Ecosystem History

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About this report

This report draws its material directly from syntheses compiled for the 2001 Florida Bay Science Conference. The Florida Bay Science Program organizes itself around five central research questions. Topical teams associated with each question consist of modelers and researchers working in the Bay and adjacent marine systems. These teams compiled the original synthesis documents.

In preparation for the 2003 Florida Bay Science Conference, the research teams have modified the existing synthesis documents to bring them up to date and implement a more uniform, common format. In some cases, entirely new documents have been drafted, such as the information here on ecosystem history and on nutrient dynamics. The present report compiles these separate documents into one and provides the reader with summary material as a guide to the contents.

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Introduction

A critical part of understanding an ecosystem as a whole is to understand the natural patterns and cycles of change, but 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. However, the ability to accurately understand natural conditions and cycles of change within Florida Bay is crucial for successful restoration and preservation of the Bay and to meet the goals of the Comprehensive Everglades Restoration Plan (CERP). Information on the historical and current natural system allows restoration planners to establish realistic baseline conditions, restoration goals, and performance measures; create predictive models; and monitor success of restoration efforts. Understanding past conditions and cycles of change also allows for better-informed planning, project implementation, and land management decisions.

Although the ecosystem history and paleoecology of Florida Bay was not specifically identified by the Florida Bay Science Program as a strategic research question, these types of studies contribute or can potentially contribute to all five strategic questions. By their very nature these studies are multidisciplinary, and integrate data to provide a holistic picture of the environment over biologically significant time scales. This chapter summarizes ecosystem history research that has contributed to the Florida Bay Science Program.

Methodology

The history of an ecosystem may be recorded in two distinct modes: 1) human records, in the form of historical accounts, reports, or archived data; and 2) natural records preserved in the sediments. Both methods can provide valuable data, but the sediment record and associated paleoecologic data can be especially important because few monitoring programs have been in place long enough to provide sufficient data to establish the range of variability in ecosystem parameters over a significant period of time. Furthermore, monitoring or experimental data are absent prior to human influence on the environment. Ideally, both human records and natural records are retrieved, compiled and compared to develop the most complete picture possible of the configuration of an ecosystem over time, and the spatial and temporal scale of changes to the system.

Human Records

Significant efforts have been made by a number of individuals and groups to compile data sets and historical records for the south Florida ecosystem and Florida Bay. It is not the purpose of this summary to list all of these compilations, but the following illustrate the variety of records available:

1. Robblee, M.B., et al (unpublished) – A compilation of over 34,000 historical salinity measurements from Florida Bay, beginning in 1947 through 1995.
2. DeMaria, K., 1996 - Changes in the Florida Keys Marine Ecosystem Based upon Interviews with Experienced Residents – A compilation of “eyewitness” accounts of 75 individuals with more than 10 years experience on Florida Keys and Florida Bay waters.
3. Smith, T.J., (unpublished) – historical reconstruction of vegetation from aerial photographs of selected islands within Florida Bay, dating from 1927. Areas of

interest include the entirety of Everglades NP, Big Cypress NP and the Water Conservation Areas.

4. Smith, T.J., et al., 2002 – digitally compiled set of scanned historical topographic sheets from the Everglades and south Florida available on CD-ROM.

Sediment Records

Retrieving historical information recorded in sediments follows basic principals of geology, (primarily the law of superposition and "the present is the key to the past") and utilizes a number of paleoecological and geochemical tools.

1. *Assemblage analyses* – the faunal and floral remains found in a sediment core allow inferences to be made about the environment in the past, including salinity, substrate, and water quality, based on modern analogue data.
2. *Biochemical analyses* – organisms with calcareous skeletons record information about the water in which they secrete their skeletons. Stable isotope analyses and metal/Ca ratios of shells or coral skeletons can provide information on salinity and sources of water.
3. *Geochemical analyses* – radiogenic isotopes are utilized to determine the chronology of cores and analyses of the geochemistry of the sediments (C, N, S, and P for example) provide data on changes in nutrient supply and sediment influx over time.

Each of these methods is limited by the resolution of the age model for sediment deposition. Typical geochronologic methods used on late Holocene sediments are lead-210, cesium-137, beryllium-7, and carbon-14 (see Holmes, et al., 2001, for explanation). The error increases down-core so that a typical core from eastern Florida Bay with a sedimentation rate of 1.0 cm/year and an error of ± 0.08 cm/year will have an average age of 1900 at one meter depth, plus or minus 8 years. Because of the error associated with increasingly older sediments, the annual banding of corals provides the most accurate age control, but only a few large corals have been found within Florida Bay that can be used to reconstruct past conditions.

Analyses of sediment cores from Florida Bay have been primarily conducted by two different groups of researchers during the last ten years (Table 3.1): 1) the University of Miami/NOAA group (Alvarez Zarikian, C.A., Blackwelder, P.L., Hood, T., Nelson, T.A., Swart, P.K., Tedesco, L.P., Wanless, H.R., et al.) and 2) the USGS group (Cronin,T.M., Dwyer, G.S., Halley, R.B., Holmes, C.W., Huvane, J.K., Ishman, S.E., Orem, W., Shinn, E., Willard, D.A., Wingard, G.L., et al.). Both groups have sought out areas of sediment accretion with minimal sediment disturbance; however, they diverge in terms of benthic habitats (Holmes, et al., 2001; Nelsen, et al., 2002). The University of Miami/NOAA group has sought out cores from bare-bottomed habitats in order to insure the presence of well laminated sediments undisturbed by roots. The USGS group has utilized cores from banks stabilized by seagrass beds because these areas are subjected to minimal erosion during storms and trap the organisms in situ that are being analyzed. Both groups x-ray and physically examine the cores for signs of sediment disruption, and use the radiogenic isotope profiles as assurance of minimal disturbance. These two diverse strategies have had the benefit of providing data from different regions and different environmental settings within Florida Bay. A comparison of the findings and results will be discussed below.

Figure 3.1 shows the sites within Florida Bay where cores and corals have been analyzed for paleoecologic information and Table 3.1 lists details about the investigations.

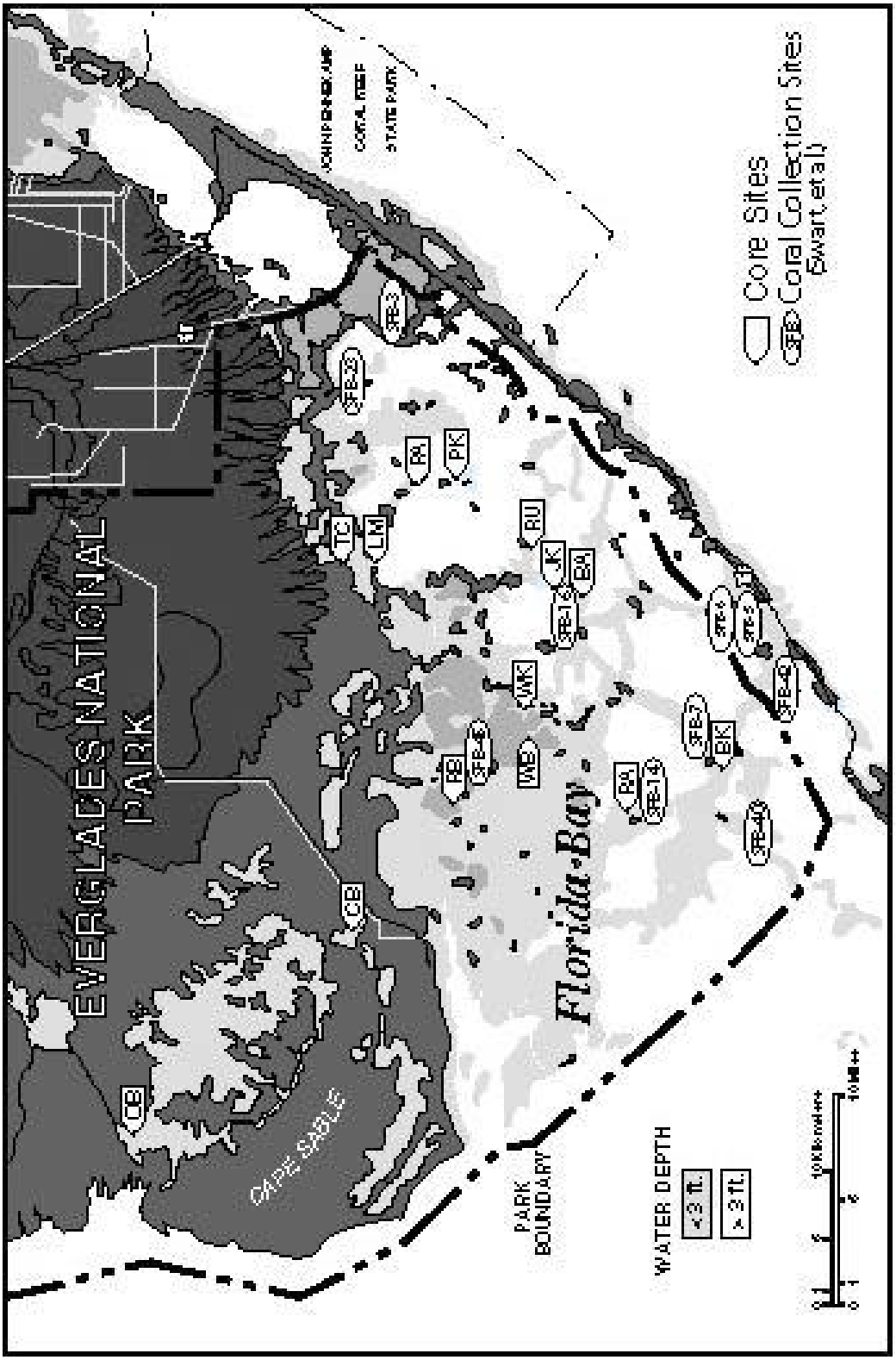


Table 3.1: List of sediment cores analyzed in Florida Bay between 1990 and present.

