by introducing salinity estimates from samples dated just prior to A.D. 1900 into the equations developed from the current hydrologic conditions. This combination of data types allows us to calculate the stage and flow necessary to produce the salinities estimated for the beginning of the 20th century (fig. 5).

Past Changes in Hydrology and Salinity

Salinity fluctuations during the last 2000 years (figs. 3 and 4) reflect changes in sea level and freshwater flow. Before A.D. 1900, the gradual increases in salinity were consistent with late Holocene sea level rise. The estuaries exhibited a typical zoned pattern of lower salinities nearshore and higher, more marine-like salinities farther out in the estuaries. During the 20th century, however, the mollusks present in the cores indicated that typical estuarine zones disappeared. Species that can tolerate wide and rapidly changing salinities predominated in the 20th century portions of the cores. The implication drawn from these results is that there was a reduction in freshwater entering the estuaries from overland and tidal creek flow, groundwater, and/or rainfall. Reduced 20th century freshwater flow to The Everglades wetlands has been documented in other paleoecologic studies (for example, Willard and Cronin, 2007; Bernhardt and Willard, 2009), and the timing of that reduced flow corresponds to emplacement of water control structures that divert water from the wetlands to the ocean.

Application of the modeling method described herein allows us to quantify the differences between freshwater flow conditions now and those prior to the 20th century. Initial findings indicate that flow through Shark River Slough prior to the 20th century was about 2–2.5 times greater than now, and flow through Taylor Slough was 3–4 times greater (fig. 5). Stage in The Everglades wetlands was 0.5 m higher on average (fig. 5) around A.D. 1900. The estimated salinities from Florida Bay cores indicate reduced flow volumes during the 20th century. Stations from the nearshore transition zone show the most significant changes in salinity after A.D. 1900, compared to the previous centuries. The impact of freshwater flow on Florida Bay salinity decreases with increased distance from shore because of increased water exchange between the Gulf of Mexico and the Atlantic Ocean with Florida Bay in open water areas.

Significance to Restoration

The south Florida ecosystem presents a laboratory of change—a series of environmental experiments over many time scales, which provide a long-term record of the combined effects of natural climate variability, land use, and water management practices on the greater Everglades ecosystem. Paleoecologic investigations from south Florida estuaries provide quantitative data on historical variability of salinity and trends that may be applied to statistical models to estimate historical freshwater flow. These data provide a unique context to estimate future ecosystem response to changes related to restoration activities and predicted changes in sea level and temperature, thus increasing the likelihood of successful and sustainable ecosystem restoration.

