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Rosenstiel School of Marine and Atmospheric Science

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Analysis of Scientific Programs and Management Plans Affecting Nutrient Loading and Algal Blooms in Florida Bay

by

Odessa E. Bowen

An Internship Report

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Florida Bay is a 2200 km^2 shallow coastal lagoon lying between the southern tip of mainland Florida and the Florida Keys. It is under the management of the National Park Service and National Oceanic and Atmospheric Administration. Changes in Florida Bay, particularly nutrient loading and nuisance algal blooms, have led to the creation of the Florida Bay Scientific Review Panel. This Panel is charged with submitting reports to the Interagency Working Group on Florida Bay. Research among several agencies is coordinated by the Interagency Program Management Committee (PMC). This Committee created the Florida Bay Strategic Plan, which charts progress made. . Although there is no standardization in reporting, findings are presented at different workshops and conferences (e.g., the Florida Bay Science Conference) and are written into the NOAA Implementation Plan. This Plan is used to guide future research and funding levels. In order to better advise the PMC, the Florida Bay Science Oversight Panel evaluates ongoing projects and makes further recommendations for future research. Due to the level of interaction among so many agencies, coordination has been difficult, and therefore comprehensive recommendations for future research have been limited.

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INTRODUCTION

Florida Bay is a 2200 km^2 shallow coastal lagoon lying between the southern tip of mainland Florida and the Florida Keys. It is part of the only tropical environment in continental United States, and is under the direct management of National Park Service (NPS) as part of the Everglades National Park (ENP) or National Oceanic and Atmospheric Administration (NOAA) as part of the Florida Keys National Marine Sanctuary (FKNMS). Under Organic Act of 1916, NPS is responsible for both protecting and preserving the Bay's unique features. Research in Florida Bay has been conducted and coordinated among different agencies by ENP.

Changes in Florida Bay were first evident in 1987, ranging from extensive loss of seagrass habitat to declining populations of economically significant species. Changes in the Bay reflect a degradation of the ecosystem, in terms of its productivity of living resources, biodiversity and stability.

For legal and political reasons, efforts to restore the ecosystem initially focused just on issues of water quality (in particular, phosphorus inputs), with limited attention to water delivery policies. However, to recapture the historical characteristics of the natural ecosystem and to achieve long-term ecological sustainability, fundamental region-scale changes in the water management system are essential. This inclination to revert to the Bay's past conditions reflects a shift in the public's attitude. In the past, wetlands were drained for settlers to support the agricultural industry with water that historically flowed into the Everglades, and to provide flood protection for urban development. However, more recent societal goals are to restore the Everglades and Florida Bay and to protect endangered species (Harwell, 1997).

This internship report is an analysis of the scientific programs in place for the study of nutrient loading and algal bloom phenomena affecting Florida Bay, and how these programs affect policy and management decision making. It will present an overview of the cooperation levels among the different federal, state and local agencies involved, as well as other private entities with an interest in the Bay. Furthermore, it will provide a timeline of past studies of nutrient loading and algal bloom phenomena and current policies that govern continued research. Finally, I will attempt to give a perspective on the future trends of scientific research and management policies concerning this issue.

BACKGROUND

Perspective on past efforts to study the effects of nutrient loading in the Bay

Deterioration of the Florida Bay ecosystem: An evaluation of the scientific evidence (Report to the Interagency Working Group on Florida Bay).

The Florida Bay Scientific Review Panel was created in early August of 1993 at the request of Mr. George T. Frampton, Assistant Secretary for Fish and Wildlife and Parks of the U.S. Department of the Interior. The panel was charged with submitting a report of findings and recommendations to the Interagency Working Group on Florida Bay. This Working Group is composed of local (largely in Florida) managers of agencies relevant to the South Florida Ecosystem Restoration –not necessarily or even predominantly science in focus (Dr. Peter Ortner, personal communication). Even though there was no specific method of standardization, the panel's goal was "to provide an unbiased and credible analysis of the deterioration in the Florida Bay ecosystem to help guide management and research priorities... by reviewing the body of scientific, historical and anecdotal literature on Florida Bay and receive oral testimony about the causes of the current decline."(Boesch, et. al., 1993). The group heard testimony on 11 presented hypotheses, which were either stated or implied, in the explanation of the degradation of the Florida Bay ecosystem.

Following the evaluation of the presented data, the panel felt that the division between a reduction of freshwater inflow and nutrient enrichment by human activities as causes of ecosystem deterioration was oversimplified and that the level and coordination of research and monitoring had been insufficient for comprehensive decision making in the Bay. Evidence tipped heavily in favor of restoring amount and timing of freshwater flow to northeast Florida Bay;

however, the potential benefits to the entire Bay (i.e., eliminating plankton blooms in the northeastern Bay) are still uncertain. It seemed unlikely that the proposed actions would eliminate western algal blooms.

The panel developed the following theories on the causes of enhanced nutrient loading:

1. Lack of major storms in the region over the last 30 years may have resulted in significant accumulation of calcareous muds and entrained nutrients.
2. The most likely source of nutrients stimulating blooms of blue-green algae in central and eastern Florida Bay is release from sediments (phosphorus and nitrogen) following mass mortality of seagrasses; phosphorus enrichment is of particular concern, because P may be the limiting factor in the eastern Bay. The relationship between P and N was determined using the Redfield ratio, which predicts the ratio of oxygen consumption to nutrient production caused by biological oxidation. The ratio of P:N is defined as 1:16 (Millero, 1992). Long water retention time and high concentrations of dissolved and particulate organic matter (DOM and POM) may also contribute to algal blooms. However, algal blooms to the west seem to predate the seagrass die-off and may be stimulated by long-term increases in land-based inputs of nutrients, especially nitrogen.

Nutrients and algal blooms

The following hypothesis was presented to the panel concerning the stipulations for enhanced nutrient loading:

"Nutrients released from sediments after the die-off of seagrasses were, and are, the principal cause of algal blooms, rather than increased nutrient inputs from land"

This hypothesis faced some problems; first, Florida Bay quantitative historical information on water quality is very limited - almost nonexistent. Second, enhanced bloom activity is suspected of being linked to increased loads of plant nutrients (primarily resuspended phosphorus and nitrogen). Also, scientists and managers have limited information available on the sources, cycling and assimilatory dynamics of enhanced nutrient loading --no studies had been conducted at the time. Another constant point of contention was the source of increased nutrient loading: is it due to a) massive seagrass die-off or b) land-based sources (ENP watershed or sewage from the FL Keys)? One study found that human activities in the Florida Keys are significantly contributing to increased N and P inputs to nearshore waters, enhancing coastal eutrophication (LaPointe and Clark, 1992).

The panel believed that an explanation for the algal blooms in the Bay was that there may be two contrasting but contemporaneous bloom phenomena taking place with increasing frequency and intensity. This is consistent with differences in location, timing and species composition of the blooms.

In the central and eastern Bay, [blue-green] cyanobacteria may be more closely related with events associated with the massive seagrass die-off (including release of "internal" sources of nutrients); these blooms are more acute and localized.

In the western and southern Bay, diatom (microalgae with silica shells) blooms are dominant and may have resulted from gradual increases in nutrient loading from varying anthropogenic sources over the time scale of years to decades.

Restricted intra- and interbasin circulation and increased water retention times may have affected the bloom potential by playing a critical synergistic role in promoting the establishment, proliferation and persistence of blooms throughout the Bay.

It is assumed that primary productivity is P-limited (P is released from sediments), since water in the central and eastern Bay is already N-rich. It is useful to note, however, that N can also be limiting, especially in western Florida Bay.

The Panel developed a speculative scenario to explain processes linking the seagrass die-offs to cyanobacteria blooms in the central and eastern portion of the Bay. This was based on knowledge of similar systems rather than direct observation. Following is the scenario:

Seagrass dies, which results in sudden, large releases of dissolved organic matter (DOM) and particulate organic matter (POM). This release of nutrients, coupled with long retention times for water leads to enhanced nutrification of sediments and water column N and P regeneration and efficient nutrient exchange between benthic and planktonic habitats. Microbial activity reduces oxygen availability to bottom sediments, which leads to enhanced nutrient release into the water column. The combined effects of high water retention time, high DOM concentrations and released nutrients results in cyanobacteria blooms. These persist because the limited flushing of sub-basins allows effective nutrient regeneration to continue without a significant net loss of either biomass or products of its decay. This is consistent with classic bloom phenomena in nutrient-enriched, shallow lakes showing periodic, long residence times (volume of water in a region divided by the rate of inflow or outflow; Pickard, 1979).

In the western portion of the Bay, conditions here may have been first reported by lobster and stone crab fishermen in the late 70's when they noticed changing water color.

Natural and anthropogenically-enhanced nutrient loading from external sources to the Bay could be the result of freshwater inputs along the Florida Gulf Coast (Shark River Slough) or on-site sewage disposal systems. One study shows that the high ratio of N to P in the freshwater of the Everglades (>350:1) suggest that even at increased flows the loading of P into northeast Florida Bay would be unimportant compared to brought into Florida Bay from the Gulf of Mexico (Fourqurean, et. al., 1993). This study also showed that at the western edge of Florida Bay, the concentrations of TN:TP was near the Redfield ratio, but in the center of the Bay extreme deviations from 16:1 were found, with a baywide average of 101:1. This indicates a severe shortage of P with respect to N in the water column for most of Florida Bay. The blooms are diatom-dominated, most characteristically of the genus *Rhizosolenia*.

Drainage for the Everglades has characteristically low P concentrations because P tends to be taken up by wetland plants whose growth is highly P-limited. The runoff contains relatively high nitrogen and ammonia, but little phosphorus.

This may be characteristic of a growing and troublesome trend of coastal eutrophication, ranging from incipient stages of bloom development to more massive and problematic concentrations of nuisance blooms (e.g., red tides).

The panel then made a series of recommendations on information and research needs, of which the following were deemed most essential:

- Determination of which nutrients limit phytoplankton production and bloom formation; also, study nutrient-production thresholds and assimilative capacities of Florida Bay.
- Characterization and quantification of the supply and fluxes of nutrients; these should include land-based and atmospheric nutrient loadings, advection

of nutrients from the West Florida shelf into the Bay, and within-Bay exchange and residence time characteristics.

- Determination of the relative importance of "external" vs. "internal" (regeneration, nitrogen fixation, etc.) nutrient inputs and losses in Florida Bay. Also, proportions of primary and secondary production that are based on external ("new production") as opposed to regenerated sources.
- Identification, monitoring, and characterization of phytoplankton and epiphyte communities in Florida Bay and immediate surroundings on appropriate spatial and temporal scales.

Critical information needs and suggested approaches in research, monitoring and modeling are identified for water flow and characteristics; nutrients, plant growth and blooms. Many of these needs and approaches are similar to those included in a recent research program plan by NPS and in recommendations from a NOAA workshop. These agency plans have been uncoordinated and are not organized around test of critical hypotheses to the degree the Panel feels is necessary.

The next step in developing a more comprehensive, objective, focused and coordinated science strategy, which could gain governmental and public support, should be an integration and honing of the Panel's recommendations and those of the NPS plan and NOAA workshop report. The resulting science strategy should be appropriately balanced among research, monitoring and modeling; it should provide for sustained support; and it should involve the coordinated contributions of state and federal agencies and regional universities.

From a managerial perspective, there are two sets of management challenges. The first one deals with the objective of restoring water levels and water quality in the more northerly portions of the Everglades and the potential ramifications to Florida Bay. Even if more freshwater is discharged, more N is coming through Shark River Slough. In such case, N-limited western Florida blooms may worsen. These consequences could even extend through the Keys out to the reef as plumes of algae transported from the Bay.

The second challenge for management deals with the relationships between the objectives of Everglades National Park and Florida Keys National Marine Sanctuary. A restoration scheme which may be beneficial to the Bay may be harmful to FKNMS. For example, a freshwater delivery policy which benefits the Bay could transport harmful algal blooms, water of high nutrient content or water with excessively high or low salinity to the Sanctuary, with grave consequences. A broader ecosystem perspective was, and is still, needed which integrates the watershed, the Bay, the Florida Keys and the reef. Also, consequences of flood control, agriculture and Everglades wetlands management on delivery of fresh water and nutrients to the Bay and interrelationships between the portion of Florida Bay within Everglades National Park and Florida Keys National Marine Sanctuary need to be addressed by both science and management. Towards this end, a Florida Bay Research Program was developed.

Florida Bay Research Program

The Florida Bay Research Program is an interagency effort based on the 1994 Florida Bay Science Plan developed for the Florida Bay Interagency Working Group. The Science Plan identifies research deficiencies and directs efforts to adequately address 72 unanswered questions concerning the condition and ecological history of Florida Bay. The Florida Bay Research Program goals are to:

a) Accurately assess the Bay's response to ecosystem changes,

b) Provide resource managers with information based on sound science.

The purpose of the program is to provide a forum in which decision-makers and scientists develop an integrated monitoring and measurement project for the South Florida coastal ecosystem. The project will do the following:

- Establish a coordinated monitoring framework to document change at the ecosystem level.
- Measure the effectiveness of ongoing and planned management actions.
- Reduce monitoring gaps and overlaps.
- Improve existing monitoring capabilities.

To meet these goals, an interagency program management committee was established.

Interagency Program Management Committee

To ensure that the broad range of scientific activities planned for Florida Bay are focused and coordinated, an interagency Program Management Committee (PMC) was created, consisting of a scientific representative from the eight state and federal agencies having jurisdictional control and/or scientific interest in Florida Bay. This PMC is chaired and coordinated by Thomas Armentano in National Park Service and John Hunt of the Florida Department of Environmental Protection. The PMC provides policy-makers with reliable scientific information and science-based recommendations relevant to the restoration of Florida Bay. Each participating agency has drafted a Florida Bay Research Implementation Plan to ensure that critical scientific priorities are being addressed by the agency best suited to do so. The PMC identifies research needs, reviews Florida Bay Research Implementation Plans, eliminates redundancy of efforts and ensures interagency communication and research collaborations. NPS, through Everglades National Park, leads deliberations on Florida Bay, sets scientific priorities, and coordinates the Florida Bay Research Program; it also uses the permitting process to track the initiation of all new research projects, encourage institutional collaborations, and improve reporting of results.

In order to expedite these objectives, the PMC developed a Florida Bay Strategic Plan. The Plan is built around five central questions, and its goal is "to produce data and models essential for understanding the Bay as an ecosystem functioning within a regional system that is strongly influenced by human forces". A plan of this type is critical to achieving the major programmatic goals that the PMC and its oversight panel have established for the interagency program. The Florida Bay Strategic Plan can be found in appendix A.

The Florida Bay research program is designed to shed light on the causes of changes that have raised social concerns for biological resources in the Bay, most visibly seagrass mortality and algal blooms. The program relates to restoration managers by being part of the South Florida Ecosystem Restoration initiative, headed by a Task Force consisting of state and federal agency heads and representatives from other interested groups, such as universities. Reporting to the Task Force are a group of regional managers of those agencies responsible for managing the environmental resources in South Florida and carrying out the restoration activities. This group has a Science Coordination Team, which deals with science issues; for example, the representatives for NOAA are Drs. Peter Ortner and Brad Brown (Dr. Peter Ortner, personal communication). Reports of the Florida Bay program are expected to provide vital information to managers of the FKNMS, located downstream of Florida

Bay, although programs conducted in the Sanctuary are not within the purview of the PMC.

In organizing the program around five central research and modeling areas, the PMC has chosen to shift focus towards questions of causality and mechanism while continuing essential surveys and monitoring. The five questions posed are discussed in terms of the information and modeling needs considered critical for program success. All are tied to achieving a comprehensive knowledge of the Bay as a complex ecosystem that has undergone profound changes in its recent past. However, no attempt is made in the Plan to provide details on questions or projects. This information is available in individual agency implementation plans, or in the annual reports and published results. Instead, the Plan is written to outline an approach for advancing the interagency program beyond an initial stage that is focused mainly on surveys and monitoring to one concentrating more on processes and mechanism essential to restoration decisions.

The central question for nutrient loading called for an examination of the influx of external nutrients and of internal nutrient cycling in determining the nutrient budget of Florida Bay and also to determine what mechanisms control the sources and sinks of the Bay's nutrients. The exchange of nutrients between Florida Bay and adjacent regions (external dynamics) and the cycling on nutrients within Florida Bay (internal dynamics) influence the entire Bay's ecological structure and function, including the occurrence of algal blooms. Through a program of monitoring and research, the question of how human activity is affecting the nutrient dynamics of Florida Bay and how future restoration actions will alter these dynamics is being addressed. In addition to the research needs previously outlined in this paper, other points that have been researched include the following:

- An area of the Bay near the north-central coast has been identified as a "core" region where water column nutrients (both organic and inorganic) are higher than in any other region of the Bay. This region is also where the *Thalassia* die-off was first noticed in the late 1980s and where algal blooms have been sustained since 1991.
- Sediments and their associated seagrass beds contain a large reservoir of organic and inorganic nutrients. Likewise, the mangrove forests in the north coast and islands of the Bay and on the Gulf coast contain a large nutrient pool in living tissue and sedimentary detritus.
- Loading of nutrients from the Everglades to Florida Bay has not been fully quantified. Estimates of nutrient inputs to the upstream wetlands of ENP indicate that N and P inputs increase with increasing water flow, but that the water is relatively poor in P.

However, the main information needs relative to nutrient cycles are an understanding of the factors that triggered and maintain the persistent phytoplankton blooms. Also critical is sufficient understanding to enable the assessment of the impact of various environmental management strategies being considered for Bay restoration. Especially important is the ability to predict the sensitivity of the Bay's nutrient cycles to changing freshwater flow to the Bay, and the resultant change in the Bay's salinity regime.

For much of the Bay, any factors that increases P availability either by increasing sources or decreasing removal, is likely to exacerbate the current problems of the Bay. Recent evidence also indicates that algal blooms in the central and western Bay are also stimulated by N enrichment.

Answering the questions outlined entails a combination of monitoring, research and modeling. The development of a water quality model for the Bay is central to this effort, because such a model not only provides a tool for environmental managers to assess the consequences of their plans and actions, but also provides a means for scientists to integrate existing information and focus future monitoring and research. Finally, experiments that explore the mechanisms that control the current nutrient cycles in the Bay are required to understand cause and effect relationships and distinguish natural causes from human induced causes of change in the Bay. Some program elements that attempt to provide results are the Water Quality Model, which is a collaboration between the Army Corps of Engineers and WES, Mass Balance Model (USGS/BRD) and Turbidity and Sediment Resuspension (USGS/GD and COE). However, funding for other studies dealing with nutrient loading is being explored among several agencies but has not yet been fully defined.

Directly tied to the question of nutrient loading is the question of what regulates the onset, persistence and fate of planktonic algal blooms in the Bay. The blooms are in part a function of the nutrients required to support them. Initiation and maintenance of the Florida Bay microalgal blooms must rely on a supply of nutrients, primarily nitrogen, phosphorus and silica, as well as essential trace elements. Also, bloom formation depends on the difference between population growth and loss, the latter primarily resulting from zooplankton and benthic filter-feeder grazing. Limited experiments suggest that most daily primary production is utilized by zooplankton grazers in the water column.

Informational needs that have to be met to address this question include a model to analyze nutrient and bloom dynamics within the context of larger ecosystem models to assess management strategies for Florida Bay; also important is the continued obtainment and evaluation of field data to fully define the history, present status and possible future trends of algal blooms, which species are key and their particular characteristics which allow them to successfully compete in the Florida Bay environment and adapt to the changing conditions. The program elements that are currently in place are Trophodynamic Studies, conducted by NOAA, Physiological Rate Measurements (DEP/FMRI and NOAA), Monitoring of Bloom Status (DEP/FMRI and NOAA) and Phytoplankton Modeling Studies (NOAA, DEP/FMRI and USGS/BRD).

Research gains in these and other projects studying nutrient loading and algal bloom phenomena were presented at the 1998 Florida Bay Science Conference, held at the University of Miami/James L. Knight International Center in Miami, Florida.

INTERNSHIP DIRECTION

Florida Bay Science Conference

On May 12-14 of 1998 I attended the Florida Bay Science Conference, which provided a forum in which scientists could share their research progress and concepts with each other and other policy managers. I experienced firsthand how different agencies interact with one another —sometimes agreeably, sometimes a bit more contentiously. Some of the research presented in abstracts were: the possibility of groundwater being a significant source of nutrients to the Florida Bay ecosystem, input of atmospheric nitrogen species in Florida Bay area, the influence of nutritional environments on secondary production and nuisance bloom dynamics, and spatial and temporal variations in primary production for Florida Bay algal blooms. These and other selected abstracts can be found in appendix B.

Researchers from different agencies would find themselves at odds in various instances, such as determining the relative merit of ecological modeling when insufficient information was applied, and the soundness of research behind some hypotheses presented. Despite all this, the conference was very valuable in terms of information and data sharing. While there was a wealth of research projects presented, they were all guided by the five central questions in the Strategic Plan for the Interagency Florida Bay Science Program and the South Florida Ecosystem Restoration Prediction and Modeling Implementation Plan (SFERPM) for 1998.

South Florida Ecosystem Restoration Prediction and Modeling Implementation Plan (SFERPM)

The SFERPM program was developed by a team of federal, state and academic regional scientists. Its elements were designed to complement other components of the FY97 NOAA South Florida Ecosystem Restoration Initiative. Also, a substantial fraction of SFERPM funds directly contributes to the Florida Keys National Marine Sanctuary (FKNMS) Management Plan and the National Coral Reef Initiative by addressing the linkages among Florida Bay, the Florida Keys, and the coral reefs tracts of the FKNMS.

The objectives of the SFERPM continue to be the delivery of timely information to South Florida Ecosystem Restoration managers. To that end, SFERPM has two basic components: Environmental Research & Modeling, in which specific projects are selected for two-year awards through an open, fully competitive, peer-reviewed process and Community Education & Outreach, which is conducted by Florida Sea Grant.

Some details of the Plan include progress toward overall goals, general objectives and accomplishments of various ongoing research projects, future goals of ongoing projects, and overall outlook for future years. A complete Implementation Plan for 1998 is presented in appendix C.

As comprehensive as the Implementation Plan is, it is nonetheless a framework for present and future research. A more direct evaluation of the ongoing projects can be found in the Florida Bay Science Oversight Panel's 1998 Report.

Florida Bay Science Oversight Panel

The Florida Bay Science Oversight Panel (FBSOP) is an independent peer-review group, charged with providing regular, broad, technical, and management review of the Interagency Florida Bay Science Program. It reviews agency plans, Program Management Committee (PMC) strategies for program development, scientific quality of research, and research results (NOAA website, http://www.aoml.noaa.gov). The Panel consists of senior scientists with significant experience in major estuarine restoration programs but without involvement in Florida Bay projects.

Thirty-three oral presentations were made at the conference, many of which summarized results from several related projects. The Panel then presented some general observations and recommendations. For example, the Panel applauded the Strategic Plan for the Interagency Florida Bay Science Program as well-focused and exemplary, yet decried the lack of a timetable for implementation. Overall, the Panel's impression is that the Program lacks a tight array of organization under which the research can function and be interrelated and under which the various agency programs complement one another. Specifically speaking to the questions of nutrient loading and algal blooms, the Panel feels that for nutrient loading more quantification is emerging and quantitative syntheses are being assumed, offering some hope that this question will be answered in the near future. Algal bloom phenomena, there is growing information, yet process studies leading to a full understanding of the formation and persistence of algal blooms in Florida Bay remain lacking. The FBSOP's complete report is found in appendix D.

CONCLUSION

This internship has provided me with valuable insight of how science and policy come together to develop strategies in an attempt to resolve problems that affect both environmental and public health issues. My scientific and policy backgrounds were tested when applied to the real world. I gained firsthand experience of the obstacles that researchers must overcome, whether it is a strained funding climate, data sharing with other researchers in different agencies —and sometimes, within their own agencies, and conveying this information to policy decisionmakers in a meaningful fashion. Policymakers also have their own hurdles to conquer; they must develop and implement a plan that would grant the greater benefits to both the environment and the public. This is accomplished with sometimes finite information, from various groups, not only agencies at the federal, state and local levels (whose reports may contradict each other in any given issue) but also universities and interested private citizens. In addition, I observed how policies and scientific programs influence and modify each other, and the process of discussion, compromise, change and implementation that ensues.

This has truly been an interesting experience. While this was merely a glimpse into the inner workings of scientific research and policy making on a comprehensive ecosystem scale, it is valuable insight nonetheless, which will aid me in my future endeavors.

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Strategic Plan for the Interagency Florida Bay Science Program. March 1997.
Prepared by the Florida Bay Program Management Committee.

APPENDIX A

Strategic Plan for the Interagency Florida Bay Science Program
March 1997
Prepared by the Florida Bay Program Management Committee
(PMC)

STRATEGIC PLAN FOR THE INTERAGENCY FLORIDA BAY SCIENCE PROGRAM

Prepared by Florida Bay Program Management Committee

March 1997

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

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

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

IV. **LITERATURE CITED**
V. **FIGURES**

FLORIDA BAY PROGRAM MANAGEMENT COMMITTEE

U. S. DEPARTMENT OF THE INTERIOR- NATIONAL PARK SERVICE
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Robert J. Brock- (Everglades National Park)- Research Coordinator

FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION
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Dr. Bill Kruzynski

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
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U.S. ARMY CORPS OF ENGINEERS
Steven Traxler- Jacksonville District

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Dr. Nancy Thompson* (National Marine Fisheries Service)
Dr. Peter Ortner* (Atlantic Oceanographic and Meteorological Laboratory)

U.S. DEPARTMENT OF INTERIOR - FISH &;WILDLIFE SERVICE
Kalani Carnes

U.S. DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY
Dr. Michael Robblee* (Biological Resources Division)
Dr. Robert Halley* (Geologic Division)

*- Writing Team

INTRODUCTION

The following Strategic Plan for the Interagency Science Program in Florida Bay has been developed by the interagency Florida Bay Program Management Committee (PMC) to focus the resources of the member agencies on a research strategy to provide science information critical to the restoration of Florida Bay. The plan is built around five central questions. The goal of the science program is to produce data and models essential for understanding the Bay as an ecosystem functioning within a regional system that is strongly influenced by human forces. This document: (1) summarizes the background, objectives and organizational function of the PMC, (2) defines the five central questions, and (3) describes the current and planned research program in each area.

Background

In early 1994, scientists from five agencies presented a draft Interagency Science Plan for Florida Bay (Armentano, *et al.* 1994) for review by managers of local, state and federal agencies and representatives from non-government institutions. The managers and representatives, meeting as an interagency working group, endorsed the plan and agreed to accept it as a guidance document for establishing an integrated science program for the Bay. The program was developed around the need to build a strong scientific information and modeling base as an essential component in plans for the restoration of Florida Bay. To assure that the many individually funded science projects were integrated into a comprehensive program addressing key research issues , the plan called for the formation of the PMC, guided by an independent science oversight panel. In the next two years, many new projects were initiated, each directed towards one of the 72 questions identified by the science plan as essential for advancing our knowledge of the Florida Bay ecosystem.

A strategic science plan is critical to achieving the major programmatic goals that the PMC and its oversight panel have established for the interagency program. The PMC's mission continues to be assuring that a comprehensive scientific understanding of Florida Bay is made available to management in a timely fashion as restoration actions are undertaken. To accomplish this role the PMC directs and coordinates a broad range of scientific activities encompassing the Florida Bay Research Program. The principal functions of the PMC are:

- Develop and implement a research strategy designed to merge scientific understanding of the Bay with management's decision making process
- Facilitate a consensus-based process for determining science needs and priorities
- Promote funding of critical science needs
- Develop and maintain an open and scientifically sound review process for evaluating research results and for advancing the program

- Communicate research results and program progress to the management and scientific community

A Scientific Program for the Restoration of Florida Bay

The 1994 interagency science plan describes a general restoration goal of "restoring Florida Bay to a naturally functioning ecosystem", but the goal needs to be expressed within a quantitative framework and in relation to a general restoration goal. Defining a restoration target is likely to be an iterative process and to extend beyond strictly scientific considerations. It depends on understanding what events, conditions and processes produced the changes in Florida Bay that have led to the call for restoration. A major programmatic goal of the interagency program, is, therefore, to develop a quantitative understanding of the major factors and their interactions that have changed the Bay, both those that can be modified by human actions such as the flows of fresh water into the Bay, and those due solely to forces beyond management control such as storms and sea level rise. The objective of the interagency science program is to provide this knowledge and combine it with data on biological responses to help define restoration goals, to predict system response to management actions, and to establish success criteria.

Although most of the projects funded by our program are unfinished and others have just begun, some results have emerged, including those presented at the 1st and 2nd Annual Florida Bay Science Conferences held in 1995 and 1996. These conferences, sponsored by the PMC, and other meetings as well as written reports, have emphasized to the PMC and its oversight panel the need to strengthen the program's focus on a research strategy while preserving the continuity set in motion by the projects already underway. In organizing the program around five central research and modeling areas, the PMC has chosen to shift focus towards questions of causality and mechanism while continuing essential surveys and monitoring. This approach will assure that we continuously monitor the changes in the physical, chemical, and biological status of Florida Bay so as to establish a spatio-temporal record of trends in the basic ecological components. Simultaneously, however, we will now direct more resources towards understand ing the mechanisms underlying the trends. Only by such a dual approach, coupled with simulation modeling, can we hope to explain the causes for the dramatic declines in seagrass cover, water clarity and the other signals of ecological change that are of primary concern.

The Florida Bay research program is designed to shed light on the causes of changes that have raised social concerns for biological resources in the Bay, most visibly seagrass mortality and algal blooms. Seagrass mortality is probably the result of slow habitat changes over many decades. These changes chiefly precipitated by human alteration of the regional ecosystem, are hypothesized by many to have altered historical patterns of circulation, water quality and biotic communities leading to the present condition of the Bay. Figures 1 and Figure 2 depict an overview and more detailed elaboration of some hypothesized changes and subsequent feedbacks believed to be operating in the Bay in several time intervals since the first decade of the 20th century. The primary thrust of the Florida Bay program is to test the validity of these hypotheses so as to understand the effects of past human actions and to provide a scientific framework for testing new hypotheses if warranted. Our ability to meet this challenge will depend on numerous factors such as the limits of the historical database, and the ability to sustain support for vital projects.

Regional Context

Florida Bay is contained within the much larger South Florida region which is the focus of the South Florida Restoration Task Force. The Bay drains much of the adjacent mainland and receives flows of freshwater from both marshes and canals in the region. Clearly then, restoration decisions on the mainland will affect Florida Bay. Fortunately the regional context of restoration incorporates Florida Bay as an important part of the system. Besides re-engineering of the entire water management network in South Florida, large scale land purchases and control of non-point source pollution are underway. Although no specific restoration target has been defined for Florida Bay *per se* , most of the Bay is within Everglades National Park and much of the rest within the Florida Keys National Marine Sanctuary. Protection of these environments is mandated by federal legislation.

An Example of How the PMC Program Relates to Management Needs

Although restoration of the Bay to any specific historic condition may not be possible, restoration to a state generally characterizing the Bay prior to the recent period of alteration is a reasonable goal. Central to this target is the establishment of annual salinity variations characteristic of the pre-alteration period of the Bay. The physical sub-program (organized around central question # 1) in conjunction with upstream hydrological modeling will determine the extent to which water management can influence Florida Bay salinity patterns. The general physical, chemical, and biological features of this earlier state will be defined by paleoecological and geochemical studies of sediments (central question #1), as well as from research on salinity tolerances of key plant and animal species (central questions #3-#5).

Assuming that findings from these studies and models are supportive, management of salinity might be expected to favor a mix of seagrass and benthic algal species in place of a grass community dominated by a single species as seen in the 1980s. Subsequent water column clarity in many areas of the Bay then would be expected to improve as pioneer seagrasses colonize die-off areas. However, this response may not follow in portions of the Bay where turbidity is a natural feature of some areas of the Bay. Studies of turbidity (central question #2), water quality (central question #2), and ecological processes (central questions #3-#5) would be designed to define those areas and the processes responsible for the variable turbidity regime.

The PMC's role will continue to be to provide a strong scientific framework for rational decision making, and if that is achieved, an important part of the restoration process will have been accomplished. Figure 3 presents an overview of how the scientific activities comprising the Florida Bay science program interrelate and support the broader social process.

Relationship to Restoration Managers

As stated, the Florida Bay Program is a scientific component of the much larger South Florida Ecosystem Restoration initiative, headed by a Task Force consisting of state and federal agency heads and representatives from other stakeholders. Reporting to the Task Force are a group of regional managers of those agencies responsible for managing the environmental resources in South Florida and carrying out the restoration activities. This Working Group has established among other committees a Science Subgroup responsible for defining and developing plans to provide the scientific and information needs of the Working Group. In doing so it has divided south Florida into a series of subregions one of which includes Florida Bay. The Science Subgroup has delegated to the Interagency Florida Bay PMC the responsibility of managing the program of research, monitoring, and modeling activities conducted in Florida Bay and its environs. Results of the PMC efforts are communicated to the Working Group and its subgroups through the annual Florida Bay science conferences, joint membership of some PMC members on the Science Subgroup, and by direct briefing of agency managers.