General Core Location (Core ID)	Researchers	Analyses Done	Status/References
1) Joe Bay	Holmes	210-Pb Geochronology	unpublished
	Willard	Pollen Assemblages	
	Wingard	Molluscan Assemblages	
2) Taylor Creek (T24) (TC-1,TC-1a,TC-2,TC-2br)	Ishman	Foraminferal Assemblages	Brewster-Wingard, et al. 2001; Cronin, et al., 2001; Dwyer and Cronin, 2001; Holmes, et al., 2001; Ishman, et al. 1996.
	Wingard	Molluscan Assemblages	
	Cronin	Ostracode Assemblages	
	Holmes	210-Pb Geochronology	
	Dwyer	Ostracode Biochemistry	
	Willard	Pollen Assemblages	
	Edwards	Dinoflagellate Assemblages	
	Orem	Sediment Geochemistry	
3) Pass Key (PK17D, PK37) (FB-1 Pass Key)	Wingard	Molluscan Assemblages	Brewster-Wingard, et al., 1998a; Brewster-Wingard, et al. 2001; Cronin, et al., 2001; Halley and Roulier, 1999; Huvane and Cooper, 2001; Orem, et al.,1999.
	Cronin	Ostracode Assemblages	
	Ishman	Foraminferal Assemblages	
	Halley	Molluscan Biochemistry	
	Holmes	210-Pb Geochronology	
	Huvane	Diatom Assemblages	
	Willard	Pollen Assemblages	
	Edwards	Dinoflagellate Assemblages	
	Orem	Sediment Geochemistry	
4) Russell Bank (RB19A, RB19B, RB 19C) (FB-2)	Wingard	Molluscan Assemblages	Brewster-Wingard and Ishman, 1999; Brewster-Wingard, et al., 2001; Cronin, et al., 2001; Cronin, et al., 2002; Dwyer and Cronin, 2001; Halley and Roulier, 1999; Holmes, et al., 2001; Huvane and Cooper, 2001; Brewster-Wingard et al.,1997; Orem, et al., 1999.
	Cronin	Ostracode Assemblages	
	Ishman	Foraminferal Assemblages	
	Holmes	210-Pb Geochronology	
	Dwyer	Ostracode Biochemistry	
	Willard	Pollen Assemblages	
	Halley	Molluscan Biochemistry	
	Edwards	Dinoflagellate Assemblages	
	Orem	Sediment Geochemistry	
5) Park Key (PKK23A)	Cronin, Dwyer	Ostracode Biochemistry	Cronin, et al., 2001; Dwyer Holmes, et al., 2001.
	Holmes	210-Pb Geochronology	
6) Bob Allen (BA6A) (FB-3)	Wingard	Molluscan Assemblages	Brewster-Wingard and Ishman, 1999; Brewster-Wingard, et al.
	Cronin	Ostracode Assemblages	
	Ishman	Foraminferal Assemblages	

Table 3.1: List of sediment cores analyzed in Florida Bay between 1990 and present.

General Core Location (Core ID)	Researchers	Analyses Done	Status/References
7) Whipray (25B)(FB-4, FB-5)	Wingard	Molluscan Assemblages	Trappe and Wingard, 2001; Cronin, et al., 2001; Holmes, et al., 2001; Orem, et al.,1999.
	Cronin, Dwyer	Ostracode Geochemistry	
	Holmes	210-Pb Geochronology	
	Orem	Sediment Geochemistry	
8) Rankin	Wingard	Molluscan Assemblages	Unpublished data; report in progress.
	Cronin, Dwyer	Ostracode Geochemistry	
	Holmes	210-Pb Geochronology	
	Orem	Sediment Geochemistry, Lignin phenols	
	Shinn, Reich	Sediment trace element geochemistry	
9) Jimmy Key (JK)	Wanless, Nelsen	Sedimentology, Geochronology	Nelsen, et al., 2002; Unpublished report, Nelsen, et al., 1999.
	Hood	Foraminferal Assemblages	
	Zarikian	Ostracode Assemblages; Ostracode Geochemistry	
	Swart	Stable Isotope Geochemistry	
	Trefry and Metz	Geochemistry	
	Blackwelder, Capps, O'Neal, Garte, Featherstone, Kang, Ellis		
10) Oyster Bay (OB)	Wanless, Nelsen	Sedimentology, Geochronology	Alvarez Zarikian, et al., 2001; Nelsen, et al., 2002; Unpublished report, Nelsen, et al., 1999
	Hood	Foraminferal Assemblages	
	Zarikian	Ostracode Assemblages; Ostracode Geochemistry	
	Swart	Stable Isotope Geochemistry	
	Tedesco	Pollen Assemblages	
	Trefry and Metz	Geochemistry	
	Blackwelder, Capps, O'Neal, Garte, Featherstone, Kang, Ellis		
11) Coot Bay	Wanless, Nelsen	Sedimentology, Geochronology	Nelsen, et al., 2002; Unpublished report, Nelsen, et al., 1999.
	Trefry and Metz	Geochemistry	
	Blackwelder, Capps, O'Neal, Garte,		

Table 3.1B: List of corals analyzed.

Location	Researchers	Analyses	References
Lignumvitae (SFB-5)	Swart, Healy, et al.	Stable istopes (C & O), Flourescence, trace elements (Ba)	Swart, et al.,1996; Swart, et al.,1999.
Lignumvitae Basin (referred to as Peterson Key Basin by Smith, et al.) (SFB-6)	Smith, Hudson	Flourescence, growth bands	Smith, et al., 1989. Hudson, et al. 1989.
Blackwater Sound (SFB-3)	Swart, Healy, et al.	Stable istopes (C & O)	Swart, Healy, et al., 1999
Arsenicker Keys (SFB-7)	Swart, Healy, et al.	Stable istopes (C & O)	Swart, Healy, et al., 1999
Rabbit Key (SFB-14)	Swart, Healy, et al.	Stable istopes (C & O)	Swart, Healy, et al., 1999
Bob Allen Key Basin / Calusa Key (SFB-16)	Swart, Healy, et al.	Stable istopes (C & O)	Swart, Healy, et al., 1999
Duck Key Basin / The Bogies (SFB-23)	Swart, Healy, et al.	Stable istopes (C & O)	Swart, Healy, et al., 1999
Lignumvitae Basin (SFB-40)	Swart, Healy, et al.	Stable istopes (C & O)	Swart, Healy, et al., 1999
Lignumvitae Basin (SFB-42)	Swart, Healy, et al.	Stable istopes (C & O)	Swart, Healy, et al., 1999
Manatee Key (SFB-45)	Swart, Healy, et al.	Stable istopes (C & O)	Swart, Healy, et al., 1999

Previous Work

Prior to 1990, few paleoecological analyses of sediment cores had been conducted in Florida Bay. The Holocene core studies that were done focused on the sediments themselves and the diagenesis of the sediments (Fleece, 1962), the mineralogy of the sediments (Taft and Harbaugh (1964), and the origins of the material comprising the sediments (Enos, 1977). Turney and Perkins (1972), in their study of the molluscan fauna of Florida Bay, examined cores to determine the persistence of sub-environments over time. They discuss the growth and migration of mudbanks based on their analyses. Wanless and Tagett (1989) did an extensive study of cores to determine the depositional history of the mudbanks within Florida Bay. All of these studies provide important information on the sedimentation and geologic history of Florida Bay, and allow for more accurate interpretation of the late Holocene ecosystem history.

Two studies were done in the 1980s on a coral from Lignumvitae Basin. Hudson, et al. (1989) compared the growth of a one meter sized *Solenastrea* to rainfall, temperature records, and human perturbations. They found a significant correlation between poor coral growth and construction of the Flagler Railroad. Smith, et al. (1989) investigated the relationship between the fluorescent banding (a result of terrestrial runoff) of the Lignumvitae coral and the flow of water in Shark River and Taylor Sloughs. They found a statistically significant difference between mean fluorescence in the pre-canal segment (pre-1932) of the coral and in the post-canal segment (post-1932). The decline in freshwater flow (as indicated by the fluorescence) began around 1912, which corresponds to the construction of drainage canals carrying water from Lake Okeechobee to the Atlantic. In addition, Smith, et al. (1989) found evidence for a 4-6 year periodicity in the historical annual flow regimes that was no longer apparent in the Shark River Slough flow record. This 4-6 year periodicity corresponds to south Florida rainfall records. They conclude that historically, prior to canal construction, Shark River Slough flow was controlled by rainfall, but by 1940 flow through the Slough was already substantially reduced and that the natural periodicity in flow regimes has been lost.

Summary of Ecosystem History and Paleoecology Research

Following are the significant research findings to date of the Ecosystem History/Paleoecology research groups, organized into the five principal Florida Bay research questions, Table 3.2.

Table 3.2: Summary of research on ecosystem history by topic

Type of Analyses / Research Questions	Faunal and Floral Assemblage Analyses	Biochemical Analyses	Geochemical Analyses
1) How and at what rates do storms, changing freshwater flows, sea level rise, and local evaporation/precipitation influence circulation and salinity patterns within Florida Bay and outflows from the Bay to adjacent waters?	Alvarez-Zarikian, et al., 2001; Brewster-Wingard et al., 1997; Brewster-Wingard et al., 1998a and b; Brewster-Wingard and Ishman, 1999; Brewster-Wingard, et al., 2001; Cronin, et al., 2001; Cronin, et al., 2002; Huvane and Cooper, 2001; Ishman, et al., 1996; Nelsen, et al., 2002; Trappe and Wingard, 2001; Wingard, et al., 1995	Alvarez-Zarikian, et al., 2001; Dwyer and Cronin, 2001; Dwyer, et al., in press; Cronin, et al., 2002; Halley, et al., 1994; Halley and Roulier, 1999; Healy, 1996; Nelsen, et al., 2002; Smith, et al., 1989; Swart, et al., 1996; Swart, et al., 1999.	Holmes, et al., 2001; Nelsen, et al., 2002.
2) What is the relative importance of the influx of external nutrients and of internal nutrient cycling in determining the nutrient budget for Florida Bay? What mechanisms control the sources and sinks of the Bay's nutrients?		Swart, et al., 1999;	Orem, et al., 1997; Orem, 1998; Orem, et al., 1999; Gough, et al., 2000; Nelsen, et al., 2002.
3) What regulates the onset, persistence and fate of planktonic algal blooms in Florida Bay?	Huvane and Cooper, 2001.	Swart, et al., 1999.	Holmes, et al., 2001; Orem, et al., 1999.
4) What are the causes and mechanisms for the observed changes in seagrass community of Florida Bay? What is the effect of changing salinity, light, and nutrient regimes on these communities?	Brewster-Wingard, et al., 1998; Brewster-Wingard and Ishman, 1999; Brewster-Wingard, et al., 2001; Cronin, et al., 2001; Trappe and Brewster-Wingard, 2001.	Dwyer and Cronin, 2001.	Orem, et al., 1999; Orem, Lerch, et al., 1999; Holmes, et al., 2001.
5) What is the relationship between environmental and habitat change and the recruitment, growth, and survivorship of animals in Florida Bay?	Brewster-Wingard, et al., 2001 (mollusks only).		Holmes, et al., 2001.

Question 1: How and at what rates do storms, changing freshwater flows, sea level rise, and local evaporation/precipitation influence circulation and salinity patterns within Florida Bay and outflows from the Bay to adjacent waters?

