1996 Florida Bay Science Conference Abstracts

Key Largo Florida * December 10-12, 1996

The Florida Bay water quality monitoring program: assessing status and trends (1989-1995).

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Environmental monitoring programs are essential for our understanding and management of ecosystems. Before one can recognize environmental changes, some idea of baseline variability must be established against which to evaluate gross deviations. In addition to temporal changes, it is vitally important to understand spatial patterns of water quality in these systems in an effort to direct management efforts. One of the purposes of any monitoring program should be to use the data gained by routine sampling to extend our understanding of the system by developing new hypotheses as to the governing processes.

Florida Bay is on the marine receiving-end of the Everglades, one of the largest wetland ecosystems in the world. Recent ecological changes in Florida Bay, i.e. periods of prolonged hypersalinity, a poorly understood seagrass die-off, sponge mortality events, and elevated phytoplankton abundances have focussed attention on this ecosystem. In response to these warning signs, a network of 28 fixed monitoring stations was established in July 1989 to address trends in water quality (Fig. 1).

The shallow mud banks which divide Florida Bay into relatively discrete basins serve to restrict water movement between basins, attenuating both tidal range and current speed. Sampling sites were distributed throughout the bay near the centers of these basins. Monthly sampled parameters included salinity (ppt), temperature (°C), dissolved oxygen (DO; mg l-1), DO saturation (%), NO3- (µM), NO2- (µM), NH4+ (µM), total nitrogen (TN; µM), total inorganic nitrogen (TIN; µM), total organic nitrogen (TON; µM), total phosphorus (TP; µM), soluble reactive phosphorus (SRP; µM), total organic carbon (TOC; µM), SiO4 (µM), alkaline phosphatase activity (APA; µM hr-1), chlorophyll<u>a</u> (Chl<u>a</u>; µg l-1), turbidity (NTU), TN:TP ratio (molar), and TIN:SRP ratio (molar).

Stations were grouped into distinct spatial zones of similar influence (ZSI) by a multivariate analysis outlined in Boyer et al. (in review). Briefly, principal component analysis (PCA) was used to extract composite variables (principal components) which were then rotated (using VARIMAX) and the factor scores saved for each data record. Mean and SD of factor scores were used in a cluster analysis to aggregate stations into distinct ZSI (Fig. 1). The result was 3 statistically different ZSI: Eastern Bay (19 sta.) - the most freshwater dominated, acts most like a “conventional” estuary; Western Bay (6 sta.) - influenced mostly by SW Florida Shelf waters; and Core Bay (4 sta.) - located in the N-central area, physically isolated, acts as an evaporative basin.
Three different analysis types were performed on the 6 year dataset in an effort to both visualize and test for temporal trends: a seasonal approach of graphing the monthly median and range of a parameter for all years using box-and-whisker plots; a 12 month moving average for the period of record; and a seasonal Kendall-tao test. The box-and-whisker plot depicts the distribution around the median (in quartiles) as well as the 95% confidence interval of the median, allowing it to be used as a graphical, nonparametric ANOVA. Pooling all data by month showed the presence of seasonal effects in the data.

The significance of these seasonal effects were also tested using the Kruskal-Wallis test. The 12 month moving average over the period of record was used to filter out annual fluctuations and thereby disclose any interannual oscillations of longer periodicity. The seasonal Kendall-tao test is a nonparametric statistic which tests for monotonic trends (whether increasing or decreasing) by determining the significance of the trend and generates a trend slope estimate (TSE; units yr-1) for the period of record. This test cannot detect reversals of direction, such as might be seen in the case of interannual oscillations, nor is it applicable with discontinuous data.

In Eastern Bay, the seasonal Kendall-tao analysis showed that salinity, DO saturation, TP, and Chla declined significantly, whereas NH4+, NO2-, TON, turbidity, TN:TP and TIN:SRP increased (Table 1). Salinity, temperature, and DO saturation declined in the Core Bay while NO2-, TOC, APA, Chl<u>a</u>, and turbidity increased. For the Western Bay there were significant declines in both salinity and temperature with increases in NH4+, NO2-, TOC, Chla, turbidity, and TN:TP.

These short term trends must be put in perspective with more long term climate changes. The 6 year period of record corresponds with a shift to wetter conditions from the dry period of the 1980's. Our next step is to determine the relative importance of precipitation, freshwater inflow, and water management activities on these water quality trends in Florida Bay.

The onset, persistence and fate of algal blooms in Florida Bay.

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One of our research goals is to determine the source of the nutrients that promote microalgal blooms in Florida Bay. The two primary potential sources our research is focussing on are benthic sediments and human activities on land. Another part of our research is focussing on the extent to which Florida Bay water with high nutrients, suspended sediments, and/or phytoplankton is transported as far as the coral reefs. If such transport occurs often enough, the ecological structure of the reef community could be altered.

Shallow tropical marine ecosystems are generally characterized by clear waters (low nutrients and microalgal biomass in the water column) and by much of the productivity being associated with the benthos (seagrasses, macroalgae, and microalgal turfs and films). Most of the nutrients in these ecosystems are sequestered in either the biota or in the sediments. In the case of Florida Bay, the system may have become destabilized by the loss of a major portion of the benthic producers (*Thalassia testudinum*, with a release to the water column of excessive nutrients from plant decay). Loss of seagrass cover can also lead to more sediment resuspension. The blooms observed today may be supported by nutrients formerly in the benthic sediments and biota.

Another potential source of nutrients is human activities that generate nutrients that enter the marine ecosystem by surface runoff or groundwater. It has been estimated that there are 25,000 cesspools and septic tanks, 281 injection wells, 4 active and 10 inactive landfills, 182 marinas with 2707 wet slips, and 1410 live-aboard boats in the Florida Keys. These sources, along with several sewage outfalls, are thought to be injecting nutrients into local waters, but in most cases are not yet proven to be significant.

We are investigating the extent to which these nutrients may be reaching various coastal ecosystems.

To address these issues, the following questions are being asked.

How large is the pool of nutrients in the sediments of Florida Bay relative to that in the water column above? Depending on the size of the sediment pool, it could potentially sustain a phytoplankton bloom long after the initial nutrients in the water column are removed.

Over a wide range of habitats, is there a general correlation between benthic and planktonic nutrient concentrations, between benthic nutrient concentrations and benthic microalgal biomass, and between benthic nutrient concentrations and phytoplankton biomass? Such correlations would provide some evidence of the strength of coupling between sediment-water column nutrient cycling and microalgal population dynamics.

Is it possible that episodic resuspension of sediments is a major mechanism for transporting benthic nutrients into the water column (where they can support microalgal blooms) and out to the reefs?

Instead of nutrient rich groundwater flow into coastal waters being uniform along the coastline, does it occur in local “hotspots” because of preferential flow along structural faults and solution holes?

Are nutrient inputs and the resulting chlorophyll concentrations higher after large amounts of rainfall, particularly after a long period of no rain because of nutrient concentration build up on land during the dry period that is then flushed out by the rain?

To address questions of water column-sediment interactions, 10 stations along the southeastern part of Florida Bay are being sampled every 3 months. To address questions concerning ephemeral inputs of nutrients and sporadic transport offshore to the reefs, as many water samples as possible are being taken from both bayside and oceanside waters from Elliott Key down to Key West, particularly after storms. Water samples are also being taken in the western area of Florida Bay to examine its interaction with the Gulf of Mexico.

To date we have collected over 600 samples throughout the Florida Keys and analyzed them for temperature, salinity, chlorophyll and turbidity. Salinity has ranged from 8 to 38 ppt. Chlorophyll concentrations have ranged from 0.12 ug/l to 9.55 ug/l. The overall trend in the observations in Hawk Channel out to the reefs so far is for lower chlorophyll concentrations in the upper Keys and higher concentrations in the lower Keys. Chlorophyll concentrations are also considerably higher in Florida Bay than on the ocean side of the Keys. Another clear trend is for higher chlorophyll concentrations in deadend canals than in the water basins to which they are connected. It also appears that chlorophyll is consistently lower in areas with extensive benthic plant communities than in nearby areas of similar depth that have no significant benthic plants. We have not observed higher chlorophyll concentrations immediately next to the coastline compared to a kilometer away. Further offshore, chlorophyll concentrations decline to “oceanic” levels, but how far offshore the decline occurs is highly variable, depending on wind and current patterns. High concentrations of chlorophyll and turbidity have been observed on occasion over the reefs and several kilometers beyond.

Turbidity ranges from as high as 99 NTUs in Florida Bay to as low as 0.01 NTUs offshore. Turbidity is much more variable, due to the influence of winds. It is persistently high in many parts of Florida Bay but quite different in different parts of the bay. In Hawk Channel and out to the reefs, it is fairly sporadic, with generally lower turbidity in the upper Keys compared to the lower Keys, and as one moves offshore.

Dissolved phosphate concentrations in the water column range from 0.01 to 0.16 uM, nitrate from 0.02 to 4.68 uM, ammonia from undetectable to 28.85 uM, and silicate from 1.83 to 127.91 uM. Nutrients are considerably higher in Florida Bay than at the offshore stations. Silicate decreases linearly from Shark River to the Keys with increasing salinity, indicating a freshwater source. Porewater ammonia concentrations range from 15.86 to 1531.15 uM, porewater nitrate from 0.09 to 2.25 uM, and porewater phosphate from undetectable to 10.75 uM. The highest porewater nutrient concentrations are at stations in Florida Bay closest to Upper Matecumbe Key.

To date, our work has focused on developing and testing methods, setting up sampling programs, surveying Florida Bay for selection of sampling stations, and collecting and analyzing samples. Now that we have about six months worth of data, we are beginning to analyze them for correlations. We plan on using those correlations to develop more specific hypotheses and then design both field and laboratory experiments to test them more rigorously.

The biotic record of change in Florida Bay and the south Florida ecosystem.

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The Florida Bay environmental record, as indicated by the biotic remains within the sediments, is one of change. Analyses of three cores from Florida Bay and the fringe environments of the Bay show that fluctuations in salinity, substrate, and other critical physical, and chemical parameters, have occurred throughout the history of the bay. During this century, an increase in average salinity and an increase in benthic faunal diversity is recorded.

The principle objective of the U.S. Geological Survey's South Florida Ecosystem History projects is to use paleoecologic tools to reconstruct the history of Florida Bay, Biscayne Bay, and the terrestrial Everglades over the last 150-200 years, as well as the last few millennia. The data gathered from these projects are being compiled to develop a broad regional and temporal picture of changes in the south Florida ecosystem. At selected sites in Florida Bay, data are gathered on modern faunal and floral distributions and environmental preferences, such as salinity, dissolved oxygen, nutrients, circulation, substrate and seagrass conditions. These data are used as proxies for interpreting down-core environmental changes as indicated by the abundance and distribution of faunal and floral remains present in cores collected throughout Florida Bay and the south Florida ecosystem. The chronology of the cores is based primarily on 210Pb analyses; this absolute age control makes it possible to interpret the rate of change of such critical parameters as salinity and substrate, including seagrasses and sediment sources. In turn, changes in salinity patterns provide information on changing freshwater flow, sea level rise, and circulation patterns. In conjunction with geochemical analyses, information on nutrient supplies also can be obtained from the faunal and floral data.

Analyses of Core 6A from the Bob Allen mudbank, central Florida Bay, and Core T-24 from the mouth of Taylor Creek in Little Madeira Bay, eastern Florida Bay, are complete. The benthic fauna were examined at 2 cm intervals in these cores. The 210Pb age model of Core 6A gives a sedimentation rate of 0.86 ± 0.06 cm/yr. Core 6A records a history of fluctuating salinity over the last 150 years, but from around the turn of the century a general increase in the average salinity has occurred. Benthic foraminifer and ostracode data indicate a significant shift occurred during the 1950's, from a period of relatively lower average salinities (~18 ppt) and relatively low amplitude fluctuations in the salinity, to a period of higher average salinities (~32 ppt) and greater fluctuations in the salinity. The mollusc data show similar patterns. During the period from around 1950 to the present the overall benthic faunal diversity and abundance increased. Patterns of pollen and dinocyst distribution within the core show shifts that correspond to the benthic faunal changes, indicating that the change was not a localized effect. Comparison of the benthic faunal record to precipitation records dating back to 1906 indicates no direct correlation between precipitation patterns and prolonged salinity changes in Florida Bay; however, further investigation is warranted.

The pattern of increasing salinity is even more apparent in Core T-24, which is located at the fringes of the Bay environment. Although a detailed chronology based on radioisotopes has not been developed for this core, the general faunal and floral patterns correspond to those at Core 6A. The relative abundance of oligohaline to mesohaline (~5-18 ppt) benthic foraminifera, molluscs, and ostracodes decreases upward in the core, and the polyhaline to euhaline (18-35 ppt) fauna increases. Benthic faunal diversity increases upward in the core. The dinocyst and pollen assemblages are consistent with the pattern of increasing salinity up-core at this site, with red mangrove and buttonwood pollen increasing and the dinocyst assemblages shifting toward more marine conditions.

Examination of selected samples from a core collected along Mud Creek near Joe Bay on the northern fringe of Florida Bay provides a long-term record of change. 14C analysis dates the base of this core (82 cm) at 2,050 BP, and 210Pb indicates that the last 150 years are included in the upper 20 cm. Preliminary analysis of molluscan fauna indicates a general trend of increasing salinity up-core. Molluscs present in the lower half of the core are limited to fresh water or terrestrial forms, but at 34-36 cm a brackish to nearly freshwater species is found. Pollen assemblages indicate relatively higher abundances of sawgrass pollen from about 600-2000 BP followed by an increasing abundance of mangrove and wax-myrtle pollen; this shift is indicative of an increase in salinity. Because of the slower sediment accumulation rate of peats, less detail is provided for the last 150 years, but cores from the fringe of Florida Bay provide a link between the Bay and the terrestrial ecosystems, and allow us to develop a broad regional and temporal picture of changes to the south Florida ecosystem.

The preliminary examination of three cores from the central and northern margins of Florida Bay indicates a Bay-wide increase in salinity over at least the last century. Examination of historical precipitation records indicate there is no strong relationship between salinity and precipitation patterns, however, other factors such as storm frequency, fresh-water flow, sea-level rise and evaporation/precipitation rates are also important. A comparison of the chronologically-placed data gathered from these cores with historical records of precipitation, streamflow and other critical parameters will facilitate understanding of the causes of salinity fluctuations in Florida Bay. In the upcoming year, paleoecologic analyses of additional cores are planned to determine if the pattern of increased salinity is upheld. Geochemical analyses of shells and sediments from these cores will be conducted to provide absolute measurements of salinity and nutrient fluctuations in the ecosystem. This information, compiled wih data gathered from other ecosystem projects evaluating salinity, circulation, freshwater flow, precipitation and evaporation, will provide modelers and resource managers with information on the causes and enduring effects of salinity change.

An integrated study of pink shrimp as indicators of habitat health in Florida Bay.

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The harvest of pink shrimp on spawning grounds in the Dry Tortugas is thought to be dependent upon inshore nursery grounds, including Florida Bay. Landings and catch rates declined substantially in the 1980s, starting a few years prior to observations of habitat decline in the Bay. The pattern of monthly size frequency distributions in landings suggests that, although recruitment to the fishing grounds is continuous throughout the year, until about 1980, two or more major waves of recruitment were detectable, one centered in late fall and the other in early spring. After 1980, only the spring wave was noticeable. Previous studies have suggested that landings and catch rates are positively correlated with indicators of freshwater inputs. Previous studies have suggested that spawning by this species in South Florida apparently is continuous, but spawning maxima coincide with maximum water temperatures on the Tortugas grounds; therefore, variation in spawning does not likely explain the major waves of recritment observed in the fishery. **The initial hypothesis of our research is (a) that two or more major nursery grounds contribute to Tortugas landings, (b) that these grounds produce recruits at different times of the year, and (c) that recruitment from these grounds is affected differently by freshwater inputs and, possibly, other environmental variables.** The focus our research has been on (1) sharpening our view of recruitment, (2) developing a juvenile abundance index on inshore grounds, and (3) exploring possible relationships of juveniles and recruits to each other and to various environmental and habitat variables that could possibly affect shoreward transport of postlarvae, juvenile growth and survival, or migration to offshore grounds. Such variables include freshwater inputs (rainfall, freshwater inflow, temperature, wind speed, and mean sea level). This work has been conducted by means of laboratory experiments (1st yr only), field studies, statistical analyses, cohort analyses, and simulation modeling. In addition, we have begun developoment of a preliminary shrimp-based ecological index of conditions in Florida Bay for immediate use in the South Florida Ecosystem Restoration Program.

Historic data from Robblee's and Sheridan's multiyear field studies in Western Florida Bay (Johnson Key Basin) provided the basis for developing a multiyear juvenile abundance index time series. Field sampling of juvenile densities was conducted in Western Florida Bay and Whitewater Bay as part of the Florida Bay Program. Data from these ongoing studies will be used to compare the magnitude and seasonal pattern of juvenile densities in the two nursery areas during the same time period. This is the first time the two nursery areas have been sampled during the same time period using the highly efficient throw trap gear developed by Robblee in the 1980s. General additive modeling (GAM) is being used to determine relationships of the juvenile time series with environmental variables.

A long-term monthly data time series of recruits to the fishery was produced by means of length-based cohort analysis using fishery landings and catch-per-unit-effort (CPUE) data. When this time series was overlain on time series of environmental variables with an appropriate time lag, certain patterns were suggested: a general concurrence of the temporal pattern with freshwater input variables during the ’60s and ’70s, a dampened variability in recruitment and some of the freshwater input variables during the ’80s, and lack of concurrence with these environmental variables during the ’90s. Several approaches to cohort analyses were tested. It was concluded that the recruitment time series might be improved if a better length-age relationship for this species could be developed and if monthly, rather than annual, estimates of the size frequency distribution within commercial catch categories were obtained.

In developing a shrimp-based ecological indicator, the approach was to remove the “rainfall” effect from annual CPUE data and use the residuals of this relationship as an annual abundance index. An index standardized for rainfall variability would more likely reflect the effect of freshwater inputs resulting purely from water management decisions (e.g., releases of freshwater into Everglades National Park from the upstream Water Conservation Areas and Lake Okeechobee). In South Florida, rainfall variability is a major problem in evaluating the environmental effect of changes in water management structures and operations. Principal findings of our analysis were (1) CPUE of both small shrimp (<= 68 count) and large shrimp (> 68 count) correlated well with Royal Palm rainfall, (2) a marked positive trend occurred in residuals of the small shrimp relationship after about 1980, and (3) a markedly negative trend in residuals of the large shrimp relationship was obvious beginning two or three years later. Inquiies with port agents and shrimp industry representatives revealed a major change in marketing practices in the early ’80s that led to increased emphasis on landing small shrimp. This may have had an effect on small shrimp CPUE. Indeed, Tortugas shrimp landings contained a larger proportion of small shrimp after about 1980 than in former years. In subsequent analyses, a dummy variable to account for the change was introduced to the model. This appears to have removed the trend in the residuals. Nevertheless, this is a good demonstration of why results of cohort analysis, because they are not dependent on CPUE, may sometimes be better indices of abundance than CPUE.

Laboratory data on survival as a function of temperature and salinity that had been developed by Zein-Eldin in the first study year recently were used to incorporate a temperature- and salinity-based natural mortality function into the growth and survival model. A second natural mortality function, one dependent on temperature, also was introduced. The two were calibrated so that, under sizes and conditions found on the fishing grounds, their sum would roughly equal previous natural mortality estimates. The model eventually will provide a view of how temporal patterns of salinity and temperature in various parts of Florida Bay and adjacent waters might affect the relative magnitude and temporal pattern of recruitment from each area. Further laboratory studies are needed to extend the experiment to lower temperatures and salinities (presently we only have data for temperatures of 25℃ to 35° and salinities of 30 ppt to 50 ppt) and to provide estimates of effects of temperature and salinity on growth (presently we have information for growth rates as a function of temperature only).

Benthic flux of nutrients from Florida Bay sediments.

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This presentation will combine four datasets from our two research programs to compare sediment nutrient inventories and potential fluxes from sediments to the overlying water column in Florida Bay and along transects from the Keys to the reef tract. The datasets to be used are 1. porewater nutrient profiles and benthic chamber flux measurements made in Johnson Key Basin in 1990, 2. porewater nutrient profiles and benthic chamber flux measurements made along transects from the Keys to the reef tract in 1992, 3. porewater nutrient profiles measured at several sites within Florida Bay from 1994 to 1996, and 4. measurements of potential fluxes from sediment to the water column by resuspension.

In January, April, July, and September 1990, we measured sediment-water exchange of ammonium, filterable reactive phosphorus (FRP), and silica in surviving Thalassia beds and die-off patches in Johnson Key Basin. Porewater equilibrators (peepers) were sampled at the same time to compare potential fluxes calculated from vertical profiles of porewater nutrients with actual fluxes measured in benthic chambers.

Peeper nutrient flux estimates of Si, NH4, and FRP in surviving *Thalassia* beds were generally higher than in die-off patches. In September 1990, for example, Si, NH4, and FRP flux estimates for surviving beds were 29, 14, and 2.6 umol/m2/d, respectively, while estimates for die-off patches were 6.9, 7.0, and 2.4 umol/m2/d.

In benthic chambers, we measured silica and ammonia fluxes of 21 and 4.0 mmol/m2/d, respectively, in surviving Thalassia beds. Fluxes of silica and ammonia from unvegetated sediments in die-off patches were negligible. Phosphorus flux was not detected in surviving grass beds or die-off patches. Silica and ammonium fluxes measured in benthic chambers exceeded by far fluxes calculated from porewater profiles, possibly as the result of rapid nutrient regeneration in the water column, at the sediment-water interface (Gardner et al. 1995) and on the surfaces of seagrass leaves.

Silica and ammonium fluxes estimated from porewater profiles at Rankin Lake, Sandy Key, and Twin Key in 1994-1996 were generally higher than 1990 estimates from Johnson Key Basin. Silica flux estimates ranged from 112 umol/m2/d for Rankin Lake to 83 umol/m2/d for Sandy Key, to 67 umol/m2/d for Twin Key. Ammonia flux estimates were highest (57 umol/m2/d) at Rankin Lake, lower (25 umol/m2/d) at Twin Key, and lowest (15 umol/m2/d) at Sandy Key. Phosphorus flux estimates were highest at Sandy Key (5.3 umol/m2/d) lower at Rankin Lake (1.0 umol/m2/d), and lowest at Twin Key Basin (0.35 umol/m2/d).

Zooplankton abundance and grazing potential in Florida Bay.