PMC APPROACH TO PROGRAM INTEGRATION

The PMC has adopted several approaches to integrating the broad range of projects it supports and in assuring their scientific adequacy. These approaches, described below, are conducted in addition to those that individual agencies carry out. Each of the sub-programs being developed around critical questions has relied on one or more of the approaches and will so continue.

Figure 4 illustrates how the main components of the interagency program interrelate and are structured to provide outputs to other program components. Sub-programs are given within boxes and include modeling and all the supporting data collection programs including monitoring,surveys, and, where relevant, experimental results. Major outputs of sub-programs required by other sub-programs are connected by arrows. Dashed lines represent outputs to managers.

As illustrated in Figure 4, the circulation, water quality, and ecological models being developed in the Bay rely considerably on modeling being conducted outside the Bay itself. These include the regional circulation models of the Gulf of Mexico and Florida Straits, hydrological models of the Everglades, and regional atmospheric models. Outputs from these models provide input to the Bay models. Results of the Florida Bay program are expected to provide vital information to managers of the Florida Keys National Marine Sanctuary, located downstream of Florida Bay, although programs conducted in the Sanctuary are not within the purview of the PMC.

Scientific Advisory Panels

Integral to the implementation of the Florida Bay Research Program is independent expert review. This need has been served by the Florida Bay Scientific Oversight Panel as defined in the interagency science plan (Armentano *et al.* 1994). The plan defines the Panel's role as providing regular, broad, technical and management review of agency plans, of PMC strategies for program development, of the scientific quality of research, modeling and monitoring, and of research results and inferences. The Panel consists of seven senior scientists with significant experience in major estuarine restoration programs but without involvement in Florida Bay projects. The Panel participated in both annual conferences by formally leading question and answer sessions and by providing a written report to the PMC presenting critical review and recommendations for advancing the program.

Additionally, the Panel has, at the request of the PMC, arranged for *ad hoc* advisory panels of experts in specialized subject areas to participate in workshops where critical research issues and questions are addressed. These workshops also lead to written recommendations that the PMC accepts as guidance in coordinating the interagency program as described above. To date, substantive workshops have included: circulation modeling (April 17-18, 1996), nutrients (July 1-2, 1996), and water quality modeling (October 22-24, 1996). The PMC will continue to involve the Florida Bay Science Oversight Panel with the Florida Bay Research Program as described above. Based on the advice of its panels, the PMC will create a standing modeling advisory group from the expert panels convened for the circulation and water quality workshops but also including modelers connected to the developing ecological program.

Research Teams

The success of the integrated science program will depend on regular communication between the scientists conducting research in the Bay. To promote and coordinate communication, the PMC will organize researchers and modelers into teams. Five teams are considered necessary: circulation/hydrology, water quality/algal blooms, seagrasses and benthic habitat, higher trophic levels, and model integration. Additional teams will be created if needed. Teams will consist of formally appointed team leaders, a PMC member, and modelers and empirical researchers working in Florida Bay. The team leaders will be modelers or empirical researchers with extensive experience and knowledge of the subject area, as well as of the research and management issues affecting Florida Bay. If appropriate, a PMC member can serve as the team leader, however, the PMC member assigned to the team will also serve as liaison to the PMC and facilitate team activities. PMC members are not prohibited from participating within teams as researchers, but function primarily as committee members within the Florida Bay program. Modelers and researchers not actively working in the Bay are welcome to participate and to contribute to team deliberations. Each research team will conduct a session at the Florida Bay Annual Conference and provide the PMC with a written annual report.

The responsibilities of each team within its subject area are to: (1) synthesize available information by developing conceptual models and specific hypotheses; (2) determine needs for monitoring, and research in support of numerical modeling ; and (3) evaluate new information for the need to revise hypotheses and modify the priorities of present and future tasks.

Program Integration

Conceptual models will synthesize our understanding of Florida Bay, and help formulate critical hypotheses about the Bay's response to upstream hydrology, water quality or other restoration actions. Models will identify information needs and assist in prioritizing those needs and identifying research tasks. Ultimately, numerical models used in a predictive mode will link research understanding of the Florida Bay ecosystem to environmental management decisions by predicting the likely outcomes of various management alternatives on the Bay. These predictions then become hypotheses about the results of management actions, which will be testable with monitoring.

The PMC envisions the need to create a full-time science program manager or executive officer position devoted to providing leadership in program integration. The manager would be an experienced marine scientist with strong quantitative skills, research project management experience and knowledge of computer modeling. The manager would take general direction from the PMC, and lead one or more of the integration teams. The position probably would operate within one of the line agencies. Funding for the position is presently being sought from FY97 funds.

The model integration research team serves a critical role in program integration, particularly because the research strategy of the Florida Bay Program calls for an integrated package of simulation models. This team will develop the interface through which these models communicate. The Florida Bay models must be linked with upstream landscape and ecosystem models and upstream hydrological models such as the South Florida Water Management Model and the Natural System Model. A model integration team would assure that this connection is made.

Agency Implementation Plans

A principal function of the PMC is to see that critical research needs are funded. As set forth in the 1994 interagency plan, agencies, within areas of institutional strength, develop implementation plans for review by the PMC with the requirement that they be consistent with needs expressed in the interagency plan. In the future, agency implementation plans will be based on written recommendations of the Florida Bay Science Review Panel, the expert panels, and the individual research teams. These teams, with PMC and advisory panel input, will then recommend program needs and priorities.

Communication

Communication of scientific results, and progress is a high priority of the Florida Bay Science Program. Following are written science reports provided by the PMC:

- An annual book of extended abstracts from the Annual Florida Bay Program Conferences.
- An annual report of the Science Oversight Panel on progress with recommendations
- Reports from each research team
- Reports from special topic workshops, including both a workshop report and, if convened with the workshop, a report of the advisory panels.

In addition, the following initiatives are being carried out by the Florida Sea Grant and Everglades National Park:

- The quarterly Florida Bay newsletter produced by Everglades National Park for the general public.
- A local Florida Bay Science Radio Station operated with limited broadcasting, by Florida Sea Grant.

Further means of outreach to the public have been proposed by Florida Sea Grant and Everglades National Park but planning for them is not yet completed as of the date of release of this plan.

All technical reports will be included on the Florida Bay PMC web page, or be available on request from Everglades National Park. Metadata connected with PMC-funded research projects, in both spatial and non-spatial formats, will be added to the Florida Bay web page.

CENTRAL QUESTIONS

On the advice of the Florida Bay Science Oversight Panel, the PMC has defined a series of core or central research questions to provide a framework for establishing program priorities. The five questions posed are discussed below in terms of the information and modeling needs considered critical for program success. All are tied to achieving a comprehensive knowledge of the Bay as a complex ecosystem that has undergone profound changes in its recent past. Each question is introduced with a brief discussion of critical knowledge already acquired, followed by a brief discussion of the critical missing information. The PMC approach is then presented with lead funding agencies noted.

The sub-programs connected to each question differ widely in maturity. Thus projects being conducted to address question #1 have already been identified, funded, and most are underway. In contrast, work for addressing the other questions is only partially underway and key projects have not begun because of funding limits.

No attempt is made in the Plan to provide details on questions or projects. This information is available in individual agency implementation plans, or in the annual reports and published results. Instead, the Plan is written to outline an approach for advancing the interagency program beyond an initial stage focused mainly on surveys and monitoring to one concentrating more s on processes and mechanisms essential to restoration decisions. To standardize references to the Florida Bay ecosystem, the PMC has proposed dividing the Bay into six subdivisions based on general physical features and circulation patterns (Fig. 5). All investigators will be expected to adopt this terminology when referencing the Bay.

CENTRAL QUESTION #1

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

What is known?

1. Florida Bay circulation is a complex function of tidal and wind forcing and sea level slopes across the Bay's ocean boundaries. Both large-scale flow and local bathymetry influence water movements.
2. Mean flows are to the southeast with considerable exchange both along the western boundary and through inlets between the Keys. Residence times within the northeastern Bay are considerably longer than in the central or western Bay. This difference may have been exacerbated both by construction of the Overseas Highway and by a sediment accumulation resulting from an absence of hurricanes over the last few decades.
3. Freshwater inputs to the Bay include surface and groundwater from the adjacent peninsula as well as intense seasonal and episodic rainfall events.
4. Mean salinity and seasonal hypersalinity may have increased within the Bay as a result of water management practices, although historical variations in salinity are large.
5. Restoration of the South Florida Ecosystem is certain to include hydrological manipulations that can cause changes in Bay salinity, water quality, and circulation.

What do we need to know?

While the set of relevant physical processes affecting Bay circulation and salinity can be enumerated, their relative importance and dynamic interactions are not known. We need to be able to make accurate quantitative predictions of how the physical (and dependent chemical) conditions in the Bay will change as with the implementation of upland hydrological modifications and other restoration efforts. The effects of natural forces such as hurricanes and sea level rise also must be quantitatively known. At the moment the general patterns of circulation are known, not the details. Exchanges with surrounding waters that produced the above patterns are poorly understood, as are the forcing mechanisms and the Bay's response. Knowledge of these details is critical if we are to relate circulation to water quality and living resources which are distributed inhomogeneously in the Bay. Better understanding of the source, magnitude, and variability of the observed net southeastward mean flow is also critical to our knowledge of relationships between the Bay and the downstream coral reefs.

General approach

Answering central question # 1 requires complementary and closely integrated modeling, empirical studies, monitoring and historical data analysis. These will be pursued simultaneously and modified interactively as necessary through collaboration and communication. The eventual product will be a fully verified regional physical model supported by continuing data acquisition (monitoring). A Florida Bay hydrodynamic model would underpin water quality and ecosystem models. Uncertainties in model outputs would be carefully delimited so that restoration scenarios (and progress) can be evaluated and predictions (with error estimates) reported to restoration managers.

Program Elements

The elements of the research program designed to address this central question are described below.

1. Florida Bay Hydrodynamic Model (COE/WES)

Given the complexity of the system there is no question that rigorous prediction requires a circulation model. Efforts to design and implement such a model have already been initiated by the Waterways Experiment Station (WES) in collaboration with other agency field scientists and modelers. The PMC has, through COE/Jacksonville, requested that WES report on progress in modeling including timetables and explicit discussion of present and planned use of NOAA physical data and models and of USGS bathymetric data.

The first step will be a barotropic finite-element model (RMA2). Currently efforts are underway to analyze the sensitivity of this model to the coarseness of the network and to incorporate the requisite modern bathymetric data. The boundaries of the model have been expanded as advised by our outside review panel, both along the western boundary and along the Florida Keys. Efforts are already underway to use the NOAA regional circulation model (see below) outputs to provide appropriate boundary conditions (tides, sea level, currents and water properties). Similarly realistic wind fields and rainfall inputs will eventually be incorporated (see below). If the two-dimensional and finite-element formulation is insufficient either because fundamental system aspects (e.g.-baroclinic forcing and/or density stratification) are not incorporated or because it is not amenable to integration with a water quality model, WES has indicated that they will adopt a more appropriate approach. In fact, as a result of discussions at the water quality modeling workshop, a fixed grid formulation, Ch3D will probably be used in the water quality model. Its adequacy will be evaluated by comparison with the full finite element model.

2. Mass-Balance Model for the Simulation of Salinity and Circulation in Florida Bay (USGS/BRD)

The goals of this project are to produce a conceptually simple mass-balance ("box") model of Florida Bay. The model incorporates current assumptions about processes controlling salinity and circulation. The preliminary model version simulates temporal salinity trends in north-central Florida Bay, but requires further calibration and testing that will be completed in the second year of the two year study. When finished the model can be used to parameterize the complex hydrodynamic and water quality models, and serve as a screening device in evaluating water management scenarios. The U.S. Geological Survey (Biological Resources Division) has identified this as a high priority for FY97 funding.

3. Regional Hydrodynamic Model (NOAA)

This project began in the summer of 1995. Investigators are applying the Princeton Ocean Model to the oceanic waters adjacent to the Bay to provide oceanographic boundary conditions and forcing to the Bay circulation model. A two-dimensional vertically integrated model with 5km resolution has been developed which uses the highest resolution coastline and bathymetry data available. After calibration of the 2-D model for tides, wind-forcing was incorporated to predict coastal water levels that can be compared to available tidal gauge data for a simulation test period. The model is now being extended to a 3-D (baroclinic) version and the effects of Loop Current and eddy shedding to provide an estimate of the importance of baroclinicity on coastal circulation and the requisite boundary information on temperature and salinity fields.

4. Regional Atmospheric Model (NOAA)

This project began in FY94 and is well- developed. It has two principal objectives: episodic wind field reconstruction and mesoscale atmospheric modeling. Mesoscale atmospheric modeling is an essential contribution relative to wind-forcing of the Bay circulation model and input of freshwater to the peninsula and directly to Florida Bay. Explicit attention to episodic events is essential since the South Florida ecosystem can be dramatically affected by seasonal but episodic tropical storms and/or hurricanes. Recent storms have been analyzed and the results made available on the internet site of the Atlantic Oceanic and Meteorological Laboratory (AOML). A high resolution of the ARPS (advance regional prediction) model has been configured for the south Florida peninsula and adjacent waters with appropriate horizontal and vertical resolution to force the oceanographic models. The effort is well underway to further improve the realism of the atmospheric model by initializing runs with the operational National Weather Service model, incorporation of rain/ice microphysics, and high resolution land cover, use, soil, and vegetation data.

5. Rainfall Estimation Improvement (NOAA and SFWMD)

This project began in the summer of 1995, and the first flights were made in the early fall. Its objective is the tuning of radar algorithms so that the NEXRAD data now being collected in Miami and soon to be collected in Key West can be used to accurately characterize rainfall amount and distribution over the peninsula and Florida Bay. The present rain gauge network provides insufficient spatialand temporal integration of the highly variable rainfall of south Florida. Given the highly convective nature of rainfall events in this system, the NEXRAD approach offers the best way to obtain the requisite data. NOAA has taken the lead to date. Over the next year (or two) as this effort changes from a research to an operational prediction mode, the SFMWD would assume the lead.

6. Microclimate Modification Through Restoration (NOAA and SFWMD)

Numerical experiments have strongly suggested that seemingly subtle changes in land surface can cause dramatic, persistent changes in the spatial distribution of rainfall. Considerable land surface change can be expected to occur as result of hydrological changes associated with restoration. The question is how and to what degree these changes will affect rainfall distribution and intensity within the South Florida peninsula. This effort would represent an explicit NOAA/SFWMD collaboration. Each agency would support its own scientific participants, and funds have been identified in the FY97 NOAA budget.

7. Energy and Freshwater Cycles in Florida Bay - development of a seasonal (monthly) climatology (NOAA)

Our advisory panels have highlighted the need for better estimates of evaporation because the difference between precipitation and evaporation, not precipitation alone that is the critical parameter for modeling. Considerable physical data has been accumulated (albeit on a relatively coarse time and space scale) in Florida Bay and the adjacent areas. However it has not yet been fully analyzed nor integrated to address this issue. A comparatively modest analysis and integration of available salinity, temperature, radiative flux, and rainfall data should improve this estimate or at least set more reasonable boundaries for its parameterization in the Bay hydrodynamics model. Funds for this initiative have been identified within the FY98 NOAA budget.

8. Physical Oceanographic Data Collection (NOAA, COE, ENP, SFWMD, EPA)

This effort began in the summer of 1995, and the first sampling cruises were made in the summer of 1996. Lagrangian Drifters, current meter moorings, and small boat surveys are being used to define circulation and exchange in the Bay and the surrounding waters. Current meter moorings have been established along the western boundary of the Bay and seaward of the tidal inlets at the Florida Keys. Expansion of this field program in FY97 and beyond will emphasize the linkage between the west Florida Shelf and the western Bay, immediately offshore of the Keys and the southeastward flow connecting the Bay to the reef tract. As stated by the Circulation Model Panel in regard to Bay modeling, "boundary conditions are inadequately addressed at this time...that the western boundary be extended over the shelf and northward of the Shark River inflow point and ... (possibly) offshore of the keys". The expansion would involve additional shipboard sampling (Acoustic Doppler Current Profile (ADCP) and ThermoSalinograph), bottom-mounted moorings (ADCP and Conductivity/ Temperature) and Lagrangian float deployments. These field studies would be closely integrated with the COE modeling effort and (along with ongoing monitoring studies supported by EPA and the SFMWD) provide the requisite physical data for parameterizing and validating Bay (and to a lesser degree regional) hydrodynamics models. Funds to markedly extend this work have been identified in the FY97 NOAA budget.

9. Bathymetric Data Collection (USGS)

Three levels of sediment elevation data are being collected by the USGS. These data form a set of nested surveys with increasing precision in support of sedimentation studies. High resolution GPS (ca.10 cm vertical resolution) bathymetric surveys in selected basins of the Bay began during the summer of 1995 and continue with completion anticipated for most basins by 1998. Bathymetry is being extended to electronically leveled profiles (resolution of ca. 2 cm) across selected mudbanks. In addition, along the profiles are meter-square survey sites with sediment elevations measured to ca. 3 mm. These surveys provide the basis for updating century-old charts for hydrodynamic models as well as establishing baseline elevations for determining sediment accumulation and erosion rates. Bathymetry data will be used to quantify sedimentation in the Bay on time scales that vary from those of individual catastrophic storms to those continuous processes occurring over decades.

10. Measuring and Simulating Inflows (USGS/NPS)

Major channels discharging flows into northern Florida Bay are being instrumented by the USGS and NPS with acoustic velocity profiling meters, water-level recorders, and specific conductance sensors to determine ratings for quantifying inflow volumes. Significant channels along the southwest coast discharging flows from upland areas of the Everglades

National Park and Big Cypress Preserve into the Gulf of Mexico are also being similarly instrumented. In addition to providing data for model calibration and for use as boundary conditions for conducting numerical simulations, these efforts to quantify inflows coupled with synoptic measurements of critical water-quality parameters, will enable scientists to evaluate nutrient loads and thereby investigate their impact on the Bay. Additional USGS project efforts focused on the enhancement of generic hydrologic and hydrodynamic models include studies to evaluate and develop improved representations of evapotranspiration effects, frictional resistance effects of vegetation, wind forcing mechanisms, seepage and precipitation gains/losses, and canal/wetland exchange mechanisms. These project efforts, supplemented by field measurements of time-varying upland and Bay inflows, together with precise measurements of land-surface elevations and vegetation characteristics also being conducted by USGS, will facilitate the development of improved models for investigating flow mechanisms governing the transport of nutrients into the Bay.

11. Retrospective Analyses (SFWMD, USGS, NOAA)

Sediment cores and coral skeletons from selected localities are being dated and analyzed to provide reconstructed records of important environmental and ecologic changes during the last 100 - 200 years. Century-old, annually-banded corals from the Atlantic Transition Zone (see Fig. 5) provide temporal resolution of less than one year, and are being analyzed as part of the SFWMD retrospective program. Corals from the central and eastern Bay, where the variation of temperature and salinity are extreme, do not survive for more than a few decades. However, sediment cores representing the Bay during the past two centuries have been identified from the central and eastern Bay (USGS/ SFWMD) as well as from the Shark River area and Everglades transition zone to the north. Temporal resolution within these cores is typically less than a decade and often a few years. Geochemical and faunal analyses of core constituents is providing constraints on several characteristics of the Bay including past salinity variation, shelly faunal change, contaminants, seagrass distribution, and possibly productivity. Reconstruction of these characteristics help define targets for restoration as well as a basis for testing models which hindcast the conditions of the Bay prior to human influence.

CENTRAL QUESTION #2

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

The exchange of nutrients between Florida Bay and adjacent regions ("external" dynamics) and the cycling of nutrients within Florida Bay ("internal" dynamics) influence the entire Bay's ecological structure and function, including the occurrence of algal blooms, seagrass growth and mortality, and the sustenance of critical species. Through a program of monitoring and research, including computer modeling, the question of how human activity is affecting the nutrient dynamics of Florida Bay and how future restoration actions will alter these dynamics is being addressed.

What is known?

1. The waters of eastern and central Florida Bay are rich in nitrogen, but poor in phosphorus. However phosphorus concentrations increase and nitrogen decreases towards western Florida Bay. Through a water quality monitoring program that began in 1991, the temporal and spatial variations of nutrient concentrations in Florida Bay waters have been quantified.

2. Inorganic P (SRP) is extremely sparse in these waters, with a mean concentration below 0.1 µM. Total P is higher, but still averages only 0.5 µM. Nitrogen concentrations are higher throughout the Bay, such that the Bay-wide molar TN:TP ratio averages about 170. Spatially, N:P decreases from east to west, averaging over 200 in the eastern Bay to under 80 in the western Bay.

3. The N:P pattern indicates that the productivity of much of the Bay, particularly in eastern and central portions, is likely to be limited by the availability of P. This inference is supported by the N:P ratios of seagrass leaves in the Bay, which have been found to be among the highest found in the world. However bioassays of phytoplankton growth have shown the increasing importance of nitrogen towards the west.

4. Bay waters have high ammonium concentrations (Bay-wide mean of 6 µM), which may indicate a bottleneck in the process of nitrification. As denitrification depends on nitrification, N loss via denitrification may be lower than in other relatively nitrogen- rich estuaries.

5. An area of the Bay near the north-central coast has been identified as a "core" region where water column nutrients (both organic and inorganic) are higher than in any other region of the Bay. This region, which includes Rankin Lake, Garfield Bight, Terrapin Bay, and Whipray Basin, is also where Thalassia die-off was first noticed in the late 1980s and where algal blooms have been sustained since 1991. Furthermore, salinity maxima found in this region during drought years have exceeded 70 ppt, higher than elsewhere in the Bay.

6. Sediments and their associated seagrass beds contain a large reservoir of organic and inorganic nutrients. Likewise, the mangrove forests on the north coast and islands of the Bay and on the Gulf coast contain a large nutrient pool in living tissue and sedimentary detritus.

7. Loading of nutrients from the Everglades to Florida Bay has not been fully quantified.

Estimates of nutrient inputs to the upstream wetlands of Everglades National Park indicate that N and P inputs increase with increasing water flow, but that the water is relatively poor in P, with molar N:P exceeding 200.

8. Because of the relatively high concentrations of P in Gulf of Mexico waters, and the net flow of water from northwest to southeast along the Bay's western boundary, the Gulf may be an important nutrient source for the Bay.

9. The Keys may be a primary source of anthropogenic nutrients affecting the Bay. Because of the high transmissivity of the limestone beneath the Keys, waste nutrients (particularly from septic tanks) can readily move into the Bay as a result of the tidal pumping of groundwater. The geographic extent to which the Bay is affected by this input is uncertain.

What do we need to know?

The main information needs relative to nutrient cycles in Florida Bay are an understanding of the factors that triggered and maintain the mass mortality of seagrasses and the persistent phytoplankton blooms. Also critical is sufficient understanding to enable us to assess the impact of various environmental management strategies being considered for Bay restoration. In particular, we need to accurately predict the sensitivity of the Bay's nutrient cycles to changing fresh water flow to the Bay, and the resultant change in the Bay's salinity regime. For much of the Bay, any factor that increases P availability either by increasing sources or decreasing removal, is likely to exacerbate the current problems of the Bay. Recent evidence also indicates that algal blooms in the central and western Bay are also stimulated by N enrichment. Thus we need thorough understanding of the Bay's nutrient cycles. Questions that the current monitoring and research program must address in order to meet these needs are as follows.

1. What are the sources of nutrients that sustain algal blooms?

Understanding the mechanisms that have triggered and are sustaining algal blooms in the Bay is fundamental to restoration decision making. This understanding entails quantifying the nutrient demands of these algae and how these nutrients are supplied.

2. What effect does changing seagrass community dynamics have on nutrient availability in the Bay? Has seagrass mortality only increased nutrient availability by releasing nutrients from this detrital source, or has seagrass mortality also caused other less direct changes, such as a decrease in the capacity of the sediments to sequester nutrients?

The lag of several years between the onset of seagrass mass mortality and the occurrence of algal blooms in the Bay argues against the hypothesis that only nutrients released from dead seagrass tissue fuel the blooms. However, the increase in nutrients from this detrital source, combined with a net decreased uptake capacity associated with seagrass mortality, may explain the bloom's temporal patterns. Thus, estimates are needed of net benthic nutrient uptake or release rates, over a range of seagrass growth rates, mortality rates, and detrital decomposition rates for different seagrass species. The accuracy of such estimates may largely depend upon understanding sedimentary nutrient transformations, including how seagrass roots affect nutrient mobility and how such processes change with seagrass mortality.

Additionally, seagrass mortality may have indirectly affected nutrient cycles in the Bay. For example, sediment resuspension increases with decreasing seagrass density, and P associated with this suspended sediment may be available to phytoplankton.

3. How will changing fresh water flow directly and indirectly alter the supply and availability of nutrients in the Bay? What effect does changing salinity have on nutrient availability in the Bay?

With fresh water flow expected from restoration of the Everglades and Florida Bay, increasing nutrient loading from the Everglades watershed also will probably increase. While the magnitude of this expected increase is unknown, this direct input may be less important than the indirect effect of an altered salinity regime caused by increased freshwater influx. Altered salinities can affect internal nutrient cycling by: (1) altering community structure, such as changing seagrass species dominance, thus changing nutrient storage and cycling, and (2) modifying specific processes, such as P surface reactions and sulfate reduction.

4. What is the effect of major events, such as hurricanes and freezes, on the Bay' s nutrient cycles? Has the absence of a major hurricane in the Bay during the past 30 years resulted in the apparent nutrient enrichment of the Bay?

For a shallow estuary like Florida Bay, hurricanes can profoundly affect the distribution of sediments and of nutrients stored in the sediments as well as the status of vegetation. Large hurricanes may export large quantities of sediment and associated nutrients, perhaps removing much of the exogenous nutrients that annually accumulate in the Bay. The recent absence of large hurricanes may have thus enabled nutrients to accumulate.

General Approach

In keeping with the general approach of the entire Florida Bay research program, answering the questions outlined above entails a combination of monitoring, research, and modeling. The development of a water quality model for the Bay is central to this effort, because such a model not only provides a tool for environmental managers to assess the consequences of their plans and actions, but also provides a means for scientists to integrate existing information and focus future monitoring and research. Monitoring includes a continued commitment to measure water column nutrients throughout the Bay and adjacent waters, and to measure nutrient pools that influence the Bay's nutrient cycles, such as sediments and seagrasses. Long-term measurements of nutrient dynamics, such as sediment-water fluxes, atmospheric inputs, and exchange of nutrients at the Bay's boundaries, are also essential for documenting the status and trends of the Bay's nutrient budget. Finally, experiments that explore the mechanisms that control the current nutrient cycles in the Bay are required to understand cause and effect relationships and distinguish natural causes from human induced causes of change in the Bay.

Program Elements

1. Water Quality Model (COE/WES)

Along with the hydrodynamic modeling that is underway, a water quality model coupled to the hydrodynamic model is needed. A workshop held in October 1996 provided the framework for a conceptual structure of the water quality model. Building on workshop recommendations, the ACOE is preparing a water quality model development work plan. The model will include water column nutrient dynamics, sediment dynamics, water column and benthic algae and at least two seagrass components. We expect that the model, along with simpler box models, will be an organizational tool that helps focus our research on those components and processes that are central to understanding the Bay's nutrient cycles.

2. Mass Balance Model (USGS/BRD)

An immediate requirement is a mass balance model to estimate the Bay's nutrient budget and evaluate the relative importance of data on components of N and P nutrient budgets. Funding for completion of a mass balance model has been obtained by USGS/BRD and is part of the COE work plan for water quality modeling.

3. Monitoring and estimating external nutrient exchanges (SFWMD, NPS/ENP and NOAA)

Water column nutrient concentrations have been monitored in Florida Bay by FIU scientists (with SFWMD and ENP support) since early 1991. This monitoring network has since expanded to include the nearshore waters from Cape Sable to Ten Thousand Islands and, with FKNMS support, the Florida Keys. Water quality monitoring within the Everglades wetlands also continues with support from the SFWMD and NPS/ENP.

4. Regional monitoring network has provided baseline information, and continues to be essential in our efforts to understand patterns of ecological change in the Bay. However, at this time, monitoring needs to be expanded from "snapshots" of water column concentrations to measurements that enable us to estimate net nutrient imports into and exports from the Bay. This largely entails monitoring flows of water and nutrients across the Bay's boundaries, including exchanges on the western boundary with the Gulf, the

northern boundary with the Everglades, and the southern boundary through the Keys' passes and with ground water under the Keys. Coupled physical-chemical-biological studies of nutrient exchange along the western boundary are being solicited in a NOAA RFP to be issued in November 1996.

5. Atmospheric monitoring should be expanded such that wet and dry deposition of nutrients in the Bay can be estimated accurately. Estimation of atmospheric inputs was included in a NOAA RFP in November 1996. FY97 funding has already been identified. The temporal and spatial scales at which all these measurements of nutrient inputs and exchanges should be made will be decided based on the development of hydrodynamic and water quality models for the Bay.

6. Systematic measurements of the stock of nutrients in pools other than in the water column are currently lacking. In particular, Bay-wide measurements of sedimentary nutrients are needed. Likewise, nutrients in other large pools, such as in living seagrass and mangroves, should be measured on a regular basis.

Measuring internal nutrient fluxes and process rates (SFWMD, NPS/ENP and DEP/FMRI)

Given the shallow depth and restricted circulation of Florida Bay, internal cycling and transformations of nutrients probably have a strong influence on the structure and productivity of Bay communities. These nutrient pathways and transformations have not been well studied. Essential measurements include nutrient uptake by primary producers (especially seagrass and phytoplankton), the exchange of nutrients between the sediments and the water-column, the diagenesis of nutrients within the sediments (especially P - carbonate reactions and N transformations), and microbial and inorganic reactions within the water column (such as nitrification and P sorption to, and removal, from suspended sediment).

7. Ongoing measurements of nutrient fluxes from sediments to the water column as measured in benthic chambers and modeled from porewater gradients will continued for selected basins in 1997 and 1998. Existing discrepancies between the results of these two approaches need to be investigated. NPS/ENP and DEP/FMRI support this work.

8. Studies of water column nutrient dynamics, including microbial processes and interaction with suspended sediments were solicited in a NOAA RFP in November 1996. FY97 funding has already been found.

9. Turbidity and Sediment Resuspension (USGS/GD and COE)

Turbidity and sediment resuspension are important aspects of water quality that directly affect light penetration and probably nutrient cycles. The USGS is documenting long-term changes in turbidity using AVHRR imagery. More than 1500 images spanning the last seven years have been processed and 600 have been selected for a database. In addition, these images can be used to constrain predictions of turbidity from current wave modeling efforts. In response to advisory panel recommendation, a USGS project has characterized physical properties of bottom sediments and estimated seagrass cover to produce a map of the Bay floor that predicts the susceptibility to sediment resuspension. As part of the study, the potential for resuspension will be measured using a device that relates turbulence to sediment resuspension in cores of selected sediment types. The results of these studies will be used to help calibrate turbidity predictions in the water quality model being developed by the COE. The USGS and COE support this work.

10. Understanding cause and effect relationships

The factors that influence the loading of nutrients into Florida Bay, and the availability of nutrients within the Bay are not well understood. In particular, we need to understand the effect that potential environmental management actions, such as increasing fresh water flow and decreasing salinity, will have on the Bay's nutrient transformations and fluxes. Experiments on suspended sediment particles and on factors that may influence the mobilization and immobilization of P in carbonate sediments are critical. Given the unusually high ammonium concentrations of the Bay and the potential for N limitation the western Bay, experiments on factors that may influence key N transformations, such as nitrification and denitrification are also needed. Experiments that explore how nutrient cycling is altered by changing seagrass community structure and physiological condition (particularly below-ground nutrient changes) is also important, but are yet to be done. Funding for this suite of studies is being explored among several agencies but has not yet been fully defined.

CENTRAL QUESTION #3

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

I. What is known?

Over the past 6 years Florida Bay has been subjected to extensive phytoplankton blooms contrasting earlier reports of high water column clarity. Although there is anecdotal evidence of algal blooms in the past, frequent and pervasive blooms lagged seagrass die-off by several years. Although not clearly established, nutrient release to the water column caused by remineralization of dying seagrass and suspension of bottom sediments appears to have stimulated algal bloom development. As a consequence, recurrent blooms have repeatedly developed in localized areas and spread into other areas of the Bay. Under the right conditions, phytoplankton-rich water from Florida Bay flows through the major passes in the Keys to the reef tract and beyond.

1. Except for rare situations, resuspended sediments are a major component of the turbidity produced during the microalgal blooms. Increases in phytoplankton are a function of

growth of cells as well as repeated suspension into the water column of benthic sediments. Both components can contribute to the "microalgal blooms" of the Bay.

2. Regularly scheduled areal surveys, as well as extensive monitoring (chlorophyll biomass,suspended particulate matter, nutrients, species abundances and composition) and process measurements of nutrient utilization and primary production, are used to map regions of the Bay where blooms tend to initiate, develop and spread. Extensive blooms occur predominantly in the fall/winter and can spread throughout the Bay. Eventually they may spread into the far western regions of the lower Keys and shelf, as well as through the Keys channels onto the reef tract.