- Salinity in Florida Bay is more strongly correlated to rainfall than any other single factor and a periodicity in salinity and rainfall data suggests linkages to El Niño-Southern Oscillation climatic patterns.
- Anthropogenic influences play a secondary role to rainfall in determining salinity for Florida Bay as a whole, but they may be a factor in the magnitude of salinity variations seen in recent times. Additionally, anthropogenic factors may act on a local basis to influence salinity patterns.
- Declines in diversity and increases in dominance of salinity tolerant species have occurred since the 1980s in several benthic invertebrate groups in different regions of Florida Bay.

Question 2: What is the relative importance of the influx of external nutrients and of internal nutrient cycling in determining the nutrient budget for Florida Bay? What mechanisms control the sources and sinks of the Bay's nutrients?

- Uranium isotope studies indicate that the phosphorus contamination at the northern end of Taylor Slough appears to be fertilizer-derived. However, phosphorus contamination in Taylor Slough diminishes to background by mid slough; therefore Taylor Slough does not appear to be a source of nutrients to eastern Florida Bay.
- Eastern Florida Bay does appear to be a source of nutrients to the mangrove zone at the southern end of Taylor Slough.
- Sediments from eastern Florida Bay (especially from sites near Pass and Russell Key banks) show indications of recent nutrient (C, N, and P) enrichment (1980 to present). This nutrient enrichment could be related to recent microalgal blooms and seagrass dieoff within Florida Bay.
- Downcore profiles of dated cores from central Florida Bay (Whipray Basin) show that productivity events have occurred historically in Florida Bay.
- A large multidecadal productivity event characterized by greatly elevated levels of organic carbon and nitrogen; dated to about the mid 1700s, was observed in two cores from Whipray Basin. Interestingly, total phosphorus was not elevated during this time span. This time period (the Little Ice Age) may correspond to a period of higher rainfall in the Everglades, and more extensive land runoff into Florida Bay, which may have triggered the productivity event.

Question 3: What regulates the onset, persistence, and fate of planktonic algal blooms in Florida Bay?

- Surface sediments from eastern Florida Bay show indications of nutrient (C, N, and P) enrichment from 1980 to the present, which could be related to recent microalgal blooms within Florida Bay.
- Multidecadal productivity event noted in sediment geochemistry from Whipray Basin cores may represent a period of extensive algal blooms.

- Downcore changes in abundance and assemblages of dinoflagellates and diatoms have been examined at some sites in Florida Bay, but additional studies of the ecology of the groups are needed to interpret the findings in terms of bloom conditions.

Question 4: What are the causes and mechanisms for the observed changes in seagrass community of Florida Bay? What is the effect of changing salinity, light and nutrient regimes on these communities?

- Frequent changes have occurred in the relative abundance of epiphytal species of ostracodes and mollusks over the last century.
- Prior to mid-20th century epiphytal ostracodes were relatively rare at sites in central and eastern Florida Bay, suggesting a greater abundance and/or density of SAV over the last 50 years, compared to the first half of the century. Epiphytal mollusks, while not rare, increased significantly in relative abundance from approximately 1940 on at most sites. These data raise the question that dense and abundant seagrass beds may not be natural and has large implications for restoration.
- A decline occurred in SAV dwelling ostracodes and mollusks in cores from Whipray, Russell, Bob Allen, and Pass Keys between the 1970s and 1980s.
- Relative abundance of mollusks with a strong preference for *Thalassia* have declined since approximately 1970 in eastern Florida Bay, and since 1910 in Whipray, while SAV generalists have increased. This may indicate an increase in the amount of macro-benthic algae relative to Thalassia.
- Downcore profiles of lignin phenols from Pass Key core shows large variations in lignin phenol distributions over short time intervals; reflecting the proximity of this site to the mangrove zone along the coast and the outlet of Taylor Creek.
- At Bob Allen Keys, the lignin phenol distributions show downcore variations in the abundance of seagrass over time. At Bob Allen, seagrass abundance appears to have been increasing since a recent minimum around 1960.

Question 5: What is the relationship between environmental and habitat change and the recruitment, growth and survivorship of animals in Florida Bay?

- Declines in molluscan faunal diversity have occurred over latter half of 20th century

Salinity Patterns and Trends

The majority of the ecosystem history / paleoecology research since 1994 has been focused on addressing the question of salinity patterns and influx of freshwater in Florida Bay. The most critical issue in the Comprehensive Everglades Restoration Plan (CERP) is to restore more natural patterns of freshwater flow through the terrestrial ecosystem and into the estuaries and coastal areas. Restoring natural flow to Florida Bay includes the timing, delivery, quantity and quality of the water; in other words, "getting the water right." In order to recreate natural freshwater flow patterns, it is essential to understand the natural patterns of variation prior to significant human alteration of the system and the natural sources of water. Changing salinity patterns, whether natural or anthropogenically induced, affect the fauna and flora of the Bay, so a first step in restoration is to understand the natural patterns and be able to set targets and performance measures for restoration.

An important tool in the restoration effort is modeling the fresh-water flow from the Everglades to Florida Bay under different restoration scenarios. The "Natural System Model" (NSM) of the SFWMD was developed in part to meet these needs. The NSM model is driven by rainfall and efforts to calibrate model-simulated fresh water flow in the Everglades using historical rainfall records have met with only partial success due to the lack of historical data on natural conditions prior to water diversion activities. A similar lack of long-term instrumental records of salinity in adjacent Florida Bay has placed constraints on restoration targets for aquatic ecosystems.

The research projects summarized below have addressed the lack of historical data on Florida bay salinity and freshwater influx. The goal of these studies has been to determine the natural patterns of salinity change and freshwater influx and to distinguish the natural patterns of change from changes in the salinity regime caused by water diversion in the Everglades during the 20th century. This section summarizes the methodology applied and the progress made towards this goal.

Methods

Basic assemblage analyses and biochemical analyses have been used by both research groups (University of Miami/NOAA and USGS) to extract salinity information from sediment cores dated using lead-210 and other methods of dating (Table 3.1). Interpretations of faunal and floral assemblages are based on observations of the modern ecology of the organisms being studied. These assemblages represent a death assemblage and therefore are time-averaged, but in the Florida Bay environment with relatively rapid sedimentation rates and little erosion and transport of silt and sand-sized sediments (Turney and Perkins, 1972; Halley, et al., 1997) decadal-scale resolution can be obtained from the assemblages. Additional evidence that different environments are not being mixed in a death assemblage is gained when several faunal groups are analyzed and compared from a single sample and the condition of the shell material is considered.

Biochemical methods are based on the analyses of individual shells and therefore capture the salinity record of the time during which that shell was deposited. Although these analyses

can provide an almost instantaneous record the data are still limited by the temporal resolution of the dating-method for the sample from which the shell was extracted.

Cronin and Dwyer have utilized the ratio of magnesium to calcium (Mg/Ca) ions in ostracode shells to reconstruct salinity from Florida Bay cores (Dwyer and Cronin, 2001; Cronin, et al. 2001; Cronin, et al., 2002; Dwyer, et al., in press). They have examined the ecology and shell chemistry of modern ostracodes in Florida Bay and have demonstrated that the Mg/Ca ions in the calcium carbonate shells of ostracodes is strongly influenced by the salinity and temperature in which the organism secretes its shell. They have focused the shell biochemical studies on the epiphytal species *Loxoconcha matagordensis*, although in some cores *Peratocytheridea setipunctata* is analyzed. Based on their ecological studies, it appears that adult *Loxoconcha matagordensis* primarily secrete their shells during spring or summer seasons (Cronin, et al., in press). Because warm season temperatures in Florida Bay are relatively invariant over interannual timescales, temperature is considered less important than salinity in influencing ostracode Mg/Ca in Florida Bay, although additional research is warranted.

Alvarez Zarikian, Swart, Hood, et al., (2001) and Nelsen, et al., (2002) have conducted stable isotopic analyses ($\delta^{18}O$ and $\delta^{13}C$) on ostracodes and benthic foraminifera to extract information on rainfall, freshwater influx, and evaporation and to infer salinity conditions from these data. Changes in $\delta^{18}O$ can be correlated to changes in salinity, and $\delta^{13}C$ can indicate influx of organic material. Evaporation of marine and brackish water preferentially removes the lighter isotopes (^{16}O) and enriches the water in the heavier isotopes (^{18}O), thus an increase in $\delta^{18}O$ indicates increased evaporation, and therefore increased salinity. In Florida Bay, however, interpretation of the $\delta^{18}O$ value is complicated by the influx of freshwater from the terrestrial Everglades. Interpretation of $\delta^{13}C$ is also complicated in coastal waters. Under normal marine conditions the $\delta^{13}C$ of calcareous organisms is primarily controlled by the physiological processes, but in areas where fresh and marine waters mix, variations in the dissolved inorganic carbon are probably the dominant factor. Freshwater from the Everglades is typically isotopically depleted in $\delta^{18}O$ and $\delta^{13}C$ whereas the marine waters from the Gulf or Atlantic are enriched in $\delta^{18}O$ and $\delta^{13}C$. By comparing and correlating $\delta^{18}O$ to $\delta^{13}C$ the researchers can interpret the relative influence of freshwater and marine waters at the core site. (See Halley, et al., 1994; Swart, et al., 1996; Swart, et al., 1999; and Alvarez Zarikian, et al., 2001, for a detailed explanation of the environmental factors that influence $\delta^{18}O$ and $\delta^{13}C$.)

Stable isotopic analyses have also been used to analyze corals within Florida Bay (Swart, et al., 1996; Healy, 1996; Swart, et al., 1999) and on a reef affected by Florida Bay waters (Halley, et al., 1994). The annual banding of corals provides a very accurate means of determining the age of the isotopic samples being analyzed. Halley, et al., (1999) utilized whole mollusks shells (*Brachidontes exustus* and *Transennella* spp.) from radiometrically date cores for $\delta^{18}O$ and $\delta^{13}C$ analyses.

Findings

The following summary is intended to briefly synthesize the key results from paleoecologic studies completed in the last 10 years. The reader is referred to the original papers for detailed results, methods, and evidence supporting the conclusions.

- **Salinity in Florida Bay is more strongly correlated to rainfall than any other single factor and a periodicity in salinity and rainfall data suggests linkages to El Niño-Southern Oscillation climatic patterns.**

  Nelsen, et al. (2002) and Alvarez Zarikian, et al. (2001) conclude on the basis of multidisciplinary studies of cores from Oyster Bay and Jimmy Key (Table 3.1, Fig. 3.1) that "anthropogenic influences play a secondary role to natural influences such as regional rainfall"(Nelsen, et al., 2002, p. 445). Their analyses showed that salinity responded directly to regional rainfall and that "microfaunal data also indicate direct correlation to rainfall patterns for temporal scales ranging from decadal down to the limit-of-resolution of geochronology" (Nelsen, et al., 2002). Even at the mouth of Shark River Slough, they found rainfall to be the dominant driver.