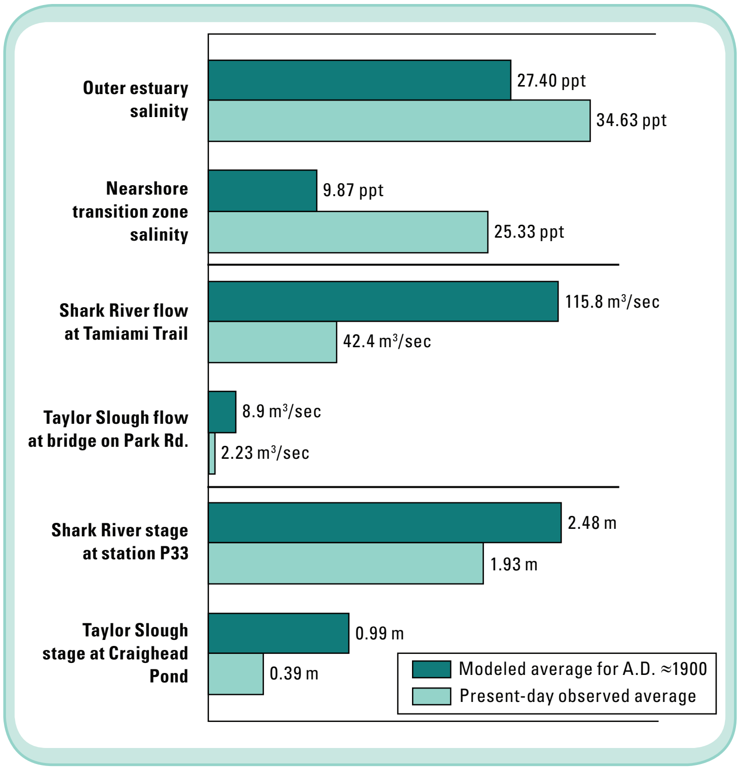

Figure 5. Comparison of averaged instrumental data collected between 1991 and 2003 with model-derived estimates for A.D. ≈1900. Data include salinity (parts per thousand [ppt]), flow rate (cubic meters per second [m3/sec], and stage depth (meters [m]). Model results shown here are based on the analysis of one sediment core. (Adapted from Marshall and others, 2009.)

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By G. Lynn Wingard, Joel W. Hudley, and Frank E. Marshall

For more information

G. Lynn Wingard
U.S. Geological Survey
lwingard@usgs.gov
Web site: http://sofia.usgs.gov/exchange/flaecohist/

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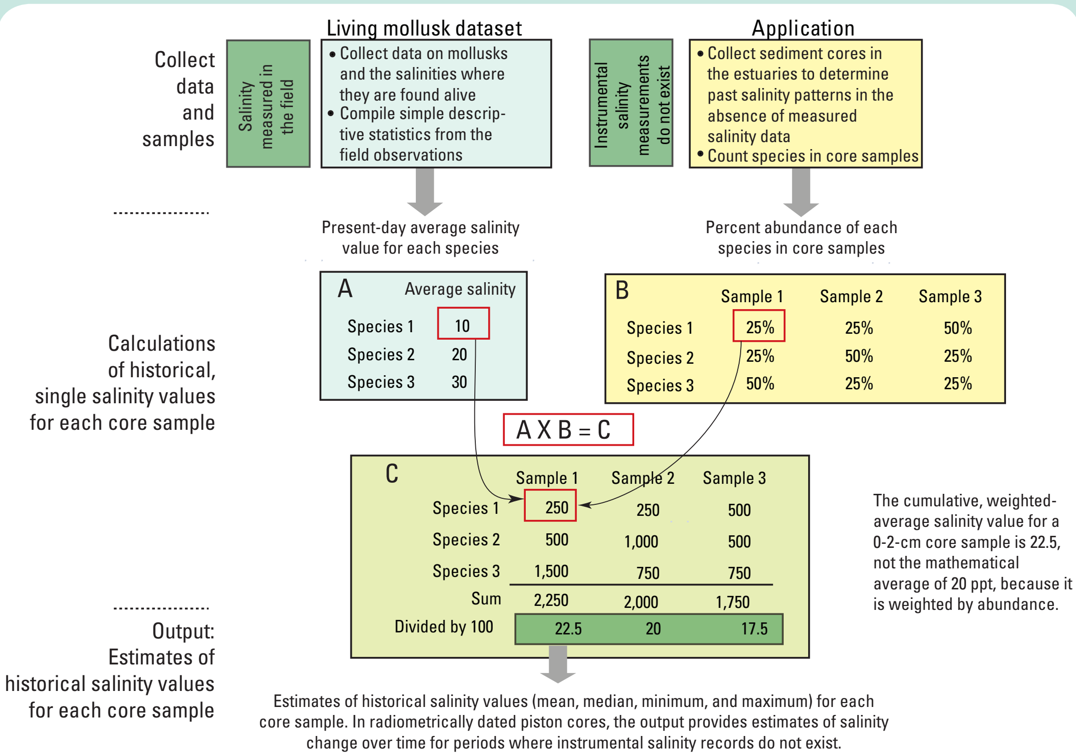

Steps to determine estimates of historical, single salinity values for each core sample. These estimates are produced from data on the salinity preferences of species in the present-day environment (step A) and measurements of the abundance of those same species in sediment-core samples collected from the estuaries in south Florida (step B). These two values are multiplied (step C), summed for each core sample, and then divided by 100 to produce a single salinity estimate for each core sample. These salinity estimates allow managers to set salinity targets for restoration of the estuaries that reflect natural patterns of change, prior to human alteration of the environment.