3. The species composition of blooms varies throughout the Bay. Communities in the western regions reflect the strong contribution of the southwest Florida shelf, with diatom species predominating. Dominant diatom genera include *Rhizosolenia, Chaetoceras,Cyclotella,* and *Thalassosira* . In the central region, where high salinities are found, the composition is numerically dominated by small species such as the blue green alga *Synechococcus elongatus*, several other blue green species, and very small (<5 µm) eukaryotic picoplankton. Diatoms are also found in the central region of the Bay and, in certain periods, dominate in terms of biomass. Although other species are present throughout the Bay, one consistent component includes the numerous microflagellates of various size classes which are abundant in all regions, particularly near the mainland. The abundance of microflagellates may be correlated with the amount of freshwater runoff. Although nearly continuously turbid, the eastern sector of the Bay is noted as having few phytoplankton blooms, perhaps reflecting its relative isolation from the rest of the Bay.

4. Phytoplankton growth rates can exceed one doubling per day with primary productivity and chlorophyll concentrations occasionally attaining values reported for highly productive estuaries of cooler temperate zones (30 ug/L) and 1 g C/m2/d, respectively).

5. The blooms are in part a function of the nutrients required to support them. Initiation and maintenance of the Florida Bay microalgal blooms must rely on a supply of nutrients, primarily nitrogen, phosphorus and silica (for diatoms) as well as essential trace elements. Iron limitation also has been reported. Data on nutrient concentrations in the Bay and results of nutrient bioassays suggest that the Bay is a primarily a phosphorus- limited system although the western and, sometimes the central portions, can be nitrogen-limited.

6. Bloom formation depends on the difference between population growth and loss, the latter primarily resulting from zooplankton and benthic filter-feeder grazing. Copepods like *Acartia* spp. are capable of utilizing the bloom species and producing eggs with appreciable hatching success. Limited experiments suggest that most daily primary production is utilized by zooplankton grazers in the water column. Microzooplankton rather that macrozooplankton account for most of this grazing.

II. What we need to know

1. Continued surveillance of bloom dynamics through a synoptic monitoring study is required. This need not be extensive but should include enough observations to evaluate if the blooms are increasing, decreasing, or generally changing. Synoptic monitoring also will be also necessary to evaluate any mitigating efforts of restoration.

2. The factors supplying the essential nutrients such as phosphorus, nitrogen and silica required for bloom formation have to be identified and their rates quantified.

3. The light and nutrient requirements and the potential growth rates of the dominant competing bloom taxa need to be determined in order to predict which species form blooms.

4. The suitability of bloom species as food and their susceptibility to grazing by benthic, macro- and microzooplankton grazers must be evaluated to determine the impact of the phytoplankton blooms on trophic structure and the potential for grazing to balance microalgae growth.

5. Finally, a model is needed to analyze nutrient and bloom dynamics within the context of larger ecosystem models needed to assess management strategies for Florida Bay.

<u>General Approach</u>

The required knowledge suggests four general approaches. First, the continued acquisition and evaluation of field data is required to fully define the history, present status and possible future trends of algal blooms in Florida Bay. The second focuses on the study of key bloom species and their particular characteristics which allow them to successfully compete in the Florida Bay environment and adapt to the changing regimes. The third emphasizes investigation of the trophodynamic structure of algal blooms. The fourth, involves the quantitative elaboration of critical bloom processes using mathematical models. Since for the most part, rate coefficients for sub-tropical estuarine systems are rare, a critical need is to provide meaningful coefficients for basic processes which are essential to building useful models.

<u>Program Elements</u>

1. Monitoring of Bloom Status (DEP/FMRI and NOAA)

Continued selected monitoring is essential to determine the present status of the Bay blooms. This monitoring will continue as part of the FMRI research program, the long-term FIU monitoring program, the Florida Sea Grant special studies and NOAA.

2. Physiological Rate Measurements (DEP/FMRI and NOAA)

Physiological rate measurement studies are needed of key phytoplankton species involved in the blooms of Florida Bay. Well defined experimental protocols will define the capacity of phytoplankton species to grow, assimilate nutrients, photosynthesize, produce toxins and overcome competing species. Autecological and carefully controlled whole community "competition" experiments are essential to understand which species which bloom under which conditions. Advanced physiological/biochemical methods are necessary to the elucidate the role of nutrient cycling.

3. Trophodynamic Studies (NOAA)

Trophic studies are needed to define rates of assimilation, utilization and eventual success of subsequent trophic levels utilizing the bloom phytoplankton species. Trophodynamic studies of macro- and microzooplankton utilization of phytoplankton, including bloom species is being emphasized in the FY97 NOAA field program. Effects of blooms on finfish community structure (e.g., variable recruitment success and effects on obligate planktivore abundance) and potential toxic algal bloom species will be investigated.

4. Phytoplankton Modeling Studies (NOAA, DEP/FMRI, USGS/BRD)

Plankton models will be supported to simulate the response of the phytoplankton community to varying environmental conditions (salinity, temperature, nutrients and light), and to shifts in nutrient processes (recycling, resuspension, adsorption, etc.) The modeling will proceed in coordination with the water quality model and the planned seagrass ecosystem model. NOAA FY97 funds will support work on a plankton dynamics model focusing on nutrient availability, taxonomic differences, grazing pressure effects, benthic-pelagic coupling and trophodynamic consequences. DEP/FMRI, USGS/BRD, and NOAA will all support field studies contributing to the modeling.

CENTRAL QUESTION #4

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

In the fall of 1987, seagrasses in dense grass beds, primarily in western Florida Bay, began dying for as yet unknown reasons. The onset of extensive and persistent turbidity/algal blooms followed several years after the initial seagrass die-off events in 1987. Die-back of seagrasses continues today, now probably largely as a result of decreased light, though limited seagrass die-off is still being observed. Seagrass die-off very likely triggered the changes observed in the Bay over the last six years and needs to be understood.

<u>What is known?</u>

1. Prior to seagrass die-off in 1987, Florida Bay was a clear water, *Thalassia* dominated

marine lagoon which was often hypersaline. Corresponding to gradients of water depth. sediment depth, and nutrient availability, seagrass community development was greatest on bank tops and decreased from west to east across the Bay.

2. The seagrass community in Little Madeira Bay and other northern bays, responding to extreme annual and seasonal fluctuations in salinity, was early successional, poorly developed, and ephemeral prior to seagrass die-off and remains so now.

3. Beginning in the fall of 1987, seagrass in dense grass beds, primarily in western Florida Bay, began dying. The process was rapid, possibly occurring primarily in late summer and fall. The size of the areas affected varied greatly; whole basins were affected (Rankin Lake), sub-basins were affected (Rabbit Key Basin), and patch- sized areas were affected (Johnson Key Basin).

4. Records indicate that only a few "seagrass die-off" events have been reported previously in Florida Bay. Most recently in 1975 and in 1983, periods when the Bay exhibited hypersaline and marine/estuarine conditions, respectively. Both events were observed in Whipray Basin in central Florida Bay, both were small in extent and short in duration and therefore not necessarily similar to recent die-off. Small, confirmed die-offs of seagrass were also observed in the 1950's and attributed to hypersaline conditions.

5. Observations indicate that isolated die-off continues today. However, die-back of *Thalassia* today is assumed to be more a result of decreased light than seagrass die-off.

6. The small scale pattern of die-off, square meter sized patches coalescing into larger and yet larger areas, suggests the role of a pathogen. Four strains of the slime mold, *Labyrinthula* sp., the same genus thought to be the causal agent in the wasting disease affecting *Zostera* , were isolated from Florida Bay. One of the four strains was able to infect *Thalassia* but not kill it under experimental conditions. However, lesions associated with *Labyrinthula* correlate with observed patterns of seagrass decline in the Bay today.

7. *Thalassia* standing crop in areas affected by seagrass die-off has decreased from 200 g dry wt/m2 in 1989 to 50 g dry wt/m2 in 1995. In Johnson Key Basin (western Florida Bay) aboveground biomass of *Thalassia* had decreased 72% by 1995 relative to 1985, *Syringodium* had disappeared totally, but there had been no change in biomass of *Halodule* . Production of *Thalassia* had generally declined over time. At stations where long-term data are available, areal productivity has decreased from 2 g dry wt/m2/d in 1989 to 1 g dry wt/m2/d in 1995. Control sites are more constant.

8. Since initial seagrass die-off events in the Bay, density and dominance of *Thalassia* has declined in western Florida Bay. An expansion of *Halodule* into areas formerly *dominated by Thalassia* and the presence of previously absent mud bottom has resulted in increased habitat heterogeneity in areas affected by die-off.

What do we need to know?

The shift in Florida Bay from a clear water seagrass system to a seagrass system characterized by persistent algal/turbidity blooms followed seagrass die-off. Understanding the dynamics associated with this change and its consequences are critical.At this time the cause(s) of seagrass die-off is unknown but conceptual models exist which can be tested with appropriate techniques. The processes involved with the onset and maintenance of extensive and persistent algal blooms in the bay and the impact these blooms are having on the present day seagrass community (light availability, altered nutrient regimes) should be investigated.

Understanding how manipulation of the quantity, quality, timing, and distribution of freshwater flowing into Florida Bay affects seagrass community structure is critical. The latter relationship is particularly important since restoration is expected to be accomplished by establishing more natural flows into the Bay. Development of a seagrass model is a critical research need. It will be used to evaluate long- and short-term hypotheses on seagrass die-off, the relationship of the seagrass community to the effects of algal blooms, and to evaluate the response of the seagrass community to upstream manipulations of freshwater flows.

General Approach

The approach to addressing question # 4 centers on development of an ecological model. A conceptual model of seagrass die-off includes both long- and short-term elements and each requires elaboration in a seagrass community model. The fully functioning model should be capable of key processes including those connected with putative causes of the die-off. The hypothesized causes of seagrass die-off are: 1) altered freshwater flows to the Bay, including relationships to hypersalinity; 2)overmaturity and susceptibility of Thalassia beds; 3) reduction in storm-mediated disturbance of the sediments and seagrass beds; 4)altered sediment chemistry such as sulfide build-up and iron limitation; 5) disease spread; 6) unusually severe climatic conditions when die-off began, and 7) an altered nutrient regime.

In western Florida Bay, seagrass beds are hypothesized to have become overmature and thus susceptible to climatic and environmental extremes. The model also must ultimately be capable of simulating realistically the influence of these factors interacting over time and space on seagrass production, succession, and turnover.

An important function of the seagrass model, along with environmental data on hardbottom habitats, is to provide the requisite information for a landscape model within which growth, survival, and recruitment of key benthic species may be simulated.

Program Elements

1. Fisheries-Habitat Assessment (USGS/BRD and DEP/FMRI)

This is an ongoing program to assess status and trends in seagrasses in Florida Bay. The program includes three elements: 1) abundance and distribution; 2) structure and dynamics; and 3) populations dynamics. These study elements provide information for spatial assessment and resolution of both intra- and inter-annual variability in the macrophyte (seagrasses and macroalgae) communities, and will provide spatially explicit change data to monitor response to water management alterations or other restoration activities. The protocols used in this program are also being used in the Florida Keys National Marine Sanctuary thus providing the opportunity for a regional database.

2. Causal Mechanisms for Seagrass Distribution (USGS/BRD, NPS/ENP and DEP/FMRI)

Progress is being made on understanding the spatial pattern of seagrass distribution and the database must be continued. To begin exploration of causal mechanisms, data from seagrass and physical/chemical monitoring projects will be brought together to examine statistical relationships. Data will be collected for selected reference sites in the northeastern embayment area, the north central area of hypersalinity, and a western site where major die-offs have occurred. Concomitant physical and chemical measurements will be conducted in the selected reference sites if they are not already fully in place. The USGS/BRD and NAPS/ENP have defined the development of a program to address these needs as a high priority for FY97 funds provided from the U.S. Department of Interior.

3. Studies of Seagrass Growth and Survival (NPS/ENP, SFWMD and USGS/BRD)

Experimental and field studies are needed which consider interactions of salinity variation, N and P levels, water temperature, and light attenuation on seagrass growth and survival. The three main seagrass species require study. Among the inadequacies are information on the responses of seagrass growth and demography, effects of epiphytes on seagrass growth, disease etiology associated with seagrass die-off and recovery, and interactions of sediment chemistry. SFWMD, USGS/BRD and NPS/ENP propose to commit funds to support an integrated experimental program.

4. Seagrass Community Model (USGS/BRD and NPS/ENP)

This model will simulate the effects of changing salinity and nutrient conditions on the growth and survivorship of seagrasses in the Atlantic tropical/subtropical carbonate-based system of Florida Bay. The model will simulate seagrass community succession and development, and be used as a tool to explore short- and long-term hypotheses on seagrass die-off. It also will provide habitat input to higher trophic level models. USGS/BRD and NPS/ ENP have identified FY97 funds from the Department of Interior South Florida Science Initiative to hold a workshop for defining model requirements and for subsequently beginning the modeling program.

CENTRAL QUESTION # 5

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

Loss of seagrasses and deteriorating environmental conditions have affected secondary production patterns in Florida Bay by altering conditions controlling the growth and recruitment of many consumer organisms. Key organisms such as sponges, lobsters, pink shrimp and many fish species have been affected. During the mid to late 1980's, for example, sponges in southwestern Florida Bay died raising concern about effects on lobster recruitment. Declines in the Tortugas pink shrimp fishery were observed that roughly corresponded to loss of seagrass habitat and hypersalinity in Florida Bay. The distribution of gamefish within the Bay were reported to have shifted in response to turbidity/algal blooms. Florida Bay is critical nursery habitat supporting both ecologically and commercially important animals, and this function is highly valued in south Florida and as such should be fully understood, especially relative to future water management modifications.

What is known?

1. Correlated with the advent of extensive phytoplankton blooms in central Florida Bay was a sponge die-off (range of loss 25 to 100%) in hardbottom habitats of central and southwestern Florida Bay. Sponges serve as critical nursery habitat for the spiny lobster, *Panulirus argus*. Initial predictions of declines in lobster recruitment of from 2-19% were not realized.

2. Mollusk communities in the southern and western areas of the Bay have changed markedly over the past two years, and may have responded positively to the reduced salinity caused by heavy rains in 1994 and 1995. But abundance remains low in the central Bay where blooms thrive, especially in the north-central region.

3. Roughly coincident with the occurrence of seagrass die-off in Florida Bay, the harvest of pink shrimp, *Penaeus duorarum* , on the Tortugas Grounds declined from an annual average of about 10 million pounds per year to a period-of-record low 2.2 million pounds in the late 1980's. Florida Bay was assumed to be the primary inshore nursery supporting the Tortugas Grounds. Seagrass loss and declining environmental conditions in the Bay have been hypothesized as causing the decline, although shrimp have recovered on the Tortugas Grounds while algal blooms and some seagrass die-off continue in the Bay. Experiments indicate that pink shrimp mortality increases in water with salinities exceeding 40 ppt at temperatures typical of Florida Bay.

4. In Johnson Key Basin (western Florida Bay) the localized effect of habitat loss and change due to seagrass die-off is distinct. Seagrass-associated fish and invertebrates including the pink shrimp were found to be less abundant (<10%) in areas of seagrass die-off compared to adjacent undamaged seagrass habitats. Adjacent areas recovering from seagrass die-off through recolonization by *Halodule* exhibited intermediate abundances.

Community dominants such as the killifish, *Lucania parva* , and the caridean shrimp, *Thor floridanus*, were virtually absent from die off areas compared to adjacent undamaged seagrass habitats.

5. Throughout Johnson Key Basin, abundance of fish and invertebrates including the pink shrimp was greater in 1985, prior to seagrass die-off, than in 1995. Caridean shrimp densities have decreased from about 160/m2 to 35/m2. Pink shrimp density in January decreased from a mean of 7/m2 to 3/m2 over the decade, with no difference observed in May. Mean fish densities decreased over the decade from 11/m2 to 4/m2. Distinct differences in species composition were also evident between 1985 and 1995. The caridean shrimp declined by 93% and the killifish declined by 97% . The bay anchovy, *Anchoa mitchilli*, a planktivore, greatly increased in abundance in 1995 perhaps in response to the presence of the algal bloom.

6. Total fish abundance throughout the Bay did not generally decrease. Decreases did occur in areas of the Bay affected by seagrass die-off and in channel habitats. In contrast, changes in species composition were striking. The fish community was dominated by *Lucania parva* and *Eucinostomus* spp. in 1985. Following seagrass die-off and the advent of algal blooms, the bay anchovy dominated the fish community, accounting for 57% of the catch.

7. For the decade 1985-1995, catch-per-unit-effort for the spotted seatrout, redfish, grey snapper, and snook was greatest in the years following seagrass die-off and the onset of persistent turbidity/algal blooms.

<u>What do we need to know?</u>

Seagrass die-off and the advent of extensive and persistent algal blooms in Florida Bay have affected the base of the food chain. The species composition of the forage fish and seagrass associated invertebrate communities have changed, presumably in response to these habitat changes. A significant zooplankton grazing community has developed in response to algal blooms. We need to understand the implications of these food web changes to higher trophic levels. Florida Bay is perceived as an important nursery habitat in south Florida. We need to understand the effects of upstream water management and salinity conditions in Florida Bay on secondary production (community structure, recruitment, growth, survivorship). Development of appropriate consumer models is a critical research need. These models will be used to evaluate restoration alternatives and to predict ecosystem response.

To understand changes in population dynamics of fishery species, it is critical to differentiate the effects of fishing from environmental factors, and to show how these interact to control stock dynamics. Fishing mortality at the stock level can be me asured and evaluated in the context of environmental change and natural mortality. For key species, the research goal is to quantitatively predict the population-level impact of the environmental changes that have occurred in Florida Bay in the past decade. Achieving a predictive capability will require data on effects of changes in fishing effort and of environmental factors upon growth, survivorship, and recruitment.

Also essential is the need to understand what is meant by "habitat change", and to quantify how the population dynamics of higher trophic level species has been affected historically by such changes. Knowing the environmental factors that affect recruitment, growth, and survival is essential for separating habitat effects from fishing effects and intrinsic, biological factors.

Data on survivorship of larval fishes is a key information need not presently being adequately addressed. Survivorship is presumably based on larvae's ability to capture sufficient prey to allow for adequate growth.

General approach

Central question #5 will be addressed by developing ecological models complemented by biological monitoring and empirical studies. An initial conceptual model depicts secondary production within the Bay as dependent on availability of suitable habitat and environmental conditions both of which can be altered by upstream water management. Models of representative species and communities will incorporate community structure, reproductive success, growth, recruitment and survivorship in relationship to habitat and communities. The representative species or communities will be chosen based on one or more criteria: (1) they carry out important Bay functions, (2) they have experienced major declines, (3) because long-term response data (e.g., harvest rates, nesting success and distribution, abundance) are available and, (4) linkages to water management are established or can be strongly inferred. Regular field surveys and experimental work are important components of this sub-program as is integration with other Florida Bay models.

Program Elements

1. Higher Trophic Level Modeling (USGS/BRD, NOAA and NPS/ENP)

As a first step in developing a higher trophic level model, a workshop will be conducted in mid 1997 to develop: (1) conceptual models of consumer processes relative to habitat, environmental conditions, and water management, (2) select representative species for modeling, and (3)determine modeling needs and model focus. The outcome of the workshop will provide the rationale for developing higher trophic level models that address the nursery function of Florida Bay. The models will simulate recruitment, growth, survivorship, and community dynamics of selected sport, commercial, and ecologically important fish and invertebrates. The models will integrate results of empirical studies around the hypothesis that secondary productivity in the Bay is limited by availability of optimal habitat, environmental conditions and water management.

2. Pink Shrimp Nursery Function (USGS/BRD and NOAA/NMFS)

Relationships will be determined between inshore populations of the pink shrimp, *Penaeus duorarum* , and offshore Tortugas and Sanibel fisheries. This is an ongoing project employing stable isotopes as tracers for the purpose of: 1) determining the relative importance of various inshore source areas to the offshore Tortugas and Sanibel shrimp fisheries; and 2) to determine the source areas supporting the fall and spring recruitment peaks in the Tortugas fishery. These data are important in order to understand the relationship of Florida Bay to the Tortugas Fishery and the possible implications of restoration actions to this fishery.

3. Assessment of Trophic Structure and Response of Fish and Shellfish to Habitat Changes in in Florida Bay (USGS/BRD).

This is an ongoing project due for completion in FY 1997. It's goal is to evaluate fish and invertebrate response to changes in habitat associated with seagrass die-off and algal blooms. The funds requested here are for continuing a contract to process the remaining benthic samples.

4. Analyses of Historical Fisheries Data- (NOAA/NMFS, NPS/ENP and DEP/FMRI)

There is a relatively robust store of historical fishery data suitable for population trend analysis. An important component of the analyses should be to separate population effects (e.g. the effect of parental stock size on recruitment) from "habitat" effects (e.g. the availability of suitable habitat for recruitment). Related research should analyze hatch-date distributions and growth from otoliths of field collected larval and juvenile spotted seatrout to determine if (a) differential survival and growth exists along a salinity gradient from north-central to western Florida Bay and (b) if differential survival exists among cohorts during the spawning season, and if so, what factors could have influenced survival. Results could allow us to understand how spotted seatrout early life history stages will respond to changes during restoration.

5. Collection and Modeling of Fishery Data (NOAA/NMFS and NPS/ENP)

Fishery data collection must be continued and the level of sampling must be species-specific. Stock- based cohort models which incorporate levels of fishing mortality and empirically based estimates of natural mortality incorporating variability and uncertainty will be completed. Results of these models will provide the predictive capability with the intent of evaluating species at risk and levels of risk under different environmental and fishing scenarios.

6. Larval Fish Energetics

Given the difficulty of obtaining data on larval fish feeding habitat in the field, bioenergetic models should be developed which utilize laboratory information on energetics costs such as respiration, egestion and excretion combined with known data. Output from the model would include consumption rates, including possible bottlenecks in food supply at larval stages, age linked growth rates and partitioning of energy into growth, respiration and non-metabolizable materials. No projects are currently funded but are under consideration for future funding by NOAA/NMFS.

Model Integration

The PMC is discussing a separately funded project focused on integration of the biological models (e.g. phytoplankton model, seagrass model, higher trophic level models) with the circulation and water quality models and the creation of an appropriate spatial and temporal framework representing the Florida Bay ecosystem. Linkages would be established with upstream simulation models (e.g. ATLSS, ELM, South Florida Water Management Model, Natural System Model) and the synoptic-scale physical and atmospheric models described under Question #1. The model integration project is still under consideration but is expected to develop procedures for configuring model interfaces providing driving variables from the physical models as input to the biological models. Within this framework, hypotheses on the response of the Florida Bay ecosystem to proposed water management modifications of freshwater flows could be generated and alternatives compared. The results would be provided as information for the management decision-making process. The project would be conducted by a team comprised of a lead modeler with participants drawn from modeling projects and selected major data collection projects. Oversight would be provided by a model integration committee reporting to the PMC. USGS/BRD and NPS/ENP is seeking funding for initiation of this work beginning in FY97 but may seek contributions from other agencies.

LITERATURE CITED

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FIGURES

Last [illegible] on 08/31/98
By Monika Gurnée
Email: gurnee@aoml.noaa.gov

APPENDIX B

Selected Abstracts of the 1998 Florida Bay Science Meeting

Proceedings

1998 Florida Bay Science Conference

May 12-14, 1998

University of Miami

Sea Grant Florida

University of Miami/James L. Knight International Center
Miami, Florida

Florida Bay Science Conference

May 12 – 14, 1998

University of Miami/James L. Knight International Center
Miami, Florida

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Florida Bay Program Management Committee

Thomas Armentano, PMC Co-Chair, National Park Service (Everglades), Homestead, FL

Robert Brock, Research Coordinator, National Park Service (Everglades), Homestead, FL

John Hunt, PMC Co-Chair, Florida Dep't of Environmental Protection, Marathon, FL

Steve Traxler, U.S. Army Corps of Engineers, West Palm Beach, FL

David Rudnick, South Florida Water Management District, West Palm Beach, FL

Robert Halley, U.S. Geological Survey, Geologic Division, St. Petersburg, FL

Michael Robblee, U.S. Geological Survey, Biological Resources Division, Miami, FL

Kalani Cairns, U.S. Fish and Wildlife Service, Vero Beach, FL

Nancy Thompson, NOAA/National Marine Fisheries Service, Miami, FL

Peter Ortner, NOAA/Office of Oceanic and Atmospheric Research, Miami, FL

Bill Kruczynski, U.S. Environmental Protection Agency, Marathon, FL

Functions of the Florida Bay Program Management Committee

The Florida Bay Program Management Committee (PMC) consists of scientific representatives from the eight state and federal agencies having jurisdictional control and/or scientific interest in Florida Bay. The PMC provides policy-makers with reliable scientific information and science-based recommendations relevant to the restoration of Florida Bay. The PMC oversees the Florida Bay Research Program and attempts to foster interagency communication and collaboration by:

1) Assuring the integration of all scientific activities conducted in Florida Bay. The PMC does this by a) holding coordination workshops for funded investigators designed to review and integrate plans and sampling protocols of related projects including data management; b) reviewing agency implementation plans and developing an integrated science plan than is consistent with PMC planning documents and recommendations from the Florida Bay Science Oversight Panel; and c) sponsoring annual science conferences.
2) Evaluating scientific quality and programmatic relevance of all funded projects. The PMC does this by convening technical workshops to review databases and models for adequacy and appropriateness relative to our directed program and to scientific standards.
3) Working with managers of our respective agencies to advance the overall science program. The PMC does this by assuring that science priorities are clearly defined and fully addressed by appropriate agencies, developing a Florida Bay Strategic Plan, and assuring that the science program needs are included in agency budgets and planning decisions.

Florida Bay Science Oversight Panel

Neal E. Armstrong
Associate Dean for Academic Affairs and Department of Civil Engineering
University of Texas, Austin, TX

A member of the 1992, 1995, and 1996 panels, Dr. Armstrong is a specialist in water quality modeling of estuarine ecosystems, particularly in relation to freshwater inflow in Texas bays. Dr. Armstrong is, unfortunately, unable to attend the conference.

Donald F. Boesch
Panel Chair
Center for Environmental and Estuarine Studies
University of Maryland, Cambridge, MD

Chair of the 1992, 1995, and 1996 panels, Dr. Boesch, a Coastal Ecologist, is President of CEES and Professor of Marine Science. He has extensive experience in reviewing and synthesizing information on coastal systems for policy development. Dr. Boesch will be stepping down as panel chair after this conference.

William C. Boicourt
Horn Point Laboratory
Center for Environmental Science
University of Maryland, Cambridge, MD

Dr. Boicourt is Professor of Physical Oceanography and specializes in physical oceanographic processes including circulation of the continental shelf and estuaries. Dr. Boicourt has graciously accepted the PMC's invitation to fill in for Dr. Armstrong.

Linda Deegan
The Ecosystems Center
Marine Biological Laboratory
Woods Hole, MA

Dr. Deegan is an Associate Scientist at the Marine Biological Laboratory (MBL). Her research has focused on fish community ecology, fisheries, and coastal ecosystem-watershed relationships.

Kenneth L. Heck, Jr.
Dauphin Island Sea Lab
Dauphin Island, AL

Dr. Heck is Professor of Marine Sciences and is a Marine Ecologist specializing in the study of seagrass ecosystems along the Atlantic and Gulf coasts of the United States. Dr. Heck is a new addition to the oversight panel.

John E. Hobbie
The Ecosystems Center
Marine Biological Laboratory
Woods Hole, MA

Dr. Hobbie is a Co-Director of The Ecosystems Center and is a Coastal Microbial Ecologist specializing in biogeochemical cycles of large coastal and wetlands systems. Dr. Hobbie is a new addition to the oversight panel.

Steven C. McCutcheon
Hydrologic and Environmental Engineering
Athens, GA

A member of the 1996 Bay Circulation and Water Quality Modeling Workshops and Co-Chair of the Model Evaluation Group, Dr. McCutcheon is a specialist in water quality issues, hydronamic modeling, sediment transport and hazardous waste management.

John D. Milliman
Graduate Dean, School of Marine Science
College of William and Mary
Gloucester Point, VA

Dr. Milliman is a Marine Geologist and formerly a Senior Scientist at the Woods Hole Oceanographic Institution. Dr. Milliman's research interests include marine carbonates and river fluxes to the oceans, at local, regional and global scales. Dr. Milliman is a new addition to the oversight panel.

Charles S. Yentsch
Bigelow Laboratory for Ocean Science
West Boothbay Harbor, ME

Dr. Yentsch specializes in primary production and remote sensing of water circulation. He is a new addition to the oversight panel but, unfortunately, is unable to attend the conference.

Organizing Conference Committee

Robert J. Brock
Marine Biologist and Florida Bay Research Coordinator
National Park Service
Everglades/Dry Tortugas National Parks
Homestead, Florida

Sharon H. Taylor
Associate Dean
University of Miami
School of Continuing Studies
Coral Gables, Florida

Pamala Wingrove
Sea Grant Extension Agent
Florida Sea Grant College Program
Tavernier, Florida

History and Organization

The Florida Bay Science Conference represents the annual opportunity for researchers to exchange technical information, share that information with resource managers and other interested conference attendees, and establish collaborative partnerships. The conference gives investigators from more than 90 research projects the opportunity to highlight their research in platform and poster presentations.

Five major issues central to an understanding of the problems affecting Florida Bay have been identified by the PMC for 1998. Investigators for established projects which have generated sufficient data related to these issues have been invited to make oral presentations. The PMC has provided guidance for preparation of abstracts and oral presentations. Abstracts submitted by both oral and poster presenters are compiled in this proceedings.

The Florida Sea Grant College Program organized the first Florida Bay Science Conference in 1995 and continues to assist the PMC in conference organization and dissemination of scientific results. Florida Sea Grant is a statewide, university-based program that not only conducts coastal research and education but also communicates scientific information through its extension activity. Florida Sea Grant disseminated material about the conference and coordinated local arrangements and program logistics along with the School of Continuing Studies at the University of Miami.

Question 2

What is the relative importance of the advection of exogenous nutrients, internal nutrient cycling including exchange between water column and sedimentary nutrient sources, and nitrogen fixation in determining the nutrient budget of Florida Bay?

Input of atmospheric nitrogen species in the Florida Bay area: Its role in the nitrogen budget of Florida Bay

Nutrient Dynamics (Atmospheric Deposition)

Pai-Yei Whung and *Charlie Fischer
Marine and Atmospheric Chemistry, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida.
*Division of Ocean Chemistry, Atlantic Oceanographic and Meteorological Laboratories, National Oceanic and Atmospheric Administration, Miami, Florida.

The magnitude of phytoplankton blooms in Florida Bay has been reported to have increased significantly in recent years. The nutrient bioassay studies in Florida Bay Research Program identified that nitrogen species is one of the three major limiting nutrients in the western and central regions of the Bay. It is important to understand the controlling mechanisms such as the sources and the sinks of nitrogen constituents, and the meteorology in the Florida Bay area. The major nitrogen input fluxes include water movements (marine, ground and surface fresh water runoff) and atmospheric deposition. Studies of nitrogen species in the Florida Bay water column have been carried out by projects currently funded by Florida Bay Research Program (FBRP), such as water quality and nutrient dynamics. The atmospheric deposition of nitrogen species has been identified by the Oversight Panel of the Interagency Florida Bay Science Program as a major unknown. The Panel recommended that greater effort should be invested to the measurements of atmospheric nitrogen over the watershed and Florida Bay. We propose to conduct seasonal and event-based measurements of particulate and gaseous nitrogen in the atmosphere over Florida Bay. The results can be integrated into ecological models for the better understanding of the controlling mechanisms for nitrogen loading in Florida Bay. A monitory station is needed to conduct continuous measurements of atmospheric nitrogen species in the Bay area.

The atmospheric nitrogen monitory station is located at the Keys Marine Laboratory in Long Key and has been operating since March 22, 1998. Meteorology parameters such as wind speed, wind direction, temperature and humidity are collected daily. The wind sector is set for receiving air masses coming from the Bay side. Atmospheric nitrogen include gaseous ammonia (NH_3), particulate ammonium (NH_4^+) and particulate nitrate (NO_3^-) are sampled using treated filterpacks. The preliminary results for the gaseous nitrogen species during the period of March and April showed that the NH_3 concentrations varied greatly (between 0.034 and 0.76 ug/m^3). The averaged particulate NH_4^+ and NO_3^- concentrations are 1.20 ug/m^3 and 2.17 ug/m^3, respectively. The observed atmospheric NH_3 concentrations in South Florida Bay are higher than the averaged NH_3 concentrations in other coastal regions (such as Tampa Bay and Chesapeake Bay). The result may suggest that the atmospheric gaseous NH_3 could make a major contribution to the total nitrogen budget in Florida Bay. However, the importance of the atmospheric nitrogen inputs to the bay area remains unanswered till more data is collected in the future. We plan on continue the air sampling for another year so we can obtain a seasonal pattern in the input of the atmospheric nitrogen to South Florida Bay.