  Dwyer and Cronin (2001) compared downcore salinity trends derived from Mg/Ca ratios from Russell Bank, Park Key and Bob Allen mudbank (Table 3.1; Fig. 3.1) to historical rainfall records. They found good correspondence between rainfall and the paleosalinity data. In addition, they found four extreme low salinity periods that corresponded to strongly negative values in the El Niño-Southern Oscillation (ENSO) index.

  Cronin, et al. (2002) conducted time series analyses on ostracode Mg/Ca ratios and ostracode abundance data from the Russell Bank core (Table 3.1, Fig. 3.1). They determined that a 5.6 year Mg/Ca based salinity periodicity existed, and that all salinity proxy data analyzed showed 6-7 year, 8-9 year, and 13-14 year periods of variability. They compared the paleosalinity data to climatic factors and conducted a time series analysis on south Florida winter rainfall and the Southern Oscillation Index (SOI), which suggested ~5, 6-7, 8-9 and 13-14 year cycles. Paleo-proxies and climate data were compared using cross spectral analyses. The results suggest "that regional rainfall variability influences Florida Bay salinity over interannual and decadal timescales and that much of this variability may have its origin in climate variability in the Pacific Ocean/atmosphere system" and may be related to ENSO (Cronin, et al., 2002, p. 233).

  Swart, et al. (1999) in an analysis of coral records from Florida Bay (Table 3.1) mentions that "a superficial comparison between precipitation from the lower east coastal region of South Florida appears to indicate that periods of lowest rainfall relate to times when the salinity was highest (1999, p. 392). However, a comparison of the $\delta^{18}O$ of the coral skeleton from Lignumvitae indicates no statistically significant correlation, perhaps due to miscalculations in the age of the coral bands or the lack of accurate rainfall data for Lignumvitae Basin. They conducted spectral analyses on the salinity values calculated from the corals and found three statistically significant signals at 4-7 years, 28 years and 12-14 years. They point out that the most significant periodicity, the 4-7 year cycle,

which accounts for greater than 20 percent of the variance, may be related to ENSO cycles (Swart, et al., p. 392-393).

These short-term cycles in salinity found in recent research are consistent with the findings of Smith, et al. (1989) in their examination of fluorescent banding in the Lignumvitae coral. They found "strong evidence for a regular 4-6 year periodicity in the historical annual flow regimes, as years of low flow alternated with years of high flow (Smith, et al., 1989, p. 280).

- **Anthropogenic influences play a secondary role to rainfall in determining salinity for Florida Bay as a whole, but they may be a factor in the magnitude of salinity variations seen in recent times. Additionally, anthropogenic factors may act on a local basis to influence salinity patterns.**

Dwyer and Cronin (2001) note a shift to high amplitude salinity oscillations after 1950 as indicated by the Mg/Ca ratio from cores in eastern Florida Bay (Table 3.1; Fig. 3.1). These higher amplitude oscillations corresponded to a period of increased rainfall variability, but human alteration of freshwater flow may also be a factor.

Brewster-Wingard and Ishman (1999) noted similar increases in the amplitude of salinity oscillations after ~1940 as indicated by foraminiferal and molluscan assemblages in cores from Bob Allen and Russell (also examined by Dwyer and Cronin; Table 3.1; Fig. 3.1). They did not conduct any statistical comparisons, but noted that the cause could be meteorological patterns, anthropogenic changes to freshwater flow, or a combination of factors.

Clear evidence of decreasing freshwater influence during the 20th century was found in the northern transition zone at the mouth of Taylor Creek by Brewster-Wingard, et al. (2001), and at Mud Creek near Joe Bay (Brewster-Wingard, unpublished data)(Table 3.1; Fig. 3.1). The changes in the molluscan assemblage from oligohaline/mesohaline fauna to predominantly polyhaline fauna could be explained by the local alteration of flow through Taylor Slough, by changes in rainfall that ultimately affect the flow, or by a combination of both.

Alvarez Zarikian, et al. (2001) and Nelsen, et al., (2002) present evidence of the local effects of water management practices in their detailed analyses of the Oyster Bay core (Table 3.1; Fig. 3.1). Several anthropogenic factors affected Oyster Bay and Whitewater Bay during the 1980s: the beginning of SFWMD's "Rainfall Plan" for managing flow, the shift of water from Shark River Slough basin into Taylor Slough basin, and the closing of the Buttonwood canal. Alvarez Zarikian, et al. (2001) note a significant decline in ostracode diversity and abundance occurred around 1980, which they state could be linked to these anthropogenic changes or could be due to the mid-1980s drought. Nelsen, et al. (2002) illustrate that regardless of the cause of the faunal changes in Oyster Bay, a comparison of rainfall and flow records show the most significant correlations prior to 1960 during the "premanagement period" and after 1983 during implementation of the Rainfall Plan.

- **Declines in diversity and increases in dominance of salinity tolerant species have occurred since the 1980s in several benthic invertebrate groups in different regions of Florida Bay.**

  Alvarez Zarikian, et al. (2001) and Nelsen, et al. (2002) see two periods of reduced diversity in the benthic microfauna at Oyster Bay: mid-1930s to late 1940s, and late 1970s to time of core recovery in 1994. Nelsen, et al. (2002, p. 444) relate the faunal changes to "the changing nature of the salinity field at Oyster Bay after ~1980." At Jimmy Key, the periods of reduced diversity are from mid-late 1930s, and late 1970s to core recovery in 1997, which they also relate to changes in the salinity field. Prior to 1950, declines in ostracode abundance and diversity were followed by rapid recovery. Following the crash in the late 1970s, the population has not recovered. The ostracode and foraminiferal fauna in the period from the late 1970s on are dominated by individual species (*Peratocytheridea setipunctata* and *Ammonia parkinsoniana typica*) that the authors interpret as exhibiting survivor-type dominance. *Peratocytheridea setipunctata* is known to tolerate extreme salinity fluctuations from <5 to 42 ppt (Alvarez Zarikian, et al., 2001, p. 140).

  Brewster-Wingard, et al. (2001), and Trappe and Brewster-Wingard (2001) note similar patterns in the molluscan assemblages from cores in eastern and central Florida Bay. In every core examined, *Brachidontes exustus*, a mollusk known to tolerate large salinity variations (10-44 measured in the field) and reduced water quality becomes the dominant species in the upper portions of the cores from approximately 1980 on. The exception is Whipray, where *Brachidontes* reaches it's peak in the late 1970s and then declines. In almost every core, with the exception of the Taylor Creek core, increases in *Brachidontes* relative abundance correspond to declines in molluscan diversity. Brewster-Wingard has interpreted this as opportunistic dominance.

Status of Research

Accomplishments – Questions Resolved

- Consensus among most researchers that rainfall and climatic patterns are the strongest driving factor in determining Florida Bay salinity patterns. Anthropogenic influences play a secondary role.
- Indications of an increasingly stressed system from dominance patterns of species that tolerate extreme fluctuations in salinity. These patterns are unprecedented in cores prior to the latter quarter of the 20th century.
- Careful comparison of faunal data and biochemical data to instrumental salinity records for the last 50 years has demonstrated the validity of using paleoecologic techniques to interpret downcore salinity patterns that extend beyond instrumental data records.
- Increased coverage of Bay with addition of new cores illustrates bay-wide trends.
- Increased refinement of proxy data allowing for more accurate interpretation of downcore results.

Recent Accomplishments (Unpublished)

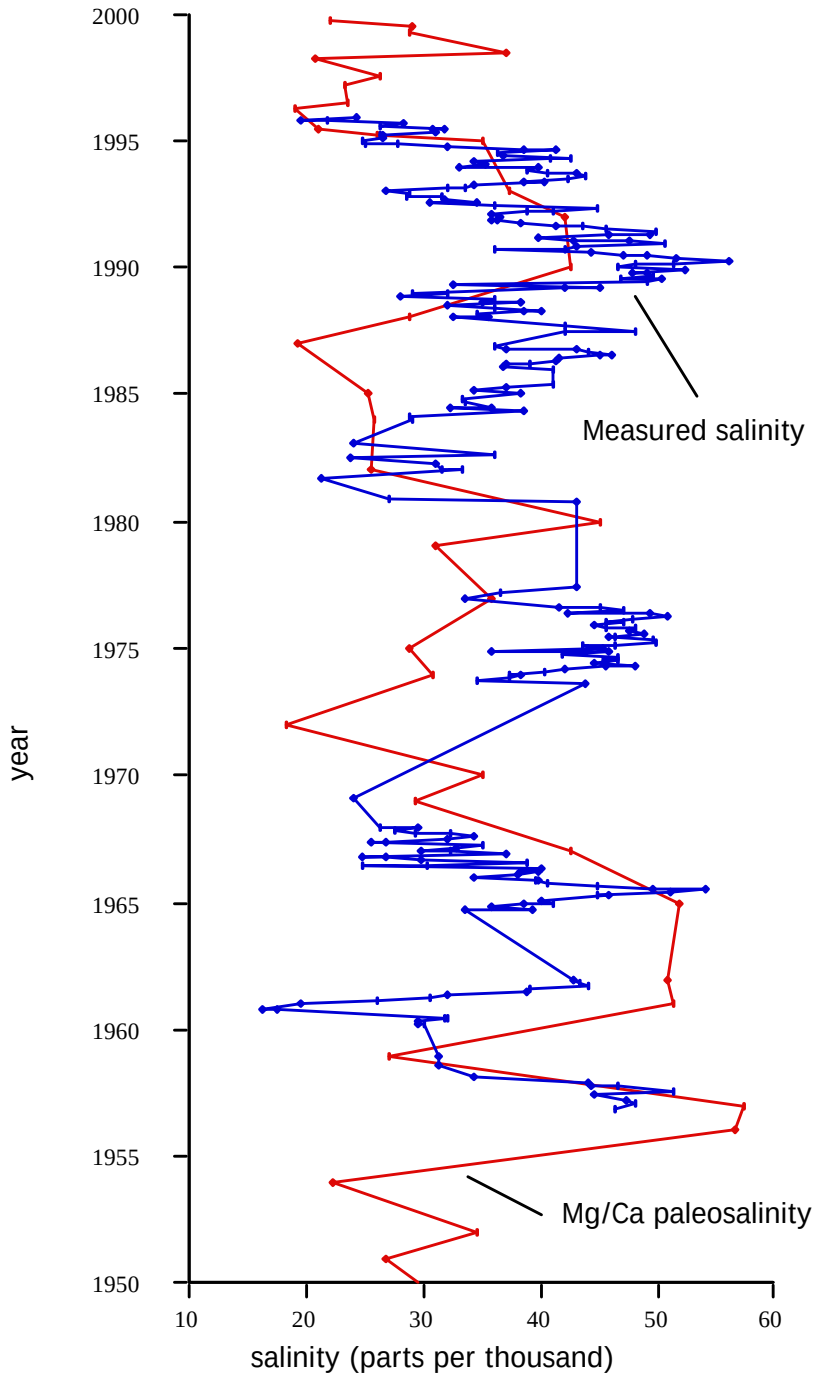
[Note: this is only a partial discussion. Not all Ecosystem History researchers responded to the author's request for information.]