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Components of the phytoplankton community that “bloom” are those in which increases from growth exceed decreases from loss processes. In most aquatic systems, the dominant loss process is zooplankton grazing. One of the objectives of our studies has been to determine the importance of zooplankton grazing in Florida Bay, and to compare grazing losses to algal growth rates or productivity rates. We hypothesized that growth in small phytoplankton is closely balanced by losses to microzooplankton grazing, but populations of larger zooplankton are not sufficient to control larger phytoplankton, which consequently can form blooms. In addition, although not the subject of this presentation, we are interested in the trophodynamic significance of the various zooplankton species; we will identify which taxa are important food sources for planktivorous larval and juvenile fishes.

Bi-monthly collections of zooplankton have been made since September 1994 at eight stations: 1/2 mile N. of Murray Key, Whipray Basin, Eagle Key Basin, Cross Bank Basin, Twin Key Basin, Johnson Key Basin, 1/4 mile SE of Duck Key and the south end of Shell Key Channel. For gut content analyses, fish larvae are being collected with 150 um neuston nets, and planktivorus fish juveniles by parallel FNMRI/ DEP trawl net deployments at the same stations. After some initial comparative experiments (earlier reported) our procedure has been to quantitatively collected larger zooplankton by towing nets of 64 um mesh, and smaller zooplankton with bucket samples passed through a 20 um screen. All samples have been sorted and all zooplankton identified and enumerated. The sizes of representative individuals from each enumerated category have been measured and corrected for preservation effects.

Zooplankton are moderately abundant throughout the year. In some seasons, molluscan larvae dominate zooplankton abundance and biomass but otherwise copepods dominate. *Paracalanus* and *Oithona* species are nearly always the dominant copepods but *Acartia tonsa* is also significant throughout the year. Other major grazers (like larvacea) are infrequently abundant.

The potential grazing impact of copepod nauplii on the phytoplankton community was estimated. The metabolic requirements of each nauplius was determined from its size using literature-derived conversion factors corrected for temperature conditions in Florida Bay. Summation of the demands from all nauplii provided an estimate of the total metabolic demand by the nauplius community. Other microzooplankton > 20 um, and all microzooplankton < 20 um, are excluded from this calculation.

The potential grazing impact of the larger copepods and meroplankton on the phytoplankton was separately estimated by a similar calculation. Measured body dimensions and temperatures where combined with literature-derived conversion factors to determine the metabolic demand of each taxa, and then multiplied by the abundance of that taxa to obtain the total community demand. Summation of the food demands of the nauplius community and the community of larger zooplankton yielded an estimate of the total demand of the metazoan zooplankton community.

These feeding estimates indicate protozoan grazers are the most important component of total grazing community.

Direct measurements of whole community zooplankton grazing (i.e. including protozoa) and whole phytoplankton community growth have been made at a single station during the past three sampling intervals. These twenty-four hour *in situ* experiments have shown that grazing by the whole zooplankton community markedly exceeds estimates described above. This indicates the organisms < 20 um, the protozoans, are the most important grazers in this system. Total community grazing is sufficient to nearly balance the daily growth of the whole phytoplankton community. Enumeration of the phytoplankton species composition at the outset and termination of these experiments samples will identify which components of the phytoplankton community are increasing and which are being controlled by grazers.

Although protozoans are more significant grazers than metazoans, the latter are more significant food sources for planktivorous fish. Close coordination of our studies with studies of phytoplankton growth, larval and juvenile fish abundance and food requirements, and physical circulation, as well as proper scaling through integrated modeling studies, is required to quantitatively assess the factors controlling bloom dynamics in Florida Bay.

Plans for the Florida Bay water quality model.

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A work plan is being prepared to define the procedures, tasks, and time and costs associated with the development and application of a water quality model of Florida Bay. The Florida Bay Program Management Committee (PMC) and various federal and state partners require this model to address questions related to the future environmental health of the Bay. The Jacksonville District, U.S. Army Corps of Engineers (CESAJ), tasked the Waterways Experiment Station (WES) to develop the work plan. The PMC, along with the CESAJ, WES, and the South Florida Water Management District (SFWMD), has planned a workshop during October 22-24, 1996, to scope the model design and specifications. Workshop recommendations will be used to develop the workplan.

Questions to be addressed by the model include the following.

- How will alterations in freshwater flows from the Everglades and the Central and South Florida Flood Control Project affect Bay water quality and seagrass?
- What is the relative importance of various nutrient loading sources on Bay water quality and seagrass?
- How are changes in seagrass related to changes in nutrient loadings?
- What is the spatial pattern of nutrient limitations on primary production?

Other model uses and benefits are: to gain an improved understanding of the Bay; to investigate fate of nutrients and their export through the keys towards the reefs; to evaluate the effects of various freshwater flow alternatives and other management options; to investigate the relative importance of key processes; to foster synergism with other Bay studies; and to help focus data needs and monitoring design.

It has been suggested that a dual track modeling strategy be pursued, where a box model of limited spatial resolution is initiated immediately while a more sophisticated model with much greater spatial resolution is being prepared. The simpler model will be used to quickly gain insights about the Bay and to help guide the detailed model. The simpler model can be an existing version of the detailed water quality model. Gross-scale circulation needed to drive the box model can be extracted from the Corps RMA2 hydrodynamic model presently being applied to the Bay to evaluate salinity regimes associated with changes in freshwater flows.

The conceptual model of Florida Bay states that nutrients affect phytoplankton and epiphytes, which affect light attenuation and, thus, seagrass growth. Additionally, suspended sediments affect light and seagrass. Changes in seagrass coverage affect currents and waves. Changes in current and wave conditions can influence sediment resuspension. Therefore, there is potentially a need for rather complex model interactions and feedback among hydrodynamics, sediment transport, water quality, and seagrass. A major challenge of this project will be to devise a methodology to reduce the complexity of model linkages and feedback to obtain practical solutions while retaining sufficient realism to provide reliable model predictions.

The detailed Florida Bay water quality model will consist of several individual model components. Components of the model package will include a hydrodynamic model (HM), wind-wave model, sediment transport model (STM), water quality model (WQM), benthic nutrient diagenesis model, and a seagrass model. The HM is required to drive the transport terms of the STM and WQM. The wind-wave model is needed to compute sediment erosion due to short-period waves. Information on suspended sediment from the STM will be used in the WQM to attenuate light and allow for phosphorus partitioning to solids. The WQM, benthic diagenesis model, and seagrass model have been developed within the CE-QUAL- ICM to work together interactively. The CE-QUAL-ICM model was originally developed during a study of Chesapeake Bay and has since been applied to a number of other systems. Revisions to the WQM and its submodels are envisioned to better represent Florida Bay.

It is recommended that the model be calibrated for several annual periods and confirmed for the past decade. The model must be operated for at least decade-long periods to forecast the effects of management options on water quality and seagrass. Therefore, it will be necessary to demonstrate that the model can capture changes in water quality and seagrass coverage observed during the past 10 to 15 years.

Several technical obstacles and data gaps that impede this model development have already been identified. Successful completion of this project will require significant partnering and collaboration among the Florida Bay scientific community and the modelers.

This presentation will summarize the conclusions and recommendations of the October workshop and the overall plans for model development and application as being detailed in the work plan, which is scheduled for completion during December 1996.

The status and trends of seagrass communities in Florida Bay.

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The Florida Bay landscape continues to exhibit dramatic changes following the onset of seagrass die-off in the late 1980's and the initiation of widespread and chronic turbidity in late 1991. FMRI's Florida Bay Fisheries Habitat Assessment Program (FHAP) and DERM's C-111/Taylor Slough water quality and biological monitoring program in northeastern Florida Bay are providing spatially-extensive, qualitative and quantitative data to assess variation in macrophyte species distribution and abundance, community structure and population dynamics in relation to the multiple stressors affecting the Bay. Between these two programs, over 400 stations in 14 basins are currently being sampled seasonally for seagrass and macroalgal distribution and abundance.

Thalassia testudinum remains widely distributed in Florida Bay, with highest abundances generally occurring in the southwestern Bay. Analyses of recent (1995/96) Braun-Blanquet (B-B) cover/abundance changes indicate that the most significant losses of *Thalassia* are occurring in western (Rabbit Key Basin, RKB) and southern (Twin Key Basin, TWN) Florida Bay (Figure 1). These basins are somewhat far-removed from the land/sea margin, and salinities dropped only slightly following the high rainfall and freshwater inflow into the Bay that occurred during summer 1995. Although all basins sampled by FHAP exhibited patchy mosaics of gains and losses, average *Thalassia* cover/abundance values were stable or increased from spring 1995 to spring 1996 in all but one (TWN) of the ten basins sampled. Basins in central-to-northeast Florida Bay, which had 5 to >15‰ reductions in salinities between April and November 1995, exhibited stable or increasing *Thalassia* abundance. In spring 1995, about 39% of the area sampled by FHAP had less than 5% cover of *Thalassia*; the amount of area with little or no cover dropped to approximately 25% by spring 1996. *Thalassia* is presently least abundant in central Florida Bay (Rankin Lake, RNK and Whipray Basin, WHP); this region experienced the most prolonged and severe seagrass die-off. Distribution and abundance of *Halodule wrightii* showed little change from 1995 to 1996, except in northern Johnson Key Basin (JKB) where substantial increases were observed. Quantitative (shoot density) and qualitative (Braun-Blanquet) abundance data for spring 1995 were strongly correlated (r2>0.7) on a Bay-wide scale. The strength of the relationship varied from basin to basin, and was weakest in areas with generally high B-B values.

In the transitional basins and coves of extreme northeastern Florida Bay, average B-B cover/abundance of *Thalassia* and *Halodule* increased from fall 1995 (´ =1.30 ± 1.15 s.d. and 0.32 ± 0.38 s.d. for *Thalassia* and *Halodule*, respectively) to spring 1996 (´ = 1.67 ± 1.38 s.d. and 0.63 ± 0.77 s.d. for *Thalassia* and *Halodule*, respectively). *Thalassia* was the most widely distributed seagrass and typically dominated were it occurred in these transitional basins. *Thalassia* was present at approximately 75% of the 72 sampled stations, but was noticeably absent from the isolated "upstream" basins of Joe Bay and Highway Creek. *Halodule* was also widely distributed, occurring at about 70% of the stations. *Ruppia maritima* occurred at 20% of the stations during the low salinity conditions (9.6‰ ±4.8) of fall 1995, but frequency of occurrence dropped to 13% by spring 1996, when conditions were more mesohaline (20.5‰ ± 2.9 s.d.). *Ruppia* distribution was generally isolated to "upstream" basins (Joe Bay, and Highway Creek) where it appeared to be seasonally dominant. Basin averages for *Ruppia* abundance ranged from >50% during months with lower salinities, to < 5% in late spring when salinities were higher. Quantitative (*Thalassia* shoot density) and qualitative (Braun-Blanquet) abundance data for the transitional basins are also well correlated (r2>0.6). This value represents all *Thalassia* data for the period December 1995 through June 1996.

Quantitative (seagrass shoot density) data varied at six fixed, long-term stations in the transitional basins sampled during fall 1995 and spring 1996. Seagrass composition and abundance at two sites in Little Madeira Bay remained unchanged, and were consistent with historical trends. At two other sites (Trout Cove, and Long Sound), *Thalassia* shoot density decreased from fall 1995 to spring 1996, falling below the historical ranges for each station. *Halodule* density at the Long Sound station increased from approximately 75 shoots m-2 in fall 1995 to about 175 shoots m-2 in spring 1996. Shoot density *of Ruppia* decreased substantially over this same period at the Highway Creek station. Recent qualitative abundance data (Braun-Blanquet, June 1996) support many of the observations from the fixed, long-term monitoring stations.

Recent losses of *Thalassia* in western Florida Bay have occurred where there has been persistent turbidity. The turbidity is caused by widespread, persistent phytoplankton blooms as well as resuspended carbonate sediments exposed by seagrass die-off, especially on the western Florida Bay banks (e.g., Sandy Key). Seagrass declines in the western Bay may be the result of light-stress induced mortality in addition to die-off. Losses in southern Florida Bay (TWN) do not appear to be related to turbidity, and the patterns of loss are similar to those observed during the die-off events of the late 1980's.

The distribution of *Thalassia* loss between 1995 and 1996 shows a relatively high spatial coincidence with the distribution and abundance of the marine slime mold *Labyrinthula*; reductions in *Thalassia* abundance are paralleled by elevated infection rates and lesion coverage (Landsberg et al., this conference). The occurrence of this marine slime mold also appears to be higher in chronically-turbid areas, and lower in basins with reduced salinities; both turbidity and low salinity are stressful to *Thalassia*.

Shoot-specific structural and dynamic characteristics of *Thalassia* generally increased between spring 1995 and spring 1996. Standing crop increased in 9 of the 10 basins, decreasing only in WHP. Shoot-specific productivity of *Thalassia* increased in all basins except TWN and WHP (Figure 2). Turnover rates increased in 7 of the 10 basins, with highest increases occurring in RNK and Crane Key Basin (CRN). These increases in turnover may be due partially to a shift in sampling time from May in 1995, to June in 1996. However, the general pattern of increased distribution, abundance, and production suggests some recovery of the seagrass community, and perhaps reflects an improvement in water quality conditions in Florida Bay.

Seagrass elemental content and epiphyte loads along the nutrient availability gradient in Florida Bay.

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Loss of seagrasses around the world has been linked to eutrophication. The mechanism of this loss has often been found to be the overgrowth of seagrasses by epiphytes in areas of enhanced nutrient availability. Seagrass loss in Florida Bay began in 1987, and continues to the present. While the causes of the initial loss of seagrasses is as yet poorly understood, it was not associated with declines in water clarity or in increased epiphytism. Four years after the initial seagrass dieoff, algae blooms and increased turbidity led to continued seagrass decline owing to competition for light with phytoplankton. It has been suggested that nutrients that had supported seagrass biomass in 1987 were released from the sediments and fueled the phytoplankton blooms in 1991 to present. The degree to which this phenomenon has led to a change in the spatial pattern of benthic nutrient availability and increases in epiphytism of seagrasses is not known.

In this study, we examined the response of the elemental content and epiphyte load of *Thalassia testudinum*, the dominant seagrass in Florida Bay, to the naturally occurring gradient of nutrient availability across Florida Bay. This nutrient availability gradient has been documented for both the water column and for the seagrass communities of the bay. Phosphorus availability is highest in north western Florida Bay, and decreases to the east. In contrast, nitrogen availability is highest in central Florida Bay. We hypothesized that areas of greater nutrient availability in Florida Bay would have higher epiphyte loads on the seagrasses. Additionally, we compared the patterns of benthic nutrient availability from before the seagrass dieoff, as indicated by the tissue nutrient concentrations of nitrogen and phosphorus, to the post-dieoff patterns as measured at 24 water quality monitoring stations in the spring of 1994.We also examined seagrass epiphyte loads with respect to distance from a point source of nutrient input in the oligotrophic eastern part of Florida Bay. This point source is a bird colony island; the point source of nutrients results from the defecation of thousands of birds.

Total epiphyte standing stock, seagrass short shoot size, P content of seagrasses, and total P concentration in the water column were all correlated. All of these variables were highest in the northwestern portions of Florida Bay and decreased to the east. Total epiphyte loads, measured as the mass of epiphytes per mass of seagrass leaves, were not correlated with any measure of nutrient availability, however. There was a statistically significant, but relatively weak (r squared =0.18) relationship between epiphyte chlorophyll loads and measures of P availability. On a baywide scale, there was a relationship between the plant component of the epiphyte community and nutrient availability, but this relationship did not explain a large proportion of the variation in the load of epiphytic plants on seagrasses. Total epiphyte load was not related at all to the availability of P or N. This result suggests that some factor other than nutrient availability, perhaps grazing pressure, is the primary control on epiphyte loads in Florida Bay. These data were collected in 1994, during the time when seagrasses were being lost due to light stress. Apparently, whatever enhancement of nutrient availability that was caused by the initial seagrass dieoff did not lead to baywide increases in epiphyte loads.

The measurement of total epiphyte loads and observations of epiphytic species composition along a transect adjacent to a point source of nutrients revealed that the effect of nutrient enrichment on epiphyte levels is pronounced but very localized. Epiphyte loads were much higher close to the point source, but epiphyte loads were not elevated above background levels further than 30m from the shore. Differences in epiphytic species composition were also observed along this transect. Various “fleshy” rhodophytes and chlorophytes (Chondria sp., *Ceramium spp., Laurencia spp.,* and *Derbesia sp.*) were abundant close to the island (15m), while epiphyte composition furthest from the island (45 m) was dominated by animal epiphytes(especially the epiphytic bivalves *Pinctada imbricata* and *Brachidontes exustus*). In contrast to the short distance from the point source that had altered epiphyte communities, previous work has shown that seagrass standing crop was enhanced up to 200 meters from the bird island and the nutrient content of the seagrass biomass showed elevated phosphorus as far as 90 meters from the bird island.

Previous studies have documented the spatial pattern in benthic nutrient availability using the C:N:P ratios of seagrass biomass that existed before seagrass dieoff. There was a striking pattern in C:P ratios, with low C:P in northwest Florida Bay and high C:P in eastern Florida Bay. C:N of seagrass leaves was minimum in the center of the bay. These patterns have been argued to be a response to the nutrient availability gradients. A comparison of the maps of C:N:P of seagrass leaves from pre- and post-dieoff indicates that the spatial pattern of benthic nutrient availability has changed very little since the dieoff.

Although epiphyte load is often touted as an indicator of nutrient availability in seagrass ecosystems, these findings suggest that seagrass biomass, species composition, and nutrient content are more sensitive indicators of nutrient availability than epiphyte load. We also found that, despite the increase in phytoplankton biomass and turbidity of Florida Bay, benthic nutrient availability was the same in 1994 as pre-dieoff in 1987.

These results have been submitted for publication in the journal Marine Ecology - Progress Series as: Seagrass epiphyte loads along a nutrient availability gradient, Florida Bay, FL, USA, by Thomas A. Frankovich and James W. Fourqurean.

Mesocosm studies of Biscayne Bay seagrass communities and the relevance to Florida Bay seagrass dynamics.

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The University of Miami's Center for Marine and Environmental Analyses (CMEA) operates experimental microcosm and mesocosm facilities located at the Rosenstiel School of Marine and Atmospheric Science campus on Virginia Key. Financial support for construction and operation of the facility currently comes from contracts and grants that CMEA administers from the U.S. Army Corps of Engineers and the National Oceanic and Atmospheric Administration Coastal Ocean Program. The experimental work conducted in the facilities along with field manipulations and observations provide empirical data to CMEA scientists for incorporation in policy-relevant models of seagrass and hard-bottom communities in Biscayne Bay.

The mesocosm facility consists of 12 fiberglass tanks (3.6m long, 2m wide, 1.4m deep, ca. 6159 liters or 1625 gallons). Each tank is half buried to aid in temperature control and stability, and can be partitioned into four separate and isolated 0.9m x 2.0m quadrants. Nine of the tanks are currently dedicated for seagrass experiments, two more will be used for hard-bottom and coral reef work, and the third will be used as a holding tank and nursery for seagrass seedlings. The nine seagrass tanks currently have a 40-cm deep sediment layer.

Water is supplied from Biscayne Bay and is settled (not filtered) before entering the mesocosms. Each quadrant has its own water supply and drain. Water is delivered at a rate of 5-6 gpm to each mesocosm tank via a 1" pipe which is diverted to 3/4" pipes at each quadrant. Standpipes (1.5") drain and skim each quadrant. These standpipes are currently set to allow a water column of 85 cm and are adjustable down to 30 cm. Water is circulated in the tanks by 1/12 hp (530 gph) powerheads placed across from the skimming standpipes.

In June 1996 construction of the mesocosm facility was completed and *Thalassia testudinum* cores (20-cm diameter) were planted in each tank at 12" centers. We are currently testing the facility to determine the best size tank (partitioned or not) to simulate natural field conditions. After two months of adjustment and acclimation to the transplanting process, monthly measures of water column and porewater nutrient levels, and water column chlorophyll concentrations have been taken from partitioned (e.g., 0.9 x 2.0m, 1.8 x 2.0m) and non-partitioned (2.0 x 3.6 m) tanks for comparison with natural seagrass beds. We are also making measures of growth, productivity, and microbial decomposition rates for comparison. Once we have established the size of tank that best simulates natural field conditions, we will begin long-term experiments to examine changes in seagrass and macroalgal community structure in response to freshwater discharge from canals. At this time, the tanks will be planted with a mixture of *Talassia testudinum, Halodule wrightii,* and *Penicillus capitatus* (the most abundant rhizophytic alga based on field sampling). Recruitment of non-rhizophytic algae occurs naturally via the settled water supplied to the facility. Half of the tanks will be pulsed (i.e., salinity dropped by 50% for a 24-hour period followed by an infusion of new, flow-through seawater) once a week with aerated domestic tap water that contains a slurry of sediments (to increase turbidity of the water column). This treatment will mimic a canal discharge event by introducing low-salinity, turbid water that is high in nutrients (levels of nitrogen and phosphate in domestic tap water are considerably higher than Biscayne Bay water). The control tanks will be pulsed with aerated seawater. All tanks will be stocked with grazers (e.g., pinfish and gastropods) at natural densities to control excessive epiphyte growth. Over time we will monitor growth and percent cover of the plant species. We anticipate these experiments to be log-term manipulations that will assess community- level responses to the collective effects of salinity, nutrient, and light changes associated with canal discharge.

Our microcosm facilities will allow controlled experiments examining how the different species of seagrass and macroalgae respond to changes in salinity, light levels, and nutrients separately and in combination. We are also assessing how salinity fluctuations affect grazing rates of herbivores. The CMEA flow-through microcosm facility contains thirty 30-gallon aquaria. The aquaria are housed in an 18' x 20' greenhouse. The system can be used for flow-through or recirculating conditions, depending on the desired treatments. The system also contains four 240-gallon head tanks, which serve as reservoirs for seawater or freshwater and as scrubbers or holding tanks.

The plumbing for this facility was designed to allow three separate water treatments at any given time. Each aquaria drains into one of three sump tanks (A,B, or C) where the water is taken up by a pump and returned to the aquaria (recirculating). The aquaria are arranged 10 to one of three tables, and each table is equipped with the three separate water supplies to allow randomization of treatments and to minimize any bias in temperature and/or lighting differences associated with position of the aquaria in the greenhouse. When recirculating, water is pumped through a particulate filter, through a chiller/heat pump, and then to the aquaria feed lines. Water flow to each aquaria is controlled by a ball valve located above each tank from each of the three water feeds (A,B or C). Each table has connections to all three (A,B, or C) drain systems leading to the desired sump tank. Water drains back into the particular sump (A,B,or C) where it is then recirculated. The pump, filter, and chiller unit can bebypassed allowing flow-through of seawater. When the flow-through system is activated, seawater is gravity fed from a settling tank (40' head) into the microcosm facility.

Each system has a feed from the header/holding (H/H) tanks. Each H/H tank has freshwater (domestic tap water and R/O), saltwater, and air supply lines. In acute salinity applications, freshwater can be diverted from the H/H tanks to the recirculating pumps in the A, B, or C lines or some combination of the three lines. The volume of water equivalent to that entering drains out of the system. The system water is then diluted and recirculated at this new salinity.