Sediment phosphorus fractionation in calcium carbonate sediments of northeastern Florida Bay

Benz, R. E., Jr.
Koch, M. S. Florida Atlantic University, Biological Sciences Department, Boca Raton, FL

Introduction
Florida Bay sediments are primarily composed of biogenic carbonate muds (Bosence 1989). These fine grained calcium carbonate sediments chemically bind inorganic phosphate, causing the sediment to act as a phosphorus (P) sink (de Kanel and Morse, 1978, Ishikawa and Ichikuni 1981). Because P may be the limiting macronutrient to primary producers in Florida Bay (Powell et al. 1989, Fourqurean et al. 1992), sediment cores from northeastern Florida Bay were studied to quantify forms of sedimentary P.

Phosphorus in carbonate sediments occurs as loosely adsorbed or exchangeable P, iron/aluminum-bound, and calcium-bound P, as well as organic forms. Exchangeable P is readily released to the pore-water by changes in ionic concentration and redox potential. Iron-bound P becomes available with the reduction of the oxide/hydroxide to which it is adsorbed (Mortimer 1941,Golterman and Booman 1988, Jensen and Thamdrup 1993). The reduction of oxides occurs naturally as sediments become depleted of oxygen. Calcium-bound P is not readily available (Golterman and Booman 1988, Short 1987) under high pH conditions. Organic forms of P are mineralized through microbial activity and decomposition (Boers 1986).

Phosphorus fractionation by sequential chemical extractions provides a method for separating and quantifying P reservoirs in sediments (Ruttenburg 1992). Fractionation methods for P in soils have been used since 1957 (Chang and Jackson 1957) and several methods have been specifically adapted for marine sediments (Ruttenburg 1992, Jensen and Thamdrup 1993).

Materials and Methods
Sediment cores for P fractionation were extracted from four sites in northeastern Florida Bay across two mangrove-seagrass transition zones: Pond 1-Little Madeira Bay and Inner -Outer Terrapin Bay. Pond 1 and Inner Terrapin are interior (mangrove) sites while Taylor River and Terrapin Out are exterior (seagrass) sites. The sediment P study is part of a larger research effort to understand nutrient dynamics in northeastern Florida Bay (Day et al., Rudnick et al.). Sites where sediment cores were taken are consistent with those where seasonal porewater nutrients (Koch et al.) and *in situ* nutrient flux studies are being conducted (Rudnick et al.).

At each of the four sites, four replicate sediment cores were collected July 25, 1997 using PVC cores (5.08 cm diameter, 90 cm height). Cores were carefully removed from the sediment and capped at both ends to limit contamination, mixing, and oxidation. The capped cores were placed in iced 5 gallon buckets for transport on the boat and then moved into coolers to be transported back to the laboratory. Each core was sectioned into 5 cm depth increments: surface to 5 cm, 5-10 cm, 10-15 cm, 15-20 cm, and 20-25 cm. Each 5 cm section was weighed and homogenized by mixing the sample thoroughly in a sealed bag. A 1.00 g sub-sample was taken from each section for sequential P extractions. Additional sub-samples were taken for the analysis of total P, the determination of percent solid and percent organic matter, the analysis of total Ca, Fe, As, Mg on an ICAP, and the analysis of C and N on an elemental analyzer.

Extraction Method - The extraction procedure utilized in this study was a modified version of Ruttenburg (1992) and Jensen and Thamdrup (1993). The extraction procedure is as follows: 1.00 g (wet weight) sub-sample of sediment is placed in 25 mL of 1M magnesium chloride at pH 8.0 and agitated for 3 hours by a mechanical shaker, centifuged for 5 minutes at 4,000 rpm, and the liquid layer decanted. This is repeated again using 24 mL of 1M magnesium chloride and shaken for 30 seconds. A 1.0 mL aliquot of 1M sulfuric acid is added to the supernate, and the samples are then refrigerated until P analysis. The sediment residues from the magnesium chloride extractions are extracted by sodium-bicarbonate-dithionite (BD) to liberate the iron- and aluminum-bound phosphates. The residue is placed in 50 mL of BD solution at pH 7.0, mechanically agitated for 3 hours, centrifuged for 5 minutes at 4,000 rpm, and the liquid layer decanted. The residue is then placed in 25 mL of 1M magnesium chloride (pH 8.0) and shaken for 30 seconds, centrifuged for 5 minutes at 4,000 rpm, and decanted. The supernate is preserved and brought to volume by the addition of 4 mL of 1M sulfuric acid and 21 mL of deionized water. Samples are then refrigerated until P analysis. Sediment residues from the BD extraction are sequentially extracted with 1N HCl to liberate calcium-bound phosphate. The sediment residues are added to a 30 mL aliquot of 1N HCl, shaken several times, and purged. This is repeated until the carbon dioxide evolution does not cause a pressure build up. The samples are then mechanically agitated for 16 hours. At the end of the extraction, 20 mL of deionized water is added to the supernate and refrigerated until P analysis.

Total residual organic P is determined by transferring the remaining sediment residue to borosilicate culture tubes which are then combusted at 550°C. The culture tubes are cooled and 10 mL of 1N HCl is added to the combusted material. The tubes are placed in an autoclave for 50 minutes at 121°C and 21 psi of pressure. The contents of the tubes are transferred to centrifuge tubes and brought to a 50 mL final volume. The samples are then refrigerated until P analysis.

Total P is determined by taking 1.00 g of sediment and placing it in a borosilicate culture tube. The sediment is then combusted at 550°C. The culture tubes are cooled and 15 mL of 5N HCl is added to each. The tubes are autoclaved at 121°C and 21 psi for 50 minutes. The contents of each tube is filtered, brought to a final volume of 100 mL, and refrigerated until analysis.

Phosphate Analyses - Blanks, spiked blanks, and calibration standards are all prepared using the same matrix as the sediment samples. The analysis of P with ammonium molybdate and antimony potassium tartrate (catalyst) under acidic conditions follows that outlined in EPA Methods 365.1. Mixed reagent is added to samples and standards and analyzed by a Spectronics 301 spectrophotometer at 880nm with a 1 or 50 mm cell. The magnesium chloride extracts were analyzed at a 1:2 dilution. The BD extracts were run at a 1:5 dilution to eliminate interference from sulfides. The HCl extracts are run at a 1:4 dilution. The total residual organic P and the total P extracts are analyzed in the same manner as the HCl extracts.

Results and Discussion (Preliminary)
The highest P concentrations were found in Pond 1 compared among all four sites. The average total P concentration in the 0-5 cm increment at Pond 1 was 369 mg kg^{-1} as compared to the next highest, 142 mg kg^{-1} at Terrapin Out (0-5 cm).

The greatest proportion of sediment P is stored in the calcium-bound or HCl extractable pool averaging 52% to 66% of the total P in the 0-5 cm sections and 55% of the total for all depths. These results are consistent with the high calcium carbonate content of the sediments. Northeastern Florida Bay sediments at all four sites were primarily calcium carbonate with calcium levels at 26% to 30% total mass. Because of the strength and affinity of calcium to P, calcium-bound P is unlikely to serve as a readily available source of P for benthic communities (Morse 1987). However, several researches have considered calcium-bound P a potential source of P (Patriquin 1972). One mechanism studied is the ability of seagrasses to release organic acids which may liberate some of the calcium-bound P into the pore-water.

The second largest P pool is in the form of residual organic P ranging from 23% to 47% of the total (0-5 cm) and averaging 42% of the total for all depths. However, the organic levels in the sediment were low, ranging between 7% at Little Madiera Bay (20-25 cm) to 19% at Pond 1 (0-5 cm). The remineralization and recycling of organic P may contribute a large portion of the P required by benthic communities (Short 1987). However, if P is recycled through mineralization, low porewater P concentrations at these sites (Koch et al. unpublished data) indicate rapid P uptake rates by seagrasses, microflora, or abiotic geochemical processes.

Consistent with low porewater P concentrations at the four sites, loosely adsorbed P never exceeded 1% of the total P at any of the sites (0-5 cm). The BD extractable P (iron/aluminum bound P) was also low. Although the P associated with BD extraction was 23% of the total in Pond 1 at 0-5 cm, it was below detectable limits at deeper depths at Pond 1 and at all depths in Little Madiera Bay, and Inner and Outer Terrapin Bay sites sites. The limited amount of BD extractable P in the study sites suggest that Fe- and Al-bound P may not be significant in northeastern Florida Bay's P cycle as it is in many silicate-dominated systems (Jensen and Thamdrup 1993). In contrast, both calcium-bound and organic forms appear to dominant the P cycle in northeastern Florida Bay, particularly in the upper sediment depths.

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The Role of Groundwater in the Florida Bay Ecosystem

Larry Brand
University of Miami, RSMAS
Miami, FL 33149
Zafer Top
University of Miami, RSMAS
Miami, FL 33149
Nutrient Dynamics and Algal Blooms

We have hypothesized that groundwater may be a significant source of nutrients to the Florida Bay ecosystem and may help explain some of the ecological changes observed in the ecosystem over the past two decades. Specifically, we are testing the hypothesis that phosphate-rich groundwater may be moving through a Miocene-Pliocene coarse-grained siliciclastic river bed that makes its way from central Florida to underneath northcentral and northwest Florida Bay. The quartz sand channel appears to be a plausible source of phosphate (the primary limiting nutrient in most of Florida Bay and other South Florida coastal waters) because quartz sand will not chemically scavenge phosphate from groundwater the way limestone does. Furthermore, it travels through phosphate rich deposits in central Florida and contains phosphorite granules.

Our approach is to use ^4He, ^3He, and ^3H as tracers of groundwater input to Florida Bay. Because ^4He and ^3He are stable, they build up in concentration in groundwater over time and help distinguish young vs. old groundwater. ^4He is accumulated from the radioactive decays of the U and Th chain of elements and enters groundwater by dissolution. To the first order, the older the groundwater the more ^4He it accumulates. Because of the well quantified decay of ^3H to ^3He, a comparison of these two tracers allows us to age the groundwater. Data shown are from the first half year of sampling in this two year research project.

The spatial pattern of the highest concentration of these groundwater tracers matches very well with the distribution of the quartz sand deposits underneath Florida Bay. These all match the distribution of phosphate and chlorophyll concentrations in Florida Bay as well, which is consistent with the hypothesis that phosphate-rich groundwater traveling through the quartz sand deposits is the major source of nutrients generating the algal blooms in Florida Bay.

We hypothesize that the phosphate rich groundwater may also explain a number of other ecological characteristics in South Florida. The most extensive calcareous mudbanks in Florida Bay are in the area of the underlying quartz sand deposits and downstream. We hypothesize that these mudbanks are the result of direct biological production of calcareous materials and/or sediment entrapment in denser biological communities resulting from enhanced primary production in the area of phosphate enrichment from groundwater. Unlike the rest of the Florida Keys, which are old limestone reefs, Tavernier and Rodriguez Keys are composed primarily of calcareous mud. These Keys also appear to be near groundwater seeps from the quartz sand channel, and we hypothesize that elevated phosphate concentrations from the groundwater led to enhanced accumulation of these calcareous muds. Another place the quartz sand channel underlies coastal waters is in the Ten Thousand Islands area of southwest Florida. High concentrations of phosphate and chlorophyll are found there as well. Most of these islands are composed of mangroves growing on top of oyster reefs that have been able to keep up with sea level rise and grow to the sea surface. We hypothesize that oyster growth is much higher in this area than elsewhere along the coastline because phytoplankton are in higher concentrations here because of the elevated phosphate concentrations from groundwater input. The distribution of early Calusa Indian settlements in the area matches well with the location of groundwater arising from deep holes in the area and artesian springs, suggesting that this groundwater was the source of the drinking water that allowed them to settle on these remote islands.

Phosphate from the phosphorite deposits in central Florida would have been traveling through the quartz sand channel into coastal waters ever since the continental shelves were flooded. This source may explain a number of geomorphological features along the South Florida coastline, but cannot alone explain the large increase in algal blooms in northwest and northcentral Florida Bay within the last two decades. What has changed within recent times is the large increase in the human population and agricultural fertilizer use on lands overlying the quartz sand channel. One hypothesis is that the large increase in algal blooms may be the result of anthropogenic injection of nutrients into the quartz sand channel and their subsequent flow as groundwater into Florida Bay. A second possibility is that increasing acidity of rain has resulted in greater mobilization of the phosphate in the phosphorite granules in the quartz sand channel. A third hypothesis is that the flux of groundwater-borne phosphate has not changed significantly. The high phosphate areas south of Cape Sable may have always been nitrogen limited, unlike most of the rest of South Florida coastal waters. Increasing agricultural nutrient inputs into the Everglades watershed may have led to the large nitrogen plumes now seen coming out of Taylor Slough and the Shark River. A careful examination of the spatial distribution of chlorophyll concentrations indicates that the highest concentrations are where the high nitrogen and high phosphate waters mix. We are presently investigating these hypothesized scenarios by which human activities may have led to the dramatic ecosystem changes in Florida Bay within the last two decades.

Natural Tracers, Nutrients, and Groundwater in Florida Bay

William C. Burnett, Jeffrey P. Chanton, D. Reide Corbett, and Kevin S. Dillon, Department of Oceanography, Florida State University, Tallahassee, FL 32306
James Fourqurean, Florida International University, Department of Biological Sciences, Miami, Florida, 33199
Steven L. Miller, NOAA National Undersea Research Center, 515 Caribbean Dr., Key Largo, FL 33037

Topical area: Water Quality

Introduction and Hypothesis

Submarine groundwater discharge (SGD) has been recognized as an important source of nutrients to some coastal environments. We hypothesize that SGD may be responsible for some excess nutrient loading to Florida Bay. If correct, then groundwater inflow may be related to the deterioration of water quality and the observed ecological changes which have occurred in the bay over the past several years. This inflow may be associated with either the tidally-driven discharge of subsurface fluids along the keys and/or related to a buried paleo-channel filled with coarse-grained sand. This channel, often referred to as the "River of Sand," may act as a conduit for groundwater flow from areas further north.

SGD is by nature patchy, temporally variable, and difficult to measure. How can one assess the quantitative importance of such a process? Our group has had reasonably good success in other coastal environments by application of natural tracers to this problem. The radioisotopes ^{226}Ra ($t_{1/2}$ = 1600 y) and ^{222}Rn ($t_{1/2}$ = 3.8 d), and the trace gas CH_4 are good tracers of groundwater flow into surface waters because they are: (1) greatly enriched in groundwater relative to seawater; (2) conservative or nearly so; and (3) easily measured, even at very low concentrations.

Methodology

We have conducted four extensive surveys of Florida Bay including three in 1997 (June 24 - July 4, August 18-22, and Dec. 3-8) and one thus far in 1998 (February 23-28). We occupied several dozen stations during each survey and collected water samples for analysis of ^{226}Ra, ^{222}Rn, and CH_4. In addition, samples of attached macroalgae were collected from some stations for analysis of ^{15}N. Many of these stations were also sampled simultaneously by our collaborators at the University of Miami (Larry Brand and Zafer Top, P.I.'s) for analysis of ^{3}H and helium isotopes.

All water samples were collected using a peristaltic pump with a collection hose positioned directly over the bay bottom. Radon and radium samples were collected in evacuated 4-liter bottles and the analyses were conducted in a field laboratory (either at NURC or at the Flamingo Lodge) using helium to sparge radon, cryogenic trapping, and counting via alpha scintillation cells. Methane samples were collected in triplicate and measured using a head-space equilibration technique and a gas chromatograph in the field laboratory within 24 hours after collection.

Nutrient samples and chlorophyll were collected using standard protocols followed by Florida International University (FIU) and NURC. All nutrient, chlorophyll, and some ^{15}N analyses were performed at FIU.

Results to Date

One difficulty in the application of natural tracers is that they seldom have a unique source. Radon and methane exist at some concentrations almost anywhere, including the atmosphere. It is thus necessary to examine patterns closely and consider all possible input terms. **Figure 1** shows an example of the distribution of ^{222}Rn in December.

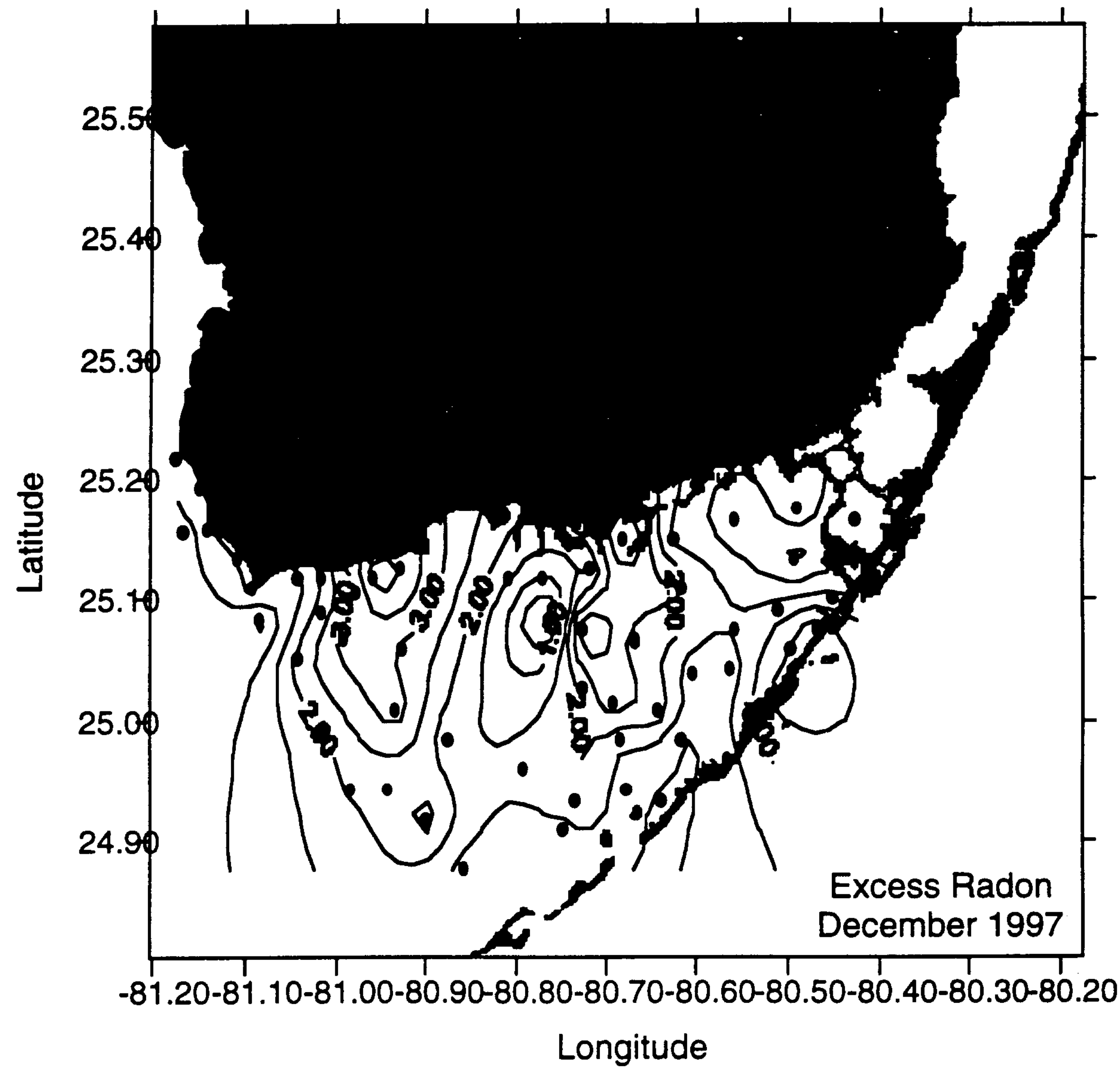

Figure 1. Distribution of ^{222}Rn in Florida Bay based on samples collected December 3-8, 1997. Contours that cross the keys are artifacts of the plotting program.

Based on the results collected thus far, there appears to be a distinct difference in tracer patterns that develop in Florida Bay during the summer than in the wintertime. In both the June/July and August samplings, all tracers show the highest concentrations along the inside of the upper keys. The waters around Rock Harbor are particularly high. The summertime surveys also show an indication of secondary highs for ^{222}Rn and ^{226}Ra in the northern bay south of Flamingo. This pattern is somewhat obscured, however, because of the extremely high concentrations near Key Largo. The ^{15}N patterns also show enriched values near the keys, possibly because of sewage inputs, typically depleted in the lighter nitrogen isotope. The ^{222}Rn patterns for both winter samplings look quite different than the summertime samplings. For example, a clear lobe of high ^{222}Rn concentrations extending south from the Flamingo area and another area south of Madeira Bay may be seen for the December sampling (Fig. 1). The general range in the concentrations are not substantially different than those observed earlier but the pattern in the north is much clearer because of the lower concentrations elsewhere in the bay. While the high tracers south of Madeira Bay may be associated with freshwater surface flow from Taylor Slough, there is no significant surface water source that could have influenced the area south of Flamingo.

We thus appear to see potential groundwater signals in two areas, along the inside of the upper keys in the summertime, and in the north-central to northwestern part of the bay in the wintertime. One possible reason for this seasonal switching is enhanced flushing from the keys during the wet season (although tidal pumping is probably responsible for most subsurface discharge). Higher wintertime groundwater fluxes in the northern bay could be related to the lower sea levels which occur at that time of year.

Our nutrient data indicate that both the inner keys and northern (near Flamingo) areas of the bay are associated with moderately high (Key Largo) to high (Flamingo) concentrations of total nitrogen (TN). The waters off Key Largo are quite low in total phosphorus (TP) however, while the Flamingo waters are elevated. An examination of the TP/TN atomic ratios shows that the highest (most P-enriched) waters are in the extreme NW portion (around Cape Sable) of the bay with a secondary high off Flamingo. Areas in the northeast portion of the bay, which have substantial freshwater surface inflow, show the lowest TP/TN ratios as do the waters off Key Largo. Thus, at least in a qualitative sense, groundwater inflow may be important for nitrogen loading in the keys and phosphorus additions in the northwestern bay.

Outlook for Remaining Work

We plan to run at least one or two additional broad surveys to further develop and verify the observed patterns of these natural tracers in the bay. We will then focus more on individual sites of interest based largely on our survey results. Seepage meter studies will also be pursued in conjunction with Tom Juster (University of South Florida) as well as time-series studies of tracers at selected locations over various time scales (e.g., tidal).

This research is being supported by a grant from NOAA's South Florida Ecosystem Restoration Prediction and Modeling Program Office (SFERPM).

Florida Bay Water Quality Model

Water Quality

Mark S. Dortch and Carl F. Cerco, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

The U.S. Army Engineer Waterways Experiment Station (WES) is developing a numerical water quality model of Florida Bay with funding from the U.S. Army Engineer District, Jacksonville, and the U.S. Environmental Protection Agency. An overview of the model plans and its status is presented.

The objectives of the study consist of the following: 1) develop a calibrated water quality and sea grass model for Florida Bay; 2) conduct nutrient budget and fate analysis for the Bay; and 3) provide results of a freshwater diversion management scenario. The study will span two years, starting December 1997, and is funded for $750,000. These time and funding constraints preclude full execution of the Florida Bay water quality model work plan (WES report MP EL-97-6), which called for about a four-year study costing several million dollars and involving considerable model development. The general plan for the present study stresses providing results expeditiously, retaining work plan features where possible, allowing future add-on features without any loss of the present investment while considering guidance of the Florida Bay Program Management Committee (PMC). Deviations from the work plan due to time and cost considerations include: 1) using the existing RMA10 hydrodynamic model, rather than CH3D; 2) using a coarser water quality model (WQM) than originally planned (about 1000 elements rather than about 5000); 3) using primarily off-the-shelf WQM code with limited model development; and 4) applying the model for fewer conditions (i.e., limited sensitivity and uncertainty analysis and scenario evaluations).

The approach is to use CE-QUAL-ICM (Cerco and Cole 1993 and 1994) for the WQM and to link it to output from the RMA10 hydrodynamic model (HM). The WQM will be two-dimensional, depth-averaged, as is the HM. Some modifications will be implemented in the WQM to allow better representation for Florida Bay. These modifications include: 1) providing for rainfall, evaporation, and cell wetting and drying; 2) providing for sediment resuspension due to wind waves and currents; 3) separating nitrate + nitrite nitrogen into two variables; 4) adding total inorganic carbon (TIC) as a state variable that interacts with sea grass; and 5) modifying the sea grass module to represent Thalassia and Halodule. The WQM will be calibrated for a two-year period (1995-1997) and confirmed for a ten-year hindcast (1987-1997). Data obtained from other scientists working through the Florida Bay Program will be used for model calibration and confirmation. The model will be used to assess nutrient mass balance and fate and to evaluate the impacts of a freshwater diversion management alternative. The WQM will have components for: 1) the water column, including nutrient, carbon, and phytoplankton interactions; 2) benthic sediment diagenesis and nutrient fluxes; 3) biomass-based sea grasses; and 4) suspended solids and their effects on the light climate. WQM state variables include: phytoplankton; inorganic phosphorus; dissolved and particulate organic phosphorus, nitrogen, and carbon; nitrite, nitrate, and ammonium nitrogen; TIC; dissolved silica; particulate biogenic silica; temperature; salinity;

total inorganic suspended solids; dissolved oxygen; chemical oxygen demand released from sediments; benthic algae; Thalassia roots and shoots; Halodule roots and shoots; epiphytes; and the light climate. The WQM will be driven by output from the HM, meteorological data, and nutrient loading data.

Existing water quality data have been gathered and examined. Obvious data limitations include TIC and suspended solids. Turbidity data exist, but a correlation specific to Florida Bay is needed to convert turbidity to total suspended solids. Additionally, measurements to relate light attenuation to suspended solids are needed.

Software has been developed to link output from the HM to the WQM. The linkage software has been successfully tested on a subset of the Florida Bay mesh. The WQM mesh, which is a coarser, congruent overlay of the HM mesh, is being developed and should be finished during May 1998.

The model will include sediment resuspension, deposition, and transport. The resuspension module is under development and will allow for one class of sediment with mass balance in the water column and bed. The resuspension rate will be related to shear stress generated by currents and waves and to a two-stage critical shear stress due to consolidated and unconsolidated bed material. Steady-state wave estimates will be performed based upon wind velocities, wind fetch, and water depth.

Work on loading specifications has been initiated. Loads will be estimated for freshwater flows from the mainland using a combination of recent measurements and results from other models. Non-point source and point source loads from the Keys will be based on land use data and management plan inventories, respectively. Atmospheric loads will be based on local measurements and literature values.

When completed, it is expected that the model will provide improved insights for nutrient source effects and fate, water quality impacts on sea grass, water quality impacts of freshwater diversions, and direction for future Bay monitoring, modeling, and research. Additionally, the model will provide a framework for future model development and application.

The South Florida Ecosystem Monitoring Integration Inventory

Higher Tropic Levels

George Henderson
Jill Trubey
Mike Dick
Florida Department of Environmental Protection, Florida Marine Research Institute
100 Eighth Avenue S.E., St. Petersburg, FL 33701-5095

Tom Culliton
Dave Lott
National Oceanic and Atmospheric Administration /SEA
1305 East-West Highway, Silver Springs, MD 20910-3281

The Everglades and its surrounding marine and estuarine environment is an area that has been altered by a myriad of human activities and is of national environmental concern. These activities have led to a decline in the health and vitality of coral reefs, degraded water quality, contaminated sediments and biota, nutrient enrichment of marine water, mass mortality of plant life, changes in animal population abundance and harvests, and habitat loss and fragmentation.

Many environmental monitoring projects are currently active within the South Florida coastal ecosystem to support a variety of management and research purposes. However, it is not clear whether the results of these efforts are generating a "complete set" of information required to meet a common set of goals and objectives. To evaluate the magnitude and scope of historical and current projects the Department of Environmental Protection and the National Oceanic and Atmospheric Administration joined forces to survey and evaluate the monitoring in South Florida.

The South Florida Ecosystem Monitoring Integration Project was a two year effort led by the Florida Department of Environmental Protection's Florida Marine Research Institute (FDEP/FMRI) and the National Oceanic and Atmospheric Administration's Strategic Environmental Assessments Division (NOAA/SEA). The project created a database and an ArcView (AV) application and hosted a series of workshops. The database contains project level metadata (data about data) for over 240 federal, state, regional, local and private environmental monitoring projects operating in the South Florida marine ecosystem.

FDEP/FMRI and NOAA/SEA gathered these data through on-site interviews with principal monitoring investigators, throughout the state of Florida, to ensure both adequate coverage of monitoring projects and consistent survey responses. Information includes: spatial coverage and monitoring site locations, temporal characteristics, which include sampling dates and seasonal groupings, data parameters measured and collected, methodology, database characteristics, and data availability. Information on each project was recorded on a survey form and entered into an

Oracle database via the Internet. The digital versions of the surveys can be viewed through the South Florida Ecosystem Monitoring Integration Project web site at *http://www-orca.nos.noaa.gov/south_florida*

Once the metadata were collected, a series of workshops were held that utilized participants' knowledge and expertise to identify management concerns and associated information needs. The first workshop was held in January 1997 and provided the basis for the second workshop, in which the attendees worked to link critical concerns and monitoring activities. The goal of Workshop II, held in May 1997, was to develop a monitoring strategy for each critical concern. The strategies that were developed identified spatial, temporal, and thematic gaps in current monitoring efforts. The strategies developed at the workshop will be included in a monitoring plan to be developed by the Core Group planning team and reviewed and evaluated by the South Florida Ecosystem Restoration Task Force, the Governor's Commission for a Sustainable South Florida, and the Florida Bay Program Management Committee.

This project is ongoing, - data gathering continues and the database continues to be updated to maintain a useful tool for scientists and managers.

The Influence of Circulation on Nutrient Distributions in Western Florida Bay.

Gary L. Hitchcock[1], Gabriel A. Vargo[2], Tom Lee[1], E. Johns[3], E. Williams[1], and J. Jurado[1]

[1]Rosenstiel School of Marine and Atmospheric Science
University of Miami
4600 Rickenbacker Cswy.
Miami, FL 33149

[2] Department of Marine Science
University of South Florida
140 7th Ave. SE
St. Petersburg, FL 33701

[3] Atlantic Oceanographic and Meteorological Laboratory
National Oceanic and Atmospheric Administration
4301 Rickenbacker Cswy.
Miami, FL 33149

The principal objective of this research program is to determine the role of advective nutrient flux in meeting the nutrient demands of phytoplankton in western Florida Bay and the Southwest Florida Shelf south of Cape Romano. The field work addresses the objective through (1.) surveys of dissolved inorganic and organic nutrients, as well as particulate nutrient measurements, and phytoplankton biomass and growth rate measurements, in conjunction with the circulation study of T. Lee and colleagues, and (2.) nutrient and phytoplankton surveys during volume transport studies in the passes and channels of western Florida Keys. A principal goal is to estimate phytoplankton nutrient demand in relation to advective nutrient flux in the region bounded by Cape Romano to the Dry Tortugas and the western Florida Keys.

Phytoplankton nutrient demands are estimated from dissolved and particulate nutrient concentrations and growth rates derived from dilution gradient measurements. Four cruises have been completed at bimonthly intervals since October, 1997. Dissolved inorganic and organic N and P, as well as inorganic Si, and particulate C, N, P and chlorophyll *a*, are determined along transects perpendicular to the shore between the Florida Keys and Cape Romano. In general, inorganic and organic nutrient concentrations decrease from typical coastal values to oligotrophic concentrations found in the Gulf of Mexico within 10 - 30 km of the shoreline. The nutrient demands of the phytoplankton standing crop are estimated from particulate matter (C, N, and P) concentrations regressed against chlorophyll *a*. Growth rate estimates are derived from dilution gradient experiments, and indicate the optimum phytoplankton community growth rates are 1.0 - 1.5 day^{-1}. The daily phytoplankton demand for nutrients are then extrapolated from the growth rate estimate times the product of the chlorophyll *a* standing stock and the average nutrient:chl *a* ratio. In general, the dissolved inorganic nutrient concentrations offshore of any influence of riverine sources are capable of supporting phytoplankton demands for, at most, a few days.

The magnitude of the advective nutrient flux into western Florida Bay will be estimated from the observed surface nutrient distributions and the surface velocities and water parcel trajectories provided by Tom Lee and colleagues. The circulation patterns and 'residence times' of surface waters in the study area can be derived from trajectories of System Argos-tracked CODE drifters, released on a bimonthly basis during the survey cruises, and several current meters that were recently deployed. Although we do not yet have a sufficiently large dataset to derive reliable velocity estimates across the boundaries of the study region, the residence time of drifters in the study region is several weeks for the period of spring to fall. In winter the passage of fronts enhances transport, and the drifters can rapidly exit the region through the passages adjacent to Long Key. Given these trends, the residence time of surface waters in the study region are 3 - 4 weeks during much of the year.