- Ground-truthing of ostracode Mg/Ca based paleosalinity reconstruction with instrumental salinity records (1950-present) confirms the Mg/Ca method yields salinity values within 1-3 ppt of salinity maxima and minima over the past 50 years.
- Method of reducing molluscan assemblage data to single salinity value developed.
- Hypothesis that decadal patterns of salinity are driven by climatological factors, including rainfall, was supported by analyses of sediment core paleosalinity record from Rankin Lake. The Rankin Lake paleosalinity record matches those obtained in earlier studies of Russell and Bob Allen Keys.
- Rankin Lake core indicates strong influence of freshwater at bottom of core.

Cronin and Dwyer (unpublished data) have tested the accuracy of their downcore salinity estimates based on the Mg/Ca ratios in ostracode shells to historical instrumental salinity records. These historical records date back to 1947 and have been compiled by Robblee, et al. (unpublished). Figure 3.2 compares the Mg/Ca paleosalinity curve against the instrumental record of salinity for the last 50 years. Both the instrumental records and the paleosalinity curve exhibit large decadal swings in salinity in central Florida Bay from salinity exceeding 50 ppt to the low 20s. For salinity maxima during the early 1990s, late 1970s and mid-1960s the difference between paleo- and instrumental salinity was ~ -1.1., 0.9, and 3 ppt, respectively. The differences in the four periods of Florida Bay salinity mimima ~ 1993-1995, the 1980s, the late 1960s-early 1970s and near 1960 were 0.3, 3.6, 1.9 and 0.8 ppt, respectively. Given the temporal gaps in the instrumental record, the error bar on the sediment core age estimates, and the spatial and temporal averaging used for both records, these comparisons provide a remarkable confirmation that the Mg/Ca-based shell chemistry method yields accurate estimates of past salinity to within < 1 to 4 parts per thousand.

Wingard has developed a method to reduce the molluscan faunal assemblage data from core samples to a single averaged salinity value (unpublished). Presence/absence data have been recorded for live mollusks in Florida Bay since 1995 (http://sofia.usgs.gov/flaecohist/) along with numerous environmental parameters including salinity. These salinity data are compiled and examined statistically to determine mean, median, minimum, maximum, standard deviation, and confidence levels for each mollusk species observed live. Any species with a confidence level above 5 or number of observations less than 15 were deleted from the modern database. The modern salinity information is then compiled with data from a core sample, weighted based on the percent abundance of each species present in the sample assemblage, and a cumulative average salinity value is produced for the entire sample. This method allows direct comparison to instrumental records and can be used by modelers.

Figure 3.2. Comparison between instrumental salinity and salinity calculated from Mg/Ca ratios of ostraocdes. Instrumental data from Robblee, et al. (unpublished). The instrumental salinity curve was constructed by computing monthly mean values for Whipray, Rankin, and Bob Allen Basins and then obtaining a grand mean for the central region.



A preliminary comparison (Wingard, unpublished) of the cumulative weighted average salinity data from three cores to the instrumental salinity records compiled by Robblee, et al. (unpublished) has been completed. It is important to note that this method is only as good as the modern data it is based upon. During the period of observations between 1995 and 2000 salinity values in excess of 48 ppt were never recorded and only four site surveys were conducted in water exceeding 40 ppt during the course of the study (Brewster-Wingard, et al., 2001; and unpublished data). This means that the modern database is skewed toward lower salinity values. Despite this problem, the cumulative weighted averages show downcore trends and can be compared to the instrumental records because they give an absolute value, unlike standard assemblage data analyses.

Ongoing Research

[Note: this is only a partial list. Not all Ecosystem History researchers responded to the author's request for information.]

- Dwyer and Cronin are continuing to examine the ecology of the ostracode *Loxoconcha matagordensis* in order to refine their understanding of the role of temperature versus salinity in the Mg/Ca of the shells, and to examine the different magnesium ionic concentrations of fresh versus marine waters. This may provide another way to determine past fresh water influx into Florida Bay.
- Wingard, Stamm and Murray are conducting growth experiments and calibrating water chemistry to shell chemistry for the molluscan species *Chione cancellata* in order to be able to extract salinity data from the metal/Ca ratios and stable isotopic ratios (^{18}O and $\delta^{13}C$) in the individual growth increments of the shell.
- Wingard, Cronin, Dwyer, Orem, Holmes, et al., are completing analyses on core from Rankin Lake. Results will illustrate whether hypersalinity bulls-eyes noted in this area over the last 15 years are a recent phenomenon, or whether these existed under natural flow conditions.
- Wingard, Stamm, and Murray are conducting salinity stress tests on common molluscan species found within modern Florida Bay and the sediment cores in order to refine the average salinity values for each molluscan species used in the cumulative weighted sample average salinity method discussed above.

Unresolved Questions / Needed Research

[Note: this is only a partial list. Not all Ecosystem History researchers responded to the author's request for information.]

- How did salinity change in Florida Bay on a seasonal basis prior to significant alteration of fresh water flow into the Bay? What were the extremes in seasonal change?
    - Wingard, et al., research on the biochemistry of individual molluscan growth increments is addressing this question.
- Did hypersalinity zones form in Florida Bay prior to instrumental data recordings in the last two decades? If so, how often, what was the duration, and were these linked to natural climatic patterns or to anthropogenic change?
    - Examination of Rankin Core by USGS group is a step toward beginning to answer these questions.

- Collect additional cores from critical areas within the Bay, for example a transect along the margins of northern and eastern Florida Bay and the Cape Sable / Ten Thousand Islands area where short-term salinity oscillations are large.
- Attempt to find areas with longer records extending back into the early 1800s to examine 50-100 years salinity patterns prior to any alteration of the environment.
- Develop a better understanding of the controls on shell biochemistry in coastal mixing areas where freshwaters and marine waters mix and the seasonality of these changes. This includes refining our understanding of the salinity and temperature impacts on shell chemistry by integrating trace elemental (Mg/Ca, and also Strontium, and Barium) analyses with stable isotopic analyses.
    - Alvarez Zarikian and Swart plan to continue their stable isotopic studies of water, ostracodes, and corals.
    - Dwyer and Cronin are continuing their studies of Mg/Ca in water and ostracodes.
    - Swart, Alvarez Zarikian, Dwyer and Cronin hope to work together on the same cores, examining both isotopic and trace elements in ostracode and foraminifer shells.
- Refine knowledge of modern ecology of organisms being used in downcore studies.
    - Wingard, et al., are continuing in situ and laboratory tests on mollusks to determine tolerance to salinity extremes.
- Test whether mean salinity or standard deviation in salinity exerts more control over benthic fauna and flora (Montague and Ley, 1993. See discussion in Nelsen, et al., 2002).
- Develop a carbon budget for Florida Bay. This will contribute to a better understanding of the carbon isotope record of the cores and provide a better means for interpreting historical freshwater influx into the bay (Halley, et al., 1999).
- Additional “groundtruthing” of paleosalinity (Mg/Ca in ostracodes, cumulative weighted sample average of mollusks) with the fairly continuous instrumental salinity record available since 1985 using new short sediment cores from key sites.
- Calibration of Mg/Ca ratios in other ostracode species for application to new areas of study within the Bay.
- More rigorous statistical analysis of measured and reconstructed salinity and forcing factors (rainfall, evaporation, groundwater, and discharge from sloughs).
- Apply paleosalinity data to natural system model simulations to test the models and see if they can accurately predict the trends determined from the paleorecord. Begin with paleosalinity data that has been “groundtruthed” by comparison to instrumental records of Robblee, et al. (unpublished).

Nutrient Patterns and Trends

Restoration efforts to restore natural rates of freshwater discharge into Florida Bay could potentially cause additional harm to the Bay if the quality of the water entering the system is not considered. It is essential to understand the pre-alteration patterns of nutrient influx into the Bay and cycling within the Bay in order to provide the baseline information for nutrient modeling.

Methods

Geochemical analyses of sediments have been utilized by both research groups (University of Miami/NOAA and USGS) to extract information from sediment cores dated using lead-210 and other methods of dating (Tables 3.1). Orem (1999) typically analyzes the sediments for organic C, total N, and total P. Nelsen, et al. (2002) analyzed organic C, total Al, and Pb. Swart, et al. (1999) discusses the possible use of trace elements in calcareous organisms as a proxy for nutrients.

Findings

Lower Taylor Slough and Mangrove Fringe

- Uranium isotope studies indicate that phosphorus contamination at the northern end of Taylor Slough appears to be fertilizer-derived. However, phosphorus contamination in Taylor Slough diminishes to background by mid slough; therefore Taylor Slough does not appear to be a source of nutrients to eastern Florida Bay.
- Eastern Florida Bay does appear to be a source of nutrients to the mangrove zone at the southern end of Taylor Slough.

Orem, et al. (1997), Orem (1998), Orem, et al. (1999) and Gough, et al. (2000), conducted detailed surveys of nutrients, metals, and major ion geochemistry in Taylor Slough, and eastern and central Florida Bay from 1996 to present. The study involved analysis of surface water, sediment porewater, and solid phase sediments from cores (Table 3.1, Fig. 3.1; Taylor Slough cores are not included in list). Cores were dated using ^{210}Pb, ^{137}CS, and ^{14}C. Results from Taylor Slough showed that there is some degree of nutrient contamination (phosphorus) at the head of the slough. Uranium isotope studies indicate that this phosphorus contamination appears to be fertilizer-derived. The phosphorus contamination in Taylor Slough diminishes to background levels by mid slough, and Taylor Slough does not appear to be a source of nutrients to eastern Florida Bay. Rather, Florida Bay appears to be a source of nutrients to the mangrove zone at the southern end of Taylor Slough.

Eastern/Central Florida Bay

- Beginning in the mid 1980's nutrification (increases in N and P) has occurred in portions of eastern and central Florida Bay as indicated by sudden shifts in organic C, total N, and total P. Pass Key, located closest to terrestrial influx, showed the most pronounced shifts and Bob Allen, the most southerly site, showed the least pronounced shifts.
- A large multidecadal productivity event characterized by greatly elevated levels of organic carbon and nitrogen; dated to about the mid 1700s, was observed in two cores from Whipray Basin.

