# REPORT OF THE FLORIDA BAY SCIENCE REVIEW PANEL

on

**Florida Bay Science Conference:** ***A Report by Principal Investigators***

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Submitted to the

**Program Management Committee**
**Florida Bay Research Program**

by

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## Florida Bay Science Review Panel

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# Introduction

## *Background*

Concern about the extensive die-off of seagrasses, proliferation of algal blooms, reduction of water clarity, and mass mortality of epibiota noted in Florida Bay during the early 1990s has resulted in a great expansion of scientific investigations of the Bay. Many of these investigations are part of the Florida Bay Research Program of strategic and coordinated studies supported by participating federal (National Park Service, National Oceanic and Atmospheric Administration, Fish and Wildlife Service, National Biological Service, U.S. Geological Survey, Environmental Protection Agency, and Corps of Engineers) and state (South Florida Water Management District and Department of Environmental Protection) agencies (Florida Bay Research Program, 1995). This program resulted from a science plan submitted in 1994 to the Interagency Working Group on Florida Bay (Armentano, et al., 1994), which, in turn, was based in part on recommendations in an assessment provided to the Interagency Working Group by a panel of independent scientists from outside the south Florida region (Boesch, et al., 1993).

On October 17 and 18, 1995 a conference was convened for progress reports by the principal investigators supported by the Florida Bay Research Program and presentations by other scientists who are or have been engaged in research relevant to Florida Bay. Another independent science review panel was assembled, half of which consisted of members of the original 1993 panel, to evaluate the direction and progress of the investigations as reflected in the conference presentations. This is the report of that Florida Bay Science Review Panel (hereinafter “the Panel”).

Twenty-eight oral presentations were made and 18 poster presentations were displayed at the conference. Extended abstracts were provided for each of these presentations. After related groups of 15-minute oral presentations there was a period of questions and discussion among a panel of presenters. The Panel’s evaluation is thus constrained by the limited depth of information which could be provided in the abstracts and brief presentations or posters.

## *Charge*

The Panel was not provided a specific charge prior to the meeting, so its first order of business was to develop a charge it thought was appropriate and which it could hope to meet. This charge was later reviewed and agreed to by the Program Management Committee for the Florida Bay Research Program. The general charge was to evaluate the quality, relevance and progress of the scientific investigations of the Florida Bay ecosystem and the factors which affect the ecosystem and to report these evaluations and make recommendations for improvement to the Program Management Committee.

Key questions posed for the Panel’s evaluation included the following:

1. Are the component projects of high scientific quality, under the guidance of competent investigators, using modern and effective techniques, and likely to answer the questions posed within the time frame indicated?

2. Do the component projects adequately address key management issues related to understanding the causes of environmental degradation and identifying potential solutions? Are there key issues which are not being adequately addressed?
3. Is project coordination sufficient to efficiently achieve desired results, encourage exchange of information and understanding, and place results of component projects into a broader context? Is there unnecessary overlap? Are the synthesis and modeling adequate to guide the overall scientific program and produce continual results that will inform management?

Because of the aforementioned limitations in information and time, these questions could not always be fully addressed. It was simply not possible to provide detailed peer review for each of the component projects represented in the presentations. Furthermore, important ancillary information such as level of funding and project schedule and duration was not available nor apparent from the presentations. Rather the Panel's evaluations are of a broader nature, with a greater emphasis on the last two questions. Even then, there is difficulty in evaluating the scope and interrelationships of the various program elements. For example, several large studies are just beginning and either results were not presented or the study plans were vague at this point.

Table 1. The research topic areas of the Florida Bay Research Program with the number of studies being supported and the total funding level for each topic area (Florida Bay Research Program, 1995).

| Topic | Number of Studies | Total Funding ($ thousands) | Number of Abstracts |
|---|---|---|---|
| Salinity and Nutrients | 8 | 788 | 9 |
| Contaminants and Toxins | 4 | 625 | 3 |
| Hydrology and Water Quality | 8 | 1,407 | 13 |
| Circulation Models and Tides | 9 | 845 | 10 |
| Sedimentation and Paleoecology | 11 | 1,385 | 9 |
| Marine Endangered Species | 3 | 96 | 4 |
| Algal Blooms and Zooplankton | 4 | 411 | 6 |
| Mollusks and Crustaceans | 8 | 359 | 5 |
| Seagrass Ecology | 7 | 363 | 10 |
| Fisheries | 7 | 852 | 6 |
| Mangrove Ecology | 2 | 60 | 2 |

## Evaluation of Specific Research Topics

The Panel members had the benefit of review of most of the abstracts contained in the final Abstracts & Program (Anonymous, 1995) approximately a week in advance of the Conference, but did not have information as to which of the presentations reported on the study elements of the Florida Bay Research Program. This made evaluation of the Program difficult. The distribution of Program studies, total level of funding, and the number of presentations (oral and poster) at the Conference among the topical areas used both in the Program and Conference is provided in Table 1.