A second objective of our program is to evaluate the flux of nutrient and pigment biomass in the channel between East Cape and Sandy Key, and in the channels adjacent to Long Key. This effort will commence in summer, 1998 in conjunction with Lagrangian studies and, at Long Key, transport estimates derived from an Acoustic Doppler Current Profiler. To our knowledge, there have been no transport or flow measurements in Florida Bay through the channel south of East Cape. Water parcel trajectories will be followed in this region during a series of drifter deployments in summer and winter, 1998. In channels adjacent to Long Key, preliminary observations show that *net* residual transports between western Florida Bay and Hawk Channel through Channels 2, 5 and the Long Key Viaduct are typically on the order of 100s $m^3 sec^{-1}$. Our objective is to supplement the drifter and ADCP studies with nutrient and standing stock measurements to quantify the net flux of chlorophyll *a* and nutrients (as nitrogen, phosphorus and silicon) through the channels. The observations will allow us to estimate the magnitude of dissolved nutrient and plankton biomass potentially imported or exported from western Florida Bay. These rates may be important in quantifying the potential flux exported to the reef track.

The fluxes will be estimated by the protocol developed for material flux at the Long Term Ecosystem Research site at North Inlet, South Carolina (Pillay *et al.*, 1992. *Est. Coast. Shelf Res.* 35: 331-345). The data will be analyzed to relate variability to tidal components and any diel periodicity due to biogenic factors (e.g., Chrzanowski *et al.*, 1982. *Mar. Ecol. Prog. Ser.* 7: 231-245). Such an analysis partitions variability into mean (μ) and tidal components where the tidal periods are 24.84, 12.42, and 6.21 hours. An error estimate, and 24 hour diel periodicity component, are also derived from the regression analysis. This analysis should allow us to model the net material flux due to tides through the channels.

An Overview of Water Quality in Florida Bay and Surrounding Waters: Current Status and Trends.

Water Quality

Ronald D. Jones and Joseph N. Boyer
Southeast Environmental Research Program, Florida International University, Miami, FL 33199
305-348-3095, 305-348-4096 FAX, serp@servms.fiu.edu

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 abundance have focused 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.

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. The 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 (%), NO_3^- (µM), NO_2^- (µM), NH_4^+ (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 a (Chl a; µg l^{-1}), turbidity (NTU), and TN:TP ratio (molar).

Stations were previously grouped into distinct spatial zones having similar water quality by a multivariate analysis resulting in 3 statistically different zones: Eastern Bay (19 sta.) - the most freshwater dominated area with a longitudinal salinity gradient; Core Bay (4 sta.) - located in the N-central area, physically isolated, acts as an evaporative basin; and Western Bay (6 sta.) - influenced mostly by southwest Florida Shelf waters. In an effort to visualize trends, the median of data for each sampling event by zone is shown for the period of record. Also shown is a centered, 12 month moving average which is used to filter out annual fluctuations and thereby disclose any interannual oscillations of longer periodicity. Significance of trends were tested using the seasonal Kendall-t test: a nonparametric statistic of monotonic trends.

Salinities in Eastern and Central Bay has declined from the hypersaline conditions of the early 1990's and has resumed a more normal seasonal pattern. Turbidity in Eastern Bay remains high for the region at ~2 NTU. In Central and Western Bays the turbidity during 1997 was lower than for previous years. TP and SRP concentrations in all zones of Florida Bay continue to decline significantly. NH_4^+ levels in Eastern Bay have declined while NO_3^- has increased. In Central

Bay there has been a sharp reversal of the recent build up in both NH_4^+ and NO_3^- with concentrations returning to pre-1995 levels. TON concentrations in Eastern and Central Bay have declined slightly over the period of record. Finally, Chl a concentrations in Eastern Bay remains at the low levels observed since 1995 (~0.5 $\mu g\,l^{-1}$). For Central Bay a phytoplankton bloom occurred in Aug.-Sept. 1997 with Chl a concentrations as high as 7.5 $\mu g\,l^{-1}$. Overall, Chl a levels continue to decline in Central and Western Bays.

These short term trends must be put in perspective with more long term climate changes. The 7 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.

Nutritional Environments of Florida Bay and their Potential Influence on Secondary Production and Nuisance Bloom Dynamics

Algal Blooms, Zooplankton and Phytoplankton Ecology

G.S. Kleppel and S.J. Limbeck, Department of Environmental Health Sciences, University of South Carolina, Columbia, South Carolina 29208

Studies of copepod feeding and egg production in Florida Bay have revealed that (1) egg production rates vary with the composition of the diet rather than the total biomass of microplankton (food) ingested and (2) egg production rates of the calanoid, *Acartia tonsa* in Florida Bay are among the lowest reported for the species, though at a location where nuisance algal blooms occur frequently, egg production rates were relatively higher than the bay-wide average. Continuing research seeks to more clearly document the causes of low egg production rates. We hypothesized that egg production by *Acartia tonsa*, an important copepod in Florida Bay, varies as a function of the availability of particulate organic macronutrients -- proteins, lipids and carbohydrates -- in the seston. This study recognizes that the availability of particulates within the size range captured by copepods may be necessary, but not sufficient, to support egg production. We suspect that qualitative attributes of the food environment rather than solely its concentration, influence secondary production. The current protocol emphasizes the nutritional attributes of the food environment, which include the entire seston, and the role that particulate organic macronutrients play in zooplankton physiology. We have focused on copepods in these studies because, although our previous research has revealed that they are not important, as adults, in controlling nuisance algal blooms, their offspring may be. Further, the protist grazers that feed on nuisance bloom species are important as food for copepods. Thus, predation pressure by copepods on heterotrophic protists, may reduce grazing pressure on nuisance species. Finally, copepods are key components of pelagic food webs, being a constituent in the diets of many fishes at various stages in the life cycle. Thus, copepod production may affect fish stocks in the bay.

To date, sampling has been conducted in July 1997, September 1997, January 1998, and March 1998. Zooplankton and water samples were collected at two stations: one in the north-central part of the bay where persistent nuisance blooms occur ("bloom" station), and the other in the southern portion of the bay, which is characterized by somewhat lower micro- and nanoplankton biomass ("low biomass" or "oligotrophic" station). In July, the two stations were located at Whiprey Basin (bloom) and off Captain Key (low biomass). During all other months, Rankin Lake and a station off Duck Key were used as study sites for bloom and oligotrophic conditions. Samples were returned to the Florida Department of Environmental Protection Laboratory at Marathon within two hours of collection, where subsamples were stored or preserved and where grazing and egg production experiments were set up. Adult, female *Acartia tonsa* were sorted into one-liter, polycarbonate containers filled with water from the collection site that had been passed through a 63 µm screen. The samples were incubated for 24-h in situ, along with controls (water but no copepods), in basket incubators at the laboratory dock. These samples were later examined under the microscope to enumerate microplankton (for feeding estimates) and copepod eggs. Samples for particulate organic macronutrient analysis, including particulate organic carbon and nitrogen (POC, PON), protein, lipid, carbohydrate, fatty acids and amino acids were stored, on ashed filters, in liquid nitrogen. Samples for microscopic enumeration of microplankton were preserved with acid Lugol's iodine. Microscopic analysis, and protein, lipid, carbohydrate, POC and PON analyses are complete. Analyses of fatty and amino acids are in progress.

Egg production rates of *Acartia tonsa* were low and variable at both stations (mean at bloom station $\pm$ st.dev. = 8.9 $\pm$ 4.8 eggs/female/d; mean at oligotrophic station = 6.6 $\pm$ 4.5), confirming observations made in prior years. Seasonal differences in egg production rates were apparent the "bloom" station. Feeding rates were high, particularly at "nuisance bloom" sites (Whiprey and Rankin), where periodically daily rations exceeded 100% of body carbon/copepod/d. Surprisingly, at the Duck Key site in March, no feeding was observed (though detrital and other undocumented particles may have been ingested). As observed previously, microzooplankton (particularly heterotrophic dinoflagellates and ciliates) tend to be important dietary components of copepods from both locations. In March, however, following the passage of a storm through the area, the microplankton was dominated (77% of microscopically measured C-biomass) by diatoms, particularly, large, benthic species. Copepod diets at Rankin Lake reflected this (though at Duck Key no feeding was observed).

Particulate organic macronutrient analyses revealed potentially significant differences between "bloom" and "oligotrophic" locations, in both the absolute and relative amounts of macronutrients in the seston. In general, particulate nutrient levels were higher at Rankin Lake than at Duck Key (or their counterparts in July). At Rankin Lake, protein concentrations were often high relative to lipid levels. C:N ratios were often relatively low (ca. 7.0) during the summer (indicating a propensity for lipid limitation of egg production) and higher (ca. 11-21) during winter. At Duck Key, C:N ratios (range 9.2-29.8) are particularly suggestive of protein limitation of egg production.

The Carbonate and Nutrient Systems in Florida Bay

Frank J. Millero
University of Miami, RSMAS, MAC
Miami, FL 33149

Nutrient Dynamics

Eutrophication and red tides in Florida Bay have been both an economic and environmental concern for many years. High nutrient concentrations resulting from agriculture runoff, industrial effluent and other sources have been considered to be the causes for the degradation of water quality as evidenced by algal blooms and the mass mortality of turtle grass. Nutrients, such as phosphate, are critical to the onset and sustainment of phytoplankton blooms.

To better understand the relationship between nutrients and the carbonate system in the Florida Bay, several cruises were completed in 1997 to survey the water quality. During these cruises, our group measured carbonate system parameters (including total alkalinity (TA), pH, total carbon dioxide (TCO_2), and partial pressure of carbon dioxide (pCO_2)), as well as salinity and nutrients. In addition to the cruises, several other groups have collected samples that have been measured in the laboratory. TA, pH, TCO_2, and pCO_2 measurements have been used in an effort to characterize the carbonate system in Florida Bay. This analysis will help to contribute to the determination of the saturation state of calcite and aragonite particles that can absoıb phosphate as well as to the examination of the uptake of inorganic carbon by phytoplankton. Surface nutrient data was collected continuously on cruises via a flowing multi-parameter nutrient system, developed in our laboratory. This system measures the concentrations of nitrate, nitrite, silicate, and phosphate from a flowing seawater line onboard a research vessel. The continuously flowing nutrient system has the advantage of providing real-time data and a greater density of measurements than discrete sampling. This greater density of measurements can, for instance, help to identify changes in nutrient concentrations due to circulation patterns of water masses or frontal movements. Chlorophyll-a data were also collected during a cruise to evaluate primary production in Florida Bay waters. The nutrient data has also been compared with the carbonate system data to help identify changes in nutrient concentrations related to degradation of plant material.

HOW FRESHWATER EVERGLADES WETLANDS MEDIATE CHANGES IN WATER FLOW AND NUTRIENT LOADINGS TO THE FLORIDA BAY ESTUARY

Water Quality & Nutrient Dymanics (Poster Only)

Parker, Frank P., Southeast Environmental Research Program & Department of Biological Sciences, Florida International University, Miami, FL 33199, (305) 348-1576 (o), 4096 (FAX), fparke01@fiu.edu;
Daniel L. Childers, SERP & DBS, FIU, Miami, FL 33199, (305) 348-3101 (o);
Christopher Madden, Everglades Systems Research Division, South Florida Water Management District, West Palm Beach, FL 33416.

Everglades restoration efforts are focusing on large-scale changes in water delivery to Everglades wetlands. These changes include increased water inputs, and associated changes in nutrient regimes, in a freshwater-estuarine system that we are currently studying in eastern Everglades National Park (ENP). In 1997, a levee was removed from along the major drainage canal that delineates the northern boundary of this ENP Panhandle region in order to increase sheetflow through these wetlands and to Florida Bay. Between this canal and the estuary, wetlands range from sawgrass marsh to mixed Cladium-Rhizophora wetland to scrub red mangrove forest, respectively. Our ENP Panhandle sampling began in Fall 1997, at which point over half of the levee had already been removed. We established a wetland transect roughly normal to the canal and behind the remaining levee. Throughout the remaining 1997 wet season, we sampled water overlying the sawgrass marsh along this transect both intensively (every 3 hours for 48 hours) and extensively (every 2 days continuously). Approximately halfway through our sampling, levee removal was completed. Our water chemistry data from before and after levee removal show that nutrient concentrations in wetland surface water more than doubled after removal of the levee, from about 0.2 to 0.4 μM TP and from about 45 to 140 μM TN. When combined with the large increase in wetland sheetflow from the new inputs of canal water, this represents a significant increase in nutrient loading to the ENP Panhandle wetlands and perhaps even to the Florida Bay estuary. However, the sawgrass marsh within 3 km of the canal appears to be removing much of this nutrient load. Interestingly, this wetland uptake phenomenon did not immediately show up as increased porewater nutrients in these wetlands. Furthermore, cores taken before and after levee removal show an inhibition of C mineralization (via aerobic respiration, sulfate reduction, and methanogenesis) in wetland soils receiving increased canal inflows; this in spite of the fact that C decompositional processes in Everglades wetland soils are strongly phosphorus limited. We have not yet observed any changes in soil porewater salinities or sawgrass productivity since the levee was removed and sheetflow increased, but we would anticipate a significant lag in response by such parameters--and levee removal was only completed in late October 1997. We will continue to quantify these parameters over the next 3 years, along 2 parallel transects. Additionally, we will extend our transects through the mangrove wetland zone and to the Florida Bay confluence, and we will

construct and sample replicate flumes immediately adjacent to the canal edge, to more accurately quantify nutrient uptake and transformations by the sawgrass marsh. Thus, our research will continue to quantify how freshwater wetlands in the ENP Panhandle region are mediating the quantity and quality of additional water inflow that reaches the Florida Bay estuary, in response to Everglades restoration efforts.

Question 3

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

Modeling Ecosystem Interactions in Florida Bay

Area of research: Algal Blooms, Zooplankton and Phytoplankton Ecology

George A. Jackson and Adrian B. Burd, Department of Oceanography, Texas A&M University, College Station, TX 77843

The aim of this two year project is to study the nutrient and trophic dynamics of the planktonic ecosystem in Florida bay using two complementary approaches. First, we are analyzing existing data for representative basins to estimate the nutrient and carbon flows between different planktonic trophic groups and their interaction with the benthos. The second approach is the development of models to explore the dynamics of these interactions.

To understand the movement of carbon and nitrogen through the planktonic ecosystem of Florida Bay we must first estimate the rates at which they pass through and are transformed by the food webs. Unfortunately, marine food webs are complicated systems having the potential for a myriad of interactions that are not easily sampled or understood. Typical ecological studies of marine food webs are able to measure only a few of the many interactions known, or suspected to be occurring within them.

The application of inverse techniques to the analysis of marine ecosystems allows estimates to be made of all the interactions taking place within the food web using a limited set of measurements. The technique (introduced by Vezina and Platt (1988)) incorporates information about known assimilation and production efficiencies of organism groups together with a description of the flows in the food web and results of field measurements.

We have applied this technique to various basins within Florida Bay using measurements made at different times of year and supplied by M. Dagg and P. Ortner. Many of the basins that make up Florida Bay have depths of less than 3m, giving the benthos a disproportionate influence on the system relative to most coastal systems. Preliminary results from our inverse model show that about half of the primary production is being exported to the benthos, either by filter feeders or by deposition and subsequent degradation. Present measurements require little flow to dissolved organic carbon (DOC) and bacterial components of the food web. However, this could be an artifact of limited measurements of the cycling of these components. Differences between Figures 1 and 2 show the effects of including measurements of bacterial productivity to the food web. If measurements of DOC cycling and bacterial metabolism indicate that they are large components of the system, we will have better estimates of benthic interactions. Exchange between basins has yet to be included and will have a characteristic time-scale which differs from the biological processes.

The analysis results indicate large scale spatial homogeneity within the central part of the Bay. Food webs for Rankin and Twin Keys using data taken during September 1997 show a considerable similarity. Comparison between results for September and July 1997 for Twin Key also indicate a shift of meso-zooplankton grazing from phytoplankton in July to micro- and proto-zooplankton in September.

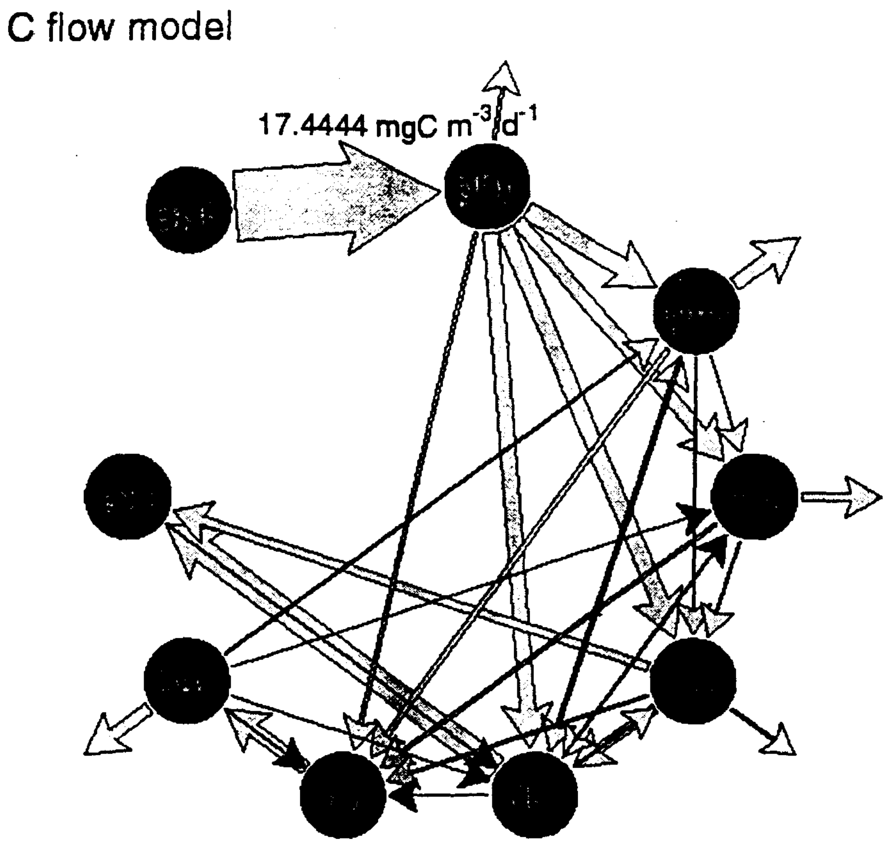

Figure 1. Carbon flows between trophic levels for Duck bay. The arrows represent flows between compartments with the arrow width being proportional to the relative flow. Arrows pointing away from the center of the figure represent respiration and production of carbon dioxide. Abbreviations include: gpp – gross primary production; phy – phytoplankton; pro – protozoa; mic – microzoa; mes – mesozoa; det – detritus; doc – dissolved organic carbon; bac – bacteria; ext – an "external" pool incorporating e.g. interactions with the benthos.

Investigating the structure of a food web using inverse analysis is a data intensive activity. We will be incorporating more data into the analysis as they become available. This will enable us to include more compartments allowing a better representation of the interactions of the system with the benthos. In addition we will be able to add and subtract compartments.

The analysis of the data using the inverse techniques gives a static picture of the food web. To investigate the dynamics of the system, we are using the results from the inverse method to construct a dynamic model of the trophic interactions within the ecosystem. These models use explicit representations of the rates of such interactions to estimate changes in populations and concentrations over time. The structure of the food web being modeled in this manner is in part determined from the results of the inverse analysis which allows us to assess which components of the food web dominate the various interactions.

C flow model

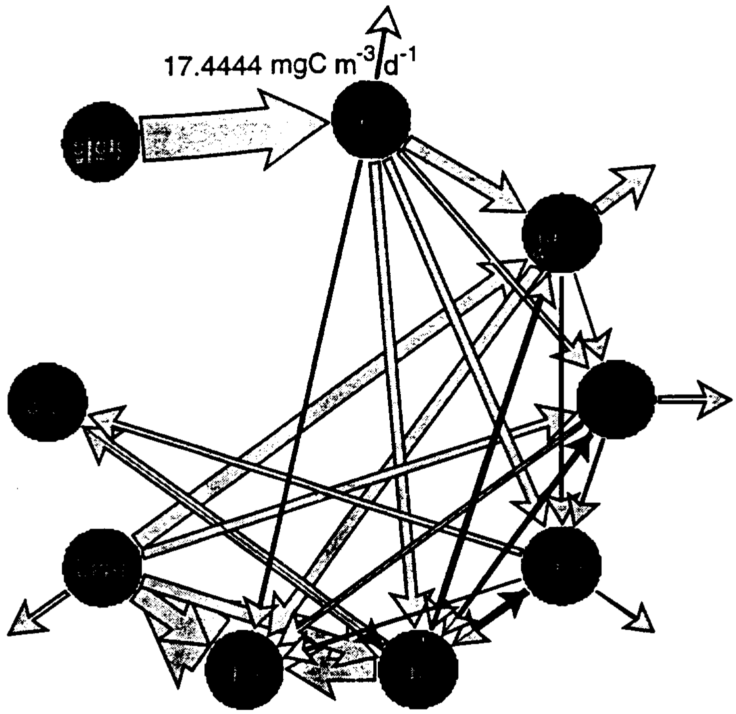

Figure 2. Results of an inverse model for Duck Key including bacterial production measurements obtained from J. Cotner (personal communication). All other information used in formulating the inverse mode is the same as for Figure 1.

Both the inverse and dynamic model are data intensive. As more data becomes available we will incorporate it into the inverse model giving a better representation of the food web structure that will be used in the dynamic model.

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Florida Bay Microalgae

Algal Blooms, Zooplankton and Phytoplankton Ecology

Karen A. Steidinger, Susan Lukas-Black, Shirley Richards, Bill Richardson, and Gil McRae, Florida Department of Environmental Protection, Florida Marine Research Institute, 100 Eighth Avenue SE, St. Petersburg, FL 33701

Persistent microalgal blooms in Florida Bay have consisted of blue-green algae (cyanobacteria), diatoms, dinoflagellates, and flagellates, many of which are in the pico- and ultraplankton size ranges. These nuisance blooms can make the water turbid and potentially alter community structure and physical aspects of a subsystem's habitat. Between May 1994 and May 1997, the Florida Department of Environmental Protection (FDEP) maintained six permanent sampling stations in Florida Bay and also sampled additional stations (not fixed) with the help of Florida Bay Watch volunteers. These stations/sites were sampled monthly until May 1996, then bimonthly until May 1997. The program had field and laboratory components to evaluate environmental variables in relation to species or group composition, biomass, production, and dominant species adaptations. The central question addressed was "what regulates the onset, persistence, and fate of planktonic algal blooms in Florida Bay?"

Environmental data (including chlorophyll a and cyanobacterial counts/biomass) support the geographic division of Florida Bay into four zones or regions: the western region, influenced by Gulf of Mexico waters; the north-central and south-central regions, influenced by resident microalgal populations and runoff; and the eastern region, which is less variable and does not typify the bloom area.

The epicenter for the blue-green colored blooms appears to be the north-central region, which contains Rankin Basin (Sta. 4), where high chlorophyll a and high cellular biomass can reach 40.58 $\mu g \cdot L^{-1}$ and 203 x 10^6 μ^3 of blue greens, respectively. Meteorological events such as storms and high winds can influence the spread of microalgal blooms from the north-central region to the south (Sta. 6, Twin Keys Basin) and to the west or from the west (Sta. 1, Sprigger; Sta. 2, Sandy Key; and Sta. 3, Johnson Key) to the central regions. Typically in spring, the microalgal blooms recede to the north-central basins.

Correlation analyses show that certain environmental variables are highly correlated. Pairwise relationships between chlorophyll a and organic particulate load, total particulate load and inorganic particulate load, salinity and temperature, and secchi depth and water depth all were apparent. These results are based on 163 samples (data sets with missing data were removed). Ordination of these environmental data via nonmetric multidimensional scaling (MDS) revealed that the north-central region is high in total particulate load, chlorophyll a, and organic particulate load, followed by the south-central region, then the western region, and, finally, the eastern region. Inorganic particulate loads are highest in the western region.

Between May 1994 and May 1997, 63 of 163 chlorophyll a values were >5 $\mu g \cdot L^{-1}$, indicating high microalgal biomass. Of these 63 values, 10 were >20 $\mu g \cdot L^{-1}$ (22.4 to 40.58 $\mu g \cdot L^{-1}$), which may constitute a nuisance bloom. For the data analyzed, blooms of >20 $\mu g \cdot L^{-1}$ chlorophyll a primarily represent coccoid blue-greens in the western and south-central regions and coccoid blue-greens and large dinoflagellates such as *Prorocentrum micans* and *Gambierdiscus toxicus* in the south-central regions. At other times in the north-central region, high biomass can be dominated by *Cyclotella choctawatcheeana*, *Synechococcus elongatus*, and *Chaetoceros* cf. *salsugineus*, with dominants shifting seasonally. Other high biomass blooms are the Rhizosoleniaceae in the western region. More than 50% of the microalgae have benthic representation, either as resting spores/cysts or directly as benthic species.

Although the database for August 1994 to August 1995 is being analyzed for community changes in time and space, interannual analyses for at least 2 years of monthly data are needed to look at change. The program being used is PRIMER©, a multivariate analyses package capable of hierarchical clustering, ordination by multidimentional scaling, and linkage of ranked community analyses and environmental variables (11) to distinguish between microalgal communities between stations or times. The same is being done for group identifications (e.g., centric diatoms and armored dinoflagellates) at the incidental stations where there are some environmental data (6 variables).

To run the MDS for the permanent stations, we reduced the number of species to 125 to fit this version of the PRIMER© matrix. This reduction was done by removing the species that were recorded only once. As Year 2 data are entered into the database, the list will change again. According to Clarke and Warwick (1994), such reductions do not reduce data resolution. These authors even suggest that such multivariate analyses can be run at a higher (e.g., genera or family) level for community change analyses. Data are being run using biomass and numerical abundances to compare results. The use of 125 species for a similarity matrix is cumbersome, and it may be that the list can be reduced to 57 species by omitting those species occurring only 3 times or having a frequency of occurrence of 1.8%.

Frequency of occurrence still can be used to look at prevalence. For example, *Rhizosolenia setigera* and *R. imbricata* dominated the Rhizosoleniaceae blooms in the western region, but eight related species co-occurred and constituted a bloom complex that discolored surface waters brown. More than 170 described species and 230 taxa have been identified from Florida Bay during this study. As more data are analyzed, more species (rare events) will emerge. The less common, rare species can be very significant. For example, *Gymnodinium breve*, a toxic dinflagellate, was a rare visitor, but its presence was very notieceable—it caused fish kills. Other toxic microalgae in Florida Bay are rare species as well; that assemblage must be accounted for to determine associations, changes, and trends. Changes in biodiversity and productivity of a subsystem can be due to one occurrence of a rare species. The resiliency of that subsystem will determine change over time.

Florida Bay Algal Blooms: Spatial and temporal variations in primary production.

Carmelo R. Tomas, Brian Bendis, and Lee Houchin, Florida Department of Environmental Protection, Florida Marine Research Institute, 100 Eighth Avenue S.E., St. Petersburg, FL 33701

Algal Blooms/Phytoplankton Ecology

Objective/hypothesis: Florida Bay has profoundly changed from a region which had primary production predominantly from rooted macrophytes to one where at times of the year primary production is now throughout the water column and packaged in single cells or chains of phytoplankton. This difference in partitioning of carbon in this ecosystem has had profound effects on the trophic structure. The major objective of this project was to define the water column primary production, document its spatial and temporal variations for major Bay regions and provide the basis for comparing secondary production as observed through micro and mesozooplankton as well as to dominant filter and suspension feeders. Statements as to trophic flow, efficiency and transfer can thus be better understood and modeled.

Since Sept. 1994, monthly primary production measurements were made from samples taken at 4 (four) reference stations representing different regions of Florida Bay. The four stations chosen were Captain Key basin (Easternmost station), Rankin Lake (Central-North Bloom station), Sprigger Bank (Southwestern shelf station) and Sandy Key (Northeastern shelf station). The rationale for choosing these stations was that they were conveniently sampled in ample time to return to the laboratory where C^{14} primary productivity could be conducted, they were distinct regions representative of the larger bay and were areas where previous or additional sampling were conducted by various study programs. At the time of the productivity samples were taken, these stations were also sampled for a suite of variables including salinity, temperature, pH, nutrients (NH_4, NO_3, PO4, Si, TN, TP, TC), Chl a, total particulate load and secchi disk depth. The monthly time period was determined as a practical matter since the research team needed to travel 300+ miles for field sampling and productivity measurements, making less than monthly intervals difficult.

The samples were taken early each morning and upon return to the laboratory were immediately processed by passing each through 163 µm mesh netting to remove larger zooplankton and particulate matter, dispensed by automatic dispensette as 50 ml aliquots into 60 ml glass stoppered BOD bottles to which C^{14} bicarbonate was added to a final concentration of 10 µCi/L. Ten duplicate light bottles plus two dark bottles were inoculated for each station. These bottles were incubated in a plexiglass tube incubator having 10 different light levels (98, 55, 43, 27, 23, 21,17, 11, 5, 0.3% incident solar radiation) and maintained at ambient bay temperature by continuous circulation of bay seawater. The samples were incubated for 4-6 hours after which the incubations were terminated by the addition of DCMU to a final concentration 10^{-5}M. Light and dark bottles were then harvested by filtering each sample through 25 mm GFF glass fiber filter which was rinsed with filtered seawater and placed into a liquid scintillation vial with 10 ml of Packard Optima Gold scintillation fluor. The samples were counted on a Packard TR1900 Liquid Scintillation Counter. Aliquots of the original sample were also assayed for total CO_2 using a Capnicon infrared carbon analyzer. Additional aliquots of the original sample were also filtered on 13 mm GFF pre-combusted filters for analysis on a Carlo Erba CHN analyzer.

For many of these samples, natural populations from each station were assayed for nutrient stimulation in a bioassay study described at the Florida Bay Conference 1997. These studies helped to define the type of nutrient limitation experienced by the phytoplankton at each of the productivity sites. Comparison of the growth rates obtained in the bioassay experiments were also made to those based on carbon turnover using either carbon derived from the CHN values or from a assumed carbon: Chl a ratio.

The greatest productivity values measured occurred at the Rankin Lake station where the greatest phytoplankton biomass as measured by chlorophyll a was observed. A maximum integrated daily rate of 4.51 $gC/m^2/day$ occurred in November 94 and values exceeding 1.20 $gC/m^2/day$ were found again in August, October and November 1995. For the remainder of the study period, the values at this station did not exceed 1.0 $gC/m^2/day$. The western boundary stations, Sprigger Bank and Sandy Key, which had the greatest influence of blooms with origins from the southwest Florida shelf, also showed elevated production rates. Sprigger Bank had values of 2.68 and 1.21 $gC/m^2/day$ in October 94, and Aug. 95 respectively while the Sandy Key station had values of 1.93, 1.61 and 1.35 for Sept., Nov. and Dec. 94, respectively, and values of 2.34 and 1.09 $gC/m^2/day$ in May.and Jul, 96. All other values at that station were between 0.126 and 0.963 $gC/m^2/day$. The lowest productivity values were found at the Captain Key Station in the eastern portion of Florida Bay. The highest values of 0.41 and 0.32 $gC/m^2/day$ were found during Sept, 94 and July 95, respectively. Elevated values of 0.243 $gC/m^2/day$ were found in Jan. 96 while values less than 0.10 $gC/m^2/day$ were found through the remainder of the study.

Clearly the greatest production was observed at the northwestern station of Sandy Key and Rankin Lake which exceeded that measured elsewhere. These values were associated with blooms in these regions and declined to lower but notable rates (Rankin Lake = >0.40 $gC/m^2/day$) for the remainder of the study period. The peaks in production were associated with blooms from differing origins at these stations. Sandy Key had a dominance of shelf species mainly diatoms as well as a contribution from the export of cyanobacterial blooms from the central Bay. Rankin Lake was dominated by the cyanobacteria species, mainly *Synechococcus elongatus* and the peak bloom periods corresponded with the peaks in primary production. The Sprigger Bank station was the next most productive and reflected to some degree the pattern of the more northern station Sandy Key. However, the values during non bloom periods at Sprigger were generally lower than Sandy Key suggesting that the station to the south had slightly different dynamics for production. The Captain Key station was consistent with regards to primary production and biomass. Of all standard stations studied, Captain Key Basin routinely had the lowest chlorophyll a, organic particulate load and phytoplankton populations. A similar pattern was discerned in the nutrient bioassays, which consistently indicated that the phytoplankton of this region had lower growth rates, was consistently phosphorus starved and attained lower biomass than any of the other regions tested.

The photosynthesis light curves obtained from the graded light series of each primary production measurement consistently indicated that the phytoplankton populations were conditioned to low light and despite the time of year were inhibited by light intensities greater than 70% ambient solar radiation. This to some degree indicates the continual conditioning of the phytoplankton in this shallow, turbid, mixed estuary. These observations are consistent with those of light penetration in the water column where actual measurements made with LiCor sensors on the bottom as well as those derived from secchi disk depths, extinction coefficients and noon time ambient light intensities, rarely showed the bottom with less than 10% ambient surface light and always above the compensation intensity for phytoplankton. The phytoplankton community was well adapted for the light available in Florida Bay.