We are currently running experiments in this facility to assess the effect of pulses of reduced salinity water (R/O water with negligible nutrient levels) on growth of macroalgae. Such experiments are currently underway with *Laurencia*, a common species of drift algae in Biscayne Bay. Following the assessment of reduced salinity stress on algal growth, we subject the algae to grazing pressures to determine if stressed algae is consumed by grazers at equal rates as unstressed algae.

CMEA also operates a static microcosm facility. This system consists of two greenhouses with two 200-gal tanks in each house. These tanks serve as water baths for individual experimental containers (aquaria, buckets, etc.). The system enables experimental units to be housed with ambient light, aeration, and constant temperature control. However, depending on the duration of experiments, water in the containers may have to be changed periodically to avoid stagnation and nutrient depletion. Unlike the flow-through and recirculating systems, this system will allow us to manipulate multiple factors simultaneously (e.g., temperature, salinity, light, and nutrients in various combinations). This will allow us to examine the effects of multiple factors and their interactions on seagrass and macroalgal growth.

While our research focuses on the effects of freshwater discharge from drainage canals on seagrass ecosystem function in Biscayne Bay, the results from our studies will have relevance to Florida Bay as well. All of the species we are working with occur in Florida Bay, and they are exposed to similar sorts of environmental stresses.

Examining the correlation between the presence of the slime mold Labyrinthula sp. and the loss of Thalassia testudinum in Florida Bay.

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One of the primary factors considered in seagrass die-off has been that reduced freshwater inflow due to drought, diversion of upland runoff, and reduced rainfall over the bay changed Florida Bay from an estuary to a hypersaline marine lagoon. Lack of direct hurricane impact over the past two decades has reduced the frequency of periods of low salinity and allowed an increased accumulation of sediment on banks and in many basins (Zieman et al. 1989). These environmental changes are thought to have allowed *Thalassia* to increase to very high densities. The apparent density-dependent die-off was initially restricted to basins in the west such as Rankin, Johnson, and Rabbit that had dense *Thalassia* populations (Robblee et al. 1991). Low-density or chronically-stressed *Thalassia* populations on banktops in lower salinity basins in east, central, or south Florida Bay were unaffected (Durako & Kuss, 1994). It has been postulated that various environmental stressors or the seagrass pathogen, *Labyrinthula* (Porter & Muehlstein, 1989; Robblee et al. 1991) were involved in seagrass mortality in Florida Bay, but no field documentation was available on *Labyrinthula* distribution, speciation, or pathogenicity.

Although Porter & Muehlstein (1989) suggested that *Labyrinthula* could have a major role in seagrass mortality in Florida Bay, this causality has not been rigorously investigated. The slime mold *Labyrinthula* has generally been considered to be a secondary pathogen that invades stressed, weakened *Thalassia*. As *Labyrinthula* infection progresses, necrotic lesions spread to cover the *Thalassia* leaf tissue. The loss of leaf cover and limitation on photosynthesis in individual shoots may ultimately lead to seagrass mortality, particularly in turbid areas or in reduced light. *Labyrinthula* impairs photosynthesis and it has been postulated that the associated decrease of oxygen available to rhizomes leads to hypoxia (Durako & Kuss, 1994). High sediment sulfide concentrations are toxic to seagrass in certain geographical locations (Carlson et al. 1994). In combination with such a situation, *Labyrinthula* can be a primary factor in seagrass die-off. Accordingly, it would not be anticipated that *Labyrinthula* would play a major role in seagrass disease and mortality in high-light, low-turbidity, and well-flushed *Thalassia* beds. When *Thalassia* is stressed by low light, low dissolved oxygen, high sulfide sediments, phytoplankton blooms, and turbid or stagnant waters, this seagrass may be highly susceptible to disease and certain *Labyrinthula* species may be extremely virulent.

We wished to determine what role *Labyrinthula* plays in the Florida Bay seagrass mortality. Our research program is designed to answer the following questions:

- How many species of *Labyrinthula* are present and which, if any, are pathogenic?
- Are stressed seagrasses more susceptible to infection?
- Is *Labyrinthula* normally present but not pathogenic in healthy seagrass?
- Is a pathogenic, more virulent form only found affecting stressed seagrass?
- Is *Labyrinthula* directly pathogenic to healthy seagrass and spreading throughout Florida Bay?
- How do ranges in salinity, temperature, and light affect the proliferation, maintenance, and pathogenicity of *Labyrinthula* in *Thalassia*?

Answering these questions is critical to clarifying the actual impact of *Labyrinthula* on seagrass in the Florida Bay system.

In April 1995, in conjunction with the FHAP program (Durako et al. this conference), we began to investigate the temporal and spatial distribution of *Labyrinthula* in Florida Bay *Thalassia* communities, and to determine its role in disease and associated mortality of seagrass. Twice yearly, in spring and fall, *Thalassia* shoots from sites in 10 basins are screened for lesion and labyrinthulid presence. These basins are representative areas of the bay system. They differ in their sediment profiles and characteristics, seagrass density and abundance, and are individually influenced by varying environmental factors. From west to east and south to north, these are Johnson, Rabbit, Rankin, Twin, Whipray, Madeira, Calusa, Crane, Eagle, and Blackwater. Health criteria of *Thalassia* sampled in 1995-1996 included: 1) the occurrence of and relative blade area covered by lesions, 2) the relative distribution and prevalence of *Labyrinthula* infection (presence/absence on individual blades), and 3) the association among the occurrence of lesions, prevalence of *Labyrinthula* infection, salinity, water clarity, and temperature.

Labyrinthulids are also isolated from *Thalassia* lesions and grown on agar plates and in liquid media. Isolated labyrinthulids are being speciated using growth characteristics at different temperatures, salinities, and light regimes; cell sizes; host specificity; and both scanning and transmission electron microscopy. *Thalassia* shoots grown axenically from seed are currently being used for transmission experiments of labyrinthulid isolates to determine pathogenicity, environmental requirements, and other factors required to induce mortality in seagrass. Once pathogenicity has been established, mechanisms for invasion will be explored experimentally in the laboratory and in the field.

To determine the distribution and relative frequency of occurrence of *Labyrinthula*, we examined leaf blades from over 8500 *Thalassia* shoots collected from 872 sites in spring and fall of 1995 and spring of 1996. Fall 1996 sampling has begun. In 1995, the prevalence of *Labyrinthula* infection in individual basins generally varied from high in the west, north-west, and south-central to low in the north-central, central, and east. In 1995, from spring to fall, there appeared to be a general increase in the prevalence of *Labyrinthula* in Rankin and Johnson through Rabbit to Twin; this has been further extended in spring 1996 to Crane. In 1996 in Crane, the prevalence of infected sites rose to 68.0% from 9.0% in 1995. In 1995, the prevalence of *Labyrinthula* in shoots was generally low, ranging from 0 to 13%. Data from spring 1996 indicate a significantly higher prevalence of shoot infection than in the previous spring (Wilcoxon Signed-Rank Test, $P<0.0001$). In spring 1996, basins in the west, north-west, central, and south (Johnson, Rabbit, Rankin, Twin, and Crane) had higher prevalences of shoot infection (5.7 - 30.4%) than basins in the north-central and eastern areas (Whipray, Calusa, Madeira, Eagle and Blackwater) which had low prevalences of infection (0.0 - 1.71%). Increased prevalences of shoot infection were observed in some basins, particularly within Johnson (30.4%), Rankin (18.5%), and Crane (17.6%). These three basins all experienced more than a 17% increase in *Labyrinthula* prevalence between spring 1995 and 1996. The frequency of lesions and the relative blade area with lesions were quantified for about 30,000 *Thalassia* blades in 1995-1996. The highest prevalence of blade lesions in spring 1995 was observed at the two western-most basins, Johnson and Rabbit, where the prevalence exceeded 30%. Significant increases of more than 21.0% prevalence of blade lesions from spring to fall 1995 were observed at Rankin and Twin, while the only significant decrease occurred at Johnson (Wilcoxon Signed-Rank Test, $P<0.0001$). By spring 1996, a blade lesion prevalence of 17.1% was observed at Crane where the lesion prevalence had increased by 13% from spring 1995. The prevalence of lesions at Johnson rose dramatically by 32.0% from the previous fall. *Labyrinthula* and the presence of lesions had apparently spread from the west/north-west to the south.

In individual basins, there appear to be differences between prevalence of infection levels in relation to site salinity. Other integrating environmental factors are likely to be important, but in general it appears that salinity is a critical controlling factor in *Labyrinthula* infections. Laboratory studies are in progress to test this hypothesis. Salinities in the fall of 1995 were lower at all basins compared to the spring of 1995. By spring 1996, salinities at all sites had increased to higher levels than those of the previous spring. The basins nearer the land-sea interface on the north-central and east side (Whipray, Madeira, Calusa, Eagle, and Blackwater) were at lower salinities (mean range = 11.9 - 21.3 ppt) in the fall of 1995 than the more westerly and southern basins (Johnson, Rankin, Rabbit, Twin, and Crane) (mean range = 19.9 -31.5 ppt). In the spring of 1996 the basins with lower fall 1995 salinities had much lower prevalences of infected sites (0 - 12.5%) than those with high fall 1995 salinities (prevalences of 33.3 - 71.4%). Rankin experienced mid salinities (19.0 - 21.0 ppt) in the fall 1995 sampling period, and had a high *Labyrinthula* prevalence (66.7%). Mean secchi disc readings at Rankin (31.1 to 35.9 cm depth, fall 1995 and spring 1996 respectively) indicate that this basin had the lowest water clarity of the 10 basins. In all cases, trends by individual basin need to be compared to historical salinity data, other environmental factors, phytoplankton bloom dynamics, and any potential effects associated with *Thalassia* abundance, age, and mortality.

Preliminary indications suggest that medium-to-high salinity basins with persistent or new *Labyrinthula* infections (prevalences of 1-20%) from spring 1995 through spring 1996 were associated with areas of declining seagrass density. Loss in *Thalassia* abundance in certain areas in Twin and Rabbit from spring 1995 to spring 1996 (Durako et al. this conference) are almost paralleled by the distribution of *Labyrinthula* and high lesion cover in these basins during the same time period. These seagrass losses, the presence of *Labyrinthula*, and percentage blade lesions present will be statistically evaluated. The increased prevalence of *Labyrinthula* in Crane and Johnson in spring 1996 may foreshadow *Thalassia* losses in these basins. Sampling this fall will enable us to determine if there is a significant impact by *Labyrinthula*. In other areas such as Rankin, where seagrass die-off and slow recovery have been occurring for some time, and where seagrass density is low, these latter factors in combination with high turbidity, lowered light, and medium salinities appear to allow persistent *Labyrinthula* infections. At Twin and Crane where environmental stressors are apparently minimized (deep basins, medium density of seagrass, good flushing, low turbidity, and good light penetration) the role of *Labyrinthula* in inducing disease and subsequent mortality of seagrass may be determined within the next few seasons of sampling.

Basins with widely fluctuating salinities with pulses of low salinity, wide salinity ranges, or low salinities from 8-18 ppt appear to have low-level prevalence of *Labyrinthula*, minimal lesion cover, and are not experiencing heavy die-off. Determining the potential for *Labyrinthula* to act as a primary pathogen that is controlled by specific environmental cues or seagrass resiliency still remains a challenge for Florida Bay research in the near future. Comparisons of laboratory results and field-collected data are beginning to provide a clearer picture of the role of *Labyrinthula* in seagrass mortality in Florida Bay. Understanding the role of *Labyrinthula* as a major contributing factor in seagrass die-off, particularly if the dynamics of the pathogen response are controlled by salinity, will enable managers to develop appropriate water management strategies and to recommend adaptive restoration options.

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Modeling relationships between external nutrient loading, water quality, and biotic phase shifts: examples from Tampa Bay, Sarasota Bay, and Florida Bay.

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Anthropogenic increases in external nutrient loading to estuaries is the most frequently cited factor correlating with eutrophication, algal blooms, and decreased seagrass cover. In Florida, there are a number of locations where external nutrient loads have been manipulated by human activities. In Tampa Bay, seagrass losses during the 1960's and 1970's were attributed to increased nutrient loads that caused increased macroalgal biomass and water column chlorophyll-*a*. Recent management actions have decreased loads of the limiting nutrient - nitrogen - by some 35 %, which resulted in decreased macroalgal abundance and chlorophyll-*a* and an 11 % increase in seagrass coverage. In Sarasota Bay, studies have shown an inverse relationship between modeled nitrogen loads and measured seagrass biomass and productivity. Recently, modeled nitrogen loads to Sarasota Bay decreased by approximately 40 %, resulting in an increase in seagrass coverage of 7-11 %.

We tested the hypothesis that seagrass distribution and health in the western regions of Florida Bay may also be inversely related to external nitrogen loads. Following the diversion of stormwater runoff from Lake Okeechobee southwards towards the Everglades in the late 1970's, commercial fishermen observed increasing macroalgal biomass in the downstream waters of the eastern Gulf of Mexico and western regions of Florida Bay. To hindcast the possibility that these blooms may have been linked to increases in external N-loading, we performed physiological and biochemical studies during 1994 - 1995 of macroalgae at four stations in Florida Bay (Duck Key, eastern bay; Rankin Key, central bay; Murray Key, western bay; and Rabbit Key, southwestern bay); the studies included measurements of photosynthesis vs. irradiance curves, midday downwelling irradiance, alkaline phosphatase activity (a measure of P-limitation), and tissue analysis for carbon:nitrogen:phosphorus (C:N:P) ratios. These studies showed severe light attenuation/limitation of scant populations of macroalgae in the western bay due to the currently high concentrations of chlorophyll-*a* and suspended solids, which indicated a phase shift from historic submerged aquatic vegetation (SAV) to phytoplankton. Alkaline phosphatase activity of the red macroalga *Laurencia intricata* decreased from the eastern bay to the western bay, indicating a trend towards reduced P-limitation in western Florida Bay. The C:N ratio of *Laurencia intricata* also decreased from ~ 20:1 in the eastern bay to 10:1 in the western bay, also indicating N-enrichment in the western bay. Thus, it appears that the macroalgal blooms in the eastern Gulf of Mexico and western regions of Florida Bay in the late 1970's and early 1980's could have resulted, at least in part, from increased N loads from the Everglades and/or eastern Gulf of Mexico.

We also examined the possibility that the dramatic increases in chlorophyll-*a* and light attenuation in the western and central bay since 1991 could have been linked to increased flows and N-loads from the Everglades. Nutrient concentration and flow data from the South Florida Water Management District were used to determine nutrient gradients through the Everglades and to estimate potential external nutrient loadings to eastern Gulf waters and western Florida Bay for the 1980's compared to the period 1991-1995. These data indicated a trend of increasing N-loading to coastal waters begining in 1991, which correlated directly with the phase-shifts away from SAV towards increased phytoplankton biomass in the western and central bay since 1991. Thus, in Florida Bay, the health and distribution of seagrasses in western regions seems to be inversely related to external N loads, as is the case in Tampa Bay and Sarasota Bay. It would seem that unanticipated side effects of increased water deliveries to the Everglades might be associated with recent decreases in seagrass coverage and increased phytoplankton biomass in the downstream waters of the eastern Gulf of Mexico and Florida Bay.

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Flow within Florida Bay and interaction with surrounding waters.

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Observational studies of the interaction and exchange of Florida Bay with the connecting coastal waters of the Gulf of Mexico and the Atlantic in the Florida Keys have been initiated to address several of the key scientific questions presented in the NOAA/COP Florida Bay Implementation Plan as critical to understanding the functioning of the ecosystem and future evolution from restoration actions. In particular, the research will address the following questions:

1) To what degree is the circulation of water within Florida Bay coupled to that of the surrounding coastal and oceanic environments?

2) What is the relationship of surface and groundwater flows through the Everglades to the salinity of Florida Bay?

3) Is the quality of the water flowing from the Bay contributing to the degradation of corals along the reef tract of the Florida Keys in the Atlantic Ocean?

Observational methods consist of a combination of synoptic shipboard surveys, in-situ moorings and Lagrangian surface drifters to describe and quantify the circulation within the Bay as related to local forcing and coupling with the waters of the Atlantic and Gulf. These observations will also help to provide necessary boundary conditions for future physical and biological models.

Field Work: The University of Miami study of Florida Bay circulation and exchange has completed five hydrographic surveys of Florida Bay and the surrounding waters, consisting of seasonal surveys of winter, spring and summer conditions that include the hydrological cycle from dry to wet seasons, and surveys before and following the passage of a major winter storm. A 20 ft. shallow draft catamaran, the R/V Miller, owned by the NOAA Southeast Fisheries Center has been equipped with a continuous flow thermosalinograph/fluorometer and a broad band 600 KHz Acoustic Doppler Current Profiler (ADCP) for conducting the hydrographic surveys in Florida Bay and nearby waters. A five mooring current meter array has been maintained since December 1995. Time series of current, temperature, conductivity and bottom pressure are being collected in western Florida Bay and adjacent southwest Florida shelf and Florida Keys coastal waters. Harbor Branch has maintained current meter moorings between Cape Sable and Marathon and in the major passes between the Keys. These data are used to determine the degree and variability of coupling of Florida Bay to surrounding waters. Un. Miami has obtained 3 month surface drifter trajectories from two satellite tracked drifters over the winter/spring period and has estimated the tidal and net transports through the major exchange passages between the Florida Keys over tidal periods during winter and summer seasons using a 600 KHz broad band ADCP mounted between the hulls of R/V Miller.

Initial Scientific Results: The Shark River discharge forms a narrow low-salinity plume that is adverted towards Florida Bay and the Keys to the southeast by a net background flow of 1 to 4 cm/s. Plume widths range from about 2 to 20 km and vertical stratification can be up to 3 psu per 3 m water depth near the river mouth. Plume shape and salinity structure is a function of seasonal and episodic river discharge, local wind forcing and tidal mixing. Extensive exchange between the waters of the western Florida Bay and the Gulf of Mexico occurred during the passage of an intense cold front, but little exchange occurred in the northeast interior portion of Florida Bay. High chlorophyll concentrations are observed in Key West Harbor and in the low salinity plume downstream of the river mouth, indicative of planktonic uptake of riverborne nutrients. Drifter trajectories show evidence of a cyclonic recirculation between West Cape Sable and Cape Romano. Synthesis of drifter trajectories from this project and those deployed in a coordinated DEP project indicate a net southeastward flow from the Gulf of Mexico to the Florida reef track through western Florida Bay that varies with season, stronger in the winter (3 to 4 cm/s) and weaker in summer (1 to 2 cm/s). Drifter trajectories are strongly influenced by local tide and wind forcing. A multiple linear regression model is used to explain approximately 70 to 80% of the subtidal variance of drifter currents due to local wind forcing. The cause and variability of the residual background currents are unknown at this time.

Net volume transport through Channels 5, 2 and Long Key Channel combined is estimated at 1500 - 2000 m3/s toward the southeast. Net flow through Seven Mile Bridge is also estimated about 2000 m3/s towards t h e southeast. This is equivalent to the peak river discharge onto the southeast U. S. shelf by all the rivers between Florida and Cape Hatteras. Approximately 1000 - 1500 m3/s flows through Long Key Channel alone, which is about 200 times greater than the peak fresh water discharge out of Shark River. These net flows have been estimated for single tidal periods in winter and summer and have not as yet been corrected for tidal inequalities. Also we found that all surface drifters deployed near Shark River and in the western part of Florida Bay were observed to exit Florida Bay toward the reef track through Long Key Channel. Therefore it appears that waters from Shark River and the seagrass die-off region of western Florida Bay will be passively adverted and dispersed toward the Florida Keys Marine Sanctuary (FKNMS) primarily through Long Key Channel by this strong mean southeastward flow. The advective/dispersal time-scale for materials in the Shark River Plume to reach the FKNMS is estimated from drifter trajectories at one to two months.

Long-term current meter data indicate that the maximum cross-shelf flow in the FKNMS from Key Largo to the Dry Tortugas occurs in the outer shelf of the Long Key region. After entering Hawk Channel and the reef track the drifter trajectories were either northeast or southwest depending on the direction of the alongshore wind. Several drifters were entrained by the Florida Current and one was ejected out of the Florida Current northeast of Cape Hatteras into a warm-core ring and recirculated within this ring as it slowly progressed to the southwest in the Middle Atlantic Bight (MAB).

The effects of hydrology on fishes of the Florida Bay mangroves zone.

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The mangrove-dominated zone that forms the interface between the Everglades and Florida Bay and Biscayne Bay is an important area for wildlife in south Florida. This polyhaline dwarf red mangrove (*Rhizophora mangle*) forest is a primary habitat of the endangered American Crocodile and West Indian Manatee and is heavily used as a feeding ground by wading birds. Historically, this ecotone may have been an important nursery ground for game fishes. Prior to the C&SF project, freshwater from the Everglades reached the Florida Bay mangroves via Taylor Slough. In recent decades, the hydrology of the mangrove zone has been altered by the construction and operation of a system of canals and levees. Outstanding among these is the C-111 canal, which diverts water from Taylor Slough to an area just east of US Highway 1, thereby disrupting the natural processes in both areas. Further complicating the freshwater flow pattern is the US Highway 1 levee which has blocked all sheet flow from the Everglades to Biscayne Bay, however large pulses of freshwater reach Biscayne Bay during storm events via the C-111 canal.

There is strong evidence that, over the past 50 years, the flora and invertebrate fauna of the mangrove zone has changed from predominantly fresh water species to salt tolerant species, indicating that the marine environment has recently intruded into this area. During this same period, the number of wading birds nesting on Florida Bay keys has declined precipitously. Since the primary foraging area for these birds is the ecotonal area, it is possible that these physical and ecological changes have adversely affected the quality of the areas as foraging grounds for wading birds. The basic hypothesis of this study is that prey base fish populations have ultimately been impacted by these changes in the hydrological regime over the last several decades, and that these changes in prey base may be implicated in the decline of wildlife throughout the Florida Bay region.

To accomplish our goal of linking manmade changes in water delivery to resident species abundance, we sampled fish populations in the mangrove zone of Biscayne and Florida Bays from August 1990 through present at four to six week intervals. A 9 m2 drop trap designed specifically for sampling fish in this environment was used to collect fish samples. In conjunction with these samples, a detailed analysis of hydrologic conditions was made through the use of continuous recorders. Sites were selected based on the proximity and hydrologic influence of Taylor Slough. Three sites north of Florida Bay were selected based on a decreasing west to east gradient of the influence of the Slough. TR (Taylor River site located in eastern Taylor Slough) received the most fresh water, HC (Highway Creek site just east of US1) received the least and JB (Joe Bay site located northeast of Joe Bay) was intermediate. The first samples were collected at JB and HC in August 1990. Collections began at TR in December 1991. A fourth site, BS (Barnes Sound site located southwest of Card Sound Bridge) was sampled starting in February 1992. Historically, BS received fresh water surface flow from the Everglades, but the construction of US1 and Card Sound Roads had impounded the area, effectively cutting off all sheet flow connection to the Everglades.