Orem, et al. (1999) conducted analyses on organic C, total N, and total P from 5 sites in eastern Florida Bay (Table 3. 1, Fig. 3.1). They found "sudden and dramatic shifts" indicating increased nutrification that could not be explained by diagenetic processes. The sediments at Pass Key showed two episodes of increased nutrification – mid-1970s and after 1985. Nutrification at Bob Allen and Russell Banks began in the early 1980s. The shifts in N and P occur just prior to the microalgal blooms and seagrass dieoff events in 1987.

Two cores from Whipray Basin, which preserve a long record dating back into the 1700s, were analyzed by Orem, et al. (1999). Downcore profiles at these sites illustrate a large productivity event that occurred in the mid 1700s. This event was multidecadal and characterized by greatly elevated levels of organic C and N, probably representing a period of extensive algal blooms. Interestingly, total phosphorus was not elevated during this time span. This productivity event occurred during the Little Ice Age and may correspond to a period of higher rainfall in the Everglades. Higher rainfall would contribute to more extensive land runoff into Florida Bay, which may have triggered the productivity event.

Western Florida Bay – Whitewater Bay Area

- Organic C records from Jimmy Key indicate hurricanes help to flush organic C out of the Bay.

Nelsen, et al. (2002) analyzed and contrasted organic C content in Oyster Bay, Jimmy Key and Coot Bay cores (Table 3.1; Fig. 3.1). They found organic C decreased by a factor of two from Oyster Bay to Coot Bay, and by a factor of four from Oyster Bay to Jimmy Key. Al was closely correlated to organic C at Oyster Bay and Coot Bay, which the authors explain is related to erosion of the mangrove peats and associated clay and quartz concentrated by storm deposits and subsequent dissolution. Large organic C excursions at Oyster Bay correspond to hurricane events due to an increase in organic detritus. The trend in organic C at Oyster Bay is towards a decline from the first to the second half of the 20th century. At Coot Bay organic C increases upcore, and at Jimmy Key it is segmented. The periods of organic C increase at Jimmy Key (1900 to mid 1930s and after mid-1970) correspond to periods of decreased hurricane activity, whereas the period of declining organic C (mid 1930s to mid 1970s) is a period of increased hurricane activity. These data support the hypothesis that hurricanes contribute to flushing of organic C out of the Bay (Nelsen, et al., 2002, p. 424, 442).

Trace element analyses of coral

Swart, et al. (1999) tested the use of barium as a proxy for nutrient enrichment. They found that Ba increased when salinity decreased. They concluded that the controls on barium were "enigmatic" and that more research was necessary to understand the distribution of barium within the Bay.

Status of Research

Accomplishments – Questions Resolved

- Multidecadal shifts in N and P have been documented prior to anthropogenic change illustrating that these events occur naturally and can be of long duration.

- Recent dramatic increases in N, P, and total C have occurred in eastern Florida Bay and show decreasing amplitude with increasing distance from Taylor Slough.

Ongoing Research

[Note: this is only a partial list. Not all Ecosystem History researchers responded to the author's request for information.]

- Orem, et al. are currently working on C, N and P analyses from Rankin Lake core.

Unresolved Questions / Needed Research

[Note: this is only a partial list. Not all Ecosystem History researchers responded to the author's request for information.]

- Certain trace elements within calcareous skeletons (Cd, Ba, Mn) may be proxies for nutrient enrichment (see Swart, et al., 1999 for discussion of previous research on method). This method could be tested and utilized on downcore specimens.
- Explore use of $\delta^{13}C$ as a proxy for nutrient fluxes in combination with other analyses.
- Conduct additional analyses from critical areas within the Bay to increase our understanding of past changes in nutrients.

Occurrence and Pattern of Algal Blooms

Only minimal ecosystem history research has been done to contribute information on past algal blooms, and little of this work provides direct evidence. However, this is an area where there is the potential to obtain significant new information.

Methods

Huvane and Cooper (2001) have conducted assemblage analyses of diatoms, microscopic "algae" whose siliceous shell or frustule is preserved in the sediments (Table 3. 1, Fig. 3.1). These species are both planktonic and epiphytic and can be indicative of many environmental factors. Edwards (Wingard, et al., 1995; Ishman, et al., 1996; Brewster-Wingard, et al., 1997, 1998) examined dinoflogellate cysts preserved in the sediments (Table 3.1, Fig. 3.1). The cysts are a stage in the life cycle of dinoflagellates, microscopic phytoplankton that are well preserved in sediment cores.

Orem (1999) has inferred bloom conditions based on analyses of organic C, total N, and total P. Swart, et al. (1999) inferred bloom conditions based on enrichment of $\delta^{13}C$ in small *Siderastrea radians* corals collected throughout Florida Bay.

Findings

- Surface sediments from eastern Florida Bay show indications of nutrient (C, N, and P) enrichment from 1980 to the present, which could be related to recent microalgal blooms within Florida Bay.
- Multidecadal productivity event noted in sediment geochemistry from Whipray Basin cores may represent a period of extensive algal blooms, either planktonic or benthic.

Orem, et al. (1997 and unpublished) analyzed surface sediments from eastern Florida Bay, including sites near Pass and Russell Key banks. These analyses show indications of nutrient (C, N, and P) enrichment over the last two decades. This nutrient enrichment could be related to recent microalgal blooms and/or seagrass dieoff within Florida Bay. The analyses of two cores from Whipray basin (Orem, et al., 1999; discussed under question 2 above) may highlight a period of intensive algal productivity during the mid-1700s.

- Downcore changes in abundance and assemblages of dinoflagellates and diatoms have been examined at some sites in Florida Bay, but additional studies of the ecology of the groups are needed to interpret the findings in terms of bloom conditions.

The findings of Huvane and Cooper (2001) and Edwards ((Wingard, et al., 1995; Ishman, et al., 1996; Brewster-Wingard, et al., 1997, 1998) have been inconclusive to date. Additional detailed studies of the biology and ecology of the groups are needed to accurately interpret the findings. In addition, because these phytoplankton are found in the less than 63 micron fraction of the sediments they are more susceptible than the benthic mircrofauna (> 63 microns) to transport, redeposition, and reworking processes.

- Increases in δ13C may indicate the occurrence of algal blooms.

Swart, et al. (1999) analyzed $\delta^{13}C$ in small *Siderastrea radians* corals collected throughout Florida Bay (Table 3.1, Fig. 3.1). They separated the corals into two groups – those with $\delta^{13}C$ enrichment from approximately 1989 to 1993 and those with $\delta^{13}C$ depletion over the same time period. The maximum $\delta^{13}C$ depletion in all corals measured, including the long record from the Lignumvitae coral, occurred around 1984. Two possible causes for $\delta^{13}C$ increases seen in the one group of corals are discussed (Swart, et al., 1999, p. 395): 1) either a relative decrease in the influence of carbon derived from marine sources or 2) an increase in photosynthesis, which may indicate algal blooms. They discuss the contradictory evidence of the $\delta^{13}C$ patterns seen in the two groups of corals and conclude "the most probable cause is increased oxidation of organic material in the northeastern portion of Florida Bay and an increase in algal blooms in the western part of the bay" (Swart, et al., 1999, p. 395).

Status of Research

Ongoing Research

[Note: this is only a partial list. Not all Ecosystem History researchers responded to the author's request for information.]

- No known active research on downcore phytoplankton remains are currently being conducted.
- Continued analyses of $\delta^{13}C$ in ostracodes, foraminifera, mollusks, and corals are part of several ongoing studies, but the primary intent of these analyses is to address question 1.

Unresolved Questions / Needed Research

[Note: this is only a partial list. Not all Ecosystem History researchers responded to the author's request for information.]

The potential exists to extract information from sediment cores about phytoplankton blooms via analyses of the remains in the core, and through inferences based on changes in sediment geochemistry, carbon isotopes, and faunal assemblages. However, a great deal of work needs to be done to understand the ecology of the living phytoplanktons and to understand the signature left in sediments following a bloom. In addition, the relationship between $\delta^{13}C$ and blooms needs to be tested and calibrated in the modern environment before information can be accurately applied to paleo-analyses. The questions that could be addressed include the following:

- Prior to human alteration of flow and circulation in Florida Bay, did planktonic blooms occur? If yes, what was their timing and duration? What natural events may have triggered blooms?
- Did the frequency and duration of blooms change following the construction of the Flagler Railroad or the alteration of freshwater flow into Florida Bay?

Seagrass Patterns and Trends

A significant amount of ecosystem history research has addressed changes in seagrasses and sub-aquatic vegetation over time, and the effect of changes in environmental components (salinity, nutrients, water quality) on the vegetation. These questions are critical to restoration. It was the massive die-off event in the late 1987-88 that focused public attention on the plight of Florida Bay, and changes that were occurring in the ecosystem. It is important to place these changes in historical context over decadal and even centennial time scales to determine if die-offs and fluctuations in seagrass abundance are natural, cyclical events. In addition, ecosystem history data from sediment cores can provide insights into long-term sequences of change preceding die-offs .

Methods

Basic assemblage analyses and geochemical analyses have been used to detect downcore trends and patterns in subaquatic vegetation (SAV) from sediment cores dated using lead-210 and other methods of dating (Table 3.1). Cronin (Cronin, et al. 2001) and Wingard (Brewster-Wingard and Ishman, 1999; Brewster-Wingard, et al., 1998; 2001) have used ostracodes and mollusks in their downcore analyses of SAV trends. Using modern field observations and samples from 1995-present they have compiled lists of indicator species for different types of SAV (field data available via http://sofia.usgs.gov/flaecohist/). (See Salinity Trends and Patterns methods section for a discussion of taphonomic and sediment transport considerations in assemblage analyses.)

In addition, geochemical analyses of sediments can provide information on the presence and distribution of seagrasses (Orem, Lerch, et al., 1999). The concentration of lignin phenols in sediments is a potential marker for historical seagrass abundance in Florida Bay. Seagrasses in Florida Bay, although angiosperms, exhibit a lignin phenol distribution similar to that of gymnosperms (e.g. little or no syringyl phenols present). Apparently the syringyl phenol content of the lignin in the seagrasses has been lost evolutionarily in the transition of these angiosperms back to the aquatic realm. This characteristic allows seagrass lignin (syringyl phenol poor) to be differentiated from the other dominant lignin source in Florida Bay (mangroves; syringyl phenol-rich). Analyses of organic C and total N (Orem, et al., 1999) also may provide information about seagrass die-offs, especially when combined with faunal assemblage and/or lignin phenol data.