For the last two years, grazing studies were conducted during the times when primary production was measured. This portion of the project is ongoing and is still to be fully evaluated. From previous analyses, it is clear that the microzooplankton certainly play an important role in consuming the primary production in the central regions where are dominated by cyanobacteria. The mesozooplankton can feed on the cyanobacteria blooms indirectly but are calculated to consume only a minor portion of the production. The remainder of the production can continue as benthic production in the well lit bottoms with occasional resuspension by winds, but for the most part appears to be exported. The full role of the benthic grazers is presently being studied and will give further details as to the possible influence of this compartment in controlling watercolumn production.

APPENDIX C

South Florida Ecosystem Restoration Prediction and Modeling FY98 Implementation Plan

SOUTH FLORIDA ECOSYSTEM RESTORATION PREDICTION AND MODELING FY98 IMPLEMENTATION PLAN

INTRODUCTION

A. Background

Within the SFER effort, NOAA's Coastal Ocean Program (COP) has continued to maintain a lead role in regard to rigorously determining the causes of present changes in the coastal ecosystem and quantitatively predicting the consequences upon that ecosystem of upstream restoration activities. The underlying concept, adaptive environmental management, was articulated in the Integrated Science Plan developed by the Science Coordination Team (formerly called the Science Subgroup of the Management and Coordination Working Group of the South Florida Ecosystem Restoration Task Force (SFERTF). In FY97, and now in FY98, the NOAA/COP South Florida Ecosystem Restoration Prediction and Modeling (SFERPM) program funds both field and laboratory research and model development. In addition, the SFERPM program has, on behalf of the overall interagency Florida Bay Science Program Management Committee, funded a substantial Community Outreach & Education effort and assumed responsibility for the Interagency Florida Bay Science Program web site.

The SFERPM program was conceptually developed by a team of federal, state and academic regional scientists. The elements of the SFERPM program were designed to complement other components of the FY97 NOAA South Florida Ecosystem Restoration Initiative (SFERI) such as the NMFS-lead Protection of Living Marine Sources and the NOS-lead Integrated Florida Bay and Florida Keys Ecosystem Monitoring programs. Moreover, a substantial fraction of SFERPM funds directly contributes to the Florida Keys National Marine Sanctuary (FKNMS) Management Plan and the national Coral Reef Initiative (http://www.gbrmpa.gov.au/~icri) by addressing the linkages between Florida Bay, the Florida Keys, and the coral reef tracts of the FKNMS.

B. Goals

The Interagency Science Program in Florida Bay has continued in its efforts to develop an understanding of the structure and function of Florida Bay in the context of South Florida ecosystem restoration. Restoration implies establishing and sustaining the natural diversity, abundance, and behavior of the marine and estuarine flora and fauna, and in Florida Bay the principal factor that appears to control these parameters is freshwater input. Timing, location, type, and quality of this input are critical to Florida Bay ecology. Clearly, upstream restoration activities have a direct impact on Florida Bay although the impacts may not be immediate. Achieving the capability of predicting these impacts continues to be the ultimate goal of the SFERPM program i.e., it implies a rigorous understanding of the physics and ecology of Florida Bay and the larger coastal ecosystem with which it is intimately connected. This understanding remains the overall objective of the Interagency Science Program in Florida Bay of which NOAA SFERPM is the largest component.

Predicting the downstream effects of Florida Bay restoration upon the sustainability of the coral reef ecosystems of the FKNMS is also critical to NOAA. While this issue falls somewhat outside the scope of the Interagency Science Program in Florida Bay, it is notable that the geographic scopes of Florida Bay hydrodynamic and water quality modeling efforts sponsored by the Interagency Program have now been expanded to include the FKNMS. As noted in the FKNMS Management Plan, "little attention was given to the degradation of water quality in Florida Bay" initially. As the plan was refined, however, this linkage became, and continues to be, a major focus of the FKNMS Water Quality and Research and Monitoring Plans and, thus, is reflected in the goals and specific program elements of the SFERPM program.

C. Objectives

The challenge to the Florida Bay research community continues to be to deliver timely information to South

Florida Ecosystem Restoration managers. While this may at times be politically difficult, scientifically based restoration is viewed as an iterative process through which management alternatives are developed and selected, the preferred alternative implemented, physical and biological responses assessed, results reported to managers, and the process repeated over and over again as restoration proceeds. It is through this adaptive process that the goals continue to be achieved. SFERPM's program has two basic components: Environmental Research & Modeling and Community Education & Outreach. In a practical political sense both may be critical to the aforementioned iterative process. Implementation of management alternatives will be impossible without public support regardless of the scientific information provided to the managers.

Environmental Research & Modeling. Specific projects were selected for FY97/FY98 (two-year awards) through an open, fully competitive, peer-review process. Announcements of Availability of Funds were mailed to academic institutions, NOAA cooperative institutes, the Science Coordination Team mailing list, and given to our interagency partners. In addition, they were distributed through State and National Sea Grant offices. After careful evaluation by the Technical Advisory Panel (TAP) and the SFERPM Program Management Committee (PMC) of all planning letters received, specific projects were targeted and more detailed work plans were requested from the investigators. The criteria for evaluation included both technical merit and program relevance, and while NOAA-academic collaborative projects were encouraged, they were not required. The detailed work plans received were again evaluated by the PMC and presented to the interagency Florida Bay Program Management Committee to ensure consistency with the overall Interagency Science Program priorities and, finally, a select number were recommended for funding to COP. As in the past, all participating NOAA investigators that were selected have been required to provide substantial matching funds. In addition, supplementary funds have been acquired from other parts of NOAA. These additional funds significantly augment what might have been achieved with COP funding alone and permitted a number of additional projects.

Community Education & Outreach. This component of the SFERPM program is (and will continue to be) conducted by Florida Sea Grant. Before final approval by the SFERPM Program Management Committee (PMC), Sea Grant's work plan was submitted to the interagency Florida Bay Program Management Committee for their review. As with all SFER public outreach and education efforts developed at that time, their activities, on behalf of the interagency PMC, were fully integrated and approved by the SFER Working Group's Public Information and Education Subgroup.

D. Organization

SFERPM has followed the distributed project management approach pioneered within NOAA by COP. This mechanism has proven highly effective in the management of interdisciplinary federal/academic collaborative programs e.g., NECOP and SABRE. Further, it has enabled managers to bridge fundamental institutional differences between various NOAA line organizations and academic institutions.

Within SFERPM, the Program Management Committee (PMC) is responsible for both funding decisions and continuing project management. Guidance for these tasks is provided by a Technical Advisory/Review Panel (TAP) that consists of federal, state, and academic natural scientists and social scientists familiar both with the South Florida ecosystem and with various SFERTF activities (Appendix III). To assure continued interagency coordination and cooperation, members of the PMC and TAP continue to serve upon both the interagency Florida Bay Program Management Committee and the Science Coordination Team of the South Florida Ecosystem Restoration Task Force Working Group. The SFERPM PMC is currently composed of one representative from Rosenstiel School of Marine and Atmospheric Science (University of Miami) and one representative from each of two different NOAA line organizations (OAR and NMFS).

FY97 ANNUAL REPORT

A. Progress Toward Overall Goals

Environmental Research & Modeling. The SFERPM Environmental Research & Modeling program was developed as an integral component (within the constraints and structures) of the overall Interagency Science

Program in Florida Bay at the direction of a NOAA Florida Bay Task Force (chaired by the director of NOAA/COP). According to the agreed upon interagency framework, individual agency research activities and implementation plans must not only be consistent with the scientific approach and priorities of the interagency Strategic Science Plan but they must also be reviewed through the interagency program management process. This was felt to be essential not only to minimize waste but also to permit sufficient flexibility in redirecting funds by collaborating agencies. The intention was (and still is) that individual agency activities be complementary rather than comprehensive i.e., that in aggregate (rather than individually) their efforts will yield answers to the basic questions posed as well as furnish timely information to restoration managers. The research objectives of the Interagency Science Program in Florida Bay were (and are) as follows:

- Develop an understanding of the condition of Florida Bay prior to significant alteration by man. This information will provide an "idealized" target for the restoration of Florida Bay. Although full restoration may prove impossible, this understanding will serve as a basis for assessing the extent and effectiveness of management restoration actions.
- Separate both anthropogenically-induced changes in Florida Bay from natural system variation. Both natural disturbances (e.g. hurricanes, freezes) and long-term climate processes (drought cycles, sea level rise) have strongly influenced the structure and function of the Bay. These same processes may mask or exacerbate the effects of anthropogenic impacts on the Bay. It is essential to develop an understanding of anthropogenic effects within the context of natural system function and variation.
- Develop the capability to predict the response to perturbation of a suite of species and/or biological processes which collectively may be considered representative of Florida Bay. Restoration of Florida Bay will require choosing among alternative management actions based on predictions of ecosystem response. Comparing the response of this "representative Bay" to potential management alternatives is one way in which our ecological understanding of the Bay can provide timely input to the decision-making processes of restoration management.

Although NOAA has become the largest supporter of Florida Bay restoration research, at present, the NOAA SFERPM program represents only 55 % of the ca. $7M committed to the Interagency program. These obligations and relationships are fully described in the NOAA Florida Bay Research & Modeling program FY95, FY 96, and SFERPM FY97 Implementation Plans signed and approved by the Assistant Administrators of OAR, NMFS, NOS, and the Director of the Coastal Ocean Program.

The "customers" of the research funded and/or conducted by the interagency partners (including NOAA) are the Interagency Florida Bay Working Group and the South Florida Ecosystem Task Force Management Working Group. NOAA's institutional expertise and its specific environmental mandates such as preserving the FKNMS and protecting living marine resources (including endangered species) have delimited NOAA's contribution to the Florida Bay Interagency program and guided the substantive content of the FY96 Implementation Plan. Specifically, NOAA was asked by its agency partners (DOD/ACoE, DOI/ENP, DOI/NBS, EPA, FDEP, SFWMD) to focus its research effort upon the larger oceanographic, atmospheric, geological and fisheries context within which Bay restoration will proceed. This implied that most NOAA resources were to be directed towards studying the Bay ecosystem's interaction with and significance to the adjacent Atlantic and Gulf of Mexico coastal marine ecosystems. In addition, resources were to be directed toward the Bay ecosystem's regulation by the larger scale oceanic and meteorological processes that so intimately link the coastal marine environment to the coastal terrestrial systems in South Florida.

Community Education & Outreach. The overall goal of the Community Education & Outreach program is to connect research, science, and ecosystem management with the diverse public audiences and individual interests living beside and visiting Florida Bay and its watershed. At present, the Florida Bay Education Office is open and functional and staffed with a water quality extension agent, a science communicator, and a secretary. A memorandum of understanding

between Everglades National Park (ENP), FKNMS, and Florida Sea Grant is in place, and education and outreach activities are underway.

Risk Assessment/Socioeconomic Analysis. Although SFERPM solicited planning letters in FY97 for Risk

Assessment/Socioeconomic Analysis, none of the submissions were funded. During the review phase it was clear that SFERPM miscalculated in combining disparate elements (risk assessment and socioeconomic analysis) into a single announcement. Not a single proposal was positively reviewed. Initially, SFERPM was hoping to use ecological risk assessment as a tool for management decisions. During the review process, however, reviewers expressed their concerns that ecological risk assessment was an inappropriate tool for this use and, in fact, management and regulatory communities may not be committed to using the information that would be generated in their decision-making processes. SFERPM shares this last concern. Moreover, given the recent reorganization of the South Florida Interagency Task Force, it was impolitic to issue an announcement of availability of funds for such policy-laden topics as risk assessment and/or socioeconomic analysis without an explicit partnership with the appropriate federal and state agencies. With the agreement of COP, the entire subject area was tabled pending the results of the recently held (February 1998) interagency workshop on the topic of socioeconomic research required by SFER and finalization of the budgets of our interagency and NOAA line organization partners.

B. General Accomplishments

Funded Research. A complete list of SFERPM funded research projects (including Community Education & Outreach) is given in Appendices I and II. In addition, SFERPM maintains a web site so that project descriptions, accomplishments (updated at least biannually), recent data and preliminary conclusions are provided as quickly as possible to the South Florida research and restoration management communities The SFERPM web site can be viewed at http://www.aoml.noaa.gov/ocd/sferpm/ . Detailed information on each project can be obtained by logging onto this site, but is also briefly summarized in the pages to follow. The Community Education & Outreach project group maintains its own web site which can be found at http://flseagrant.org/flbay.htm . It is also linked to the SFERPM program home page. In addition to research projects, SFERPM has funded two research support items: Data Management/Administration and Small Boat Operations.

Data Management/Administration . One measure of program success is whether or not research data is easily accessible by interested parties. The Panel noted that "...data management systems should be developed in order to facilitate data sharing and accessibility by investigators and to ensure data preservation... and to develop networks that link distributed data bases...including GIS." At the behest of SFERPM, a data management policy has been endorsed by the interagency PMC and data management team members have been assigned. A raw data database is in the early stages of design and collection of data from investigators has already begun within SFERPM with the hiring of data management personnel. As noted earlier, an augmentation of our data management/administration effort included assumption by SFERPM of the interagency web site located at http://www.aoml.noaa.gov/flbay/ .

Small Boat Operations. A special purpose high-speed shoal draft vessel has been acquired and is being fitted with state of the art physical, biological and chemical sampling instrumentation. This vessel can be deployed from the Key Largo Ranger Station or other convenient sites and is provided to all SFERPM projects at no charge. It is already being used by SFERPM investigators for regular surveys of the Bay as well as servicing the various fixed moorings and tower sampling platforms SFERPM maintains throughout the Bay and the FKNMS.

C. Individual Project Year One (FY97) Accomplishments and Year Two (FY98) Plans

In FY97, SFERPM funded projects addressed three general topics: improving our physical understanding of Florida Bay; characterizing the Florida Bay ecosystem and the changes it has undergone; and anthropogenic influences.

Improving our **physical understanding of Florida Bay and/or modeling of Florida Bay's interconnection and dependence upon regional oceanographic and meteorological processes** are the general goals of the projects below. These projects represent NOAA's contribution to an interagency effort attempting to develop, initialize, and run in an operational mode a Florida Bay Circulation model. This model is, in turn, part of a still larger effort to develop, initialize, and run in an operational mode a coupled oceanographic, hydrological, and atmospheric model of the South Florida peninsula to provide requisite inputs to coastal water quality and ecological models.

Regional Boundary Conditions for Florida Bay , Aikman et al.

Objectives: The goal of this project is to provide accurate physical (water levels, currents, temperature and salinity) boundary condition information to modelers and investigators working in the South Florida region and in Florida Bay. Water level is probably the single most important parameter for any hydrodynamic modeling effort in Florida Bay, thus this project is initially focusing on providing such, coordinating as closely as possible with the Corps of Engineers Florida Bay Circulation Modeling effort. To this end the Princeton Ocean Model (POM) is being applied to the Gulf of Mexico/Caribbean (GOM) region to provide this information, based on atmospheric and tidal forcing of a barotropic (two-dimensional; vertically integrated) version of the POM.

Accomplishments: The model bathymetry has been established (a GOM and two subdomains) and tidal simulations, based on open ocean tidal boundary conditions, compare well with previous model results. Moreover, three different gridded wind fields for different simulation periods have been prepared and purely wind-driven simulations of the GOM and Florida Shelf (FS) domains are underway. The observed coastal water level gauge data has been assembled at stations around the GOM domain for these time periods and will be used to evaluate the model results.

A 14-month (September 1, 1995 to October 31, 1996) barotropic FS model simulation of wind-plus-tide-forced water level and currents has been completed, and results are being evaluated using NOS water level gauge data plus recently obtained observations of bottom pressure and both moored and drifting buoy current meter data from Tom Lee (RSMAS) and Ned Smith (HBOI). This includes estimates of the cross-FB sea level slope. Preliminary results indicate that the barotropic model water levels are in close agreement with the observations around FB (RMS difference apx. 7 to 8 cm; correlation coefficient apx. 0.9) and that the model cross-FB sea level slop is in qualitative agreement with the observations.

FY98: Barotropic (2-dimensional) FS model results will be analyzed against available data and "best-analyzed" wind fields will be generated for the FS to test the model in a nowcast/forecast mode. This will be coordinated with an independently funded similar effort being conducted on the Texas shelf which will provide open ocean water level boundary conditions for a Galveston Bay nowcast/forecast system.

All project milestones have been met and we expect this project to become purely operational (along with the ACoE Circulation Model or its successor) by FY2000. It's deliverables in FY98 include transferring modeled wind/water level data to the ACoE (Q2) and collaborative completion of the ACoE Bay Circulation Model verification effort (Q4).

Simulations of Regional Climatic Patterns Which Impact the Florida Bay Water Cycle , Craig Mattocks

Objectives: This project has had two principal objectives: mesoscale atmospheric modeling and episodic meteorological event reconstruction. The former is critical to wind forcing of the Bay circulation model as well as rainfall inputs to south Florida and the Bay while the latter was deemed critical to understanding the south Florida ecosystem which can be strongly influenced by episodic storms and/or hurricanes, as noted by the Panel. A high-resolution version of the Advance Regional Prediction System (ARPS) model has been extended to actually predict the amount and the distribution of rainfall, not just moisture convergence and the locations of dry convective cells, as well as replication of realistic looking precipitation patterns along the sea breeze front. Moreover, ARPS has recently been enhanced to also predict the planetary boundary layer (PBL) height as a function of time and stability. Work in progress for initializing ARPS from real-time operational model history files and initializing ARPS from a realistic 3-D heterogeneous atmospheric state should substantially improve the realism of the atmospheric simulations.

Accomplishments:

- Configured the Center for Analysis and Prediction of Storms' (CAPS) Advanced Regional Prediction System (ARPS) nonhydrostatic cloud-/mesoscale atmospheric numerical weather prediction model to simulate persistent, locally-forced weather regimes (sea/land/lake/urban heat island breeze circulations) which generate thunderstorm complexes over the Everglades and coastal areas that provide roughly one-third of Florida's annual rainfall.
- To assess the impact of changes in the surface characteristics (as might be created through Everglades restoration projects) on the evaporation/precipitation and wind fields, two ARPS model simulations were carried out. In the first simulation, a homogeneous surface (sand-clay-loam soil with grass-shrub cover) was used to represent all land grid points, while the temperature of the oceans/lakes was held constant. In the second simulation, realistic soil and vegetation/land use distributions were extracted from 1993 LANDSAT satellite imagery and incorporated into the ARPS surface energy budget at land grid points.
- Working closely with scientists at the South Florida Water Management District (SFWMD), the ARPS grid domain has been reconfigured to match that of their hydrology models. High-resolution GIS soil/vegetation, land cover/use surface characteristics, and terrain elevation data from SFWMD are currently being incorporated into ARPS, and the surface conditions (where ponding exists, depth to groundwater, etc.) will be prescribed for the natural system vs. present-day conditions. Through direct comparisons of the simulations and by selectively reverting isolated areas of urbanization and drainage to their natural state, any distinctive microclimates (urban heat islands and associated shifts in the rainfall distribution) which have emerged over the past century will be identified. One of the most intriguing potential applications of this (eventually) coupled model approach is the prediction of the environment's response to "What if ...?" impact assessment scenarios, such as the urbanization/development of pristine areas or the restoration of natural habitats.

The achievement of these 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.

FY98:

- Finish the processing and correction of the SFWMD GIS surface characteristics data sets, then incorporate this information into the latest version (4.3) of ARPS.
- Finish modifying the microphysics drop-size distribution in ARPS. Run test simulations with the new spectra to assess the impact of incorporating the more realistic parameterization. Derive probability distribution functions (PDFs) for ARPS in order to compare/calibrate the predicted rainfall with the rain rates measured by gages and NEXRAD WSR-88D Doppler radars. Fuse together the real field measurements of rainfall (from NEXRAD and airborne radar, rain gages, NOAA P-3 aircraft, hydro-met monitoring sites, etc.) using an optimum interpolation (OI) error-minimization algorithm to produce a hybrid rainfall product.
- Repeat FACE case study sea breeze simulation (3.22 km resolution, SFWMD soil/vegetation/land cover, Willis drop size distributions, new version of ARPS). Estimate the total freshwater input from rainfall over the Florida Peninsula. Generate evaporation estimates from the ARPS surface energy/soil module. Calibrate results against a composite of real measurements.
- Working with NOAA/AOML's Mark Powell and Sam Houston, use optimum interpolation objective analysis software to create a near real-time "operational" surface winds analysis product over Florida Bay. Feed the analyzes to a live web site at NOAA-AOML for use by environmental scientists.
- Collect GriB, surface, upper-air data and surface winds analyzes in interpolation objective analysis software for a strong cold frontal passage over Florida Bay. Initialize ARPS with non-homogeneous 3-D fields constructed from NMC/NCEP Eta/Meso model forecast fields merged with the collected real data. Conduct ARPS simulations and contrast the predicted wind forcing over Florida Bay from this advective cold front case against the more locally-driven sea breeze case.

The principal deliverable from this project in FY98 will be making realistic wind and evaporation fields available to the restoration management community though WWW project site dissemination of model outputs (Q3).

Circulation and Exchange of Florida Bay and the Connecting Waters, Lee et al.

Objective: The goal of this effort is to obtain the physical data required to support the Florida Bay Circulation Model (ACoE) and the NOS Florida Shelf Model and to gain sufficient understanding of the underlying physics to assure model accuracy.

Accomplishments: Field work began December 1995 and consists 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. Field work includes five seasonal hydrographic surveys of Florida Bay and the surrounding waters, in conjunction with both a time series (since Dec. 1995) of CTD and bottom pressure data from a five meter array in western Florida Bay and adjacent southwest Florida shelf and Florida Keys, and 3-month surface drifter trajectories from two satellite tracked drifters. These observations have begun documenting the highly-variable, low-salinity Shark River discharge plume which is advected towards Florida Bay and the Keys; extensive exchange between the GOM and western, but not eastern Florida Bay; high chlorophyll concentrations indicative of planktonic uptake of river borne nutrients; a cyclonic recirculation between West Cape Sable and Cape Romano; as well as a net southeastward flow from the Gulf of Mexico to the Florida reef track through western Florida Bay.

Physical modelers guiding the Interagency Florida Bay PMC stressed these data as critical to model development and operation, especially exchange across the dynamic western boundary. Moreover, this NOAA project is leveraged by data and information exchange with Ned Smith (HBOI), through funding from EPA, as well as freshwater flow data from the USGS and the SFWMD.

Accomplishments:

- Initial observations of circulation show that a strong southeastward flow on the order of 1000 m3/sec is responsible for the transport of algal blooms and turbid waters from western Florida Bay to the coral ecosystem of the Florida Keys National Marine Sanctuary.
- The magnitude of the southeastward flow coupling western Florida Bay and the reef tract is about 200 times greater than the fresh water discharge from the Everglades and about 10% of the average magnitude of the Mississippi River. The flow is constricted by the bathymetry to take place primarily through Long Key Channel.
- The source of the southeastward flow appears to be local southeasterly wind forcing that causes sea level to stand higher in western Florida Bay than in the Keys coastal waters thus driving a southeastward flow down the sea level slope through Long Key Channel.
- Northeasterly winds that occur in the fall can have the opposite effect and cause a north westward flow through Long Key Channel from the reef tract into western Florida Bay.
- The persistent nature of the southeastward flow makes Florida Bay and the reef tract susceptible to river inputs and red tide from the West Florida Shelf that can result in fish kills as observed in June 1996.
- We are optimistic after our first years measurements that the circulation in western Florida Bay can be reasonably well modeled and predicted from the local wind field.

The principal deliverable of this project in FY98 will be dissemination of data to the modeling and field sampling research communities and the FKNMS management community via the WWW project site (Q3).

Field Observations to Initialize and Verify Computer Simulations of Florida Bay Circulation, Ned P. Smith

Objective: The primary goal of this study is to assemble observations of currents, winds and water levels, and then to analyze the data in such a way that the results can be used to verify a hydrodynamic model of Florida Bay. Five specific objectives have been identified:

- Over a one-year study period, quantify the movement of water through a tidal channel in the interior of the bay, and determine the relative importance of winds and tides in producing the net movement.
- Obtain harmonic constants (amplitudes and phase angles) of the principal tidal constituents in four

channels in the interior of the Bay.

- Obtain harmonic constants of the principal tidal constituents that exchange water across the open western boundary of the Bay (taken to be the 81°05' W meridian).
- Quantify the response to wind forcing along the western boundary of the bay by comparing measurements at two study sites with wind data recorded northwest of Long Key.
- Test the suitability of a two-dimensional, one-layer hydrodynamic model by quantifying the correlation and directional shear of flow in near-bottom layers.

Accomplishments: Field work began in mid July, 1997, and it will continue through the end of June, 1998. A long-term monitoring site was established south of Gopher Keys on July 17th. Data from this site will describe seasonal variations as well as tidal exchanges between adjacent sub-basins. Two study sites along the 81°05' meridian were occupied from late August through late November to investigate tidal and nontidal exchanges with shelf waters of the Gulf of Mexico. Additional short-term study sites will be maintained in the interior of the bay (near Spy Key and Jimmy Key), and along the Intra coastal Waterway on the southeastern side of Florida Bay (in Bowlegs Cut, Steamboat Channel and Cowpens Cut). All of these time series will be used to verify simulated currents in the corresponding part of the model, and under the same wind conditions.

FY98: This data collection effort will be continued through the end of June 1998. Data analysis will be continued through the spring of 1999 with present funding. The activity is not required after that since the ACoE model will be fully verified and on-line and the geographic scope of this project is comparatively limited.

The principal deliverable of this project will be delivery to the ACoE of the interior Bay station data needed to complete verification of their circulation model (Q4).

Monitoring and Evaluation of Radar Measured Rain Estimate over Florida Bay and the Everglades, Marks and Willis

Objective: This project was initiated in the late summer of 1995 and the first flights were made in the early fall of 1995. Its objective is the tuning of radar rain estimation algorithms so that the NEXRAD data now being generated from the Miami site, and the newly commissioned Key West site, can be effectively used to accurately characterize the rainfall amount and distribution over the peninsula and Florida Bay. The present rain gage network is simply too sparse and inaccurate given the highly convective nature of rainfall events in the Florida Bay/Everglades system, to provide an adequate measure of the rainfall input to the system.

Accomplishments: The standard NEXRAD algorithms were developed largely for non-tropical conditions, and may not be applicable to this system. The best possible NEXRAD product is the only way to obtain the requisite data. Airborne rain drop distributions, a continuous point measurement of surface distributions from a distrometer at the Everglades Research Center, and surface measurements from a mobile van, as well as all available rain gage data, are being used to tune the radar-rain algorithm for the specific conditions that prevail over the Florida Bay/Everglades system. Preliminary NEXRAD rainfall products have been made available on the Internet at http://storm.rsmas.miami.edu/~jgottsch/fbay.html .

FY98: To date, the NEXRAD hydrologic product, the Digital Precipitation Array (DPA) has been archived. This product has been found to have serious shortcomings as a product to meet the needs of Florida Bay freshwater input. At many sites, the product seriously underestimates the rainfall at rainfall rates greater than about 8 mm/hr. To better define the nature of this problem and the necessary corrections or adjustments, a rather large sample of raw, full resolution radar data will be compared to an extensive gage data set over Florida Bay and the Everglades area. After FY99 we anticipate this project will shift from a research to an operational mode and will require no further SFERPM support.

The principal deliverable of this project in FY98 will be a rigorous statistical analysis of NEXRAD predicted rainfall and rain gage data leading to an improved algorithm formulation approach (Q4).

The SEAKEYS/C-MAN Project: Environmental Monitoring of the Florida Keys and Florida Bay, Ogden et al.

Background: The Florida Institute of Oceanography's (FIO) SEAKEYS (Sustained Ecological Research Related to Management of the Florida Keys Seascape) program began in 1989 and has continued until the present. This program, now being supported through NOAA's South Florida Ecosystem Restoration, Prediction and Modeling Program (SFERPM), implements a framework for long-term monitoring and research along the 220 mile Florida coral reef tract and in Florida Bay at a geographical scale encompassing the Florida Keys National Marine Sanctuary (FKNMS). The impetus for such a framework was the perceived marked regional decline in coral reefs and the critical need to provide data and options for resource management. The network consists of six instrument-enhanced Coastal-Marine Automated Network (C-MAN) stations, cooperatively managed with NOAA's National Data Buoy Center, plus a proposed new one in northwest Florida Bay. These stations measure the usual C-MAN meteorological parameters, such as wind speed, gusts and barometric pressure, but are enhanced with oceanographic instruments measuring salinity, sea temperature, fluorometry and turbidity.

Accomplishments:

- Efforts are nearing completion to upgrade the existing stations at Fowey Rocks, Molasses, Sombrero, Sand Key, Dry Tortugas, and Long Key. Meetings among Principal Investigators from FIO, AOML and NDBC resulted in a constructive redesign and re-implementation of the existing network, including testing of the new WetLabs fluorometer and transmissometer sensors before deployment at the Sombrero and Long Key stations.
- A complete SEAKEYS monitoring station has been planned for northwest Florida Bay in cooperation with the West Florida Shelf monitoring program at the Department of Marine Science, University of South Florida. After a survey by Tom Lee, the physical oceanography researchers for Florida Bay have agreed upon a location at 25° 05'00" N, 81° 05'30" W. It was installed last month by the USGS and efforts are presently underway to instrument it.

FY98: In FY98 all upgrades will be completed and backup instrumentation sensors will be purchased minimizing the time off-line for any single station. Software improvements will be a principal focus of the data processing side of the project.

The principal deliverables of this project in FY98 include first bringing on line the NW Florida Bay station (Q4) and second, the coding and initial testing of a neural net expert system utilizing these in cooperation with the FKNMS to assist them in predicting events such as coral-bleaching (Q4).

Characterization of the Florida Bay ecosystem and documenting an understanding of the processes responsible for rapid changes during the past few decades is the goal of the following biological projects and one geological/paleoecological project.

Circulation, Nutrient Influx, and Phytoplankton Growth in Florida Bay: G. Hitchcock and G. Vargo

Objectives: Given ambient nutrient concentrations in Florida Bay and the adjacent SW Florida Shelf and the results of ongoing circulation studies indicating substantial exchange and interconnection between the western Bay and the SW Shelf (see Lee et al.), it is apparent that nutrient flux across the western boundary of the Bay represents an appreciable component of the overall nutrient budget within the Bay. Moreover, these waters are the ones most likely to impact the FKNMS. The objective of this study is to document that flux and determine how it is effecting phytoplankton growth/algal bloom generation.

Accomplishments: This project began near the end of FY97 with $50K in funding provided by NOS as part of their Integrated Ecosystem Monitoring Program. Specifically the investigators were charged with augmenting the Lee et al. Physical Circulation Study by sampling nutrients along a transect line from the Dry Tortugas to Cape Romano. At the same time they took the opportunity to begin work on other aspects of the problem including measurements of

phytoplankton growth on some of the cruises. Data is just becoming available and will be discussed at the

Annual Florida Bay Science Conference

FY98: In FY98 this program will be expanded to address its full set of objectives using SFERPM funds made available by the termination of some projects and Program funds used in FY97 for acquisition of a small boat. A joint RV/CALANUS small boat cruise is planned for June 1998 during which a Lagrangian tracer study will be performed over a one week period near the western boundary. We also anticipate receiving again $50K in funding from NOS to permit continuation of the Cape Romano-Dry Tortugas line since is was given the highest priority within the base funding (no increase) scenario for Integrated Ecosystem Monitoring.

The principal FY98 deliverable from this project will be conducting a Lagrangian process study of flow into and through the western Bay (Q4) and dissemination of the nutrient transect data at the annual Florida Bay Science Conference (Q3).

Fish Recruitment, Growth, and Habitat Use in Florida Bay, Hoss et al.

Objective: This project repeats a survey of the Bay conducted by some of the same scientists a decade ago to address changes in the distribution and abundance of living resources in Florida Bay, and the response to declining seagrasses, increased plankton blooms and altered salinity conditions relative to the previous decade.

Accomplishments: Bay-wide sampling is demonstrating that there are numerous areas of the Bay where seagrasses have declined considerably since 1984, and that there have been changes in the spatial distribution and densities of resident fish and shellfish. Changes in the composition of the fishery community also are being observed relative to 1984-85, specifically increases are seen in *Gobiosoma robustum* and *Harengula jaguana* and decreases in rainwater killifish. The changes noted continue to indicate a shift from a benthic-epibenthic feeding community, in large areas of the Bay, to one dominated by planktivores. This latter noted shift is an extremely significant result as emphasized by the Science Review Panel. While icthyoplankton aspects of this study will continue within the COP program the pure habitat aspects will henceforth receive support from the NMFS Living Marine Resources program.

FY98: This coming year the focus will be upon sea trout and bay anchovy. Both species were minor constituents a decade ago but are dominant species today. Current research emphasizes functional responses such as growth and recruitment of fish and shellfish in relationship to habitat changes that may accompany restoration activities in the Everglades and in Florida Bay. These responses will be incorporated in ecosystem models of Florida Bay in order to better predict consequences of human activities in south Florida as they effect important commercial and recreational fisheries resources.

The principal product of this effort in FY98 will be the data analysis presented in the Upper Trophic Level section of the Florida Bay Science Conference (Q3).