A wide variety of hydrologic conditions occurred over the six years of data collection ranging from drought conditions in 1990 to extremely high water events in 1994 and 1995. Combined with the spatial variability in fresh water flow to the sites, this interannual variation will be used statistically to demonstrate how different hydrologic regimes affect the prey base. Preliminary numerical analysis indicate that prey fish density and biomass are adversely affected by lower rates of fresh water inputs however, there appears to be some maxima beyond which more fresh water input resulted in no net increases in fish abundance.

Data collections will continue through August, 1997 and at that time the possibility of continuing this type of work will be evaluated. How the amount of fresh water flow into the system impacts the prey base is not well understood and is the subject of associated studies. Surveys of macrophyte vegetation are being conducted in connection with fish collections. The response of the macrophyte community to hydrological conditions may provide insight into the fluctuations in prey base fish populations. Growth enclosure studies are being performed at all sites using 1 m2 enclosures to determine how different hydrologic conditions affect growth of fishes and epiphytes. Stable isotope and gut analyses are being performed on fish specimens collected over the six year period to determine trophic relationships of the prey base community. An evaluation of the impact of the exotic Mayan Cichlid is ongoing. Recent investigations include an analysis of the life history of this species in the southern Everglades. Future experiments will look at the impact of this species on the prey base community and its relative value as a prey item to game fishes and wading birds. Funding for past and ongoing studies has been provided by the South Florida Water Management District, the U.S. Army Corps of Engineers and the John D. and Catherine T. MacArthur Foundation.

An assessment of mollusks as indicators of environmental change in Florida Bay.

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OBJECTIVES: Knowledge of the relationships between environmental change, habitat change, and the recruitment, growth, and survivorship of constituent fauna is requisite for restoration efforts to be effective in Florida Bay. The work reported here is intended to describe the composition and map the distribution of benthic faunal assemblages in the bay, using mollusks to represent those assemblages, and to assess the impact of salinity fluctuations on those assemblages. The information acquired will enable managers to more accurately predict the consequences of proposed restoration activities that involve alterations of Florida Bay salinity.

Mollusks are important components of the bay fauna, influencing the composition and structure of its sediments and serving as food for other life forms (Lyons, 1995). Even the concept of subenvironments, now adopted by researchers in several disciplines, was promulgated from evidence of dead mollusk shells, whose distributions indicated distinctive assemblages in several regions of the bay (Turney and Perkins, 1972). However, Florida Bay is a dynamic estuary where environmental conditions, especially salinity, fluctuate widely, so faunal composition should shift, at least temporally, in response to environmental perturbations. Evidence of relatively recent faunal shifts has been found in shallow cores from Florida Bay (Wingard *et al.*, 1995a, b), and similar shifts seem evident among data from some of Turney and Perkins' sites, where shells of brackish, marine and even semi-terrestrial species were found mixed in single samples. By restricting observations to living animals, we can produce relatively instantaneous "snapshots" of assemblages, thereby allowing more precise correlations between the assemblages and their ambient environmental parameters.

PROGRESS: Using methods described by Lyons (1995), we sampled mollusks quantitatively at 101 sites distributed throughout the bay in summer 1994. Most of the bay exhibited varying amounts of hypersalinity; bottom salinity ranged upward to 52 ‰, exceeded 36 ‰ at 75 of the 101 sites and exceeded 30.0 ‰ at 97 of the sites. Discolored waters due to phytoplankton blooms occurred in zones of higher salinity in the central bay. Elsewhere, turbid wind-driven waters bearing silt and organic detritus from breakdown of the seagrass beds swept westward onto and across banks and deeper areas near the western bay boundary.

Ninety-four species and nearly 14,000 specimens of mollusks occurred in the 1994 samples. Most of the species showed discrete distributions. Intersite comparisons of species composition and abundance among the 60+ more common species indicated four groupings of contiguous sites: an east-central and a western group, each with three subgroups; a peripheral Gulf boundary group; and a northern interior brackish-water group. Species richness was generally lower in zones of highest and lowest salinities. Because most species have been found to live in discrete assemblages, the more wide-spread distributions of their dead shells probably result from environmental fluctuations. Live-collected animals of some species have been found distributed in a pattern suggesting that they avoid or cannot tolerate very high salinity; the more widespread occurrence of their dead shells probably indicates more moderate conditions in earlier times. These living assemblages can also be useful in interpreting conditions indicated by fossil evidence. A relatively young fossil molluscan assemblage found at the Bob Allen Keys (Wingard *et al.*, 1995a) was absent when we sampled there during the 1994 high-salinity event, but the assemblage was found at several sites a few kilometers away. Data from those sites can provide insight into prior environmental conditions at the Bob Allen Keys.

The hypersaline conditions of summer 1994 were followed quickly by rains that reduced salinity throughout the bay. The highest salinity measured among 105 sites in August 1995 was 35.5 ‰; salinity ranged from >28.0-35.5 ‰ at 70 sites, from >20.0-28.0 ‰ at 21 sites, and from 0-20 ‰ at 14 sites. Hypersalinity had disappeared from the bay, and hyposaline conditions prevailed at many sites. The plume of silt and organic detritus had also abated by summer 1995, and sediments began to stabilize at the western banks. Thirty sites selected by stratification among the 1994 groupings were resampled during August 1995, and another site peripheral to the bay was added to investigate faunal transitions. The 31 sites yielded 2,853 specimens in 86 species, including 17 “new” species not recorded in 1994 samples; all of the “new” taxa were uncommon or rare. To examine seasonal influences and to further monitor species richness and abundance, 15 of the 31 sites were resampled in November- December (fall-winter) 1995, yielding 542 specimens in 64 species, including 5 species not recorded in prior samples. Sixteen of the sites were again resampled in early April (spring) 1996, yielding 795 specimens in 78 species, including 8 “new” species. Finally, the 102 sites were all resampled during July-August 1996.

Results that follow are from the 30 sites sampled in the summers of 1994, 1995, and 1996, and from the subset of those sites that was sampled up to five times during slightly more than two years. The cumulative list of species represented by living animals has increased from 94 to 124 since 1994, but all the additional species are uncommon or rare and contribute little to the characteristic fauna, whose composition has remained stable. The most dramatic changes during the period include a general decrease in molluscan abundance and marked faunal changes along the northern rim of the bay where salinity changes have been greatest. Results from fall-winter 1995 and spring 1996 indicate moderate declines in species richness at most eastern bay sites, where salinities have remained around the low 20’s. In the western bay, species richness and abundance have increased at the shallow sites where siltation has diminished. Species richness has also increased at southern sites nearest the Keys.

The general decrease in molluscan abundance from 1994 to 1996 is attributed principally to a single species. Abundance in 1994 was much influenced by a mussel, *Brachidontes exustus*, that occurred at half of all sites and contributed 78% of all specimens. The species occurred throughout the eastern and central bay, usually in low numbers, but it was abundant at a few sites along an arc from Madeira Bay to Pontoon Bank. Mussels were most abundant near Triplet Keys, but its numbers diminished there as they did nearly everywhere in 1995 and 1996. However, a recruitment event near Pass Key during spring-summer 1996 suggests that the population may again be increasing.

Where salinities were highest in the north-central bay, salinities are now moderate but the molluscan fauna has suffered what may be a temporary collapse. Mollusks were rare in Rankin Lake during summers of 1994 and 1995, but a moderately abundant and distinctive fauna was found at both Garfield Bight and Rankin Bight in 1994. That fauna disappeared from Rankin Bight by summer 1995, was gone from Garfield Bight by fall-winter 1995, and did not reappear there in spring 1996. However, *Tellina tampaensis* and *Anomalocardia auberiana*, the bivalves that characterized the assemblage at those sites in 1994, reappeared in August 1996. Likewise, *Macoma mitchelli*, a bivalve that favors mesohaline environments, constituted 94% of all specimens at Joe Bay in 1994 but virtually disappeared in summer and fall 1995, when salinities fell to near zero. However, its abundance began to increase again in spring and summer of 1996, when salinity climbed back into the mesohaline range.

SUMMARY: We have described and mapped distributions of molluscan assemblages throughout the bay during the prior hypersalinity event. Next, we monitored species composition and abundance at 15-30% of the sites for two years to elucidate seasonal faunal shifts and to assess regional trends during the period of transition as bay waters shifted from hypersalinity toward hyposalinity and then back toward a more moderate regime. Finally, we have resampled all of the original sites during summer 1996. After those samples are processed, we will identify and map the constituent assemblages as they occurred under conditions of moderate salinity, and we will describe changes that have occurred during the bay's recovery from the hypersalinity event.

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Simulations of regional climatic patterns which impact the Florida Bay water cycle.

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Persistent, locally forced weather regimes, such as sea (land/lake/urban heat island) breeze circulations, generate thunderstorm complexes over the Everglades and coastal areas that provide roughly one-third of Florida's annual rainfall. Heavy rain episodes have profound effects on the salinity and nutrient content in Florida Bay, cause sewage system overflows, and result in eutrophication by fertilizer/pesticide/contaminant runoff from agricultural and industrial areas. In addition, the horizontal distribution of saturated soil or standing water sets up a complicated surface heat/evaporation feedback cycle, which alters the location of subsequent thunderstorm formation.

In a quest to increase the precision and accuracy of estimating the rainfall/evaporation over Florida Bay, the Center for Analysis and Prediction of Storms' (CAPS) Advanced Regional Prediction System (ARPS) cloud-/mesoscale atmospheric numerical weather prediction model has been configured to simulate the sea breeze regime over the Florida Peninsula and surrounding waters at high resolution. During the past year of this project, the ARPS model's capability has been extended (by incorporating warm rain and ice-phase microphysics) to predict the amount and the distribution of rainfall. Previously, only moisture convergence and the locations of dry convective cells could be predicted. Realistic precipitation patterns have been replicated along the sea breeze front in an August 1975 case study from the Florida Area Cumulus Experiment (FACE).

A two soil-layer force/restore surface energy budget, with multiple categories of soil and vegetation, has been used to simulate the atmosphere's response to diurnal heating. A by-product of the calculation of radiation and the vertical flux of water vapor is the prediction of evaporation - at the ground surface, from the fraction of foliage covered by intercepted rainfall, and from transpiration by leaves.

Because the development of the sea breeze, the onset of convective systems, and the dispersion of atmospheric pollutants are sensitive to the depth of the planetary boundary layer (PBL), its determination is of great practical concern. ARPS has recently been enhanced to predict the PBL height as a function of time. This innovation prevents the artificially excessive storage of heat within the turbulent layer near the earth's surface and, thus, eliminates the unrealistic explosive growth of convective cells when they suddenly penetrate "capping" atmospheric inversions. Inclusion of a full 3-D radiation physics package, for simulating the absorption/transmission of solar radiation by the atmosphere and clouds, now prevents "runaway" (not self-limiting) convection.

Working closely with scientists at the South Florida Water Management District (SFWMD), ARPS-predicted rainfall and evapotranspiration patterns will be used to drive both the Natural System Model (NSM) and the South Florida Water Management Model (SFWMM), then assess the relative sensitivities of the natural vs. present-day surface/groundwater flows to the precipitation. Several classes of typical summer day weather scenarios (east/west coast sea breeze, upper-level cold low instability, hurricane) will be defined, GIS soil/vegetation and land cover/use databases will be incorporated, and the surface conditions (where ponding exists, depth to groundwater, etc.) will be prescribed for the natural system vs. present-day conditions. By selectively reverting isolated areas of urbanization and drainage in the simulations, any distinctive microclimates (urban heat islands and associated shifts in the rainfall distribution, for example) which have emerged over the past century will be identified. The impact of proposed modifications to the groundwater flow and the future urbanization/development of pristine areas will also be investigated. Results from these experiments will provide a basis for the development of a fully-coupled hydrometeorological model in subsequent research efforts.

The achievement of these important milestones in the development of the ARPS atmospheric numerical weather prediction model makes the generation of high-resolution simulations of rainfall and surface winds, and their application as tactical decision aids (TDAs) in Everglades restoration management, a near-term possibility.

A monitoring program for the endangered American crocodile in Florida Bay.

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The American crocodile is a federally listed endangered species, whose main population center is in an area of northeastern Florida Bay likely to be affected by C-111 and Taylor Slough projects. Although the status of the American crocodile has long been a matter of concern it now appears that the population has stabilized in this region. However, as for other species of wildlife in southern Florida, the survival of crocodiles has been linked with regional hydrological conditions, especially water levels and salinities. Alternatives for improving water delivery into Florida Bay via Taylor Slough and the C-111 system may change salinities and water levels in the receiving water bodies. To insure the continued survival of an endangered species in a changing environment it is important to monitor the population.

In the Taylor Slough/C-111/Florida Bay system a successful endangered species monitoring program should investigate population parameters likely to be affected by alternatives proposed for ecosystem restoration. For crocodiles population parameters most susceptible to hydrological conditions are distribution, growth, survival, and nesting effort and success.

The objectives of the crocodile monitoring program were:

1. To monitor nesting effort (number of crocodiles that attempt to nest) and success (number of nests that hatch) of the American crocodile in Everglades National Park.

2. To assess the patterns of growth and survival of crocodiles from nests from different locations and habitats.

Crocodile nesting effort and success was determined by searching known and potential nesting habitat in Everglades national Park during April and May (effort) and July and August (success) for activity (tail drags, digging or scraping) or the presence of eggs or hatchlings. When nests were located and their vegetation, substrate, distance from shore, dimensions (lxwxh) and salinity of adjacent waters were recorded. Hatched eggshells or hatchling crocodiles are evidence of successful nests. The number and causes of egg failure was noted whenever possible.

Growth and survival of crocodiles was assessed by capturing and marking them during nest surveys, followed up with periodic efforts at recapturing them. Over 800 crocodiles have been marked in Everglades National Park since 1978 (over 2500 in south Florida). Recapture of crocodiles tagged from previous studies will yield valuable information on long term growth and survival of crocodiles. Twenty nests were located in 1994 (70% successful, 20% depredated by raccoons and 10% failed for unknown reasons) and 21-23 in 1995 (43-47% successful, 30-33% depredated, 17% flooded and 10% failed for unknown reasons).

Ninety-three hatchlings were marked in 1994 and fifty-four were marked in 1995. Six non- hatchling crocodiles were captured.

It is important not to over interpret two years worth of nesting data. The number of nests continues to increase, but nesting success (proportion of nests that produce at least one hatchling) took a notable plunge in 1995. Is this natural variation or the beginning of a trend that we should be concerned about? Increased nest failure due to flooding is not surprising during a wet year. Increased nest predation could be due to an unrelated reason or perhaps, could be the result of a concentration of raccoons avoiding flood conditions by moving to higher ground where crocodiles nest.

It is worthwhile to review aspects of crocodile nesting biology as they relate to the moisture content of nests. The moisture content of nests, including catastrophic flooding events is most dependent on local rainfall. However, high ground water levels near creek nest sites have been correlated with upstream water discharges into C-111. Although the sudden rise in water level that floods a nest is caused by rainfall, the frequency at which rain events flood nests may be increased because of high water levels caused by upstream discharges. This may have happened in 1995. Whatever the causes, the dramatic increase in nest failure was concentrated in northeastern Florida Bay in an area likely to be influenced by C-111/Florida Bay restoration plans.

Although useful as a general indicator of the health of a crocodile population, monitoring nesting success alone is not adequate to evaluate effects of hydrological changes. Adding nesting effort (locations of all nests, and hence failed nests) to nesting success is more indicative of the effects of alternative water delivery plans, and is the minimum level of monitoring that should be undertaken. The shortcoming of using the number and location of nests as the only measure of crocodile population responses is that some effects may not become evident for several years. Growth and survival of hatchling crocodiles, and the distribution of all size classes of crocodiles would be more sensitive measures of population responses to experimental water deliveries.

This is particularly relevant here. We hypothesize that increased freshwater flows into northeastern Florida Bay could increase growth and survival of hatchling crocodiles. It is possible that an increase in survival could more than compensate for any loss of successful nest nests (high water related or not). There are little field data to support this hypothesis. We will continue to capture crocodiles to address this issue.

Response of submerged macrophytes to freshwater inflow to Florida Bay.

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Surface water enters Florida Bay at the northern land margin and eventually evaporates in the open parts of Florida Bay to the south and west. Submerged macrophytes are potentially influenced by the flow of surface waters in ways that range from subtle to direct. Presumably the influence of surface water discharge should be greatest near the northern land margin of the bay. Work begun 10 years ago on the effect of freshwater discharge on submerged vegetation in the northern land margin resulted in a salinity fluctuation hypothesis. This is now being tested.

During 1986-87, benthos, water quality, and other environmental variables were checked at twelve sites in northeastern Florida Bay 11 times in 18 months. The work was part of a study funded by the Everglades National Park and the South Florida Water Management District to determine the major factors that control ecological development in the region influenced by the C-111 canal. The purpose was to identify controlling variables that could be influenced by canal management and to quantify the relationship of such variables to the degree of ecological development among sites. For the benthic study, density of plants and animals was used as the measure of ecological development.

Bearing in mind that only periodic spot checks were being made, most of the measured environmental variables did not correlate with density of animals or plants. Light at the bottom, for example, did not correlate to plant density and was greater than 25% of incident light, which seems enough to support healthy beds of submerged vegetation of the type found sparsely in the area (e.g., *Ruppia maritima, Chara hornemanni, Halodule wrightii, Thalassia testudinum*). Some variables correlated, but were considered effects of biotic densities, not causes. Water-column nutrients, for example, were lower at sites with greater plant density. Only mean salinity, mean temperature, and the <u>standard deviation</u> of salinity experienced at each station correlated to plant and animal density. The best correlate was standard deviation of salinity, which indicated that salinity fluctuation might be the most important effect.

A working hypothesis was developed that salinity fluctuation rather than light, nutrients, temperature, or average salinity is the single most important variable determining the distribution and abundance of submerged vegetation at the northern land margin of Florida Bay. Several predictions can be made based on this hypotheses. Among these are: 1) survival and growth of the common species of submerged vegetation will be drastically reduced by rapid, sudden, and extreme changes in salinity; 2) density of submerged vegetation will be lower at sites with less salinity fluctuation; and 3) hydrodynamic models that can make good predictions of salinity fluctuation can also predict the distribution and abundance of submerged vegetation. Tests of these predictions are now underway.

Since the 1986-87 study, a network of continuous salinity recorders have been installed along the northern land margin of Florida Bay, and convenient portable salinity loggers have become more readily available. In addition, conditions have changed somewhat in Florida Bay. The northern land margin has been fresher with the return of wet years, and the outer bay water has been more turbid with the onset of a massive algal bloom. A new opportunity has been afforded to re-measure the relative effects of nutrients, light, and salinity fluctuation and to judge their relative importance.

Monitoring stations have been established along the northern land margin of Florida Bay in proximity to salinity recording stations, and at stations along two salinity gradients. The western salinity gradient (Terapin Bay to Seven Palm Lake) includes large volume estuarine lakes, while the eastern gradient (Taylor River) contains very small ponds. The monitoring stations in the large lakes are expected to span the same salinity gradient as the stations in small ponds. The large lake sites, however, should experience less salinity fluctuation, so more submerged vegetation is expected on average at these stations. Stations in the middle of the salinity gradient are likely to be most variable in salinity because they receive alternating surface drainage and bay water with every shift in wind speed and direction, and every rain event over the watershed. These stations are expected to have the least submerged vegetation. Light penetration, nutrient concentration, temperature, and the absolute value of salinity may also influence or confound these field data, so are being monitored.

Controlled experiments with the effect of salinity fluctuation on submerged vegetation can help pinpoint the role of salinity fluctuation without confounding from other field variables. To this end, an experimental mesocosm facility has been designed, approved, and will soon be under construction on Key Largo. The facility will consist of 12 experimental 1000 l tanks fed by mixtures of saltwater and freshwater from large head tanks. Salinity fluctuations of specified frequencies, amplitudes, and waveforms will be produced by manipulating flows from each head tank. As many as four patterns can be produced simultaneously (with each pattern distributed to three randomly chosen experimental tanks). Other combinations are possible.

Model predictions of abundance and distribution depend in part on the validity of the salinity fluctuation predictions, and the ecophysiological linkage of these to species of submerged vegetation. The mesocosm experiments together with studies of the osmolality of the tissues of the plants involved, will be used to calibrate and refine an existing model of the relationship between salinity and plants. This model can be expanded to include nutrient, light, and temperature effects as quantitative evidence of their influence develops.

<u>General survey of submersed macrophytes (D. Morrison)</u>. This project is a descriptive survey of the seasonal distribution, abundance, and community structure of submerged macrophytes in the Everglades - Florida Bay mangrove ecotone. The study will correlate macrophyte seasonality with seasonal patterns in physicochemical parameters, especially salinity. The project will provide baseline data to develop manipulative field and laboratory experiments; to identify and evaluate potential biological indicators of freshwater inflow; and to assess the ecological effectiveness of management actions to restore more natural freshwater inflow patterns. Project duration is October 1995 to December 1996. The geographic focus of the study is the lakes and embayments along the north shore of Florida Bay from Seven Palms Lake west to East Cape Sable. Two sets of sites are oriented along freshwater flow paths from inland to the Bay. These are the system comprising Seven Palm Lake, Middle Lake, Monroe Lake, and Terrapin Bay; and the system West Lake, Long Lake, The Lungs, and Garfield Bight. Additional waterbodies sampled to the west of these systems are Coot Bay,and East Cape Lake. Two sampling regimes are used for submerged macrophytes. All study waterbodies are sampled at the end of the wet (October) and dry (May) seasons to assess species distributions and abundances on a waterbody-wide scale. Six to ten sites are sampled for macrophyte percent cover (10 to 15 random quadrat samples at each site) in each study waterbody. Biomass sampling (15 random 1/8 m2 quadrats per site) is conducted every two months in 1996 at one site in each of the following waterbodies: Seven Palms Lake, inner Terrapin Bay, outer Terrapin Bay, West Lake, The Lungs, and Garfield Bight. The following physicochemical parameters are sampled at least monthly in each study waterbody: salinity, nutrients, temperature, secchi depth, water depth, and turbidity.