For brevity, specific presentations are referred to by the name of the author or lead author of the abstract and the page number in the Abstracts and Program on which the abstract appears. For example, Wingard (118) refers to the study "Florida Bay Ecosystem: Measuring Historical Change" by Wingard, Cronin, Willard, Ishman, Edwards, Holmes and Weedman, the abstract for which appears on pages 118-120.

### *Salinity and Nutrients*

A variety of efforts are underway to monitor salinity and nutrients in Florida Bay. These include a multi-year water quality monitoring program by Fourqurean (13), citizens monitoring as described by Decker (11), and the extension of the physical monitoring program conducted by the Everglades National Park (ENP) as described by Smith (25). All three are essential and should be sustained. The long-term salinity records from the ENP monitoring program are critically important. The Fourqurean water quality monitoring program is particularly valuable because it extends into freshwater environments of the Everglades, thus providing essential connections, and now extends over a long enough period to allow very useful multivariate and trend analyses. These data and patterns are particularly appropriate to the issues of nutrient flux and dynamics, but because these issues are integral to the issue of plankton blooms further discussion is reserved for the topic of Algal Blooms and Zooplankton. The nutrient dynamics work of Gardner (16) is also discussed in that section. The citizens monitoring program is making important contributions not only in the data it provides but by engaging a large and growing number of citizen volunteers, building support for good science and greatly increasing the pairs of eyes watching the Bay.

The remaining projects listed under the topic Salinity and Nutrients include a rather eclectic group of studies of nutrient and organic fluxes from land and bottom sediments, most of which are just getting underway. The strategic relevance of these studies to the key issues of degradation of the Bay ecosystem is not clear to the Panel at this point.

### *Contaminants and Toxins*

Studies on contaminants and toxins include ongoing chemical contaminant monitoring under the National Oceanic and Atmospheric Administration (NOAA) Status and Trends Program as described by Cantillo (33), the ecotoxicological assessment of agricultural pesticides of Scott (34), and an application of the Environmental Protection Agency (EPA) Environmental Monitoring and Assessment Program (EMAP) approach described by Summers' (36) poster. The Panel is concerned that too much effort may be expended on monitoring and assessment of toxic contaminants in the absence of *prima facie* evidence of the importance of contaminants (other than nutrients) on the Florida Bay ecosystem. Our concern is based on the quixotic approaches to toxicants which have been taken in other coastal areas. It is not surprising that measurable concentrations of pesticides are found near discharge points from land drainage, nor that there is mortality or reduced condition of test organisms at such discharge points, e.g. the end of drainage canals. A more important question is whether these toxicants are responsible for widespread contamination and, even sublethal, effects. The EMAP effort is particularly confusing and on its face appears to duplicate the efforts of many other studies of contaminates, seagrasses, and water quality. Furthermore, the particular relevance of an extensive probabilistic monitoring program, in contrast to the temporal trend assessment of other programs, to the strategic science issues of Florida Bay is not clear.

### *Hydrology and Water Quality*

As stated in the 1993 assessment (Boesch, et al., 1993): "Knowledge of water flow, both within the watershed (hydrology) and within the Bay (coastal hydrodynamics) is essential to understanding changes in the delivery of fresh water and the nutrients it contains to the Bay and to understanding the distribution and dynamics of salinity, nutrients, and organisms within the Bay. It is the linchpin on which the capability to predict future conditions and the effects of management actions on them will be based." With this admonition, the 1993 panel identified four specific hydrodynamic information needs: (1) the quantification of the effective flow of fresh water into estuarine transition zone, including both surface and groundwater flows; (2) the relationship of water stage and timing of release on effective flow both in the nearfield (below Tamiami Canal) and the farfield (above the Canal); (3) exchanges between the Bay and Gulf of Mexico to the west and the Bay and Hawk Channel; and (4) circulation within the Bay and exchange rates among basins. Studies which to varying degrees address the first two needs are included in this topic area, while the next two topics are addressed under the following topic, Circulation Models and Tides.