Experimental Investigations of Salinity and Nutrient Effects on Florida Bay Plankton and Larval Sea Trout, Clarke and Bollens

Objective: Dramatic changes in the biota of Florida Bay have occurred over at least the past decade. Several environmental parameters have been postulated to be the causal factors in these changes, chief among them increasing salinity and eutrophication. However, the effects of changing salinity and nutrient conditions on the plankton community are poorly known and understood. To identify the causal mechanisms underlying these changes and, thus, be able to predict future ecosystem response, requires going beyond simple monitoring of long term environmental trends (for which few data on plankton exist in any event) and applying field and laboratory experiments employing well replicated and controlled treatments. We are conducting such a set of experiments, the results of which can help provide a basis for the analysis of historical changes in the Bay and thus guide future management decisions on its restoration.

Accomplishments: This project was initiated in late summer 1998. It uses well-controlled and heavily replicated experimental mesocosms to investigate the importance of salinity and nutrients in controlling the plankton dynamics in Florida Bay. The first experiment conducted tested the effects of salinity (23 ambient, 42 ppt) on the composition and abundance of phytoplankton, protozoan, zooplankton and larval fish.

A raft was constructed in protected waters adjacent to the Keys Marine Laboratory and from it a series of 2.3 m3 polyethylene enclosures were suspended. Plankton and larval sea trout were stocked in the bags at natural densities and salinities were manipulated by adding DI water or saline to ambient subsurface seawater. This first experiment was just successfully completed. Our next experiment will include experimental manipulation of nutrients in enclosures.

FY98: In FY98 a series of additional experiments will be performed in the test facility just constructed. Experimental variables will include not only salinity but also nutrient concentration.

The principal FY98 deliverable will be creation of test facility in Marathon (Q2) and dissemination of initial experimental results at the annual Florida Bay Science Conference (Q3).

Trophic Pathways in the Pelagic Environment of Florida Bay , Dagg et al.

Objective: Surprisingly, no quantitative zooplankton data was available for Florida Bay prior to the inception of this study. It seeks to answer the following questions:

1) What is the importance of zooplankton consumption in Florida Bay and how does this vary within the Bay as the salinity and temperature distributions change throughout the seasonal cycle?

2) What is the relative abundance of micro zooplankton and macro zooplankton and how does this vary within the Bay as the salinity and temperature distributions change throughout the seasonal cycle?

3) What species and types of zooplankton and/or micro zooplankton are the primary food of larval and near juvenile fishes and how does their distribution vary within the Bay as a function of temperature and salinity throughout the seasonal cycle?

Accomplishments:

- During 1997 cruises continued at bimonthly intervals beginning in January and ending in November. In May additional experimental sites were added and more recently synoptic primary productivity experiments have been made at the same experimental sites.
- Dilution experiments and metabolic estimates confirm that zooplankton grazing is a significant source of mortality, perhaps the predominant one, for the entire phytoplankton community.
- The excess of primary production over grazing was most intense in the western Bay where blooms are most frequently reported while the balance was closest in the eastern Bay and along the Atlantic Transition zone where blooms are rare perimeter. Moreover, the greatest imbalance occurs during those months when blooms are reported to occur.
- The gut contents of only a few juvenile fish have been examined to date. These confirm utilization of holoplanktonic and meroplankton fauna by both pelagic anchovies and canopy dwelling killifish albeit on an opportunistic basis.
- A conceptual model was developed from data collected at four stations in the bay. The conceptual model compares bay-wide average copepod dynamics with those observed at Rankin Lake, a perturbed site characterized by extensive cyanobacteria blooms. The model suggests that the perturbed site is the location of a much enhanced planktonic biomass but, perhaps more importantly, that a shift in energy flow has occurred relative to the bay-wide average. We have begun to suspect that qualitative aspects of the food environment are important in driving egg production and perhaps other aspects of secondary production in Florida Bay.

FY98: In FY98 bimonthly sampling will be continued along with additional western Bay, SW Florida Shelf sampling provided by the Lee et al. physical oceanographic cruises. Data will be put in the appropriate form and provided to the pelagic ecosystem modeling effort. Collaboration with FDEP will continue in regard to synoptic primary production estimation.

The principal deliverable of this project in FY98 will be a first order estimation of the percent of phytoplankton production consumed by zooplankton (Q3). This is required to parameterize the model described below.

Development of Models to Describe Ecosystem Interactions in Florida Bay , Jackson and Burd

Objective: First, to analyze existing data for representative basins to estimate the nutrient and carbon flows between different planktonic trophic groups and their interactions with the benthos; second, to develop models to explore the dynamics of interactions among the different planktonic groups.

Accomplishments: This project was initiated in late summer 1997. Currently, two models of the plankton system are being developed. The first project is to develop estimates of all the important material flows by using an inverse technique; the second project is to use the flow estimates to construct and test dynamic models of the planktonic system. In all of this, there will be a constant examination of the extent of interactions between benthic and planktonic systems.

A preliminary description of carbon flows in Duck Key basin using different data available has been developed. Investigators hope to add ammonia and nitrate supply from the sediments, C and N supply from seagrass production, and C and N losses to benthic suspension feeders. They will also add an extra trophic level to account for fish interactions with the plankton. They will investigate if it is useful to divide phytoplankton into two classes to differentiate between the smaller forms, such as *Synechococcus* , from the larger diatoms and dinoflagellates. If there is sufficient information, losses and gains associated with advection from separate basins will be addressed.

Fasham et al. (1990) have developed a simple model of planktonic systems. Parts of the model, such as those describing the effect of mixed layer changes, are inappropriate for shallow Florida Bay and will be omitted from out model. Several new compartments

need to be added for describing a basin in Florida Bay, where the small alga *Synechococcus* and associated micro zooplankton dominate in some areas and larger diatoms, dinoflagellates and zooplankton dominate in others. Adding a second phytoplankton species and a second zooplankton species will allow investigators to describe the interactions between two different food webs; adding a fish compartment will allow us to study the role of planktivorous fish. In addition, mortality terms corresponding to benthic filter feeding, detrital and DOM release rates typical of seagrass systems, and terms describing lateral exchange will be added.

FY98: These modeling studies should synthesize the results of many of the field studies being made in the Florida Bay. At the least, this work should show where there are crucial gaps in our understanding that need to be studied and should help us to understand the nature of size-structured systems in coastal environments. Hopefully, these models will provide tools which can be used for management purposes. Among the predictions which may be possible will be estimates of light irradiances in the sea grass beds as functions of anthropogenic inputs and insights into factors affecting fish production.

The principal FY98 deliverable will be initial model formulation and encoding including preliminary parameter estimation (Q4).

Pools and Fluxes of Nutrients in Florida Bay Sediments , Szmant et al.

Objective: Florida Bay has experienced extensive algal blooms since 1992. One contributing factor may nutrient loading from decaying sea grass and resuspension of destabilized barren sediment patches. The objective of this project is to determine the relationship between present-day sediment nutrients and algal blooms by mapping the distribution of sediment nutrient concentrations (pore water ammonium, nitrate, phosphate, total N, total P, silicate, and bulk sediment N and P), and nutrient efflux rates as measured by core incubations.

Accomplishments:

- P is expected to be the nutrient most limiting to phytoplankton in the carbonate dominated Florida Bay system. Preliminary results indicate that sediments are low in bulk P content(1-4 ug-at P/gm of sediment) towards the NE and central parts of the Bay and increase to >6 ug-at P/gm towards the west supporting the Gulf of Mexico as the source of P.
- Bulk N content is more variable but also lower to the NE and increases to the SW and S (towards Florida Keys). Porewater nutrient concentrations and flux rates do not correlate well with bulk nutrient content. They indicate an area of elevated efflux of phosphate, nitrate and silicate in the western part of the Bay, south of Flamingo. This is historically a more productive area and may indicate an area of groundwater seepage (see Burnett et al. below).

FY98: In FY98 field sampling will be continued to provide at least first order estimates of the contribution to water column nutrients arising from sediment resuspension events.

The principal FY98 deliverable is data on the flux of nutrients from Bay sediments into the water column as required by the ACoE/WES Water Quality Model (Q3).

The Role of Groundwater Nutrient Fluxes in the Nutrient Budget of Florida Bay , Burnett et al.

Objective: We have hypothesized that groundwater may be a significant source of nutrients to the Florida Bay ecosystem. Specifically, we are testing the hypotheses that phosphate-rich groundwater may be moving through an ancient coarse-grained siliciclastic river bed that makes its way from central Florida to underneath north central and northwest Florida Bay; and that sewage from septic tanks in the Florida Keys may travel through groundwater into Florida Bay. The siliciclastic channel appears to be a plausible source of phosphate (the primary limiting nutrient in most of Florida Bay and other South Florida coastal waters) because it will not chemically scavenge phosphate from groundwater the way limestone does. Furthermore, it runs through phosphate rich deposits in central Florida and contains phosphorite granules.

Accomplishments:

- Concentrations of excess 4He and 3He respectively in Florida Bay correlate well indicating that much of the groundwater was formed relatively recently (since the 1950s and 1960s).
- The spatial pattern of the highest concentration of these groundwater tracers matches very well with the distribution of the siliciclastic deposits underneath Florida Bay.
- Both correlate with chlorophyll concentrations in Florida Bay consistent with the hypothesis that phosphate-rich groundwater traveling through the siliciclastic deposits is a major source of nutrients contributing to algal bloom generation at least during winter when there is reduced hydrostatic pressure and less rainfall flushing.

FY98: Additional data will be collected and similarly analyzed. It will also be compared to groundwater pressure head data (USGS) being collected upstream of sampling sites. It will be critical to obtain data over one or more seasons and particularly over a range of rainfall conditions. Unfortunately the project to date has sampled a particularly rainy period.

The principal FY98 deliverable is data on the flux of nutrients from groundwater into the water column as required by the ACoE/WES Water Quality Model (Q3).

Atmospheric Deposition of Nitrogen and Phosphorus to the South Florida Bay Ecosystems, Whung et al.

Objective: Measurements of nutrient input from wet deposition processes are limited in South Florida, with only one station located at the Everglades National Park. The dry deposition rate is largely unknown. Dry deposition of nitrogen can be in the form of both gas-phase (HNO_3), and particulate form (NO_3^- and NH_4^+) in both small and coarse aerosols. The objective of this project is to assess the relative importance of the atmosphere as a source of nutrients to Florida Bay. This was identified by the Oversight Panel of the Interagency Florida Bay Science Program as a major unknown. This study is intended to yield:

- The weekly, seasonal and annual deposition rates of phosphorous and nitrogen to the Florida Bay region.
- Potential relationships between the distribution of atmospheric nitrogen concentrations and that in the water columns in the central and western bay.
- A preliminary assessment of the episodic nature of phosphorous and nitrogen dry deposition in the Florida Bay region.

Accomplishments: One monitoring station (Keys Marine Laboratory) is up and running.

FY98: When the setup at the Keys Marine Lab is debugged, this project will collaborate with FIO and USF to install a second air monitoring systems at the NW corner of the bay on the

C-MAN/SEAKEYS platform. This has already been constructed and is in the process of being instrumented (see Ogden et al. above).

The principal FY98 deliverable is data on the flux of nutrients from the atmosphere into the Bay water column as required by the ACoE/WES Water Quality Model (Q4).

The Role of Suspended Calcium Carbonate in the Phosphorus Cycle in Florida Bay , Miller and Zhang

Objective: Biogenic calcium carbonates (calcite and aragonite) are the major components both in the suspended material and in the sediments in Florida Bay, and are likely to be the important chemical mechanism of phosphate removal. There have been few systematic measurements of the carbonate system and its relationship to nutrient availability. The objective of this project is to combining field measurements with critical laboratory studies to understand this complex relationship.

Accomplishments:

- A series of cruises have been completed during which the carbonate system parameters (including total alkalinity (TA), pH, total carbon dioxide (TCO_2), and partial pressure of carbon dioxide (pCO_2), as well as salinity and nutrients were measured. A flowthru multi-parameter nutrient system was developed and used on several of these cruises to continuously monitor nutrient concentrations.
- TThe results of phosphate adsorption as a function of time show that the adsorption of phosphate on calcite and aragonite is a fast process. Aragonite has higher adsorptive capacity compared to that of calcite when the same amount of solid is used. Aragonite offers more active surface and more active adsorptive sites compared to calcite.
- TThe desorption of phosphate from aragonite surface is also a fast process. The results show that calcium carbonate can act as a fast scavenger for phosphate. The resuspended carbonate sediment may act as a source of phosphate to the water column.
- FFrom pH 8.7 to pH 7.4, the adsorption of phosphate decreases. The reasons for the apparent pH dependence of phosphate adsorption onto carbonate surfaces is not clearly understood at present, but it may involve an undiscerned change of the phosphate species and or the interaction of the phosphate species with major ions such as Ca and Mg.

FY98: In FY98 field data will continue to be collected in collaboration with the alternate bimonthly cruises of Dagg et al. (see above) and Lee et al. (see above). In the laboratory the adsorption of phosphate onto carbonate surfaces as a function of phosphate concentration will be studied. Combined with the kinetic data and other experimental results, the interaction mechanism of phosphate with carbonate will be elucidated.

Future laboratory investigations of phosphate interaction with calcium carbonate will include studies to quantify the effects of external factors such as temperature and salinity on the adsorption process. The effects of natural organic matter and iron oxide on the surface properties will also be investigated using suspended sediment collected during future research cruises.

The principal FY98 deliverable is a quantitative initial assessment of the relationship between dissolved and particulate water column calcium carbonate and the availability of phosphorous for plant productivity as required by the ACoE/WES Water Quality Model (Q3).

The Sediment Record as a Monitor of Natural and Anthropogenic Changes in the Lower Everglades/Florida Bay Ecosystem , Nelsen et al.

Objective: The objective of this project is to understand the relative roles and importance of daily sedimentation/transport versus impacts of event-driven episodes of sedimentation on this ecosystem by reconstructing the history (the last 100+ years) of the critical interface between lower-peninsula Florida/Everglades and the Florida Bay. This information is essential to set restoration objectives.

Accomplishments:

- To date, analysis of cores indicate recovery of interpretable stratigraphic sequences with time horizons that extend back at least 100 years. Relative to anthropogenic activities, a geochemically supported baseline for natural Hg levels in sediments shows that Hg concentrations were 5X natural levels in sediments deposited at the south of Shark River Slough since 1950. A similar trend was observed for lead.
- As a proxy for paleo-water-column conditions, preliminary carbon and oxygen isotopic analyzes of ostracod valves reveals changes associated with inputs of freshwater at certain intervals in the core while the overall ostracod community structure and morphologic variability within particular species are also strongly salinity related.
- Progress in palynology includes both the creation of the first tropical-pollen reference set for the Everglades, the first WWW site for such, and critical detailed pollen facies maps for current surface environments that will allow meaningful interpretation of observed paleoecological shifts.

FY98: This project has been tasked with providing the ACOE Restudy estimates of the natural range of salinity variation within the Bay and adjacent upstream embayments over the past 100 years. The information is essential to evaluate restoration alternatives. A paleoecology workshop recently sponsored by the interagency PMC has yielded specific recommendations on how this effort and the USGS one can most fruitfully be integrated in the future. In FY99 and beyond we anticipate that these investigators will be funded primarily through the USGS.

The principal FY98 deliverable from this project will be a summary report to the Florida Bay PMC as to the Bay salinity history which the PMC is charged with providing the ACoE Restudy (Q4).

Only one study of **anthropogenic pollution** was funded by the NOAA SFERPM program in FY97. It was continued because initial results suggest it is potentially relevant to pelagic ecosystem and upper trophic level ecosystem effects. As previously agreed with NMFS (see FY97 SFERPM Implementation Plan) it will be supported by NMFS and the EPA in FY98 and beyond.

Monitoring of Pesticides and Chemical Contaminants, Scott et al.

Objective: Endosulfan is used heavily on vegetable crops in South Florida and has a high acute toxicity potential. The objective of this project was to determine if it is entering Florida Bay or likely to enter it at ecologically significant concentrations.

Accomplishments: Results indicate that during 1993-95 the presence of endosulfan and other pesticides was detected in agricultural areas and surface waters from Florida Bay. Approximately, 5.6% of the bay sites sampled had endosulfan concentrations which exceeded the marine water quality criteria (0.0085 ug/l) while 3.3% of the sites sampled had concentrations which exceeded the freshwater water quality criteria (0.056 ug/l) for endosulfan. Data for the spatial distributions of endosulfan II suggest that the source of the endosulfan is from agricultural runoff. Results of chronic toxicity potential tests of study-area sediments indicated significant ($p < 0.05$) impact on the marine benthic copepod *Amphiascus tenuiremis*.

FY98: Relative to non-point source pollution, the EPA and state environmental agencies have the overall lead and have begun a sampling program in conjunction with this NOAA project. SFERPM funding for this exploratory project ended in FY97.

The principal FY98 deliverable from this project will be a final report estimating the potential risk to the Florida Bay ecosystem of endosulfans introduced from agricultural runoff as the result of changes in water management practices (Q3).

D. Applications From FY97 Funded Projects

Management Applications. The long-term goal of research, such as the work currently sponsored for south Florida, is that the products of these research efforts ultimately manifest themselves in tangible benefits to the environment and economy. To do so, it must be applicable to the managerial decision-making process at all levels and the projects funded herein are designed to fulfill such a role either directly or indirectly. Relative to the latter, the products of many scientific projects will find their applicability over a longer time horizon by providing environmental data as ground truth to modeling efforts. On a shorter time horizon, some benefits have become available for such decision making as the research progresses as in the following examples:

- The Advanced Regional Prediction System (ARPS) has been extended to actually predict the amount and the distribution of rainfall with realistic looking precipitation patterns that have been replicated along the sea breeze front. The SFWMD is discussing the use of this model to predict microclimate variations with alternate water management scenarios given their impact upon vegetation patterns. 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 and stability and to predict evaporation.
- In the retrospective analysis of sediment cores to date, there has been a clear signal of when anthropogenic inputs (mercury, lead) originating on the Peninsula reached the Bay and their change with time as well as variations in water flow regime. The information is being used in the ACOE Restudy to set restoration objectives that are being used to evaluate water management scenarios.
- Pollution-related results indicate that the insecticide endosulfan (high acute toxicity potential, endocrine disrupter), used on south Florida crops, was detected in some Bay sites in excess of water quality criteria with spatial data suggesting that the source is from agricultural runoff. In addition, current results for mercury (Hg) indicate that concentrations in bay anchovies, from eastern Florida Bay are of the same magnitude as in the same species from Lavaca Bay, Texas, a Superfund site. Based on these preliminary results, the ACOE is reassessing water management scenarios for the Dade

Agricultural area and the Frog Pond in terms of their affect upon pollutant introduction. Prior to this water quantity and timing were being considered.

Partnerships Funded or Built Through this Program. Partnerships benefit programs in today's research climate by increasing the resource pool in terms of expertise and in leveraging funding. Partnerships encouraged by the NOAA South Florida Ecosystem Restoration Prediction and Modeling include, but are not limited to, the following:

- Mutual model simulation test periods for Florida Bay Boundary conditions between our investigators and the ACoE/WES.
- Leveraging of the regional atmospheric modeling effort and boundary layer research involved in this project to receive partial (3 months salary/year) funding for a 5-year, $1 million/year research proposal entitled "Remote Sensing and Prediction of the Coastal Marine Boundary Layer" from the Office of Naval Research (ONR).
- Application of the Doppler radar wind/reflectivity retrieval techniques currently being developed at CAPS to assimilate full volumetric scans from NEXRAD radar sites (Melbourne, Miami, Key West and Tampa) into ARPS to obtain the highest-resolution, state-of-the-art regional atmospheric analyzes and forecasts possible (a NWS-OAR partnership).

- Working closely with the South Florida Water Management District (SFWMD), a proposal has been drafted to use ARPS-predicted rainfall and ET patterns to drive both the Natural System Model (NSM) and the South Florida Water Management Model (SFWMM).
- In cooperation with the National Biological Service scientists stationed at Florida International University, a "concept letter" on the development of a model to assess ecosystem response to a tropical cyclone landfall has been developed.
- In cooperation with ONR and the NWRP, AOML scientists are developing a collaborative effort on the effect of hurricanes on landfall including Florida Bay and adjacent coastal waters.
- With the assistance of students from Florida International University and MAST Academy, the program is setting up an archival of images of the wind fields on the AOML World Wide Web (WWW) site for access by other Florida Bay researchers.
- The NOAA sediment retrospective analysis program has pooled expertise between NOAA and four universities as well as a cooperative effort with similar USGS efforts. In an agreement with the USGS (Dr. R. Halley) NOAA has investigated the lower Everglades/Florida Bay interface while the USGS has focused on Florida Bay proper.
- Our Florida Bay circulation study is a close collaboration between RSMAS, AOML, and Harbor Branch Oceanographic Institution in the field with the ACoE/WES and NOS modeling activities.

FY98 OVERALL PLAN

A. Background

Under the RFP issued by SFERPM in FY97, all projects were awarded two-year contracts subject to the availability of FY98 funds. Two of those projects, however, were scheduled to be continued with NMFS funding in FY98 and are, therefore, no longer part of the FY98 SFERPM program. In FY98 SFERPM is essentially level funded. While COP is by far the major contributor, other NOAA line organizations as well as the National Park Service are making significant contributions (Figure 1).

As in FY97, research, monitoring, and modeling projects are supported. Within NOAA, three line organizations (OAR/AOML and ARL, NMFS/SFSC. and NOS) are major participants in the SFERPM program, but the majority of SFERPM COP funding goes to academic university participants (Figure 2). In addition to these science activities, Florida Sea Grant will continue to receive level funding in FY98 for conducting an Outreach/Education program on behalf of the entire Interagency Science Program in Florida Bay. A complete list of the FY98 awards is given in Appendix II. Individual project activities were earlier.

B. Management and Operations

NOAA/OAR/AOML will continue to be responsible for program management, data management/administration, and small boat operations. As in years past, explicit funding will be required for program management. Given the expanded scope of the effort, the position of Executive Director has been established to give the Program Management Committee Chair the requisite staff assistance. Program management funding also contributes to data management (where we have taken the lead on behalf of the overall Interagency Science Program in Florida Bay), interagency meeting/workshop support, and secretarial support services. Program management funds are also being used to equip, maintain and operate a dedicated SFERPM trailerable research vessel as previously mentioned.

OUTLOOK (FUTURE YEARS)

A. FY99

Environmental Research & Modeling. It is generally agreed that the problems in the coastal ecosystem (particularly in Florida Bay) are exacerbated during unusually dry weather. With drought, the first priority for water managers has been to sustain the flows required for agriculture and the water demands of the human population. As such, hypersalinity (possibly the preconditions for seagrass die off) results. The last two years, however, have experienced much greater than average rainfall and now with El Nino well upon us, this year is

likely to be the wettest of the century! Because of this anomalous situation, our plan for FY99 is to fund **essentially the** same projects without a formal RFP process (assuming satisfactory progress as indicated by **TAP review** of mandated submissions to the SFERPM program office). This extension will, we hope, afford **the opportunity** of sampling at least a normal, if not a dry, rainfall period. The same strategy is being **undertaken** by our partners in the Interagency Florida Bay Science Program subject to availability of funds **within their agencies** and is consistent with the long-range climate forecasts currently available.

Risk Assessment/Socioeconomic Analysis. Our FY97 Plan was developed with the expectation of a $1.9M **request for SFERPM** in the Administration's FY99 budget. It called for initiating a comparatively small Risk **Assessment** and Socioeconomic Analysis. This was not done last year for reasons discussed above. As noted **therein, future** involvement in the latter area was dependent upon the outcome of a Socioeconomic SubGroup **Planning Workshop** being convened under the auspices of the South Florida Ecosystem Task Force Working **Group** and the Governor's Commission. Our sense is that this topic has become moot. At the direction of the **Governors** Commission the Army Corps of Engineers has already initiated a three year $5M regional **socioeconomic** predictive analysis and the subject is moreover one of the principal foci of the present NOS **South Florida** Integrated Coastal Ecosystem Monitoring initiative. Since other funding sources appear to be sufficiently addressing socioeconomic concerns, we have no plans to do so with a SFERPM RFP.

Community Outreach/Education . FY99 will be a pivotal year for this effort and the onus will be on Florida Sea Grant to unequivocally establish the utility of this activity to our partners in the interagency program beyond assistance in conducting the Annual Conference in which they have been invaluable. In subsequent years (see below) SFERPM will no longer have sufficient resources to continue this project at the same level and if that is required the additional funds will have to come from collaborating. federal and state agencies.

B. FY2000 and Beyond: Collaborative Planning and Fiscal Leveraging

COP initiated SFERPM prior to the NOAA South Florida Ecosystem Initiative request using substantial base funds. These funds are scheduled for other uses in FY2000 and beyond. Accordingly, SFERPM must consider how best to accommodate a substantial reduction in award able funds. Our plan includes termination of project areas scheduled for completion as well the transition of all or part of some project areas from a research to an operational mode or to more appropriate funding sources. **A dialogue between SFERPM and both NOS and NMFS (as well as with other federal agencies such as USGS) has already been initiated in this regard.** This change can be accommodated within the South Florida Ecosystem Initiative budget requests for Ecosystem Monitoring (NOS) and Living Marine Resources (NMFS) respectively. In principal projects with substantial ecosystem monitoring components would be either transferred in their entirety to NOS or the monitoring aspects of the activities underwritten by NOS and projects directed specifically at commercial or recreational fisheries would be transferred to NMFS. In addition, we are already discussing with our interagency PMC partners, collectively, the desirability of other agencies contributing to the PMC's Community Education & Outreach effort when we are no longer able to fund it entirely with SFERPM funds. These plans are depicted in the accompanying GANTT chart (Figure 3) that depicts funding year cycles rather than actual project durations (at present offset by a half year or more).

In spring of FY99, we plan a fully competitive RFP process to again make two-year awards (FY2000 and FY2001) for research and modeling projects. This will permit decisions as to individual proposals prior to FY2000 and will put us in closer synchrony with the fiscal year cycle. Evolution in principal investigators and their attendant perspectives is essential if SFERPM is to evolve and to remain responsive to the needs of SFER and the interagency program. Based on our experience in SABRE, a renewed competitive announcement will result in the necessary evolution. The RFP would likely address the same general project areas along with specifically soliciting "Additional Nutrient Studies - Water Quality Model Support" being added (see Figure 3). A Water Quality model has become a high priority for the interagency Florida Bay PMC and its oversight panel and one is currently being developed under its aegis by WES of the Army Corps of Engineers (ACoE). The Dept of Defense will not, however, be able to support the process research currently deemed relevant and is looking to NOAA and the EPA to provide those critical data. No further detail about the FY2000/FY2001 RFP can be provided at this juncture. As in previous years we will endeavor to be as responsive as possible to the guidance provided the interagency program by its Oversight Panel after each Annual Florida Bay Science

Conference. The next conference is scheduled for May 12-14, 1998 in Miami.

FY2001 ($1.3M) would be similar to FY2000 ($1.3M) and would represent the final year of full COP/SFER funding. In FY2002 funds would be reduced for the remaining activities to 50% ($650K) of the FY96-2001 level and in FY2003 to 25% ($325K). COP, but not NOAA, involvement is seen as terminating in FY2004 ($0). By then activities will be predominately operational (or monitoring) and the role of basic research much reduced. Monitoring the success of restoration is, however, seen as an essential NOAA task that may extend for considerably longer than the COP/SFERPM program as Restoration efforts progress upstream.

C. Projected Resource Issues

We anticipate that OAR will continue to provide 60 days per fiscal year of leased ship time for the RV/CALANUS or its replacement vessel as an award to CIMAS. Subject to funding a letter of commitment to this effect was provided earlier this year. The replacement vessel is to come on line in the fall of 1999. Continuing this chartered ship time, along with the small high-speed catamaran purchased by SFERPM but operated through the RSMAS Marine Department, will cover all anticipated ship time requirements through FY2000. When the NEXRAD rainfall project becomes operational, it will no longer require aircraft time. Until that point, it will be provided as part of the base allotment provided to AOML's Hurricane Research Division.

APPENDIX D

Florida Bay Science Oversight Panel 1998 Report

FLORIDA BAY SCIENCE OVERSIGHT PANEL 1998 REPORT TO THE PMC

Donald F. Boesch, Chair
University of Maryland Center for Environmental Science
Cambridge, Maryland

William C. Boicourt
Horn Point Laboratory
University of Maryland Center for Environmental Science
Cambridge, Maryland

Kenneth L. Heck, Jr.
Dauphin Island Sea Laboratory
Dauphin Island, Alabama

Steven C. McCutcheon
Hydrologic and Environmental Engineering
Athens, Georgia

John E. Hobbie
Marine Biological Laboratory
Woods Hole, Massachusetts

John D. Milliman
Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, Virginia

INTRODUCTION

The Florida Bay Science Oversight Panel (FBSOP) is an independent peer-review group, charged with providing regular, broad, technical, and management review of the Interagency Florida Bay Science Program. It reviews agency plans, Program Management Committee (PMC) strategies for program development, scientific quality of research, modeling and monitoring, and research results (Armentano et al., 1994; 1996). The Panel consists of senior scientists with significant experience in major estuarine restoration programs but without involvement in Florida Bay projects.

This is a period of turnover of membership of the FBSOP. Three original members, Drs. James Cloern, Ronald Perkins, and Susan Williams, rotated off the Panel after nearly three years of very effective service. They have been replaced by Drs. Charles Yentsch of the Bigelow Laboratory for Oceanography, John Milliman of the Virginia Institute of Marine Science, and Kenneth Heck of the Dauphin Island Sea Lab, respectively. In addition, the charter-Chair of the Panel, Dr. Donald Boesch, announced his intent to step down from the Panel after the 1998 Conference and review. Dr. John Hobbie of the Marine Biological Laboratory has been invited by the PMC to succeed Dr. Boesch as Chair and participated in the 1998 review in order to ensure continuity. Dr. Neal Armstrong, a regular member of the Panel, could not participate in the 1998 Conference and review and was replaced by Dr. William Boicourt as an alternate. Unfortunately, Drs. Deegan and Yentsch also were unable to attend because of late developing requirements.

The FBSOP submits a more-or-less Annual Report that assesses progress and directions in the Program based on its participation in the periodic Florida Bay Science Conference. Previous Annual Reports were produced in November 1995 (Boesch et al., 1995) and February 1997 (Boesch et al., 1997). The authors of this third report are those panelists and alternates who were in attendance at the Science Conference. However, Drs. Armstrong, Deegan, and Yentsch also reviewed a draft of the report and contributed comments.

The third Florida Bay Science Conference was held on May 12-14, 1998, in Miami, Florida. There were 33 oral presentations made at the Conference, many of which summarized results from several related projects (Anonymous, 1998). These were organized around the five central questions identified in the Strategic Plan for the Program (Armentano et al., 1996), with additional presentations on upstream assessments and paleoecology studies relevant to several of the central questions. A member of the PMC introduced each Central Question, and the groups of presentations were followed by questions from the FBSOP and audience and general discussion among the presenters. The oral presentations are cited here by reference to the last name of the first author. A large number of posters also were displayed during the Conference.

The FBSOP also arranged for *ad hoc* committees of expert reviewers in specialized subjects to participate in three workshops where critical science issues were addressed during 1997 and 1998. For continuity, members of the FBSOP chaired each of these committees. Reports from the committees were submitted to the PMC on the three workshops:

- the higher trophic level initiative, November 4-5, 1997 (Deegan et al., 1998);
- seagrass modeling (Williams et al., 1998); and
- paleoecology and ecosystem history (Boesch et al., 1998).

In addition, the Model Evaluation Group, a standing advisory committee operating under the FBSOP auspices met just prior to the Science Conference on May 11, 1998 and will shortly issue a report.

GENERAL OBSERVATIONS AND RECOMMENDATIONS

1. **Synthesis Reports.** The Interagency Florida Bay Science Program has reached a level of duration and accomplishment that Synthesis Reports would be very useful in forging scientific consensus, guiding future research and monitoring, and informing environmental and resource managers, policy makers and the general public. Such Synthesis Reports should: address each of the Central Questions (other overarching or highly specific reports also may be warranted); extensively use Program results; present the current understanding and uncertainties; and be cogent and easily readable. They should be completed in approximately a one-year time frame. They should be regarded as interim, rather than final, reports except in those instances in which major study elements are being concluded. Electronic communications media (websites, CD ROMs, etc.) should be used to supplement printed reports.
2. **Research Teams.** The FBSOP has previously stressed the importance of Research Teams of investigators in program integration and direction, ensuring rigor in interpretation of results, and consensus building. Of particular importance is identifying points of agreement and disagreement and future measurements or analyses needed to resolve disagreements or address emerging questions. While some Research Teams have been formed and are active (e.g. physical oceanography) or have been recently begun planning activities (seagrasses and higher trophic levels), other issues cry out for teams to work actively on interpretation and program direction (e.g. paleoecology, modeling and nutrient-algal bloom dynamics). Active communication within and among the Research Teams prior to workshops could make these workshops more goal-oriented and effective. Furthermore, the Research Teams should be taking the lead in development of Synthesis Reports and formulation of timetables, as discussed below.
3. **Timetable.** Although, the FBSOP has commended the Strategic Plan for the Interagency Florida Bay Science Program as well-focused and exemplary, the Plan lacks a timetable for implementation. Consequently, it is unclear how a set of "mature" program activities, such as those related to paleoecology and ecosystem history, are concluded and how open-ended other new activities, for example, the higher trophic level initiative should be. Of course, we realize that timetables depend on funding (push) and the timing of information needs (pull) as well as inherent limits to the pace of science. Nonetheless, we firmly believe that an overall program timetable, closely linked with the Central Questions, would be extremely helpful in making resource allocation decisions, inspiring focus, developing syntheses, and improving accountability to sponsoring agencies.
4. **Scientific Program Manager/Chief Scientist.** The FBSOP is pleased to learn that a full-time science program manager, as previously recommended by the FBSOP and specified in the Strategic

Plan, is expected to be appointed shortly. Attention to synthesis reports, the organization and coordination of Research Teams, and development of performance schedules and timetables, as recommended above, should be central priorities for the scientific program manager.