In West Lake, an “upper” lake, macrophyte abundance, Chara and Ruppia, was greater at the end of the 1996 dry season than the 1995 wet season. Salinity did not change greatly between seasons (1995 wet 3-4 ppt; 1996 dry 7-9 ppt). However, the secchi:water depth ratio, an indicator of light penetration, in the 1996 dry season was twice that in the 1995 wet season. Preliminary 1996 wet season sampling indicates little difference in plant cover and secchi:water depth ratio from the 1996 dry season. Water depths are lower and water clarity higher in the 1996 wet season than the 1995 wet season. Irradiance appears to be a more important factor than salinity affecting macrophyte distribution and seasonality in West Lake. In the Lungs, the “middle” lake in the West Lake system, macrophyte abundance (primarily Chara) was greater in the 1995 and 1996 wet seasons than the 1995 dry season. Salinity seasonal variation was greatest in the Lungs (<5ppt wet vs. >40 ppt end of dry). The macrophyte abundance declined considerably in the Lungs following high salinity in April and May. Macrophyte seasonality in the Lungs is correlated with salinity seasonality. Seven Palms is an upper lake like West Lake; however, water clarity is greater and less seasonal and salinity seasonality is greater in Seven Palms than West Lake. Chara abundance was greater at the end of the 1995 wet season than the 1996 dry season; whereas Batophora exhibited the opposite pattern. Macrophyte seasonality and distribution was correlated with salinity. The lakes in the mangrove ecotone zone exhibit different submerged macrophyte seasonal patterns. The same lake may exhibit different seasonal patterns from year to year. These patterns are influenced by freshwater inflow quantity and timing which affects salinity and light penetration. This study emphasizes the need for manipulative field and laboratory experiments to elucidate and model the factors that determine macrophyte dynamics in the ecotone zone.

The sediment record as a monitor of natural and anthropogenic changes in the Lower Everglades/Florida Bay ecosystem: A high resolution study.

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In the absence of historical data and records for the lower Everglades/Florida Bay ecosystem, a proxy-record such as that potentially recorded in the sediments must be evaluated for long-term trends. An understanding of such a proxy-record can be complicated by disruption such as bioturbation and other processes such as storm-induced sediment removal and deposition. To overcome these potential complications, clearly stratified sedimentary sequences were sought for this study. The stratified records vary with respect to continuity of record, persistence of sediment deposition, local reworking, and presence/absence of erosional hiatuses. The nature of the sediment-biotic-geochemical record is dependent on the style of sediment deposition in the area.

The most difficult and critical part of the field program is locating meaningful, stratified sediment sequences. Layered sequences are associated with areas of focused sediment deposition during tidal, winter storm, freshwater flood events, and/or hurricane events. Day to day tidal processes, potentially provide the most detailed sediment record, but do not alone transport and accumulate sufficient sediments in an area to provide a discernible record. The finest scale records found occur where focused tidal flow decreases and deposits sediment provided by winter storms and river flood resuspension events. These records are preserved in areas protected from erosion by winter storm, flood, and hurricane erosion conditions. The least detailed sediment records are formed in areas subjected to hurricane events in which the surficial bio-sedimentary environments is smothered by a hurricane event deposit. These smothering events however, provide a highly detailed preservation of the benthic environment at the time of the hurricane.

This presentation is focused on an example of our work and is of a core selected to document the effect of changes in freshwater discharge from the main drainage system of the Everglades on the adjacent marginal marine water and environment. Using historical aerial photographs combined with our published knowledge of south Florida sediment-body dynamics, we have defined the physiographic features of the Shark River drainage system, Whitewater Bay and northwestern Florida Bay most likely to contain interpretable historical sediment records. Integrating this with field coring reconnaissance, we have defined sites that have striking stratified sequences.

In order to understand the responses of the Florida Bay ecosystem, to natural and anthropogenically-induced changes, we are focusing our work on the following three testable hypotheses:

1. "*Anthropogenically-induced changes in freshwater flow across and out of the Everglades, over the last century, have caused changes in the adjacent coastal environment. This has lead to changes in the biogenic community structure which are both recorded in, and interpretable from, the sediment record.*"

2. "*Sedimentary records are interpretable with sufficient resolution that anthropogenic influences can be differentiated from natural changes associated with sea-level rise and natural catastrophic events.*"

3. "*Sediments, from within the Everglades freshwater system seaward into the estuarine environment, record an interpretable time-history of anthropogenic pollutants such as the heavy metals, Hg and Pb.*"

The core selected for this presentation, 9510-2, is from northwestern Whitewater Bay but related to the lower Shark River outflow system by a side channel which has strong tidal flow. The site is protected to the north and east by very shallow water and by mangrove shorelines less than 50 m away. The sample site is at the southern edge of the very shallow water and is a barren, very-soft muddy bottom that is extending southward as a gently sloping mud wedge. Tidal currents sweeping southward from the Shark River side channel weaken across the broad, deepening flank of the shallow bank. This results in deposition of much of the sediment load carried southward from this side channel. The sample site is protected from the northern and northeastern winds of the waning stages of winter storms, tidal scour and focused wind waves or currents during winter storms and hurricanes.

The core consists of 1-4 mm thick alternating laminae of light carbonate silt- and clay-sized particles and dark, fine, woody organic detritus. The lighter laminae are provided by winter storm resuspension both from the interior Whitewater /Oyster Bay system and from introduction from offshore. Organic laminae are provided by tidal erosion and suspension transport during prevailing conditions. As shown by Pb210 dating, the larger historical hurricanes to affect the area have caused 2-5 cm of erosion of the sequence.

Minor burrowing, although visible in X-radiographs of the core and in split sections, are small and scattered and have left the core sequences essentially undamaged by mixing or surface introduction of particles.

The geochronological record for sediment cores from the lower Everglades and northern Florida Bay shows accumulation rates that are typically about 1 cm/yr. High resolution sampling and analysis downcore reveal very good age comparisons between 137Cs and excess 210Pb. In addition to providing a sensitive time-line and accumulation rate information, a variety of fine-structure has been observed in the profiles including sediment erosion/deposition bands from dated hurricane events over the time interval of interest to this study.
Total Hg and Pb concentrations in the sediments range from 5-240 ng Hg/g and 1-30 µg Pb/g respectively. To help identify natural levels of Pb in sediments, Pb vs. Al plots were useful as demonstrated in other areas. However, Hg vs Al relationships were not useful because of high TOC levels in Everglades sediments (up to 35%), thus a Hg vs. [Al+TOC] function was successfully developed. Results showed that sediment with 1% Al and 30% TOC could have about 65 ng Hg/g relative to about 10 ng Hg/g in sediment with 1% Al and 2% TOC. Baseline data for natural Hg levels were used to show that sediment Hg levels were in excess of natural levels by 150 ng/g in sediments deposited since 1950 near the mouth of Shark River Slough and 20-30 ng Hg/g in post-1950 sediment from the lower Shark River and the more isolated Coot Bay. Pre-1950 sediments show no distinct Hg enrichment. At present, lower Hg/TOC ratios in surface sediment cannot be directly linked with recent decrease in Hg inputs relative to diagenetic alterations.

The predominantly organic nature of sediments at this location necessitates multi-step processing for microfaunal analysis. We have developed a new protocol for sample treatments, which has resulted in considerable reduction in processing time. Ostracodes, benthic foraminifera and micromolluscs isolated from this core are being characterized, and selected subsamples are examined for isotopic composition. To establish a salinity/benthic community data base, we have collected surface stained samples, and taken salinity measurements from several localities to examine ostracode and foraminifera benthic community structure/salinity relationships. In surface samples, major shifts in foraminifera community structure are not dramatic, however within the *Elphidium* genus, and the milliolids, significant species shifts were observed. Most of the members of the ostracode group are salinity sensitive. Even the euryhaline species appear to exhibit morphologic variability related to salinity differences at these sites.

Shifts in vegetation communities or assemblages are useful indicators of environmental change, especially in areas where plant communities are strongly controlled by changes in salinity and hydroperiod. The lower Everglades/Florida Bay ecosystem is such an area. Pollen grains incorporated in sediments during deposition record detailed information about shifts in past vegetation systems. Changes in Everglades floral communities record subtle shifts in the balance between fresh and marine waters. From this laminated sediment core, taken adjacent to the lower Shark River drainage, a detailed, high-resolution record of changes in the watershed and ecological response to changes in the ecosystem is preserved. Sediments deposited during different water management regimes in the Everglades/Florida Bay Ecosystem have been analyzed for contained pollen. Preliminary analysis has focused on samples representing distinctly different water management strategies including (a) unregulated flow through an undisturbed system (pre-1920); (b) unregulated flow through culverts under Tamiami Trail (1925-1960); (c) overland flow partially disrupted by construction of water conservation areas and Hurricane Donna (1960-1962); (d) an assortment of short term management practices (1962-1970); (e) static portion of water allocated to the park each year in the 1970’s; (f) S-12 structures left open so water delivery is a function of hydraulic gradients between water conservation areas and the park (1983-1984); and (g) the rainfall plan (1985-present). Pollen analysis, to date, has compared unregulated flow (a) to overland flow prior to and following Hurricane Donna (c) to hydraulic gradient delivery (f) to present management plans. Sediments deposited prior to 1920 have significantly different species compositions compared to those currently being deposited. Sediments deposited circa 1880 are dominated by species representing wet prairies, freshwater marshes and hammocks. Surficial sediments record significant decreases in freshwater species, especially wet prairie and hammock species and increases in red mangrove.

When viewed together, current results and anticipated progress provides a positive outlook for being able to place, within a temporal context, anthropogenic impacts on the lower Everglades/Florida Bay ecosystems, as preserved in the sediment record. We consider our seasoned approaches to this work to have opened the door for fruitful continued detailed paleoenvironmental reconstruction throughout our study area. From this, we anticipate, establishing a pre-anthropogenic paleoecological baseline against which to measure: a) restoration effort; b) paleo-water-column conditions for a historical context in which to place ongoing water-column studies; and c) as a reference for validation of hindcasts, and perhaps forecasts, of water-quality modeling efforts central to larger managerial issues.

Florida Bay as a nursery ground: assessing larval and juvenile fish communities.

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Unprecedented seagrass die-off events accompanied by algae blooms and a reduction in water quality in Florida Bay have caused concern as to the effects these disturbances might have on the function of Florida Bay as a nursery area for fishes. Of particular concern is the spotted seatrout, *Cynoscion nebulosus*, that spends its entire life history in estuarine waters and whose prime spawning habitat is located in the western portion of Florida Bay, an area where extensive seagrass die-off has occurred. To determine if these disturbances affected the juvenile and larval fish community, we have been comparing the abundance and distribution of juvenile and larval fishes prior to the seagrass die-off (1984-1985) to their present (1994-1995) distribution and abundance.

Since August of 1994 FDEP has been conducting a monthly trawl (6.1 m otter trawl, 3 mm mesh codend liner) and seine (22.3 m center bag seine, 3 mm mesh) survey at 31 fixed sites throughout Florida Bay (Colvocoresses). Qualitative comparisons of the preliminary results of this survey with historical data collected with similar gears indicates that the species composition and distribution patterns of many fish species has remained similar on a bay-wide basis, but that dramatic changes in species composition and relative abundance have occurred at sites in western and central Florida Bay where extensive seagrass die-off has occurred. This observation supports those by staff of NMFS, USGS and DEP in areas of seagrass die-off. Although the populations of small forage fishes and juvenile gamefishes vulnerable to these sampling gears have undoubtedly been impacted by the recent ecological disturbances, especially in the areas that undergone severe structural habitat changes, on a large scale basis these results indicate that the mobility and generally wide environmental tolerances of the estuarine fish community may serve to make it more resilient to these changes than other, more immobile, portions of the Florida Bay fauna. There are indications (see Thayer et al., This Symposium) from sampling with a high speed, small mesh (3 mm mesh cod end) bottom trawls, which more effectively sample the planktivorous fish community that certain planktivores have increased in abundance during recent times, suggesting that a shift in trophic patterns in the fish community has occurred.

To compare the present assemblage of larval fish with the historical assemblage, we sampled ichthyoplankton from September 1994 through August 1995 using the same sampling techniques, stations, and in the same months as in 1984-1985. In addition, we expanded our sampling to include previously non-sampled areas (central and northeastern Florida Bay) to increase our knowledge of spotted seatrout spawning habitat. A decadal comparison will be accomplished when samples, which are being sorted by the Polish Sorting Center, are processed.

The spawning habitat of spotted seatrout has now been defined. The collection of trout larvae at stations previously not sampled, along with data collected in 1984-1985, indicated that spotted seatrout spawn: (1) in the western portion of Florida Bay adjacent to the mainland from Cape Sable to Crocodile Point and adjacent estuarine waters where salinities are greater than 20 ppt; (2) along the edge of the Gulf of Mexico; and (3) in a portion of the central and western interior. Spawning does not appear to occur in waters adjacent to the Keys, in eastern Florida Bay adjacent to the mainland, or in waters approximately <20 ppt. Otoliths of spotted seatrout larvae and juveniles are being examined to (1) analyze hatchdate distributions and growth of larvae and juveniles to determine if differential survival and growth exists among cohorts, (2) identify environmental factors that could influence survival and growth, and (3) compare larval growth and spawning intensity along an east-west transect and compare these with changes in environmental factors (e.g., temperature and salinity).

A protocol for examining daily increments in otoliths was established from 68 juveniles collected from May through September, 1995 with an otter trawl and from 14 larvae collected from June through August, 1995 with ichthyoplankton gear. There was a good relationship between body length and the number of increments in the otoliths, suggesting that the number of increments were proportional to the age of the fish. Variability between size-at-increment number reflected variability in growth. We are presently examining the source of this variability to determine if it is influenced by environmental factors. Juvenile spotted seatrout, which were used to calculate hatchdate distributions, were most abundant in September 1995 collections. August was the dominant birthrate month, suggesting either intensive spawning during that period and/or favorable conditions for cohort survival. Data from ichthyoplankton collections will be used to determine the intensity of spawning by month during the sampling period from September 1994 through August 1995 and from April 1996 through September 1996. A preliminary analysis of the distribution of hatchdates of juvenile trout collected from May 1995 through September 1995 indicated that certain monthly cohorts (April and June 1995) were absent in our collections at the end of the sampling period (September 1995). This indicates a movement out of the sampling area or an indication of weak monthly cohorts. Analysis of otoliths from larvae that have yet to be processed along with the inclusion of more juvenile fishes should allow us to relate the survival of cohorts to environmental factors. When all ichthyoplankton samples are processed we will analyze our spotted seatrout data within the context of temperature and salinity. Available information suggests that strong salinity gradients occur in Florida Bay and salinity may influence spotted seatrout spawning and along with temperature may also influence hatching success. Existing strong salinity gradients may also influence total ichthyoplankton composition.

Sediment transport processes and sea-floor mapping in Florida Bay.

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Within Florida Bay, circulation and outflows are inherently linked to the processes of sediment resuspension, transport, and deposition. The complex bathymetry of the Bay, a product of sediment production and transport over time, constrains flow and limits mixing. Resuspension events cause increased turbidity, the recycling of nutrients, and facilitates the export of sediment-laden waters. Understanding how sediment transport processes and the overall bathymetry of the Bay respond to processes such as sea-level rise, storm events, and changing flows will allow us to predict future responses, both natural and man-made, and provide important data for hydrodynamic and water quality modeling efforts.

Three projects at the USGS are underway to investigate 1) bathymetric change in Florida Bay, 2) the processes and rates by which sediments accumulate and erode, and 3) to understand the timing and distribution of sediment resuspension. Individually, these projects will provide information essential to understanding ecosystem dynamics, and in combination, they provide an unprecedented baseline of data to evaluate the impact of future storm events on the bathymetry and sedimentology of Florida Bay.

The bathymetry of Florida Bay has not been systematically mapped since the 1890's, and some shallow areas have never been surveyed. In the 1930's, depth measurements were documented principally in the intercoastal channel just north of Key Largo and more recently, spot soundings have been conducted to better delineate the location of cuts and navigational hazards. A modern, digital map of Florida Bay bathymetry is needed to provide numerical modelers with an accurate base map, and to aid in the assessment of long-term patterns of sediment transport and deposition. Through the comparison of historical data with a modern bathymetry data set, areas of net erosion or deposition within the Bay can be identified.

The sea-floor mapping project focuses on the collection of an updated bathymetric data set for Florida Bay, the digitization of historical and modern data for comparison, and the production of quality maps and digital grids of both historical and present-day bathymetry, as well as those changes which have occurred.

Bathymetric data collection with a GPS based hydrographic system began in the summer of 1995 in the northeast quadrant of the Bay. The area east of Russell Key/Upper Matecumbe Key will have been surveyed by the end of 1996. Completion of the bathymetric survey is anticipated in 1998. Digitization of the historical bathymetric data was initiated in 1995. It is anticipated that the majority of digitizing of both the bathymetry and shorelines will be completed in 1996. All relevant information is being archived in a ARC/Info database.

In another project, we are addressing sediment resuspension processes in Florida Bay. Sediment resuspension within the Bay is principally a function of wind-driven waves and the properties of the sediments and sea-floor. A computer simulation of wave development within the Bay is being used to understand the effects of typical wind events. Preliminary results show the importance of the Bay's bathymetry and seagrass cover in controlling wave-driven flow. Current work focuses on the incorporation of varying bottom friction within the model. For this purpose, a map of bottom type and cover is currently being produced based on over 600 sampling sites throughout the Bay. In addition, to delineate the sediment properties controlling resuspension, over 100 surface samples are being analyzed for grain size, mud, water, carbonate, and organic content. Using statistical analysis of the data, a finite number of bottom and sediment types are being identified, these include areas of hard-bottom, dense seagrass, inermediate seagrass, sparse seagrass, open mud areas, a mudbank suite, and shell ridges. We will also quantify the resuspension potential in each of the bottom and sediment types identified using a portable resuspension device.

Using the results of wave modeling, sediment and bottom type analyses, along with the measurement of resuspension potential we expect to quantify the frequency and pattern of sediment resuspension in Florida Bay. This information will aid in our understanding of sediment export events, nutrient recycling, and patterns of turbidity within Florida Bay. Calibration for wave modeling will entail the deployment of a pressure sensor array in the Bay during one or more wind events. Satellite imagery of turbidity events, discussed elsewhere in this conference, will also be used for comparative purposes.

The third study focuses on the quantification of long-term sedimentation and erosion rates through the use of geochemical analyses of cores, multi-year surveys from monitoring stations, and detailed mudbank profiling. Five high-resolution profiles ($\pm$ 2 cm) across mudbanks show that they are shaped more like small mesas or plateaus with extremely flat tops rather than the mud mounds they have been compared with in the geologic record. Along each of three of these profiles, five elevation survey stations ($\pm$ 3 mm) have been established to monitor very small accumulations or losses of sediment. Stations and profiles provide the basis for determining long-term accretion or erosion and provide a baseline for major storm events. Where appropriate, downcore analyses of lead-210, total lead, and cesium-137 are also used to establish sedimentation rates during the last 100 years. These data together with sea-level rise estimates allow prediction of which portions of the bay will deepen, shoal, or remain the same during the next century. This predicted bathymetry can then be used to evaluate future changes in circulation in the Bay.

Baseline elevation measurements and profiling have been completed. Subsequent measurements will be made at least twice annually over the next two years. Core analyses are underway and results expected in the near future.

Hydrodynamic/salinity model to evaluate the impacts of alternative freshwater releases on salinity in Florida Bay.

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The Corps of Engineers, Jacksonville District (CESAJ) is considering a variety of freshwater release scenarios for operation of the C-111 canal system. Proposed operation plans will release freshwater into the Everglades and Florida Bay. The changes that these freshwater flows will have on circulation and salinity distributions in Florida Bay are at present unknown. The mixing rate of the freshwater under the influence of tides, storms, local evaporation and precipitation can be studied using a numerical model for hydrodynamics and salinity.

The USACE Waterways Experiment Station (WES) is developing a two dimensional (2D), vertically averaged numerical model for water surface, velocity, and salinity in Florida Bay. In conjunction with a groundwater flow model of southern Florida, the hydrodynamic/ salinity model will be used to estimate the effects of various C-111 operation plans on Florida Bay. A very large, detailed numerical mesh (approximately 35000 computational nodes and 13000 computational elements) has been developed. The mesh encompasses all of Florida Bay, part of the Atlantic Ocean south of the Florida Keys to the continental shelf, and part of the Gulf of Mexico has been developed. Because circulation in the Bay is strongly controlled by small scale bathymetric features, this detailed, unstructured grid will permit engineers to examine physical mixing process that are difficult to measure in the field. Once verified, the hydrodynamic model will accept freshwater flow information from the groundwater model and calculate the resultant salinity behavior of Florida Bay.

To model the effects of alternative freshwater releases on the circulation of Florida Bay, one must resolve the horizontal bathymetry of the basins, the partially submerged mudbanks, the mangrove swamps, and the coastal boundaries. Since the water column is generally well mixed, a two-dimensional, vertically averaged model of circulation in the Bay is adequate to simulate the majority of the hydrodynamic phenomena that have been observed. The equations that describe horizontal circulation and mixing in the Bay are the vertically averaged shallow water equations, the advection-dispersion equation for dissolved salts, and an equation of state relating salinity concentration to fluid density. The model to be used must be capable of resolving the complex horizontal distribution of mudflats, islands, and mangrove swamps that control circulation in the interior of the bay. The model must include an algorithm for describing the flooding and draining of the islands and mudbanks as water levels rise and fall. The modeling system that is being applied is the TABS-MD numerical modeling system that was developed and is maintained by WES.

At the heart of the TABS-MD system is the finite element model for two-dimensional, vertically averaged free surface flows known as RMA2-WES. This model was originally developed by Dr. Ian King at Resource Management Associates (RMA) under contract to WES. A sophisticated, user friendly, graphical user interface (GUI) known as the Surface Water Modeling System (SMS) has been developed at WES to facilitate the pre-processing of input files and the post-processing of model outputs. This GUI allows the user to visualize model results in a variety of ways, including contour maps, vector maps, and animated displays of time dependent solutions. A model of Florida Bay developed using these tools will be readily available to the local sponsors for in-house modeling studies.

The TABS-MD system uses an unstructured finite element grid to discretize the flow domain. The unstructured grid approach permits elements to be locally refined in the vicinity of small scale bathymetric features and locally graded to a coarser resolution in areas where the flow is more uniform. Simulation of flooding and draining over mudbanks requires a flexible grid system that accurately depicts shoreline movement. The TABS-MD system incorporates state-of-the-art algorithms for representing moving shorelines, while retaining the computational advantages of a fixed Eulerian grid.

WES is undertaking a field data collection effort to provide synoptic measurements of hydrodynamic fluxes through tidal inlets between the Keys that will be used to verify model behavior. Salinity maps and sediment bed maps provided by the USGS are being used to develop model initial conditions, boundary conditions, and verification data for the model. Open ocean boundary conditions and wind fields are being provided by NOAA for the model verification periods. The National Park Service, the

South Florida Water Management District, the CESAJ, and the Florida Department of Environmental Protection are providing additional data for the model. Dr. Barbara Hayes of Rutgers University is assisting WES in the development of boundary condition data sets derived from these data sources. In a cooperative research effort, Dr. Ned Smith of the Harbor Branch Oceanographic Institute will provide analysis of the model time series to determine the quality of the simulations when compared to long term data records.