Findings

- Frequent changes have occurred in the relative abundance of epiphytal species of ostracodes and mollusks over the last century.
- Prior to mid-20th century epiphytal ostracodes were relatively rare at sites in central and eastern Florida Bay, suggesting a greater abundance and/or density of SAV in the latter half of the 20th century, compared to the first half of the century. Epiphytal mollusks, while not rare, increased significantly in relative abundance from approximately 1940 to the 1970s at most sites. A decline occurred in SAV dwelling ostracodes and mollusks in cores from Whipray, Russell, Bob Allen, and Pass Keys between 1970s and 1980s, followed by subsequent increases. These data raise the question that dense and abundant

seagrass beds may not be natural, and this has large implications for objectives set for restoration.

- Relative abundance of mollusks with a strong preference for *Thalassia* have declined since approximately 1970 in eastern Florida Bay, and since 1910 in Whipray, while SAV generalists have increased. This may indicate an increase in the amount of macro-benthic algae relative to *Thalassia*.

  Cronin, et al. (2001) found ostracode assemblages from 1900-1940 were characterized by moderate to large proportions of *Peratocytheridea*, typically found associated with mud and *Halodule* substrates. Ostracode species associated with *Thallassia* and macro-algae were less common during this time period. From approximately 1930 to 1950 *Peratocytheridea* declined significantly, while *Loxoconcha* and *Xestoleberis* (both SAV dwellers) increased (Fig. 3.3). This pattern of long-term decline in a *Peratocytheridea* coincident with an increase in species associated with *Thalassia* and macro-benthic algae was seen in cores from central, eastern and northern Florida Bay. This shift suggests greater abundance and or density of SAV in central Florida Bay over the past 50 years compared to the first half of century. A second shift occurred in the 1970s and 1980s when a decline in *Thalassia* and algal dwelling species occurred in most cores. Cronin, et al. (2001, p. 176) state "although the strength of the decline varied by species and by site, the stark contrast between the abundance of epiphytal species during the 1950s and 60s and the very low abundance at times during the following two decades suggests a broad regional shift occurred at this time." These shifts in the 1970s and 80s may be related to large-scale seagrass die-offs.

  Brewster-Wingard et al. (1998), Brewster-Wingard and Ishman (1999), Trappe and Brewster-Wingard (2001) note frequent and relatively dramatic shifts in the populations of the epiphytal species of mollusks. Cores from Whipray, Russell Bank, and Taylor Creek all show increases in epiphytal mollusks beginning around 1940, so the molluscan data agree with the ostracode data (Fig. 3.3). There is a general increase in epiphytal organisms during the latter half of the 20th century, indicating increased SAV coverage during this time period relative to the first half of the century. The molluscan epiphytal species were split into two groups based on modern field observations (Fig. 3.3): 1) species that have a strong preference for *Thalassia* and 2) non-specific SAV dwellers that may be found on either *Thalassia* or macro-benthic algae. These data illustrate an interesting trend – the relative abundance of *Thalassia* dwellers has declined since approximately 1970 at Bob Allen and Russell and since 1910 at Whipray, while the non-specific SAV dwellers have increased. The ostracode *Xestoleberis* is a non-specific SAV dweller, and its trends in abundance agree with the molluscan data.

- Downcore profiles of lignin phenols from Pass Key core shows large variations in lignin phenol distributions over short time intervals; reflecting the proximity of this site to the mangrove zone along the coast and the outlet of Taylor Creek.
- At Bob Allen Keys, the lignin phenol distributions show downcore variations in the abundance of seagrass over time. At Bob Allen, seagrass abundance appears to have been increasing since a recent minimum around 1960.

Downcore profiles of lignin phenols were analyzed from Pass Key and Bob Allen Keys (Orem, Lerch, et al., 1999). The Pass Key core shows large variations in lignin phenol distributions over short time intervals; reflecting the proximity of this site to the mangrove zone along the coast and the outlet of Taylor Creek. At Bob Allen Keys, the lignin distributions show downcore variations in the abundance of seagrass over time. At Bob Allen, seagrass abundance appears to have been increasing since a recent minimum around 1960.

- Surface sediments from eastern Florida Bay show indications of nutrient (C, N, and P) enrichment from 1980 to the present, which could be related to recent seagrass dieoff within Florida Bay.

  The analyses conducted by Orem, et al. (1999) (discussed under question 3 above) at sites near Pass and Russell Key banks indicate that nutrient (C, N, and P) enrichment from 1980 to present could be related to recent seagrass dieoff within Florida Bay.

Status of Research

Accomplishments – Questions Resolved

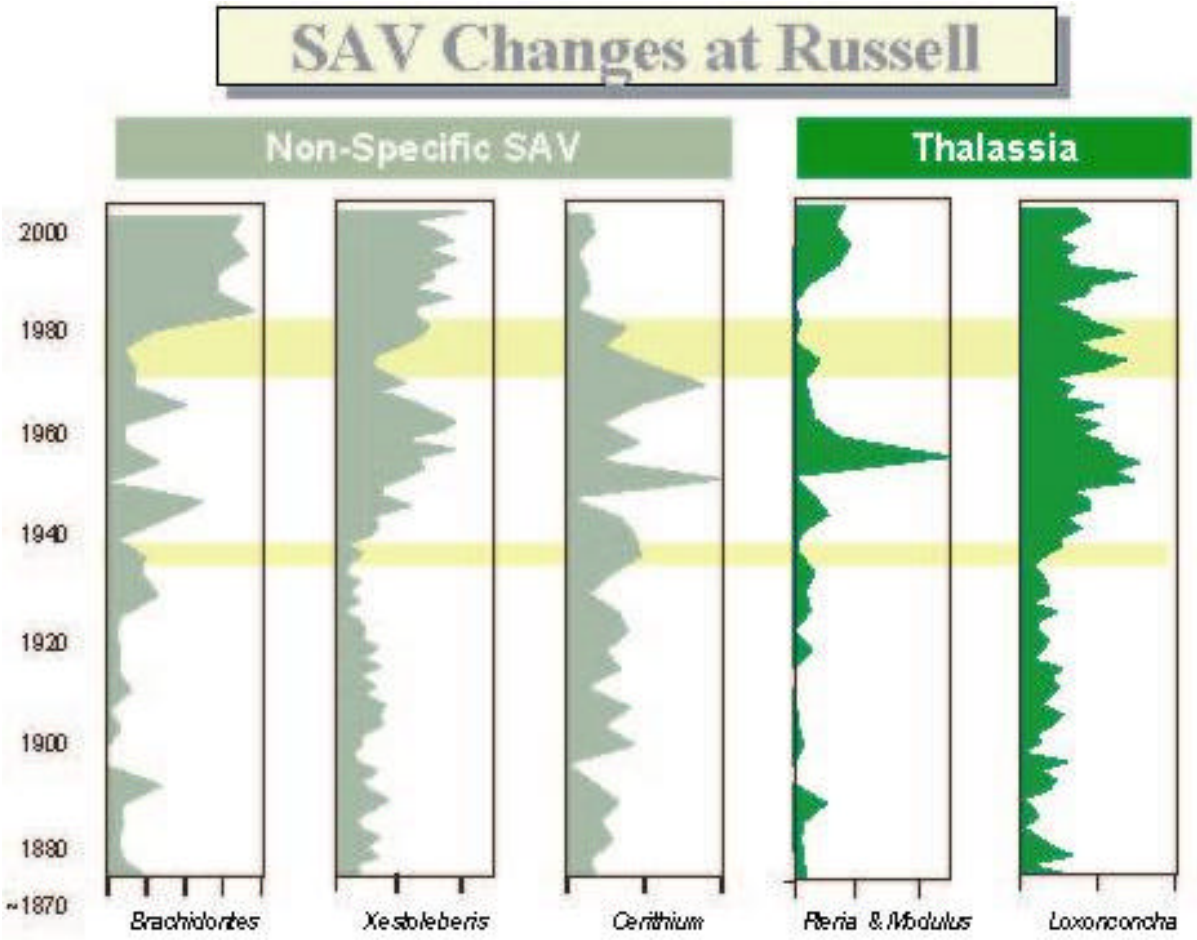
- Common trends in epiphytal species across basins and regions of Florida Bay indicate that while substrate and seagrass coverage may be patchy, it appears that there are Bay wide forcing factors affecting the abundance and distribution of the beds.
- Frequent and relatively rapid changes occur in the epiphytal indicator species, implying the SAV itself goes through frequent and significant changes.
- There is evidence of increasing macro-benthic algae in Florida Bay.
- Trends in SAV distribution throughout the 20th century imply that dense and abundant seagrass beds occurred in an already altered system. This has strong implications for restoration.

Ongoing Research

[Note: this is only a partial list. Not all Ecosystem History researchers responded to the author's request for information.]

- Current USGS work is focused on completing analyses of core from Rankin Lake. Core was sited in area of documented seagrass die-off (P. Carlson, pers. comm.) and was collected to examine the long-term (decadal-scale) sequences of change in a number of variables prior to the die-off event in 1987-88. Ostracode and molluscan assemblages, ostracode geochemistry (Mg/Ca), sediment geochemistry, and lignin phenols are being analyzed downcore.
- Additional core from site of seagrass die-off at Barnes is currently being processed and will be analyzed by the USGS group for faunal assemblage data and Mg/Ca ratios. A core from Whipray Basin will be analyzed for lignin phenols.
- Samples have been collected and processed to begin to quantify the relationships between molluscan species and SAV species.

Figure 3.3: Paleoecological indicators of benthic habitat.



Unresolved Questions / Needed Research

[Note: this is only a partial list. Not all Ecosystem History researchers responded to the author's request for information.]

- The question of causes of seagrass die-off is still poorly understood. Detailed studies of sediment cores from sites of known die-off should help address this question by examining decadal-scale sequences of change that have led up to the events. Multiple forcing factors are undoubtedly at play in massive die-off events, and long-term data may allow researchers to better understand the interaction of these factors prior to die-offs.
- Potential influence of climate variability and its role in factors that directly affect sea-grasses, such as light attenuation, disease, and salinity fluctuations, needs additional study.
- A quantitative analysis of modern vegetation and epiphytic species would allow more refined interpretations of the downcore assemblages.

Higher Trophic Level Species

Ecosystem history research and analyses of sediment cores have contributed very little to Question 5, in large part because question 5 has been focused on the higher trophic level groups and these are generally absent or not well represented in the cores. The one exception is the molluscan fauna. As Brewster-Wingard, et al. (2001) point out, the mollusks are well preserved in the cores, and they represent a number of tropic categories because different species employ different feeding strategies including filter feeding, grazing, scavenging, and carnivory. Simple measures of molluscan faunal diversity have been examined for cores in eastern and central Florida Bay and have illustrated patterns of change over time (Brewster-Wingard, et al., 2001, Trappe and Brewster-Wingard, 2001), but these have not been rigorously tested. An apparent trend toward decreasing diversity has been observed in the upper portions of most of the cores beginning between 1960 and 1980.