5. **FBSOP Accountability.** The FBSOP appreciates the written responses it received from the Program Management Committee following the Panel's February 1997 report. However, as indicated in that report, it would be helpful if a "score card" of accomplishments and responses to various FBSOP recommendations could be received just prior to the next Science Conference and Panel review. In addition, there is a need to improve on-going communication about Program progress and issues to the FBSOP so that the panelists feel less "in the dark" leading up the annual review. Toward that end, perhaps the Scientific Program Manager could produce informative, routine briefing documents that would also serve to improve communication among principal investigators and with the management community.
6. **Geographic Expansion.** The PMC has recently been given broader geographic responsibility for interagency science activities in the marine and coastal environments of South Florida beyond Florida Bay, including Biscayne Bay, the Florida Keys and reef tract, and southwestern Florida. While this makes some sense from a management perspective and reflects the successes of the Florida Bay PMC, the FBSOP is concerned that geographic expansion should not dilute resources or PMC attention to the critical issues related to Florida Bay. It is our opinion that the Interagency Florida Bay Science Program has considerable financial resources that are adequate to address the Central Questions in a timely fashion. However, this would not be the case if those resources, without amendment, had to be applied to the science needs for the reef tract and southeastern and southwestern regions as well. The PMC should develop an organizational strategy that allows it to address its geographically expanded mandate while preserving necessary attention on Florida Bay.

PERSPECTIVES FROM THE 1998 FLORIDA BAY SCIENCE CONFERENCE

The inclusion of a number of new members on the FBSOP challenges the Panel to get "up to speed" on the very extensive and complex research being undertaken in the Interagency Florida Bay Science Program and by others operating outside of the auspices of the program, but it also affords some fresh perspectives. New Panel members were struck with the extremely interesting interweaving issues and challenges to environmental science and by the outstanding opportunities afforded because of the resources available to the program and the need to influence management decisions. For these reasons, the Interagency Florida Bay Science Program is very important on regional, national and global scales. While admitting some naivete and yet incomplete understanding, the perspectives of new Panelists potentially reveal some truths which those close to the program, including veteran FBSOP members, may not see. In that regard, a strong impression is that despite the well-framed Central Questions, the Program lacks a tight matrix of organization under which the research can function and be interrelated and under which the various agency programs complement one another. The candid, overall impression is that the architecture of the Program is at least in part based on fitting in the science interests of individual agencies, their intramural scientists and extramural partners, rather than visualizing the final structure and identifying the components needed to build it.

Below the Panel provides evaluation and recommendations regarding investigations that address each of the five Central Questions of the Strategic Plan plus the Paleoecology Program. Some of the questions (e.g. Central Question #1) are treated in greater detail than others (e.g. Central Question # 5). This is a reflection of a number of factors, particularly the stage of development and integration of studies which address each question and the recent completion of relevant workshop reviews, rather than the relative level of importance assigned to the questions.

PALEOECOLOGY AND SEDIMENTOLOGY

Paleoecological and sedimentological studies were treated separately from the five Central Questions because they provide historical insights relevant to several of the questions. Progress in developing the paleoecology and ecosystem history of Florida Bay was recently reviewed at a January 1998 workshop and reported on by an *ad hoc* committee of the FBSOP (Boesch et al., 1998). Therefore, the Panel's comments here are abbreviated. Also, comments are made concerning the presentations given during the paleoecology and sedimentology sessions under discussions of several of the Central Questions, below.

Two particularly important issues emerged during these presentations and the ensuing discussions. First, the informal consensus which the *ad hoc* committee reported (Boesch et al., 1998) that the salinity of Florida Bay had increased during the last half of this century was challenged by Swart. Second, the important and provocative historical analysis of satellite imagery by Stumpf provided new perspectives on the time course and distribution of seagrass die off end algal blooms from 1985 to the present.

Swart and co-workers have used detail chronology and geochemical proxies in banded head corals to derive a rather careful analysis of environmental conditions in the lower Bay. The ability to relate these parameters and history to the inner Bay, however, rests on the extent to which they represent conditions throughout the Bay and can be related to proxy parameters in calcareous microfossils laid down in unconsolidated sediments as studied by Cronin and his USGS colleagues. This is an extremely difficult problem, however, because chronological controls in sediment cores are inherently less accurate than annual banding in a sessile coral, and the geochemical proxies used also seem less certain. Added to this probable mismatch, moreover, environmental histories in the inner and lower Bay may be quite different. Nevertheless, these types of disconnects must be addressed if there is to be any hope of constructing an environmental history of Florida Bay. Proxies must be constant or extreme care must be taken to relate dissimilar proxies.

Halley presented the results of an informal survey conducted among Florida Bay researchers following the January 1998 Paleoecology Workshop. The investigators were asked to provide estimates of salinity conditions in Florida Bay over the last century. This is a very important step toward answering Central Question 1 and defining ecosystem restoration goals, but, in itself, it does not provide sufficient synthesis. Rather, the Paleoecology Research Team should as a matter of priority build on this to produce a consensus reconstruction of salinity trends and variability in Florida Bay, particularly as they may be related to climatic variability and water management practices.

Stumpf's synthesis and interpretation of AVHHR imagery provides useful insight into the sediment dynamics of Florida Bay as well as into the dynamics of algal blooms and seagrass die-off end recovery (discussed below). Furthermore, Prager's coupling of observations and models of sediment resuspension shows the importance of biogenic binding of sediments. There are opportunities to interrelate Prager's model of critical wave height-wind velocity and Stumpf's satellite observations to provide a larger scale and historical perspective.

Finally, Orem presented results of studies of down-core geochemistry as it relates to nutrient and seagrass history. While these results are intriguing, we caution against overinterpretation of trends, particularly when the results are based on a limited number of cores that often show different patterns.

CENTRAL QUESTION #1

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

This question, as with the other Central Questions, is well posed and should serve as a strong focus for the investigations. Although the physical modelers and observationalists seem the most together of any of the research teams, the driving question does not appear uniformly foremost in the minds of the all participants. Variation in the degree of focus is perhaps to be expected at this stage of the research, yet the time for specific recommendations to support management actions seems to be drawing nigh. Regardless of this timing, the duration of research support must be considered. Specific time lines and goals would prove helpful for both research and management.

Evidence for decadal shifts in salinity associated with runoff and evaporation was presented in the paleoecology studies discussed above. Swart's conclusion that there was no increase in salinity during the last half of this century is based on extending observations made in corals in the Atlantic Transition Zone to the Central and Eastern Bay based on autocorrelations among contemporary salinity records. However, the correlative extension of this result northward does not preclude significant salinity shifts in the regions closer to the coast most likely to be affected by water management practices. The correlations provided by Swart are simply not sufficiently strong. Furthermore, the inshore signals can be highly correlated with the offshore signal, but have markedly higher amplitude. The FIU/SERP water quality data set is attractive, both in its record length and its spatial coverage (which includes the central portion of Florida Bay, a region not well covered in other salinity surveys). But, this data set does not seem to be extensively used by many investigators in their attempts to address Question No. 1. Although interpretive maps and other products based on these data are available on a website and in reports (e.g. Jones et al., 1998) the full database does not appear to be accessible. Without such wide accessibility to these essential data, the ability to achieve a successful resolution of Question No. 1 is severely compromised.

The University of Miami (Lee) observations seem well suited for answering the majority of boundary condition issues, including the nearshore structure of buoyancy-driven flows and the larger-scale throughflow if the region. The current meter array covers the entering flow from the northwest boundary, which is an important region from the standpoint of nutrient inputs and pathways. Boundary conditions are also well sampled during the serial surveys along the Keys and through the array. The Lagrangian measurements are extremely valuable here, but unfortunately they are few. Some specific effort should be made in conjunction with the Eulerian measurements to gauge the representativeness of these temporally and spatially sparse measures. Moreover, as previously noted by the MEG, some effort should be undertaken to examine the vertical flow structure over the central portion of the Bay, even to the point where a high-resolution ADCP be placed close to the existing sediment surface in the deeper portions of an interior basin.

The preliminary nutrient budget suggests that a specific effort should be undertaken, perhaps with additional current meter arrays, to address the nutrient input (and export) across the entire western boundary of the model domain, particularly across the banks and channels separating the Gulf Transition Zone and Western Florida Bay. There is an obvious difficulty here in dealing with small differences between large numbers because the western boundary is deep compared to the shoals of Florida Bay. A set of modeling scenarios should be reserved for addressing nutrient pathways and budgets.

For the salinity balance in this region freshwater flow and evaporation are of paramount importance. The hydrological model appears as the only source of freshwater flow estimates, and they are possibly off by a factor of two or more in some regions. Apparently, the importance of evaporation measurements (despite their difficulty) has been recognized and a program has been initiated. This program should include some attempt to measure spatial structure of evaporation; wind patterns and local circulation are expected to create such structure in this region.

Nutrient input estimates, including those from the atmosphere, seem notably sparse, given their importance to the Florida Bay program. Although nutrient concentrations may be related to flow out of the Everglades, the relationship is insufficiently tight to support the assumption that we can provide accurate estimates from flow measurements alone.

The NEXRAD rainfall measurements appear to be sufficiently accurate that the rainfall map products will prove a valuable tool in analyzing the salinity trends. However, it is not clear how these maps are being analyzed or incorporated into the trend detection efforts. Furthermore, it is not clear how the effects of storms are being addressed within this program.

Ground water and its role in freshwater flux to the Bay constitute a major problem that clearly has significance to salinity and circulation and issues regarding nutrient inputs: to what extent are dissolved constituents discharged to the ocean via ground water as opposed to surface and riverine discharge, and where? Brand et al. suggested that a major groundwater source enters the Bay near Cape Sable and offered as evidence high concentrations of both dissolved P and radon. In the two posters by some of the same investigators, however, the picture is somewhat less clear. Brand and Top show one set of data, whereas Burnett and Chanton show no obvious link between P and radon concentrations; in fact, some of the Florida State University cruises found no P anomalies near Cape Sable. Thus, while the authors in the Brand et al. oral presentation state one thing, separately their posters seem to show results that apparently are contradictory. Taken another step, this seeming lack of communication is seen in the USGS study that shows pore water concentrations within a number of bore holes (on land and in bay). Why were P and radon (as well as other stable and unstable isotopes) not run on waters from these bore holes? Were the USGS scientists communicating with the University of Miami and FSU scientists? This deficiency in ongoing communication among investigators was apparent in the criticisms by USGS scientists of Brand's restatement of the "river of sand" hypothesis and his lack of awareness of coring results, which showed that this subsurface deposit contains significant calcareous inclusions and is nonconductive.

The USGS wave measurement and modeling effort is very relevant and of high quality. The application of the HISWA model and its calibration to seagrass and bare bottom was innovative and successful. Given the importance of flow over mudbanks during high tide, a cooperative effort should be undertaken between USGS, RSMAS, and the WES modelers to address this question. Admittedly, flow over the banks will require some innovative adaptation of instrumentation such as ADVs and pressure sensors that can be placed in such a climate without altering the sediment structure. Obviously, flow through the channels should be monitored concurrently.

The physical regime inside of Florida Bay proper is not as clear as claimed. For instance, Lee shows impressive isopleths based on his cruises around the Bay—until one realizes that his isopleths for the lower Bay are based only on deep-water measurements to the west and east of the Bay; they were not based on measurements in the Bay itself! There is a need to integrate the underway hydrographic measurements made by the University of Miami shallow-draft vessel, the FIU water quality data, and the oceanographic observations made outside of the Bay proper.

CENTRAL QUESTION #2

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

The sources of nutrients to Florida Bay were the subject of a number of talks and posters during the May 1998 Science Conference. Although the nutrient source and effects issues remain contentious, more quantification is emerging and quantitative syntheses are being undertaken, offering hope that this Central Question can be answered in the near future.

Nutrient Budgets

While the collection of data on nutrients, chlorophyll, oxygen and salinity continues over Florida Bay and incoming waters, there is finally a first cut at an annual budget for the entire system (presented by Rudnik et al.). As is typical for budgets of this type, the dissolved organic forms of nitrogen and phosphorus dominate both in the marine and freshwater sources.

The panel recommends that attention be paid to the question of the use of the organically-bound nutrients by microbes including bloom algae. This is not an easy question, so definitive answers are not expected. Instead, the latest information could be brought into the information pool and perhaps some clever experiments carried out to produce a rough idea. After all, if the residence time of water in Florida Bay is three to four weeks, then there is enough time for the DON and DOP to become available to algae. Another and related question concerns the large quantities of nutrients that appear to enter the Florida Bay system from the northwest. To what degree do these nutrients traverse the Bay through the channels between the mudbanks?

The budget approach leads to the conclusion that P in the freshwater input is unimportant to Florida Bay, that the N input in freshwater is large enough to be important, and that the marine input is most important. This is true for inorganic and organic forms. However, budgets of this type can be misleading because ocean inputs usually consist of large quantities of water with low concentrations of nutrients. The question remains of the actual impact of this material on the biota.

Finally, the information presented shows that the impact of nutrients derived from sewage from houses and villages of Florida Keys is a very small fraction of the amount entering Florida Bay. This does not mean that sewage-nutrients are unimportant but that their impact is low and probably confined to the nearshore environment of the Keys.

Nutrient Geochemistry and Cycling

The studies of phosphorus-carbonate geochemistry continue to provide information on the fundamental chemistry. While these are valuable, concurrent studies should be begun using carbonate sediments from the natural system. In other words, both laboratory and field experiments should go forth.

Hitchcock et al.'s report on a study of western Florida Bay pointed out that concentrations of inorganic nutrients in water near the river mouths were only sufficient to sustain algal productivity for a few days. Obviously nutrient recycling dominates as the only source of nutrients for algae. Some rate measurements are needed of the recycling (isotopes?) and of controls.

Water Quality Model

The presentation by Dortch and Cerco outlined the numerical water quality model of Florida Bay. This model will be used "to assess nutrient mass balance and fate and to evaluate the impacts of a freshwater diversion management alternative." Because the model will include planktonic and benthic nutrient cycling components, it is intended to help scientists put bounds around the nutrient recycling implications of the primary productivity data. The modeling activities were the subject of a separate one-day review by the Model Evaluation Group, but we here offer a variety of perspectives from the multidisciplinary FBSOP based on presentations and discussions during the Science Conference

The RMA-10 hydrodynamic model should be completed and validated as soon as possible. Output from this hydrodynamic model will be used to drive the water quality model. The FBSOP and Model Evaluation Group has previously expressed some concerns about the feasibility of this linkage and we suggest that the functionality of this linkage be demonstrated as soon as possible. Moreover, it is evident that the biological and geochemical components of the water quality model have not been tested and accepted by Florida Bay researchers. The Panel recommends that the various components of the water quality model be explained to and discussed with geochemists and ecologists working in the Bay so that the latest understanding of the various processes involved can be appropriately incorporated.

The PMC and investigators have made some advances in the cooperative efforts needed to develop the water quality and seagrass models. As discussed above, the physical data collection team has come together in an exceptional way to advance a broad scientific understanding of the Bay that simultaneously supports the various modeling efforts. Aikman, Swain and other modelers are clearly committed to providing ocean and freshwater boundary conditions for the RMA-10 and water quality-seagrass models. As also previously mentioned, investigators of nutrient dynamic processes are advancing scientific understanding while beginning to develop budgets and define important boundary conditions needed for the water quality model. The seagrass team has been advancing insight into physiological and ecological processes of this important resource assisted by the October 1996 modeling workshop and the January 1998 seagrass modeling workshop. Nevertheless, the failure to involve the primary WQ-seagrass modelers in the January 1998 workshop was a missed opportunity to advance coordination of research and development.

Overall, a useful suite of hydrodynamic, salinity, water quality and seagrass models is under development. Budget shortfalls have left one gap that the USGS has filled with the FATHOM model. Dortch questioned whether a coarse, basin-scale salinity and nutrient mass balance is needed in the near-term and dropped this from the COE modeling plan. Yet, Johnson clearly shows the need for simpler model to guide development for Florida Bay and the Everglades. Jackson needs water quality exchange between basins for investigation of trophic-level cycling of carbon and nutrients. Rudnick's nutrient mass balances should be followed with a coarse-scale box simulation that could be based on the FATHOM compartments.

From a water quality modeling perspective, FATHOM is a new box model, the descretization of which has not been adequately coordinated with other model efforts. A new model requires extensive review before use in management decisions. FATHOM was peer-reviewed in 1995 and the scientific validity of the linear-reservoir theory called into question. The model ignores baroclinic, and for that matter, vital residual circulation.

Therefore, the PMC is faced with a decision: is a reliable coarse-scale box model needed to address a variety of ecological questions and, if so, should FATHOM be validated and further peer-reviewed or should the COE WQ modeling team be commissioned to use the (marginally acceptable) RMA-10 and the (more valid) CE-QUAL-ICM to provide information useful to biologists and other project scientists over the scales of interest? The October 96 modeling workshop favored a coarser-scale CE-QUAL-ICM application to conduct a 1998 nutrient budget. The MEG should be asked to specifically address this issue in an upcoming meeting. So as not to put Nuttle et al. at a disadvantage they should also provide a fuller interim report to members of the MEG.

Finally, the progress in coordination should be stimulated by more specific definition of restoration goals. The Restudy seems to demand specific time lines to generate an impact assessment before the final alternative is selected. Research teams have generated specific conceptual models and specific hypotheses to be tested. The role of the WQ-seagrass model and the RMA- 10 model in (1) testing these hypotheses, (2) providing critical flow and transport data to research groups, (3) testing other specific scientific hypotheses, and (4) simulating management scenarios, is only marginally defined. Both the PMC and the COE modelers (and USGS and FATHOM developers if this model is to be adopted for hypothesis testing and management simulation), should define specific modeling objectives, set definitive time lines, and formalize the process research support in a few critical cases like trophic level kinetics, sediment dynamics, and seagrass dynamics and effects.

The RMA-10 model seems to have reproduced tidal height and salinity reasonably. This necessary but not sufficient step in the calibration and verification process has been overdue. However, although tidal exchange is likely to constitute a major transport mechanism for salt, the residual circulation is of paramount importance to the ecosystem processes of concern. For this reason, we recommend more direct interaction with the physical oceanographic observational program to test the ability of the model to accurately simulate the residual circulation. These simulations should go beyond matching the seasonal mean flows. From the observations, a set of synoptic (5-10 day) scenarios should be developed that describe responses to the most common patterns of physical forcing.

Previously, the MEG and FBSOP recommended that the need (with respect to answering important management questions) for three-dimensional considerations in at least some components of the models be evaluated. Despite the shallowness of the majority of the Bay, two-layer, wind-driven circulation is expected, especially over the middle and western basins. Two-layer flow may also be especially important, as acknowledged, in the vicinity (20-30 km) of the buoyancy sources, especially the Shark River to the west. One of the most important products from the model is salt and nutrient transport. In a shallow region such as this where tidal oscillations and wind-driven flows dominate, substantial cumulative errors can result when the third dimension is ignored. Furthermore, many biological questions are likely to involve the vertical dimension. Biological transport is inherently Lagrangian; constructing particle trajectories from models requires high Eulerian accuracies. The need to include three-dimensional considerations in the models should be explicitly evaluated and these evaluations reported to the MEG and FBSOP.

The multiplicity of models should be regarded a strength of the program, and not a sign of unnecessary duplication. With modeling being so fundamental to the effort here, the series of complementary models is attractive. In that regard, could the NOS POM model be extended into Florida Bay with reduced coverage outside the region? It may serve this application, despite the sigma-coordinate pressure-gradient difficulties over steeper topography. Moreover, NOS is commended in its provision of offshore boundary conditions for the WES model.

The WES water-quality modeling group has demonstrated great skill in reproducing basic stocks and rate processes in the Chesapeake Bay. They have simulated primary production and seasonal oxygen depletion with remarkable accuracy. However, when this model has been extended to higher-order ecological processes such as submerged aquatic vegetation, the results have been less successful. This difficulty is by no means surprising, with the science of seagrass ecology not yet at the stage where it can quantitatively support such a model, particularly considering that very different ecological factors may govern the distribution and dynamics of seagrasses in Florida Bay. The water quality model should not be pushed overly hard in these directions, especially because these understandable failures cast unwarranted doubts about even the accurate simulations. If the Florida Bay water-quality model could accurately simulate even the nutrient and production stories, it would be a substantial asset to research and management.

Although it is understood that the modeling efforts are not ready for prime time, it would be more encouraging if there were evidence that the specific applications of these models were firmly in the minds of the modelers. We heard little discussion of specific scenarios that are to be run for either research or management. Five water-management alternatives were presented, but there was no mention from the modelers that these were going to be run, or when. Furthermore, we see these models as invaluable in the attempt to determine the causes underlying observed environmental changes, yet little has been said about model applications for this purpose.

As designed, the utility of the full WQ model for research and management of Florida Bay is limited to prescribed runs. Once calibration and verification have been completed, steps should be taken to reduce grid resolution and improve computational efficiency so that the model can be run conveniently on a fast workstation. Neither researchers nor managers should be assumed to have access to supercomputers for application of this model to Florida Bay. Given the importance of models for research and management of this complex ecosystem (especially to help in developing accurate water, salt, and nutrient fluxes), and given the state of the modeling art (and the speed of workstation computers), models with sufficient resolution, but not so detailed as to preclude running on a workstation, should ultimately be developed and be made available to the research and management communities.

CENTRAL QUESTION #3

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

Continued research has focused on the distribution of phytoplankton biomass, composition and production rates in space and time, nutrient limitation, and zooplankton grazing rates. Based on station-based measurements by Steidinger, Tomas, and Boyer, satellite imagery interpreted by Stumpf, and areal observations of water color by Flamm, planktonic algal blooms within the Bay proper have been centered in the northern part of Central Florida Bay, particularly around Rankin Basin. However, depending on wind conditions these blooms may spread outside of this epicenter. Steidinger has found that these blooms are dominated by resident cyanobacteria *(Synechococcus),* small diatoms *(Cyclotella coctawatcheeana),* dinoflagellates and picoplanktonic flagellates. Occasional blooms in Western Florida Bay tend to be diatoms associated with intrusions of advection of water from the Gulf Transition Zone.

Steidinger characterizes high microalgal biomass as chlorophyll *a* concentrations of >5 F g l^{-1} while nuisance blooms are > 20 F g l^{-1}. Biomass can reach can reach 40 F g l^{-1} . This can be contrasted with Stumpf's estimates from satellite imagery of chlorophyll *a* concentrations <1 F g l^{-1} outside of Florida Bay, in Eastern Florida Bay, and in the Bay prior to November 1988. Notably, Tomas et al. (presented by Bendis) reported that chlorophyll *a* levels and primary production rates have declined in Central Florida Bay since the end of 1995.

The nutrient limitation bioassays conducted by Tomas et al. and Brand, the Central Florida Bay region is a zone of transition between strong P-limitation to phytoplankton growth to the east and primarily N-limitation to the west. Thus, the sources and dynamics of both major nutrients in the region are important to understand. Richardson has been experimenting with batch cultures of dominant phytoplankters to deter-m-ire the importance of competition of nutrients among the taxa. Tomas et al. have also developed phytosynthesis-light curves and concluded that light in this shallow, but occasionally turbid system is always above the compensation intensity for phytoplankton.

Ortner summarized studies of zooplankton composition, production and grazing rates. While mesozooplankton may be trophically important as food for fish larvae, it is clear that mesozooplankton grazing is too low to influence or regulate phytoplankton production and algal blooms. Micozooplankton grazing may be more important, but it is not clear that the ongoing studies will provide an understanding of microzooplankton-phytoplankton dynamics at the appropriate time scale of those dynamics. Jackson presented results from his developing models of the flows of carbon and nutrients between different trophic groups and their interaction with the benthos. Early results show that these flows vary dramatically depending on assumptions about the role of bacteria and dissolved and particulate carbon pools—processes not being directly measured in the program While the zooplankton and planktonic modeling research is of high quality, a strong case for the importance of zooplankton as important factors in the onset, persistence and fate of algal blooms has not yet been made. The role of the microbial loop and benthic-pelagic exchanges loom as important factors that are not being addressed. In addition, these studies currently lack a clear tie to the WQ model and, thus, to the management issues it is intended to address.

Despite this growing information on bloom phenomena and limiting factors, process studies leading to a full understanding of the formation and persistence of algal blooms in Florida Bay remain lacking. Given the variety of candidate explanations for the blooms and seagrass die-offs in the north central region of Florida Bay, a special focus on the causes and interrelationships of the die-offs, blooms and pelagic and benthic grazing in that area is merited. Distinguishing among allochtonous and autochtonous and benthic and pelagic sources of nutrients is difficult in this shallow water column, but it appears that understanding nutrient dynamics and their relationship to phytoplankton production are central to the question of whether there has been an ecosystem shift, and, if so, what the causes may be.

CENTRAL QUESTION # 4

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

The results presented at the 1998 Science Conference echoed to a significant degree many of the results presented at the Seagrass Model Workshop, held in January 1998 (Williams et al., 1998). However, there were also important new results presented at the Science Conference, that addressed issues raised at the Workshop, as well as some progress reported in implementing Workshop recommendations. These new developments are the primary focus of the following discussion.

First, it is important to note that changes in seagrass distribution continue to take place, with some areas gaining and some losing seagrasses (Durako et al.; Eichinger et al.; Zieman et al.). In general turtlegrass *(Thalassia)* seems to be declining in the western Bay and on some mud banks, while shoalgrass *(Halodule)* is increasing in abundance. Continuing efforts will document further changes in seagrass abundance and species composition, and recently enhanced monitoring of PAR and other abiotic variables (a Workshop recommendation) will provide data for statistical modeling of relationships between physico-chemical variables and seagrass biomass and species composition.

Of special significance to Central Question 4 were the presentations by Cronin et al., Hood et al., Swart et al. and the poster by Brewster-Wingard et al. These contributions, while not part of the agenda for Central Question 4, described attempts to resolve the prior distribution of seagrasses in Florida Bay. Stumpf et al. used AVHRR satellite imagery to reconstruct patterns of seagrass distribution from July 1985 to the present. Their conclusion that significant and previously undetected large seagrass losses occurred west of Everglades National Park before the well documented changes within the Park boundaries, suggests that seagrass losses might be much greater than originally documented. Stumpf et al. also note seagrass recovery during the 1991-1997 period. While additional groundtruthing in the western grass beds is advisable, continued analysis should provide valuable information on the recent past and current status of the seagrass resources in the Bay. The contributions of Cronin et al., Hood et al., and Brewster-Wingard et al. rely on the use of seagrass-associated microfossils and mollusks to reconstruct conditions hundreds to thousands of years ago. This work is based on small

sample sizes, but holds promise for indicating past patterns in seagrass presence and absence. Selected results suggest that seagrasses have fluctuated substantially at various times in the past, but appear to have generally increased in abundance during the 1900s. Concurrent salinity changes may be involved with prior seagrass changes. Whatever the cause, these paleoecological studies are important for placing the recent changes in seagrass abundance into the historical context of cyclic patterns of increase and decrease.

There are very important studies that remain to be done of the single and combined effects of salinity and temperature change on seagrass survival and growth, which have been strongly implicated by Zieman in the initial loss of Florida Bay seagrasses. The mesocosm facilities and studies described by Chiapouras and Montague and Anastasiou and Montague hold promise for answering important questions about the environmental tolerances of the various seagrass species. However, operational difficulties have delayed the production of useful data. Given the importance of knowing the tolerances of the dominant seagrass species to changing patterns of salinity and temperature, it is imperative that high quality data from mesocosm studies become available soon. If the present efforts cannot bear fruit in the very near future other alternatives for obtaining such data should be sought.

Studies of the possible role of *Labyrinthula* infestation in the loss Florida Bay seagrasses continue with the presentation by Blakesley et al. Current emphasis is on field mapping of infestation and laboratory studies of the effects of salinity on pathogenicity. What is not clear at this time, however, is the extent to which *Labyrinthula* causes seagrass mortality under various field conditions, or whether it was a causative agent in the initial or subsequent seagrass die-offs. After the substantial amount of time that has elapsed since the hypothesized role of *Labyrinthula* in Florida Bay seagrass losses, it is now time that these critical questions be answered as conclusively as possible.

Recent information by Kenworthy et al. on substantial losses in the large *Syringodium* meadow to the west of the Park boundaries are cause for concern, especially since Stumpf et al. suggest that this is where major seagrass die-off began in 1985. The disappearance of seagrass and subsequent sediment erosion discussed by Kenworthy et al., presumably owing to reduced water clarity, suggests that if conditions continue unchecked there will be massive amounts of sediment (and nutrients?) flowing southward toward the reef tract. In addition, Sharp et al. document the destruction of substantial amounts of this *Syringodium* meadow by sea urchin overgrazing. The exact areal extent of the grazing losses is unknown, but estimated to be at least 10 square kilometers, and perhaps four times this amount. The fact that this "urchin outbreak" has persisted for the better part of a year, with urchin densities reaching several hundred per square meter, and the fact that *Syringodium is* unlikely to substantially recover from a grazing stress of this magnitude, suggests that this is significant event. Given the ongoing threats to this large and strategically placed *Syringodium* meadow, expanded study of its dynamics are needed promptly.

CRITICAL QUESTION #5

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

A strategy to address this Central Question was discussed at a November 1997 workshop, reviewed in a FBSOP report (Deegan et al., 1998) and presented in a draft report of a Higher Trophic Level Workshop Group (Browder et al., 1998). This draft strategy was presented at the Science Conference by Eklund together with results from ongoing studies on pink shrimp recruitment (Browder), mesocosm studies on the effects of nutrient enrichment on spotted seatrout larvae and their zooplankton prey (Clarke), the effects of habitat on fish larval growth (Hoss), modeling the effects of habitat dynamics on spiny lobster recruitment (Butler), changes in the distribution of molluscan communities (Lyons), and potential toxic effects of agricultural chemicals on higher trophic levels (Scott).

The FBSOP has the following summary comments on the direction and current scope of higher trophic level studies:

- The recommended research program strategy is a major step in the right direction and will help avoid duplication of efforts previously observed (Boesch et al., 1997), focus on priority issues, place results in the context of population and/or trophic models which provide understanding of cause and effect and improved predictive capabilities, and relate the dynamics of higher trophic levels to important environmental changes (seagrasses, algal blooms, salinity shifts, circulation, etc.).

- Having said this, it is also clear that the research plan is too broadly focused and open ended. It outlines many "life works," includes too many species, and is not based on realistic schedules. The FBSOP was struck with the focus and elegance of the approach to modeling of spiny lobster dynamics by Butler, which allows research to be focused on issues critical from the lobster's perspective, rather that trying to fill all the boxes in trophic or ecosystem models (Browder et al., 1998).

- Mesocosm studies may allow more realistic experimentation. They could provide a bridge between laboratory experiments such as those by Hoss and field observations. However mesocosms are fraught with potential difficulties in operation and interpretation. Clarke's experiments did not deal effectively with such classic mesocosm issues as vertical mixing and yielded results which are hard to interpret with regard to the complexity of potential food chain interactions.

- Fundamental to the effort of separating anthropogenic changes from natural cycles is the effort to relate the recently observed processes and their variability to long-term records. Clearly, the paleoecological work addresses this directly, but for other studies, especially in the higher trophic levels, the interval of intense investigation seldom extends beyond a decade, and most only cover 3-5 years. For the pink shrimp, 60 years of record were mentioned. Would this record support a retrospective analysis, bolstered by the new knowledge amassed by the Florida Bay Program? For longer-term perspectives, Stumpf's satellite work is of great value. The inshore data appear to be corroborated by *in situ* measurements. The major shift indicated seaward of the Bay should be investigated, not only for further validation of the model, but also for determining the cause of the offshore shift. Such a dramatic large-scale shift would may be related to changes in the Bay ecosystem that may be of consequence to fisheries production and catch statistics.

- The ecotoxicology studies have thus far failed to establish a case that toxic agricultural chemicals are implicated in the broader ecosystem problems (seagrass die-offs, algal blooms, fisheries declines) and, at most, it seems that they may cause problems in the vicinity of drainage canals.

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