The model development effort will produce a detailed, two-dimensional hydrodynamic and salinity model that can be used to test several different freshwater release scenarios for the C-111 canal system. The hydrodynamic/salinity model verification will be completed in calendar year 1997. The use of the model for evaluating alternative freshwater release scenarios will follow the release of the verified groundwater model which is scheduled for 1998. In advance of the groundwater model release the hydrodynamic model may be used to improve our understanding of circulation and mixing in Florida Bay, and to evaluate other possible scenarios, such as structural changes to widen the tidal inlets at selected locations in the Keys.

Nutrient exchange between Florida Bay and the Everglades' salinity transition zone.

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Efforts to restore the Everglades and Florida Bay largely entail changing the supply of fresh water to these ecosystems. Changing fresh water inflow to the Bay may affect its ecological structure and function via several mechanisms. Our research is focused on quantifying how changing fresh water inflow affects the cycling of nutrients within the mangrove dominated ecotone between Florida Bay and the Everglades and affects the net transport of nutrients through this ecotone. Understanding nutrient dynamics in this ecotone is important because this region contains a large pool of nutrients and its importance as a source or sink of nutrients may change with changing fresh water flow. Furthermore, salinity in this ecotone has a wide range and high variability; the effects of changing salinity on nutrient biogeochemical cycles should be most evident in such a region.

Our research program includes both the measurement of nutrient fluxes and experiments and simulation modeling that will help us understand the mechanisms that influence these fluxes. Field sites have been chosen along three north-south transects: through the Joe Bay - Trout Cove area, the Taylor River - Little Madeira Bay area, and the Seven Palm Lake - Terrapin Bay area. Each of these areas are important sites of freshwater inflow to Florida Bay and each spans a wide range of salinity. The distribution of transects also spans a wide range of nutrient availability, with increasing nutrient availability from east to west.

Quarterly measurements of nutrient fluxes in the Taylor River area started in January 1996, and will continue for 3 years. Fluxes in the two other areas will measured for at least one year. Net nutrient exchange between the Bay and the wetland is being calculated from measurements of water flow at the mouth of Taylor River (or other creeks) concurrent with frequent (every 3 hours) sampling for all major nutrient species in the flowing water for 10 day periods. In addition to these intensive quarterly sampling periods, daily samples are being taken year-round, with flow measurements, to calculate total N and P exchange.

Along with these measurements of net exchange, nutrient fluxes within the wetland, the mangrove creeks, and in the coastal ponds and embayments are being measured during the quarterly sampling periods. Benthic fluxes in ponds and bays are being measured using dark and light in situ chambers with continuous mixing. Mangrove prop root community - water column fluxes are being measured using duplicate 15 m long flumes along the creek banks and using corrals around small mangrove islands in the scrub mangrove zone. Fringe, basin, and scrub mangrove tree net productivity and litter fall is being measured in plots with marked individual trees and litter traps. Litter and soil decomposition rates are being measured with litter bags and the measurement of sulfate reduction and methane production. Net ecosystem production is being estimated from net exchange calculations and the long-term measurement of sediment accretion or subsidence using sediment elevation tables along the transects.

In addition to these flux measurements, we are measuring the spatial distribution of water quality parameters (pH, D.O, salinity, temperature, chlorophyll, nutrient concentrations) in the coastal region and the distribution of submersed aquatic vegetation in this same region (see abstracts by Montague, Chipouras, and Morrison, and Durako and Hefty). These spatial measurements will help us to understand the relationship of nutrient dynamics to landscape features and plant community structure and also provide data necessary for future landscape model calibration.

Experiments on mechanisms that influence nutrient dynamics will include studies on the effects of salinity change on sediment nutrient fluxes and prop root community fluxes, as well as experiments on the nutrient limitation of soil decomposition processes. To date, initial experiments have been done on the influence of different water sources on the prop root community. Comparing fresh water from Taylor Slough water and higher salinity ambient water, we found that prop roots with a dense epibiont assemblage exposed to Slough water had significantly higher water uptake rates than roots with few epibionts or any roots exposed to ambient water.

To integrate information generated from our study and related studies of Everglades - Florida Bay interactions, we are concurrently developing a simulation model of material fluxes between these ecosystems. The unit model includes nutrient exchange and transformation processes in the water column and sediments. This simple model is being implementing in a spatial manner, with upstream and downstream cells. This will enable us to asses the fate of conservative and non-conservative elements as they are transported through each of the sampled creeks and enable us to test the influence of changing water management regimes on nutrient dynamics.

Assessing the origin and fate of ground water in the Florida Keys.

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The origin and fate of nutrient-rich ground water is being addressed in three ways: 1) by direct subsurface measurement of direction and rate of flow using dye tracers (Shinn et al.), 2) by detection and measurement of methane, radon, and an artificial tracer, sulfur hexafluoride (Chanton et al.), and 3) by measurement of environmental isotopes (H, He, O, C, N, S) and tracers (chlorofluorocarbons, SF6, coprostanol) (Böhlke et al.). Combined results indicate a potential for rapid local ground-water movement of anthropogenic contaminants along with a tendency for export of Florida Bay ground water toward the Atlantic.

1) Two circular well clusters were core drilled in 1 to 2 m of water on either side of an undeveloped portion of Key Largo. Each cluster consists of 8 equally spaced wells arranged in a 200-ft-diameter circle. The wells contain two piezometers; one screened between -6 and -7.6 m and one between -12 and -13.7 m. The zones are separated by a Portland cement plug and a subaerial unconformity. An identical well is located in the center of each cluster. A fluorescein dye solution was pumped into the shallow zone of the central well and rhodamine dye was injected into the deep zone. These zones were periodically sampled in the 8 monitoring wells and dye concentrations were determined with a fluorometer. Movement of ground water was found to be most rapid in the shallow zone. Both rhodamine and fluorescein were detected in the shallow zone of two bay-side monitoring wells 18 days after injection. Rhodamine in the shallow zones of monitoring wells indicates upward movement of ground water and is consistant with seepage discussed later. Dyes were detected only in the seawardmost monitoring wells in each well cluster, confirming that net flow is toward the Atlantic on both sides of Key Largo. Rates of flow range from 0.5 to 2.0 m/day. Tidal pumping combined with elevated water level in Florida Bay apparently drive net flow toward the Atlantic.

Pressure measurements taken from piezometers at 15 minute intervals show that bay ground-water pressure, where tides are minimal, is precisely tuned to Atlantic tides and ground-water pressures in the Atlantic. Ground-water pressure is negative under the bay when the tide is low in the Atlantic and reverses during high tide. The difference in elevation, >1 m during low tide in the Atlantic, causes seaward flow of bay-side ground water through the permeable limestone underlying the Keys. The gradient is slightly less during high tide, resulting in reduced flow in the opposite direction. Tidal pumping also causes seepage of ground water into the overlying water column. Other chemical data, summarized below, were obtained from water collected from seepage meters, well clusters, and other monitoring wells.

2) Direct measurements of seepage confirmed that areas with high concentrations of natural tracers also exhibit high seepage rates. The natural tracers, 222Rn and CH4, are elevated in ground water relative to surface water and serve as indicators of the release of ground water into Florida Bay. Two independent surveys confirmed that concentrations of both tracers are significantly enriched in areas of Florida Bay near the Keys (especially near Key Largo), relative to the northern, middle, and northeastern portions of the bay. Direct measurements of seepage were consistent with this assessment. At a site near Key Largo, seepage was observed to change in harmony with Atlantic tidal stage. Water seeped into Florida Bay

when ground-water pressure was positive and reversed when negative. Rates of seepage varied from 15 to 40 ml/m-2/min-1. Measurements over a tidal cycle indicate that variations of tracer concentrations within Florida Bay waters are controlled by tidal stage on the Atlantic side of Key Largo.

Sulfur hexafluoride, an inert, artificial, non-reactive, non-toxic tracer, was injected into a well at the Key Largo Ranger Station during a rising Atlantic tide. Located about 1 m above bay level, the well is screened from -1 to -12.2 m. The tracer moved ~50 m and was detected in Florida Bay surface waters 6 hours later. The experiment was replicated with similar results. During low Atlantic tide, the plume moved toward the Atlantic and was detected in a monitoring well 3 m away within 3 hours. After several more hours, the plume passed through the well a second time. The maximum extent of plume movement toward the Atlantic could not be measured due to lack of additional monitoring wells. These results, however, confirm oscillation and lateral movement of ground water driven by Atlantic tides. The well, which is open to the limestone 1 m below the surface, is considered more representative of a septic tank or cesspool system than a modern disposal well.

Sulfur hexafluoride was injected into a modern disposal well between -18 and -27.4 m at the Keys Marine Laboratory on Long Key. Within 1 hour, the tracer was detected at -18 m, 5 m away on the Atlantic side of the injection well. The tracer was observed 4 hours later at -4.5 m, 10 m away from the injection well. At other surrounding wells, the tracer was observed at a variety of depths. These results indicate mobility of the tracer associated with channels or conduits within the karst aquifer, rising of the freshwater plume in a saline aquifer, diffusion, and a hydrologic gradient dipping toward the Atlantic. These results are consistent with dye, microbial, and phosphate studies being conducted jointly at this site by the USGS, University of South Florida, and Pennyslvania State researchers.

3) Although small-scale tracer studies indicate rapid, local, lateral movement of water in the subsurface, and water level monitoring studies indicate hydraulic potential for ground-water flow from the bay side to the ocean side, those results do not address directly the large-scale extent of N-S ground-water transport and origin of nutrients observed in ground water far offshore. We are testing the use of a variety of environmental isotopes (He, H, C, O, S, and N) and tracers (chlorofluorocarbons, SF6, coprostanol) to see what can be learned from them about ground water sources, the scale of the ground-water flow systems, and the fate of injected contaminants from the Keys. In February 1996, 33 sites were sampled to provide a preliminary comprehensive survey of surface and shallow ground water representing the potential recharge sources and the major regional types of ground water in the vicinity of the Keys and offshore areas to the north and south. Analyses of those samples for isotopes and tracers, plus major ions, nutrients, and dissolved gases, are in various stages of completion in various laboratories.

Measurements of H and O isotope ratios and salinities indicate at least 4 mixing components: 1) seawater, 2) meteoric water, 3) evaporated seawater, and 4) evaporated meteoric water. Bay-side ground water generally was enriched in 2H, 18O, and salinity compared to offshore marine surface water. These data are consistent with recharge by evaporated marine bay water during times of relatively high bay salinity. Ocean-side ground water had ¶2H, ¶18O, and salinity values generally equal to those of offshore marine surface water and consistent with ground water recharge by normal seawater. Several ground water samples from under the Keys and from short distances (less than a few hundred meters) offshore had isotope compositions consistent with transport of bay water to the ocean side, and one nearshore sample indicated transport of seawater to the bay side. Isotope data for tap water, waste water, and injected waste water all are consistent with a common freshwater source on the Florida mainland, and with mixing of waste water and marine ground water in the subsurface near a waste-water injection site.

Concentrations of CFC-12 indicate that the residence times of marine ground water on both sides of the Keys range from years to decades or more, and that the apparent ages generally are stratified. Degradation apparently has altered the concentrations of CFC-11 and CFC-113 in some samples. Minor CFC contamination was detected in water from the Port Largo canal and in waste water at the Keys Marine Laboratory, but it does not appear to be widespread (though degradation may have altered some occurrences). Additional samples are being analyzed for tritium and He isotopes that, when combined with CFC results, should provide more insight into the ground-water age distributions in the region. Ambient concentrations of SF6 are also being investigated for comparison with CFC data.

Nutrient analyses confirm that reduced ground water throughout the area contains significant amounts of ammonium. Concentrations of sulfide, methane, and bicarbonate were also elevated. The concentrations and isotopic compositions of sulfate and sulfide in the reduced ground waters are consistent with minor sulfate reduction. The concentrations and isotopic compositions of dissolved inorganic carbon (DIC) indicate varying contributions from both organic carbon oxidation and carbonate mineral recrystallization. Additional samples are being analyzed for 14C, which may provide evidence about the ages of carbon sources for the DIC and methane. The concentrations and isotopic compositions of dissolved N2 were nearly consistent with atmospheric equilibration over a small range in temperature, but there was evidence for small amounts of excess N2 in many samples that may have been derived from denitrification (reduction of nitrate to N2). Relatively large amounts of excess N2 in waste water and in mixed ground water near an injection site apparently were the result of denitrification of nitrate in the wastewater. Isotope analyses of nitrate and ammonium are underway and should provide important additional constraints on the fate of anthropogenic nitrate and the origin of ground-water ammonium.

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Florida Bay microalgal blooms: composition, abundance, and distribution.

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Persistent blooms of microalgae have occurred in Florida Bay for the last several years. The blooms consist of mixed microalgal populations often dominated by pico- and ultraplankton consisting of blue-green algae (cyanobacteria), diatoms, flagellates, and a eukaryotic picosphere. The composition (size classes and species composition) and distribution of blooms varies by region,e.g., western, central, and eastern portions of Florida Bay as well as seasonally. One of the regions, the central, can be seasonally divided into north and south components when the blue-green or blue-green-diatom-picosphere blooms spread from the apparent northern seed area around Rankin Basin to the southern portion of the Bay in late fall/winter. The abundance of these pigmented algae contributes to extensive surface water discoloration. Resuspended carbonate sediments and organic material can add to the discoloration and turbidity. Any persistent autochthonous bloom of planktonic blue-greens or other picoplankter in an estuary isabnormal and a symptom of system dysfunction or alteration.

Florida Bay microalgal blooms have been studied by several groups including a study group from the Florida Department of Environmental Protection’s Florida Marine Research Institute (DEP) and a study group from the University of Florida’s Department of Fisheries and Aquatic Sciences (UF). The studies were designed to address several questions, one of which is “What regulates the onset, persistence, and fate of planktonic algal blooms in Florida Bay”. To address these questions you need to know the microalgal composition, biomass, and distribution of blooms in time-space and how the blooms are influenced by physical, chemical, geological, and biological variables. What initially fuels and drives the microalgal blooms can ultimately influence total community structure and ecosystem function. Although sampling stations, time of collections, and methods differ between the two groups, their data bases are being evaluated for their unique contributions as well as their commonality. It would appear that both data bses support the division of Florida Bay into four zones or regions: the western region influenced by the Gulf of Mexico; the north and central regions influenced by resident populations of blue-greens-diatoms-picospheres and runoff, and the eastern region which is less variable and only occasionally influenced by micoalgal blooms.In addition, there are seasonal differences in physical, chemical, and biological variables within these regions that need to be defined by hydrological seasons. Biologically, the background community components appear to be pico- and ultraplankters such as *Synechococcus elongatus* and *S.*spp., *Cyclotella choctawatcheeana,*and other very small centrics <10 um, and the picosphere which are influenced by salinity, light and other environmental variables. Superimposed on this oscillating background there are peaks of larger diatoms and dinoflagellates. For example, the winter blooms of Rhizosoleniaceae (e.g., *Rhizosolenia imbricata*) diatoms in the western region, the summer blooms of Chatocerotaceae (e.g., *Chaetoceros* cf. *wighamii*) diatoms in the north Central region, or the blooms of large dinoflagellates such as *Pyrodinium bahamense, Prorocentrum mexicanum, Ceratium hircus, Gyrodinium instriatum, Gymnodinium sanguineum*, and others seasonally in different regions of the Bay, particularly from June through September and occasionally in winter. Even the Rankin station can be dominated by abundant large desmokont and dinokont dinoflagellates that have high cell volume.

The DEP database for February 1994 to September 1996 represents monthly sampling at six permanent stations and up to 34 nonfixed stations. In total, there have been 230 station samples in the western region, 102 samples in the north central region, 125 samples in the south central region, and 167 samples in the eastern region. Currently, Principal Component Analysis and other tests are being applied to the database (salinity, total particulate load, organic load, inorganic load, blue-green algal numerical abundance, and chlorophyll a) to assess variability by region and season. Eventually the intent is to assess community composition (over 120 diatom, 75 dinoflagellate, and 30 other algal taxa have been identified from Florida Bay),biomass, seasonality, and distribution in relation to environmental variables. The north central region has the highest chlorophyll a (mean:8.76 ug L-1; range: 0.29 to 40.58 ug L-1 while the western region is second, the south central region is third, and the eastern region is fouth in chlorophyll a mean values. Organic particulate load values follow the same trend as for chlorophyll a and ranged from a mean of 1.55 to 6.42 mg L-1. The mean numerical abundance of blue-greens was highest in the north central region and second in the south central region followed by the western region and then the eastern region.The values for inorganic particulate load differed in that the western region had the highest values; the means for the regions varied from 3.88 to 10.31 mg L-1. It would appear that the western and north central regions are most influenced by resuspension events. The UF database shows similar regional differences in physical, chemical, and biological variables. The DEP and UF databases can help further refine the designation of bloom regions.

For microalgal species to bloom and persist, there must be a seed population or inoculum present, a suitable physical environment, available and sustained nutrient input, and a competitive advantage over other microalgal species. Species occurrence, distribution, and biomass have been attributed to species specific life cycle strategies and reproduction and loss rates in response to a number of environmental and biotic factors. A portion of the DEP’s 1996-1997 study is to determine through laboratory experiments, why the dominant microalgal species (e.g., *Synechococcus elongatus, Cyclotella choctawatcheeana, Chaetoceros* cf. *wighamii, Rhizosolenia imbricata*, and a eukaryotic picosphere have an advantage in the different portions of Florida Bay and outcompete the other microalgae. If salinity, turbidity, light, and/or nutrient availability regulate the dominant microalgae and consequently bloom development, then knowing the environmental regulators or modulators will help evaluate restoration options and theirpotenital success. Laboratory studies involve a series of light growth rate experiments, salinity growth rate experiments, growth kinetic (Monod-type) experiments, and nutrient-limited competition experiments involving static and fluctuating salinities. Preliminary data for salinity confirms that the salinity tolerance curves for the study species differ in their optimal ranges and upper and lower tolerance limits. Both the DEP and UF results for *Synechococcus* suggest that this blue-green algal group tolerates a wide salinity range, high turbidity and low water clarity. The preliminary results for experiments with four dominant microalgae in Florida Bay are given in the poster presentation by Bill Richardson, Florida Department of Environmental Protection's Florida Marine Research Institute, entitled "Salinity, light and nutrient requirements of several dominant microalgal taxa of Florida Bay".

Remote sensing of water turbidity and sedimentation and their relationship to algal blooms.

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A decline in water clarity in Florida Bay has been observed following the seagrass dieoffs starting in the late 1980's. Algal blooms and discolored water have been reported in Florida Bay over the last several years and factors such as resuspension of material and nutrients from the bottom have been suggested as a cause. Monthly monitoring programs by Florida International University (FIU) and Florida Department of Environmental Protection (FDEP) have provided documentation of blooms through chlorophyll measurements. This study is using remote sensing to examine resuspension events, the distribution of turbid water and changes in the patterns of water clarity in the Bay.

The Advanced Very High Resolution Radiometer (AVHRR) on NOAA meteorological satellites has been used in this study. Currently, over 600 usable scenes are available from some 1500 covering a period from December 1989 to the present. AVHRR has a pixel size of about 1.1 km. The data sets are processed for water reflectance, which is related to water turbidity variables such as attenuation, Secchi depths, total particulate matter, and nephelometric turbidity. Tentative relationships with these variables have been made. (Sea surface temperature is also determined.) High reflectance corresponds to high attenuation or particulate loads or shallow Secchi depth. The individual scenes are also processed to obtain monthly and seasonal means, with winter corresponding to the period of December to March and summer to June through September. Initial analyses include the points corresponding to fixed stations occupied at a monthly interval by FIU or FDEP.

In examining the average reflectance of the entire Bay, the satellite imagery does not show a trend between December 1989 and September 1996. The seasonal pattern of high turbidity in winter and low in summer is evident. Trends over the time period appear in subsections of the Bay. A substantial increase in water reflectance is evident in the north-central Bay (which has been documented in field studies), this region includes Rankin Lake and Johnson Key. However these appear to have different phasing, with Johnson Key showing an increase in turbidity about two years earlier than Rankin Lake. Both sites show the decline in both winter and summer. Twin Key, which has the clearest water in the Bay, has shown a slight increase. The southwest portion of the Bay, west of Sprigger Bank, has shown a decrease in reflectance, indicating clearer water.

The project is conducting comparisons between chlorophyll values collected from the shipboard monitoring programs and pre-cruise reflectances to assess whether there is a link between resuspension events and algal blooms. The next stage in the project is to expand the AVHRR data set backward to before the seagrass dieoffs and to incorporate Landsat data for limited high resolution analysis.

Measuring and modeling the freshwater discharge at the Everglades-Florida Bay ecotone.

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With the current interest in the flow across the Buttonwood embankment, a hydrodynamic model of the embankment and surrounding area would yield useful information. The majority of the flows to Florida Bay have been thought in the past to occur through the numerous sloughs and creeks in the area. However, there is no doubt that at higher water levels, overland flows occur in the mangrove swamps. This flow must cross the Buttonwood Embankment to reach the bay. Sufficient data will be necessary to model the area accurately. Topography is especially important, since the times and frequency of the overtopping of the embankment are of crucial interest. The surveying effort must be done with great attention to accuracy, since the topological relief in the area is flat and small differences create large effects on flow. Frictional resistance coefficients, always difficult to parameterize, are needed for the mangroves along the embankment. Determining these values in an analytic sense will be difficult. In many models, the frictional resistance term is a calibration parameter, adjusted to make a best fit to field data. Since field data of flows across the Buttonwood Embankment are not available, only water-level data measured at stations an appreciable distance from the embankment can be used for calibration. Additionally, different field data collection and data analysis techniques will be explored to determine the most suitable technique for gaging flows in the shallow and slow moving estuarine streams discharging into Florida Bay.

Analyzing the isotopic composition of coral and mollusk skeletons to relate past salinity and nutrient levels in Florida Bay.

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Under normal conditions the oxygen isotopic composition of waters changes in response to the amount of evaporation experienced by the water and therefore the oxygen isotopic composition usually shows a positive correlation with salinity. This signal of salinity, modified by temperature, is in turn recorded in the skeletons of various calcium carbonate secreting organisms as variations in the 18O/16O (d18O) ratio. Hence analyses of the d18O of skeletal material which can be well dated, is able to provide a retrospective view of salinity changes in an estuarine situation. These principles can also be applied to Florida Bay. A major exception however is that the region is influenced by evaporated freshwater derived from the Everglades which under normal or drought conditions has an oxygen isotopic signature similar to evaporated seawater. Consequently relationships between salinity and oxygen needed to be understood in the Florida Bay system. In addition to d18O, the ratio of 13C/ 12C (d13C) provides an indicator of the source of waters and the degree to which they are influenced by the oxidation of organic material. Waters with negative d13C values are found associated with the Everglades while more positive d13C waters are found in more marine areas. At RSMAS, a program has been initiated both to investigate the relationship between the d18O and d13C of the water and salinity in Florida Bay and to use the d18O and d13C of the calcareous material to interpret salinity variations over the past several hundred years.