If question 5 were to expand and examine the lower invertebrates, paleoecologic data could contribute more valuable data from the benthic microfauna. Some of these trends are discussed under questions 1 and 4 above.

Status of Research

Ongoing Research

[Note: this is only a partial list. Not all Ecosystem History researchers responded to the author's request for information.]

- No active research on higher trophic levels, other than molluscan faunal assemblage analyses, is occurring. The current focus of the molluscan studies is to address questions 1 and 4, but molluscan changes in response to salinity and benthic habitat will provide secondary information to address question 5.
- Benthic microfaunal assemblage analyses also are contributing data about changes in the Florida Bay benthic habitat over time.
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Unresolved Questions / Needed Research

[Note: this is only a partial list. Not all Ecosystem History researchers responded to the author's request for information.]

- Significant questions exist about changes in benthic habitat that could be addressed (and in part are being addressed) by expanding question 5 to include lower invertebrates. These organisms form the bottom of the food chain and are therefore essential to the survival of the higher trophic level organisms. Since the lower invertebrates are more readily preserved in sediment cores, this would allow decadal to centennial scale analysis of environmental change and its effect on animals in Florida Bay.
- More rigorous analyses of the molluscan faunal diversity data should be conducted.
- The use of mollusks as proxies for higher trophic level diversity should be explored.

References

Alvarez Zarikian, C.A., Swart, P.K., Hood, T., Blackwelder, P.L., Nelsen, T.A., Featherstone, C. 2001. A Century of Variability in Oyster Bay Using Ostracode Ecological and Isotopic Data as Paleoenvironmental Tools. Bulletins of American Paleontology 361:133-143.

Brewster-Wingard, G.L., and Ishman, S.E. 1999. Historical trends in salinity and substrate in central and northern Florida Bay: a paleoecological reconstruction using modern analogue data: Estuaries, v. 22, n. 2B, p. 369-383.

Brewster-Wingard, G.L., Ishman, S.E., Holmes, C.W. 1998. Environmental impacts on the southern Florida coastal waters: A history of change in Florida Bay. Journal of Coastal Research, special issue 26:162-172

Brewster-Wingard, G.L., Ishman, S.E., Waibel, N.J., Willard, D.A., Edwards, L.E., and Holmes, C.W. 1998. Preliminary paleontologic report on Core 37, from Pass Key, Everglades National Park, Florida Bay. U.S. Geological Survey Open-file Report 98-122.

Brewster-Wingard, G.L., Ishman, S.E., Willard, D.A., Edwards, L.E., and Holmes, C.W. 1997. Preliminary paleontologic report on cores 19A and 19B, from Russell Bank, Everglades National Park, Florida Bay. U.S. Geological Survey Open-file Report 97-460.

Brewster-Wingard, G.L., Stone, J.R., and Holmes, C.W. 2001. Molluscan faunal distribution in Florida Bay, past and present: an integration of down-core and modern data. Bulletins of American Paleontology, special volume361:199-231.

Cronin, T.M., Dwyer, G.S., Schwede, S.B., Vann, C.D., Dowsett, H. 2002, Climate variability from the Florida Bay sedimentary record: possible teleconnections to ENSO, PNA, and CNP. Climate Research 19:233-245.

Cronin, T. M., Holmes, C.W., Brewster-Wingard, G.L., Ishman, S.E., Dowsett, H., Keyser, D., Waibel, N., 2001, Historical trends in epiphytal ostracodes from Florida Bay: implications for seagrass and macro-benthic algal variability: Bulletins of American Paleontology 361:159-197.

DeMaria, Karen. 1996. Changes in the Florida Keys Marine Ecosystem Based upon Interviews with Experienced Residents. The Nature Conservancy, Washington, D.C.

Dwyer, G.S., Cronin, T.M. 2001. Ostracode Shell Chemistry as a Paleosalinity Proxy in Florida Bay. Bulletins of American Paleontology 361:249-276.

Dwyer, G.D., Cronin, T.M. and Baker, P.A. in press. Trace elements in marine ostracods. In AGU Monograph: The Ostracoda: Applications in Quaternary Research, Chivas and Holmes, editors.

Enos, Paul. 1977. Part I. Holocene sediment accumulations of the South Florida Shelf Margin. *In* Enos, P. and Perkins, R.D., Quaternary Sedimentation in South Florida, Geological Society of America, Memoir 147, p. 1-130.

Fleece, J.B. 1962. The carbonate geochemistry and sedimentology of the Keys of Florida Bay, Florida. Sedimentation Research Lab, Contribution 5. Florida State University, Department of Geology, Tallahassee, Florida.

Gough, L.P., Kotra, R.K., Holmes, C.W., Orem, W.H., Hageman, P.H., Briggs, P.H., Meier, A.L. and Brown, Z.A. 2000. Regional geochemistry of organic-rich sediments, sawgrass, and surface water, Taylor Slough, Florida. U.S. Geological Survey, Open-File Report 00-327.

Halley, R.B., Swart, P.K., Dodge, R.E., and Hudson, J.H., 1994, Decade-scale trend in sea water salinity revealed through $\delta^{18}O$ analysis of *Montastraea annularis* annual growth bands. Bulletin of Marine Science 44:670-678.

Halley, R.B., Holmes, C.W., and Prager, E.J. 1997. Florida Bay mudbanks: relatively new piles of mostly old sediment. U.S. Geological Survey Open-File Report 97-385, p. 26-27.

Halley, R.B., and Roulier, L.M. 1999. Reconstructing the history of eastern and central Florida Bay using mollusk-shell isotope records. Estuaries 22:358-368.

Healy, G. 1996. A decadal perspective of South Florida water quality and climate using Florida Bay corals. M.S. Thesis. University of Miami, Miami, Florida.

Holmes, C.W., Robbins, J.A., Halley, R.B., Bothner, M., Ten Brink, M., Marot, M.. 2001. Sedimentary Dynamics of Florida Bay Mud Banks on a Decadal Time Scale. Bulletins of American Paleontology, 361:31-40.

Hudson, J.H., Powell, G.V.N., Robblee, M.B., and Smith, T.J., 1989, A 107-year-old coral from Florida Bay: barometer of natural and man-induced catastrophes? Bulletin of Marine Science, 44:283-291.

Huvane, J.K., and Cooper, S.R. 2001. Diatoms as indicators of environmental change in sediment cores from northeastern Florida Bay. Bulletins of American Paleontology 361:145-158.

Ishman, S.E., Brewster-Wingard, G.L., Willard, D.A., Cronin, T.M., Edwards, L.E., and Holmes, C.W. 1996. Preliminary paleontologic report on Core T-24, Little Madeira Bay, Florida. U.S. Geological Survey Open-File Report 96-543.

Montague, C.L., and Ley, J.A. 1993. A possible effect of salinity fluctuation on abundance of benthic vegetation and associated fauna in northeastern Florida Bay. Estuaries 16:703.

Nelsen, T.A., Garte, G., Featherstone, C., et al., 2002. Linkages between the South Florida peninsula and coastal zone: a sediment-based history of natural and anthropogenic influences. *In* Porter, J.W., and Porter, K.G., (eds.), Everglades, Florida Bay and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook, CRC Press, Boca Raton Florida, pp. 415-449.

Orem, W.H. 1998. Taylor Slough and eastern Florida Bay: geochemical studies in support of ecosystem restoration in south Florida. U.S. Geological Survey Information Sheet.

Orem, W.H., Holmes, C.W., Kendall, C., Lerch, H.E., Bates, A.L., Silva, S.R., Boylan, A., Corum, M., and Hedgman, C. 1999. Geochemistry of Florida Bay sediments: nutrient history at five sites in eastern and central Florida Bay. Journal Coastal Research 15:1055-1071.

Orem, W.H., Lerch, H.E., Bates, A.L., Holmes, C.W., and Marot, M. 1999. Lignin phenols in sediments from Florida Bay as indicators of seagrass history [extended abs.]: 1999 Florida Bay and Adjacent Marine Systems Science Conference, Key Largo, FL, November 1999, Program and Abstracts, 191-193

Orem, W.H., Lerch, H.E., and Rawlik, P. 1997. Descriptive geochemistry of surface and pore water from USGS 1994 and 1995 coring sites in south Florida wetlands. USGS Open-File Report 97-454.

Smith, T.J., III, Hudson, H., Robblee, M.B., Powell, G.V.N., Isdale, P.J., 1989. Freshwater flow from the Everglades to Florida Bay: a historical reconstruction based on fluorescent banding in the coral *Soleastrea bournoni*. Bulletin of Marine Science, 44:274-282.

Smith, T.J., III, Foster, A.M., Briere, P.R., Jones, J.W., and Van Arsdall, C.R. 2002. Conversion of Historical Topographic Sheets (T-sheets) to Digital Form: Florida

Everglades and Vicinity. U.S. Geological Survey, Open-File Report 02-204. CD-ROM.

Swart, P.K., Healy, G.F., Dodge, R.E., Kramer, P., Hudson, J.H., Halley, R.B., Robblee, M.B. 1996. The stable oxygen and carbon isotopic record from a coral growing in Florida Bay: a 160 year record of climatic and anthropogenic influence. Palaeogeography, Palaeoclimatology, Palaeoecology 123:219-237.

Swart, P.K., Healy, G.F., Greer, L., Lutz, M., Saied, A., Anderegg, D., Dodge, R.E., Rudnick, D. 1999. The use of proxy chemical records in coral skeletons to ascertain past environmental conditions in Florida Bay. Estuaries 22:384-397.

Taft, W.H. and Harbaugh, J.W. 1964. Modern carbonate sediments of southern Florida, Bahamas, and Espiritu Santo Island, Baja, California and comparison of their mineralogy and chemistry. Publications in Geological Science. Stanford University, California.

Trappe, C.A., and Brewster-Wingard, G.A. 2001. Molluscan fauna from Core 25B, Whipray Basin, Central Florida Bay, Everglades National Park. U.S. Geological Survey Open File Report 01-143.

Turney, W.J. and Perkins, B.F. 1972. Molluscan distribution in Florida Bay. Sedimenta III. University of Miami, Rosenstiel School of Marine and Atmospheric Sciences, Miami, Florida.

Wanless, H.R., and Tagett, M.G. 1989. Origin, growth and evolution of carbonate mudbanks in Florida Bay. Bulletin of Marine Science, 44:454-489.

Wingard, G.L., Ishman, S.E., Cronin, T.M., Edwards, L.E. Willard, D.A., and Halley, R.B. 1995. Preliminary analysis of down-core biotic assemblages: Bob Allen Keys, Everglades National Park, Florida Bay. U.S. Geological Survey Open-File Report 95-628.