An important prerequisite in using d18O and d13C of calcareous material is the ability to date the material accurately. Coral skeletons fulfill this criteria because they contain annual growth bands composed of dense and less dense material. By counting these bands from the surface of the coral it is possible to obtain an annual chronology. Assuming a constant growth rate within a year allows intra-annual comparisons to be made. We have been able to calibrate the relationship between salinity, temperature and the d18O of the species *Solenastrea bournoni* by performing high resolution sampling of the coral skeleton over the last six year time period for which good salinity and temperature data exist. We have then been able to utilize specimens of the species of up to 160 years in age from Lignumvitae basin to obtain a history of the water quality in this region. These results suggest that the concentration of the railway from Miami to Key West was a major factor in the decline of the health of Florida Bay. Synchronous with railway construction, the range of inter-annual salinity variability decreased and the overall salinity increased. In addition there was a large decrease in the carbon isotopic composition suggesting the increased retention of the products of the oxidation of organic material within Florida Bay.

Coral of this age do not grow throughout Florida Bay and are restricted to regions of the bay which experience more marine and equatable conditions. In order to ascertain whether we could see similar patterns in salinity in other areas of the bay, we utilized specimens of the species *Siderastrea radians*. This species is very resistant, but only grows to about 20 to 30 years in age and therefore is not suitable for reconstructions over longer periods of time. Nevertheless, our study indicates that variations in salinity over the 1985 to 1995 time period could be detected in all the basins from which these corals were retrieved. These variations were similar in timing, but considerably larger in magnitude (Swart et al, poster session). Future work will concentrate on the analysis of two longer cores collected from Manatee Bay and near Crane Key.

A further method whereby the isotopic composition of calcareous organisms can be used for paleoenvironmental reconstruction is to make use of fossils in well dated sediment cores. This approach has been employed by the USGS group in cores collected from three localities in northeastern Florida Bay. In particular this group is examining the d18O and d13C composition of mollusks from cores dated by using both radioisotope and anthropogenic tracers. These cores do not have the dating resolution provided by coral cores, but they provide information in the northeastern bay where old corals do not live.

In order to interpret isotopic signatures from cores, a survey of mollusks was made from the tops of cores taken at several localities across the bay. Among these mollusks a positive covarying trend is taken to indicate a marine signature, whereas a inverse trend is suggested to be more representative of Everglades conditions. The covariant distribution of mollusk d18O and d13C values from the western bay reflect “normal marine” conditions. In contrast, the distribution of mollusks from the northeastern bay, which has a highly variable salinity regime, display a wide range in both d18O and d13C. Other basins throughout the Florida Bay show isotopic distributions that are intermediate between these two end-member environments (see Roulier and Halley, poster session).

Stable isotope analyses of mollusks collected down core vary widely, but show significant shifts in mean isotopic values during the past 150 years. A negative shift in d13C beginning near the turn of the century is similar to that from coral records, but appears to have taken several decades to stabilize at current levels of variance. Excursions toward heavier d18O, indicating more evaporitic conditions, began several decades later.

Isotopic analyses from both corals and mollusks, together with a rigorous examination of the oxygen and carbon isotopic systematics of the water column, should allow us to quantify past salinity and water quality changes across Florida Bay.

A model of organic matter production and fate in Florida Bay: estimates of nutrient cycling.

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The flux and cycling of organic material (OM) is one of the least well understood aspects of the Florida Bay ecosystem, yet remineralization of OM is critical to the understanding of the cycling of nutrients, consumption of oxygen, production of hydrogen sulfide, and consequently the health of the entire bay. This presentation will outline some of the current knowledge regarding the sources of organic material and discuss the implications of these estimates to questions regarding the recycling of nutrients.

Based on the current geometry of Florida Bay mudbanks it is estimated that there are approximately 4 x 1012 moles of carbon present as organic carbon in Florida Bay sediments. This amount of carbon has accumulated over the past 4,000 years as sea level has risen and flooded the Pleistocene aged bedrock and therefore the amount of OM present in the sediments is a product of a dynamic series of interactions including the oxidation, burial, and export of OM to the adjacent marine environment. As a first approximation, the sediments in Florida Bay can be roughly separated into the sediments present as a thin veneer above the limestone floor in the basins and the sediments contained in the mudbanks. Based on the thickness and areal extent of the mudbanks, we estimate that there are approximately 3 x 1012 moles of OM stored in this reservoir. In contrast, the sediments in the basins contain an order of magnitude less carbon (6 x 1012 gms). The carbon in the basins does not accumulate here, but instead is rapidly recycled and exported either to the adjacent marine environment or to form new mudbanks within Florida Bay. The mudbanks are considered to be a temporary/permanent sink of organic material. The nature of organic material in mudbanks relative to the basins has not been well characterized, but the mudbank material is likely to have a higher concentration of the more refractory and therefore less labile organic material. Although, these mudbanks are gradually formed and destroyed at rates related to the occurrence of storms, there is a net increase in the area of mudbanks with time. Large storms resulting in the significant destruction of mudbanks will result in substantial input of organic carbon into the basin reservoir. Its diagenetic potential however is likely to be less than new OM and therefore resuspension and consequent oxidation will have less of an influence on the release of P and N than an input of new OM.

Based on our analysis of data published by numerous workers in Florida Bay and in addition data collected by our group, we have calculated that there is an input of organic carbon into Florida Bay of between approximately 1010 and 1011 M/yr-1. This input is derived from three principle sources, the Everglades (1010 to 1011 M), in situ production from sea grasses and algae (1010 M), and phytoplankton (1010 to 1011 M). In addition minor amounts of production results from coastal mangrove production and production from islands within Florida Bay. If one assumes that (I) the mudbank organic carbon is relatively immobile, (ii) that approximately 99% of all incoming organic carbon is oxidized, and (iii) there is only minimal export of organic carbon from the bay, then the residence time of organic carbon is between 300 and 2000 years. This range is extremely large and reflects the uncertainty in the estimates of organic carbon derived both from the phytoplankton and the Everglades. Regardless of the uncertainties involving amounts of organic carbon in Florida Bay, its oxidation releases large amounts of nutrients. For example, based on our input estimates of an annual input of 1010 M/yr of OM from sources such as the Everglades, and coastal mangrove production and a preservation rate of 1%, then between 106 and 107 moles of phosphate and 108 and 109 moles of nitrogen are released annually depending upon the C:N:P ratio of the organic material. This flux is large compared to an inorganic flux from the Everglades and the nutrient input associated with precipitation.

Although there are uncertainties regarding the input of organic material in Florida Bay, there are several methods whereby better fluxes can be calculated. First, the fluxes can be measured in a temporal and spatial manner. This method has been utilized by our group and data will be presented indicating fluxes over an annual cycle. Second, the OM in the sediments can be measured and certain tracers analyzed to determined how much material is derived from the relevant sources. One set of such tracers are the stable carbon, nitrogen, and sulfur isotopic compositions of the OM. An initial approach using the carbon isotopic composition will be presented. This indicates the significant influence of the Everglades on the organic content of western Florida Bay sediments, decreasing towards the central bay region.

The work presented here is ongoing and will be designed to provide an integrated model of organic matter flux and consequent nutrient release in Florida Bay. We are currently conducting surveys of C, N, and S isotopes to further constrain end members and fluxes. Future work will examine specific biomarkers characteristic of source environments and resolve source and diagenetic influences.

Response of fish and shellfish to changes in habitat in Florida Bay.

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In the fall of 1987, a widespread, rapid die-off of turtle grass, *Thalassia testudinum*, began in Florida Bay. *Halodule wrightii* and *Syringodium filiforme* habitats appear to have been affected as well. Rapid, but often ephemeral recolonization of many of the die-off areas has occurred often resulting in patchy bottom habitats. It has been hypothesized that these changes coupled with other environmental modifications could have effects on the nursery function and fisheries of the Bay. To address these concerns, staff from the USGS, NMFS and Florida DEP have been conducting research to address the question: What are the changes in the distribution and abundance of living resources that have occurred as a result of habitat changes in Florida Bay? This is being done through decadal comparison of fauna (1994-present vs 1984-1987): Johnson Key Basin bank, basin and near-key habitats (Robblee); banktops representing five different vegetational subenvironments in the Bay (Matheson and Camp); and basins of the Bay southwest of a line from Little Madeira Bay to Tavernier Creek (Thayer and Hoss).

Sampling reported was conducted during January and May 1995 using the same sampling stations and protocol used a decade ago in Johnson Key Basin, one of the earliest areas affected by the die-off. Quantitative 1 m2 throw trap samples were taken and fauna cleared using sweep nets;quantitative measures of seagrass standing crop biomass (above and belowground) and composition also are taken. Analyses are demonstrating that there have been changes in composition and dominance of both plant and faunal communities. Aboveground biomass of *Thalassia* has decreased 72% relative to 1985; *Syringodium* has disappeared totally; and there has been no change in biomass of *Halodule*. Therefore the basin seagrass community has changed from one dominated by *Thalassia* to one co-dominated by *Thalassia* and *Halodule*. Caridean shrimp densities have decreased from about 160 m-2 to ~35 m-2 in 1995. Pink shrimp density in January decreased from a mean of 7 to 3 m-2 over the decade, whereas no difference was observed in May sampling (both ~2 m-2). Fishes also decreased over the decade from averaging about 11 to 4 m-2. *Thor floridanus* (down 93%) and *Periclimenes longicaudatus* declined radically among the caridean shrimp, while *Lucania parva* (down 97%), *Floridichthys carpio*, and *Opsanus beta* showed precipitous decreases among the fishes. Other species of carideans and fishes, however, increased in density: e.g., *Alpheus heterochaelis, Anchoa mitchilli, Gobiosoma robustum.*

We designed the banktop throw-trap sampling program as a comparison with the studies conducted by the National Audubon Society (Powell, Sogard, and Holmquist) during 1984-86. The sampling gear, sites, and methodology of the previous study were used to investigate the effects of environmental changes since 1986 on the resident fishes and crustaceans of these shallow seagrass beds. During 1994-96 we sampled the lee side of banks at six sites in five different subenvironments of the Bay: the Atlantic near the Buchanan Keys, the East Central on Cross Bank, the Northeast near Eagle Key, the Interior near Coon Key and near the Dump Keys, and the Gulf near Oyster Keys. Additionally, in 1995-96 we sampled vegetated and die-off sites on another bank in the Gulf subenvironment: near Rabbit Key. Among the six original bank sites of Powell et al., our data showed that only the Dump Keys site experienced significant seagrass loss. Some faunal changes occurred over the decade at several of the sites, but the most draatic changes occurred at Dump Keys. This bank was productive for resident fauna (relative to other banks) during both studies, but much of the production switched from canopy to benthic species. *Thor floridanus* and *Lucania parva* experienced precipitous declines at Dump Keys, whereas *Alpheus spp., Gobiosoma robustum,* and *Microgobius gulosus* experiences significant increases. Among the other sites, faunal diversity patterns remained constant (highest diversity at sites with strong marine influence), and abundance of both individual species and ecological groups (canopy vs benthic species) experienced relatively minor fluctuations (especially compared to those at Dump Keys). At Rabbit Key we compared areas with apparently recent seagrass die-off with nearby areas of dense *Thalassia*. In the die-off areas, benthic and canopy fish declined by factors of approximately 3 and 2, respectively. Canopy shrimp (primarily *Thor*) also declined by a factor of more than 40, but benthic crustaceans (primarily hermit crabs) increased by a factor of approximately 4. The pink shrimp, *Penaeus duorarum*, was found at similar densities at both sites, but their average size was greater at the vegetated site. We speculate that the changes observed at our Dump Keys site indicate that this area will be relatively productive with or without seagrass, but that the predator which forages on this bank must be flexible (i.e., not a specialist on canopy dwellers) in order to avoid a serious decline in food resources. At the other five Powell et al. sites, the phytoplankton blooms and episodes of increased turbidity that have plagued the Bay seem to have caused few if any changes in banktop seagrass beds or their fauna. At Rabbit Key sites, recent die-off areas have lost much of their faunal production and have probably declined in value as foraging habitat for all species except those that specialize in benthic crustaceans.

Our basin-wide study is using a stratified random sampling design and sampling protocol established in 1984. The sampling area is subdivided into Atlantic, Central and Gulf strata based on the general distribution of benthic vegetation plus an additional stratum comprised of channels. Fauna are collected at the approximate center of randomly selected cells within each stratum using a 3.4 m otter trawl pulled between 2 boats for 2 minutes at a speed of 3.5-4.5 knots. At this point, we have pooled data from within each of the strata. Pooled bottom habitat data show a decrease in all species within each stratum, with *Thalassia* having about 65% lower average short shoot densities than during 1984-1985. Decreases were observed for both *Halodule*, which occurred in each of the strata, and *Syringodium* which occurs only in the Gulf and Channel strata. Many stations, however, have or are showing evidence of recolonization. Channel habitats as a whole, which generally seem to be ignored as an important habitat, are displaying the most persistent loss of all three of the seagrasses (e.g., 1984-85 mean short shoots m-2 values for *Thalassia, Halodule,* and *Syringodum* of about 800, 1100, and 150, respectively compared to respective values of 150, 300, and 30 currently).

Pooled data for fishes indicate a decrease in the mean density for the study area and a shift in composition. During the 1984-85 study we sampled a total of just over 155,000 m2 collecting almost 27,000 fish for an average of 170 per 1000 m-2. A decade later we have sampled in excess of 174,000 m2 of Bay bottom collecting almost 25,500 fish with a mean density of 147 fish per 1000 m-2. These densities are considerably lower than those observed using throw traps, but also cover areas of the Bay, e.g., areas of both the Atlantic and Central strata, that have known low densities of both vegetated bottom and fishes. Only the Channel stratum is exhibiting a decrease in average fish density. Whereas the communities we sampled a decade ago were dominated by *Lucania parva, Floridichthys carpio, Lagodon rhomboides,* and *Eucinostomus spp.* (all of which have decreased in abundance since 1984-85), *Anchoa mitchilli* represents in excess of 60% of the fishes we have collected since 1994. Several species show little change in mean abundance between decadal periods (e.g., *Bairdiella chrysoura, Opsanus beta*) and several have increased in mean density (e.g., *Monacanthus ciliatus, Gobiosoma robustum, Harengula jaquana*). Many of the species exhibiting an increased average abundance, particularly the bay anchovy, are planktivores as opposed to benthic feeders, suggesting a shift in trophic patterns of the fishery communities we sampled.

Our faunal-related sampling since late 1994 has been designed as comparisons to work carried out in the same habitats, at the same stations, and with the same gear a decade previous. Many of the sites have displayed no major changes in the seagrass community over the decade, whereas areas of Johnson Key Basin, several banktops, and many of the other basins are displaying both decreases in *Thalassia* and evidences of seagrass recovery, particularly through colonization by *Halodule*. The resident and transient fish and invertebrate communities of those areas unimpacted by the seagrass die-off appear not to have changed much over the 10 year period. However, where seagrasses have declined there have been both decreases in total abundance and shifts in faunal composition. In general canopy dwelling fishes and invertebrates and some benthic fishes have declined; benthic crustaceans and at least at least one benthic and a pelagic fish component have become important. Thus, where there are changes in the seagrasses, the resident fishes now appear dominated by a few benthic as opposed to canopy feeders, and the transient fishes (collected by both throw traps and bottom otter trawls) are overwhelmingly dominated by the plankton feeding bay anchovy.

The role of nutrients in initiating and supporting Florida Bay microalgal blooms and primary production.

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Since March 1994, monthly phytoplankton studies conducted by FDEP/FMRI were made to survey the bloom areas consisting of joint observations by aerial surveillance to map bloom locations and at the same time sampling from 6 fixed locations and as many as 30+ additional stations for bloom composition, distribution, chlorophyll a and phaeopigments, total particulate solids and dissolved and particulate nutrients. In addition to this routine monitoring activity, process measurements were made from four selected locations to define the nutrient dynamics and limitations of the natural populations, their potential growth rates and primary production. In addition to these process measurements, secondary trophic studies were conducted at the same time to define the linkage between the primary and secondary trophic compartments.

From the early years of this decade, phytoplankton blooms have become a permanent feature of the Florida Bay ecosystem. The questions regarding the appearance of these blooms center around two major hypotheses, namely 1) that the blooms are a function of a few opportunistic species which have been able to exploit open nitches afforded by the presence of excess nutrients, and/or 2) that a major trophic dysfunction has occurred whereby grazing pressure has been reduced or eliminated, thus allowing the accumulation of phytoplankton biomass. The latter hypothesis is being addressed in another presentation at this meeting and will not be discussed here. The first hypothesis was examined via the study of nutrient bioassays and primary production measurements. These studies were oriented at defining the limiting nutrient(s) and an estimate of potential growth by the natural populations exposed to these nutrients. The primary production was conducted to give an independent estimate of carbon fixation and therefre growth and as a measure of rates from the first trophic level for subsequent trophic studies.

Natural populations from four stations were sampled monthly from March 94 through July 96. The stations included, Sprigger Bank and Sandy Key areas located in the western regions of the Bay which are heavily influenced by marine waters from the West Florida Shelf where blooms were noted previously. Another bloom area studied was the Rankin Lake region in the north central portion of the Bay. Again, this regions was found to be heavily impacted by the phytoplankton blooms dominated by cyanobacteria. The Rankin area is also one where sea grasses have disappeared and where extremes in salinity in excess of 40-50‰ were found. The fourth area routinely sampled was the basin adjacent to Captain Key. This basin had consistently low phytoplankton biomass values, sparse sea grass and physical-chemical characteristics more similar to the eastern region of the Bay. The full suite of monitoring parameters were conducted at these four stations as well as the nutrient bioassay and productivity studies.

Nutrient bioassays were conducted using the natural phytoplankton populations for the four stations by first prefiltering through 163 mm mesh netting to remove larger animals and detritus and dispensing as 40 ml aliquots into triplicate 60 ml screw cap culture tubes. Two general types of treatments were made. One set had eight treatments of nutrients additions either as single additions or in combination. A second set had nutrient enrichments including all but one of the major nutrients and thus was tested for the deletion of either nitrogen, phosphorus or silica. A total nutrient enrichment included additions of nitrogen (as nitrate and ammonia), phosphate, silicate, trace metals, and vitamins while a control had no nutrients added. Phosphorus was added at two levels, low (5 mM/L) and high (10 mM/L) singly and combined with nitrogen and silica at the low and high treatments. Nitrogen, as an equal combination of nitrate and ammonia, was added at two levels, low (15 mM/L) and high (30 mM/L), singaly or in combination as low and high treatments with phosphorus and silica. Silica was added at one level (30 mM/L) to the combined low and high nitrogen and phosphorus addition as well as in the complete additions. In summary, the nutrient addition bioassays included 3 low phosphorus, 3 high phosphorus, 3 low nitrogen, 3 high nitrogen, 3 low phosphorus + low nitrogen and silica, 3 high phosphorus + nitrogen and silica, three full enrichments and 3 unenriched controls. In addition, a nutrient exclusion series consisted of three replicates containing all nutrients except, nitrogen, phosphorus or silica. The minus N, P and Si treatments were compared with the enrichments series to confirm the potential limitation. All tubes were incubated in a constant temperature water bath at a temperater similar to that of the stations sampled. All tubes were under constant illumination from cool white fluorescent light at a fluence rate of approximately 100 mE/m2 sec. Growth was measured as *in vivo* fluorescence measured with a Turner Designs 10 AU fluorometer twice daily at the same time each day for 4 days. At the end of the incubation period, the triplicate tubes were pooled from which duplicate chlorophyll determinations were made and from which a small sample for species composition was preserved for examination at a later date.

On separate aliquots from each station, primary production was measured using the standard C14 bicarbonate incubation at 10 light intensities during incubations generally lasting 4 hours. The productivity measurements were run in duplicate, corrected for dark absorption of C14 and maintained at ambient temperatures in a tube incubator having circulating sea water and natural light. The gradient was produced by the use of neutral density screening. All samples were harvested on GFF filters, placed into glass scintillation vials with 10 ml of Optima Gold fluor and read on a Packard TR900 liquid scintillation counter. Net activity was converted to weight carbon per meter square per day. Monthly values were used to obtain an integrated estimate of yearly production from each of the regions tested.

The nutrient bioassay studies identified three major types of limitation for phytoplankton in Florida Bay. The stations in the western Bay (Sprigger and Sandy) showed limitation by either nitrogen or silica. This was consistent with the blooms of diatoms common in that region. The exclusion assays confirmed the nitrogen and silica limitation. In addition, occasionally very high growth and biomass was developed in the total enrichment indicating that other factors besides nitrogen and phosphorus were involved. Here trace metals, perhaps iron, may be also limiting. Growth at these stations could be elevated and did exceed 1 division per day particularly during bloom periods suggesting a rapid total community growth consistent with the biomass in Chl a measured there. The central region of the Bay at Rankin Lake indicated an alternation between nitrogen and phosphorus limitation for most of the year with a rare occurrance of silica limitation. The extensive blooms there, dominated by cyanobacteria and ditoms are apparently receiving enough nutrients to maintain the extensive blooms there. While growth rates here were much lower (< 0.6 div./day) than at the western stations, the biomass present during the bloom times indicated that these modest growth rates represented a sizable growth overall. The exclusion assays confirmed that both nitrogen and phosphorus were limiting with with little difference between the presence of absence of that nutrient. This suggest that slight nutrient imputs can alternate the limitation from nitrogen to phosphorus and back again. The nutrient delivery and cycling is very important in maintaining the bloom populations observed there. The easternmost station, Captain Key, was one where phosphorus was consistently shown to be limiting. Again, both additions of low and high levels of phosphorus as well as exclusion of phosphorus showed the degree of limitation by this nutrient. This station also consistently had low phytoplankton biomass and modest to low sea grass abundance Comparing this station with other regions, it behaved consistently with the eastern Bay areas and was less like the central and western areas. The modest phytoplankton biomass was consistent with the low growth rates (<0.4 div/day) and pronounced phosphorus limitation found there.

The variations in primary production closely followed biomass fluctuations. The highest daily rates measured were observed at the Rankin Lake station during bloom periods. Daily fixation rates in excess of 3 gC/m2 day were common during blooms. Values less than 1 were found during the summer months when chlorophyll biomass was less than 1 mg/L. Annual production at this station exceeded 400 gC/m2 for each of two years studied. The western area was the next most productive area. Here again, daily rates between 1 and 3 gC/m2 day were found when phytoplankton biomass levels were elevated. Although these production rates were not as high as those from the north central bloom area, they do represent a sizable carbon production equivalent to 200-300 gC/m2 year. The least productive area was the Captain Key site where daily values rarely exceeded 300 mgC/m2 day and annual production was below 75 gC/m2 year. These low production values were consistent with the low biomass and growth rates measured there under chronic phosphorus limitation.

The results of these studies indicate that the nature of the nutrient limitation of the phytoplankton blooms varies with region of the Bay and may be related to the delivery and/or cycling of nutrients locally. Nitrogen plays a more important role in the central and western regions whereas, phosphorus which can be important at times in the central region limits the eastern portion of the Bay. Growth from natural populations from the four stations indicated a potential for rapid growth in excess of 1 div./day for the central and western regions. These chlorophyll based growth rates were in general agreement with the primary productivity rates when examined as carbon doublings. The agreement of nutrient based doubling times and carbon based doubling times suggest that the phytoplankton populations in Florida Bay are extremely active in maintaining population densities and that their growth far exceeds losses in producing blooms. The eastern Bay station, consistently phosphorus limited, having the lowest pytoplankton biomass for most of the time and with low or modest growth, showed features which contrasted the other Bay regions. This region may reflect the availability and delivery of nutrients as well as an uncoupling or weak cycling of nutrients needed to maintain the populations at the other regions. The quantity and supply of nutrients to the Bay regions is a major regulator in the inception and maintenance of these blooms. The fate of these blooms may be more closely tied to the cyclic nature of nutrient delivery and assimilation of the nutrients but also importantly tied to the control exerted by secondary trophic levels.

Biogeochemistry and forest development of mangrove wetlands in southwest Florida: Implications to nutrient dynamics of Florida Bay.

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The biogeochemical properties of mangroves are the least understood of ecological processes along the transition from upland to coastal margin ecosystems. Thus the specific nature as to how the distribution of nutrients influences mangrove structure and productivity, and the role of mangroves in the fate of nutrients in sub-tropical estuaries, are poorly understood. There has been much investigation related to the issues of water management in south Florida including projected impacts of nutrient enrichment on the Everglades and associated wetland ecosystems. However, the responses of mangroves to changes in water quantity and quality and the role of these land-margin ecosystems to mitigating nutrient enrichment in the coastal zone have received little attention. We have been investigating the biogeochemical properties of mangroves along longitudinal gradients of the estuary and the response of these processes to Hurricane Andrew. Together with an initial effort to develop an ecological model of these processes, we have determined the significance of phosphorus and nitrogen to the structure and productivity of mangroves in this region. Continued efforts monitoring these biogeochemical processes, together with further development of ecological models, will provide important information on the projected response of mangroves to changes in water managment in this coastal watershed.

Nutrient, light, salinity, soil redox potentials, and other soil characteristics were determined across a range of mangrove forest heights across the South Florida peninsula encompassing large stature trees (>10 m) on the west coast and dwarf forms (<1 m) in the southeast Everglades. Relationships were established between abiotic factors and *Rhizophora mangle* seedling growth rates in four height (cm) classes, 25-40, >40-55, >55-70, and >70-85. Light in open canopy gaps was an important determinant of seedling growth. Growth rates in gaps (0.32 ± 0.04 to 1.89 ± 0.18 mm d-1) were two- to five-fold greater than adjacent closed canopy forests (0.14 ± 0.01 to 0.40 ± 0.07 mm d-1). Among open canopy sites, labile soil phosphorus and soil redox potentials were significantly correlated to growth ($P < 0.05$; $r = 0.98$ and 0.89, respectively). Interstitial salinity ranged from 0 to 27 ppt across sites, well below hypersaline conditions. Thus, under low salinity stress and high light availability, soil fertility is proposed to be the dominant factor controlling *R. mangle* seedling development to a sapling stage (>85 cm) in South Florida mangrove forests. In addition, soil anoxia is hypothesized to be an important stressor in lagoonal-bay estuaries and marsh-mangrove ecotones with minimal tidal exchange.

Patterns of biomass allocation and C-fixation rates in *Rhizophora mangle* seedlings were investigated in the Florida Everglades at sites with variable light and soil nutrients. Soil nutrient levels and light availability significantly influenced light-saturated C-fixation rates. Photosynthetic rates at light saturation decreased from 7.8 to 5.5 µmol CO2 m-2 s-1 with decreasing soil P. Low light under the canopy suppressed average daily photosynthetic rates 64% relative to an adjacent gap. Biomass allocation to photosynthetic tissue was also dependent on high light and soil nutrients. Photosynthetic tissue comprised approximately 50% of the total above-ground biomass in open canopied, high nutrient sites, whereas under low soil P, only 12-13% of the total biomass was allocated to leaf tissues. A general trend was found across size classes in open and closed canopied sites: biomass partitioning to leaves increased with size class in the gap, while under the canopy, leaf biomass increased initially, but subsequently decreased with increasing size. The inability of *Rhizophora mangle* to allocate increasing biomass to photosynthetic tissues to compensate for low C-fixation rates under closed canopies, identifies this species as shade intolerant. Whole plant C-fixation rates were strongly correlated to seedling growth rates in southwest Everglades sites. These results indicate the importance of both C-production and foliar biomass partitioning for early mangrove development. However, further study is needed to reconcile limited growth in response to C-production in dwarf mangrove forests in the southeast Everglades.

The spatial gradients of soil nitrogen (N) and phosphorus (P) mineralization rates, extractable N and P pools, and P fractionation were examined in a mangrove land-margin ecosystem along the Shark River estuary in the Everglades National Park. The mean tree height of mangrove forests linearly declined with distance from the mouth near the Gulf of Mexico to the oligohaline regions of the estuary. Mangrove forests along the estuary represented a landscape gradient of soil N and P availabilities. Higher amounts of extractable ammonium were found in the marine site of the estuary near the Gulf of Mexico. Mean rates of net ammonification and relative ammonification per unit of total N based on 45 d incubation periods decreased exponentially with distance from the estuary mouth to inland sites. N mineralization was positively correlated with total P and available P, but negatively with N:P ratio. Total P and available P increased from the oligohaline to marine sites. There was no net P mineralization in the marine sites based on 45 d incubation periods. Residual P was the largest P fraction in all soils and decreased from 70% in the oligohaline site to 45% in the marine site along the estuary. The percentage of Ca-bound-P increased from 3.3% at the oligohaline site to 32.3% at marine sites. Ca bound-P pool was larger than Fe-Al-bound P pool in the marine sites, while the reverse was found in the mesohaline and oligohaline sites. The landscape gradient of P in the study area indicates that the Gulf of Mexico is the major source of P in this mangrove land margin ecosystem rather than direct terrigenous input from inland watershed.

Mangrove forest structure, growth, soil nutrient resources and pore water stressors were examined along the longitudinal gradient of the Shark River estuary in the Everglades National Park. Patterns of forest structure were based on 34 yrs of growth since Hurricane Donna destroyed most of the mangrove resources in this region in 1960. Forest basal area increased from lower values at the upstream and intermediate locations of the estuary (19.61 and 20.72 m2/ha, respectively) to nearly double these values at two downstream locations (40.36 and 39.67 m2/ha) near the mouth of the estuary. Tree density with dbh >10 cm was 1900/ha in the downstream location, which indicated a more mature stand than in the upstream location where only 334 trees/ha were >10 cm dbh. *Laguncularia racemosa* had a higher importance value in the downstream location, whereas *Rhizophora mangle* dominated in the intermediate and upstream locations. Biomass increments were higher at the downstream sites (10.73 and 11.96 Mg·ha-1·yr-1) than at the lower stature forest in the upstream and intermediate sites (3.23 and 4.20 Mg·ha-1·yr-1). Pore water salinities in mangrove soil were < 35 g/kg at all three sampling seasons and sulfide concentrations were generally < 0.15 mmol/L. There was no spatial trend of total C and N contents per unit soil volume, nor in C:N ratios among the sites. However, total P, extractable P and extractable ammonium contents increased from the upstream sites to the sites at the mouth of the estuary. Soil properties in the downstream marine region of the Shark River estuary include high levels of nutrient resources and low concentrations of toxic stressors supporting a region of optimum growth of mangroves. A regression of mangrove basal area on concentrations of soil total P per unit volume suggest that the landscape gradient of mangrove forest development is associated with soil P resources along this subtropical estuary.

The vertical distributions of organic matter, nitrogen and phosphorus in mangrove soils were investigated with a mechanistic and process based model. The nutrient mangrove model (NUMAN) was developed from the SEMIDEC and CENTURY soil organic matter models and parameterized with data from four mangrove sites along the Shark River estuary. The soil characteristics in the four mangrove sites varied greatly in both concentrations and profiles of soil C, N and P. Organic matter, expressed as percentage of ash free dry weight, decreased from 82% in the upstream locations to 30% in the marine sites. Comparisons of the simulated and observed results demonstrated that the landscape gradient of soil characteristics can be adequately modeled by accounting for plant production, litter decomposition and export, and allochthonous input of inorganic materials. The results illustrated that the increase in organic matter content and decrease in soil bulk density from mangrove sites at the mouth of the estuary to those at upstream locations was controlled mainly by variation in allochthonous inputs of inorganic material and mangrove root production. Model simulations showed that the greatest change in organic matter, N, and P occurred in the soil surface, but changes were also evident at depths ranging from 1 cm to 5 cm at some of the sites. The rapid decomposition of labile organic matter was responsible for this decrease in organic matter. Simulated mineralization rates of nitrogen decreased quickly with depth, which corresponded with the decrease of labile organic matter. Fitting the simulation results of the model to observed nutrient profiles indicated that N and P dynamics are tightly linked to organic matter retention. In the future, NUMAN will be modified and linked to a mangrove forest gap model to simulate the feedback mechanisms of soil nutrient recycling, which controls development of the mangrove wetlands.

A computer model (MANGAL) derived from an individual-based gap model (FORMAN) and a soil organic matter model (NUMAN) was developed to investigate mangrove forest dynamics in relation to soil characteristics. Simulated forest structure was compared to that of three mangrove forests along the Shark River estuary, Florida, with a known disturbance history. Simulations of total and species specific basal area of each mangrove site fit well with data from field surveys of the forests. Low nutrient availability in the intermediate site of the estuary limited the forest development. The measured size-class distribution of *Rhizophora mangle* showed higher frequencies for the smaller size classes, however, that of *Laguncularia racemosa* was bell-shaped. The model accurately tracked this pattern for each species. Mangrove succession was projected using the present stand condition of the downstream marine site in the estuary. Without disturbance, dominance of *L. racemosa* was eventually replaced by *R. mangle* or *Avicennia germinans*, depending on the recruitment rate of *A. germinans*. Simulated basal area of the three mangrove species along gradients of soil nutrient resource and salinity illustrated a change in competitive balance among the three species over time. *L. racemosa* dominated in fertile soils with low stress at early stages of recovery, but its abundance decreased while *A. germinans* increased in this region. The dominance of *R. mangle* was limited to regions with low nutrient availability and low salinity.

The relative ecological significance of nutrient availability varies among fringe, basin and dwarf mangroves according to tidal inundation frequency from lower to upper regions of the intertidal zone. Fertility may also vary for each ecological type of mangrove depending on allochthonous inputs from riverine environments, compared to the lack of allochthonous inputs in lagoons and carbonate environments. Nutrient cycling in mangrove ecosystems in areas with high tidal or riverine forcing would be considered ‘open’ with high rates of material exchange across the mangrove-estuarine boundary. Whereas, less frequently inundated systems, such as inland basin mangroves, have a greater accumulation of leaf litter resulting in higher remineralization within the forest. Thus the ecological types of mangroves across geomorphological regions with contrasting fertility may have different plant and ecosystem strategies of nutrient conservation. We propose that the biogeochemical properties of mangroves such as accumulation, mineralization, exchange, and nutrient-use efficiency will vary among sites along the nutrient gradients of the south Florida terrace. Thus the implications to regional water quality are very distinct across these fertility gradients from peat to marl sediments.

Controls on phytoplankton populations in Florida Bay: clams and eggs.

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Water column microalgal blooms were first noted in Florida Bay in 1987 following the die off of seagrasses (primarily *Thalassia testudinum*). Blooms of a small cyanobacterium, *Synechococcus* sp. in the central portions of the bay, and diatom blooms in the western regions have occurred with increased frequency and duration. One hypothesis that has been suggested to account for these blooms is a reduction in loss rates due to reduced grazing by water column phytoplankton populations by zooplankton and benthic filter and suspension feeders.

The impact of the cyanobacterial bloom on zooplankton populations and their grazing and reproduction rates was unknown. Also, a major loss of benthic organisms particularly in the central and southern portions of the Bay occurred. Such information led us to suggest the following hypotheses:

1. Reduced grazing activity by benthic filter and suspension feeders has contributed to the maintenance and prolongation of water column phytoplankton blooms.

2. Reproduction rates and subsequently grazing rates by zooplankton are reduced within the area of the cyanobacterial bloom.

The first hypothesis was tested in a pilot study at Keys Marine Laboratory during June, 1996. The purpose of the study was to determine the magnitude of filtering and ingestion rates of representative benthic suspension and filter feeding invertebrates common to Florida Bay; to test experimental protocols for obtaining these rates and recommend modified procedures; to determine the general groups of phytoplankton that were ingested in field collected samples and in laboratory grazing studies; and ultimately to estimate the impact of filter and suspension feeders on water column phytoplankton biomass in Florida Bay.

Seven species of benthic invertebrates were used in our experiments: The bivalves *Argopecten irradians*, and *Chione cancellata*; the mangrove tunicate, *Ecteinascidia turbanata*; and the sponges, *Chondrilla nucula*, *Cinachyra sp.*, *Halichondria sp.* and *Haliclona sp.* Representative specimens of each species were exposed to a range of chlorophyll concentrations derived from water collected from 3 locations; Sprigger Bank, Captain Keys and Rankin Basin with suitable controls. Three approaches were used to estimate grazing rates: 1. a static protocol with triplicate specimens of each species exposed to a range of 5 chlorophyll concentrations; this approach was discarded for logistical reasons and specimen requirements; 2. a static protocol with triplicate specimens incubated in water with a range of chlorophyll concentrations sequentially from lowest to highest concentration; and 3. A closed system protocol with a specimen enclosed in a chamber through which phytoplankton enriched filtered sea water is pumped through a fluorometer which records changes in fluorescence over time. In all the approaches incubation time ranged from 20 to 40 minutes at ambient light in the laboratory and calculations of filtering and ingestion rates are based on control corrected initial and final extracted chlorophyll determinations and all values are normalized to dry weight. Samples were also taken for cell counts but have not been completed. Qualitative determinations of the types of phytoplankton ingested will be based on HPLC analysis of selected carotenoid pigments. These analyses are also awaiting completion.

The second hypothesis was tested using a combination of feeding and egg production experiments using animals and water collected from several locations in Florida Bay. Egg production was determined by incubating representative species for 24 hours in water from four locations. An additional 24 hour incubation was used to determine hatching success. Microzooplankton grazing rates were determined monthly by the Landry dilution method with water from two locations, Rankin Basin and Captain Keys while macrozooplankton grazing was determined by standard incubation methods every other month.

Results

Average filtration and ingestion rates for all benthic species, irrespective of the water type and chlorophyll concentration ranged from 100 to 850 ml/g dw/hr and 0.08 to 2.11 ugChl/g dw/hr, respectively. Maximum filtration and ingestion rates exceeded 3000 ml/g dw/hr and 20 ugChl/g dw/hr, respectively. Higher filtration and ingestion rates were obtained in the closed system compared to the static systems for the purple sponge, Haliclona sp. (>1000 ml/g dw/hr vs. 335 ml/g dw/hr, respectively). Both filtration and ingestion rates were dependent upon the source of water. Water from the KML raceway produced consistently lower rates than any other source water. Average rates for Chione and Ecteinascida were higher in water from Captain Key whereas Argopecten had little preference. All species except Chondrilla and Cinachyra had relatively high rates in water from Rankin Basin. There were no obvious relationships between filtration and ingestion rate and chlorophyll concentration for any species tested.

Microzooplankton grazing rates were highest in samples taken from the cyanobacteria bloom in Rankin Basin. Macrozooplankton (copepod) gazing rates were also high in this region however the species investigated were mainly feeding on microzooplankton and flagellates rather than on the cyanobacterium. Egg production at all locations was low relative to other areas or estuaries however, the hatching rate was extremely high; usually >80%. Egg production in Rankin Basin water was higher than other locations during summer but the overall seasonal average was essentially the same for all locations.

Impacts

Estimates of the impact of grazing by benthic filter and suspension feeding on the water column cannot be calculated until quantitative areal estimates of biomass distribution are available. A preliminary assessment can, however, be made based on some assumptions and a limited amount of data. Turney and Perkins (1972) report areal distribution values for Chione cancellata in several areas of Florida Bay. Values range from 3 to 24 animals/ft2 for the interior region of Florida Bay which translates to 32-258 animals/m2. With a maximum filtering rate of approximately 200 ml/animal/hr, Chione could filter

6400 - 51,600 ml/m2/hr or 67% to 386% of a 1m3 water column (10,000 liters). A similar calculation can be made using the filtration rates for Halichondria and Haliclona sp.; 300-500 ml/animal/hr. If we assume a population density of 2 animals/m2, such values translate into particle removal from 6% to 10% of a 1 m3 water column per hour; or essentially the entire water column in one day. Our rates may also be underestimates relative to rates recalculated from Reiswig (1974). His rates for several different species of sponges, normalized to gram dry weight, range from 5400 to >18,000 ml/g dw/hr; approximately 5 to 10 times higher than our measured maximum rates. Thus, the impact of filtration of water column phytoplankton by benthic suspension feeders can be significant on a daily basis.

In addition to the benthic filter feeders, microzooplankton grazing rates were also elevated in the bloom areas. Macrozooplankton appeared to take advantage of the presence of these micro-grazers by using them as a food resource. With added egg production and high hatching success rates, zooplankton populations were being maintained within the bloom area of Florida Bay. Therefore, at least on first analysis, water column grazing and benthic grazing should be operating as a control mechanism in the region of the cyanobacterial bloom. However, we were not able to find any viable benthic suspension and/or filter feeders with the bloom area on our sampling trip. Therefore, losses by grazing from this component of the ecosystem potentially did not occur. A final analysis will be based on the results of the FDEP benthic study currently underway.

Evaluating the precipitation and evaporation patterns in and around Florida Bay.

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The freshwater input from precipitation, directly, and through flows resulting from over-land rain immediately to the north, is a crucial parameter in many analyses; e.g., salinity studies, ecological studies, and hydrological and ecological modeling of Florida Bay. This study addresses the effect of rainfall inputs directly into Florida Bay, and the rainfall over land areas to the north over the Everglades which are of paramount importance in the short term freshwater flows into the Bay. Because of the tropical convective nature of the summer rainfall in South Florida, gage measurements of rainfall only give representative rainfall measurements for long averaging periods and can often miss, or erroneously assess the magnitude of, significant convective rainfall events. The new digitized and recorded next-generation WSR-88D Doppler weather radars (NEXRAD) at Miami and Key West are capable of producing rainfall estimates over the entire Florida Bay/Everglades area at a time and space resolution not previously possible. These recently installed NEXRAD radars certainly have great potential for providing the rain input required at the shorter time, and the smaller spatial scales. Because of the difficulty of operating gages over open water areas, the radar data will provide the only rain measurement over some areas.

However, despite the superb time and spatial resolution, the quantitative measurement of surface rainfall, or freshwater flux, with radar is not without problems. An initial comparison between radar rainfall estimates and gage measurements at four locations (NOAA/NCDC Tech Rept 96-03, 1996) show in some cases good agreement, but in some cases rainfall totals differing by a factor of two. Some of the error is in the methodology of the gage/radar comparison, and gages are not trouble free instruments, i.e. wind effects, exposure, etc. But, some of the difference is due to the interaction of the radar and rain drop size distributions, i.e. a few large drops and a very large number of very small drops look the same to the radar, but may have a very different rainfall rate. The NEXRAD algorithms used to convert radar reflectivity to surface rainfall have been developed largely for mid-latitude subtropical regimes, and may not be fully suitable for the more tropical summer convective conditions of South Florida. The purpose of this study is to assess the accuracy of the present NEXRAD rain products, and to refine the radar-rain algorithms as required.

The primary hydrological product provided in the suite of NOAA NEXRAD products is the hourly digital precipitation array. This has a time resolution of one hour and a spatial resolution of approximately 4 km. The first part of this study is a comparison between this product and the rain gage network over the Florida Bay Everglades area. This comparison is shown for the 1996 rainy season. In addition to the hourly comparisons, comparisons for longer periods, 6, 12, and 24 hours are shown.

Further, it is assessed whether modifications to this product can form the basis for an adequate rainfall product for Florida Bay, or whether higher resolution radar data has to form the basis of a Florida Bay rainfall product. To this end case studies are presented where a developmental algorithm is applied to the full resolution radar data (6 min, and 1 km) and the results compared to gage measurements. The tuned Z-R relations based on the drop size distributions made in support of this program are applied here. This algorithm includes a separation of the radar data into stratiform and convective groupings and the application of an appropriate tuned Z-R relation for each, and a preliminary assessment of the efficacy of a convective-stratiform rain separation method for this area is made.

In addition to the radar gage comparisons, several field measurements have been made to tune and refine the radar-rain algorithms for use in the Florida Bay/Everglades system. These include airborne drop size measurements from several NOAA P-3 flights over the area in the summers of 1995 and 1996. These airborne drop size measurements are compared to the airborne radar data collected during these flights, and to the NEXRAD radar data. During the summer of 1996 a near continuous record of drop size distributions was also measured using a surface drop distrometer at a station in the Everglades National Park, and with a mobile van. These measurements, and preliminary indications of their relevance to the radar- rain algorithm, are discussed.

Seagrass dieoff in Florida Bay (USA): Long-term trends in abundance and growth of Thalassia testudinum and the role of hypersalinity and temperature.

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Beginning in late 1987 Florida Bay experienced a large and unprecedented dieoff of *Thalassia testudinum*. The dieoff occurred only in stands of dense *T. testudnium*. The largest dieoff zones were in western Florida Bay, but with some dieoff in the denser beds of the eastern Bay. The abundance and productivity of *Thalassia testudinum* was measured at 5 stations associated with the seagrass dieoff and 3 control stations, including one on the seaside of Key Largo, outside of Florida Bay, from 1989 to 1995. Early in the study salinity was very high, exceeding 46 psu, and decreasing to 29-38 psu in recent years. Seagrass standing crop and either short shoot density or mass per short shoot declined at nearly all stations. Areal productivity declined at 3 dieoff stations while mass-specific productivity increased at all dieoff stations and 1 control station. Seasonality was pronounced, detrended standardised residuals showed responses for all of the parameters to be greater than the yearly mean in spring and fall and less than the mean in fall and winter. Detrended residuals also showed decreased productivity to be correlated with increased salinities in the summer. Temperatures showed the greatest deviations from long-term means in the years of dieoff initiation.