Several studies are assessing groundwater inputs. Chanton (41) has used both indirect ($^{222}Rn$ and $CH_4$ concentrations) and direct (seepage measurements) techniques to measure flux though sediments on the Bay floor, while Shinn (68) has analyzed groundwater exchanges through porous carbonate rock driven by tidal height differences between Hawk Channel and Florida Bay. Fitterman (44) is using airborne and surface resistivity measurements to map the freshwater-saltwater interface along the north shore of the Bay; these measurements can indicate where movement of ground water to the surface is occurring. However, this mapping does not measure flow of either surface or ground water. While these approaches provide some insights into mechanisms and locations of groundwater fluxes, there is a need to advance far more quantitative efforts to estimate groundwater fluxes in order to be useful for hydrological modeling of the Bay. In addition, the importance of groundwater fluxes to the nutrient budget of the Bay should be assessed.

Several investigators presented results in oral and poster presentations and abstracts on surface inputs of freshwater to the Bay. These included Patino's (58) measurements of flows in selected streams in the Taylor Slough-C-111 area using sophisticated instrumentation suited to the difficult measurement conditions of the area; Nuttle's (55) studies of the effects of freshwater flows and the water budget of Shark Slough on the marsh-mangrove transition; Johnson's (47) combination of statistical models with the South Florida Water Management District (SFWMD) regional hydrology model to show the impacts of flow modifications to Florida Bay salinities; and the aforementioned resistivity mapping of Fitterman. These studies fall short at present in providing a comprehensive picture of the volume and location of freshwater inflows into the Bay; however, they may provide useful input or validation of the comprehensive surface and groundwater model being developed by Richards (60). This model has the potential to generate freshwater flows to the Bay under various management conditions, but it is unclear whether it includes flows through southwestern Florida which may also affect the Bay.

Rainfall data from ground measurement stations are available as described by Smith (25), but Willis' (70) tuning of algorithms which allow the conversion of NEXRAD Doppler weather radar reflectivity to rainfall rates over the Bay would provide more accurate, reliable and continuous monitoring. Recreation of surface winds and rainfall during episodic events by Mattocks (49) adds to these monitoring data. Several investigators, however, pointed out the critical need for reliable data on evaporation rates for accurate water budget modeling.

### ***Circulation Models and Tides***

Studies under this topic were basically of two types: 1) field measurements of tides, currents and winds; and 2) mathematical models of circulation in the Bay. Field measurements of Lee (80), Wang (94) and Smith (89) aim at quantifying the exchanges between Florida Bay and the Gulf of Mexico to the west and between Florida Bay and the Atlantic Ocean to the south and east. They provide valuable information on flows across the relatively open boundaries of Florida Bay, which can be related to predictions from sea surface height as measured by satellite by Maul (81). In addition the *in situ* monitoring at stations along the reef track by Vargo (92), although lacking in current measurements, provide valuable insight into events which may advect water out of the Bay. There is need for more current measurements in the Bay and for the extension of boundary conditions up the southwest coast to include nearshore flows from Shark River Slough region.

At least five circulation models are being developed or applied to Florida Bay. These include Nuttle's (82) finite-segment, mass balance model for water and salt which run on a personal computer; two-dimensional hydrodynamic models by Wang (97) and Roig (64); and three-dimensional models of Galperin (77) and Sheng (86). The pursuit of various modeling approaches in order to see which performed best was a purposeful strategy. The pilot models which were presented (Galperin did not present his model for review) have made great progress and seem to simulate important bay conditions, such as salinity, fairly well. The Panel believes that a central three-dimensional modeling approach should be selected and further developed. Sensitivity analysis run on this model may be very helpful in guiding the research effort to the most important questions. There may also be a place for easier-to-run, mass balance models, but these should not be seen as alternatives to a sophisticated, three-dimensional hydrodynamic model.

### ***Sedimentation and Paleoecology***

Historical reconstruction is an appropriate key goal in Florida Bay studies at this juncture. Cantillo (103) presented a poster which assembles what is known of the chronology of human alterations, natural events such as hurricanes, and observations of recent degradation which will serve as a useful context for a wide array of study results.

Several geological studies are addressing the history of salinity patterns and variations in the Bay. Several use the powerful tool of stable isotope analysis to reconstruct paleoconditions. The baseline study of $\ast^{13}$C and $\ast^{18}$O composition of mollusc shells along a present day salinity transect by Halley (104) is of high quality and shows promise as an analytical technique for evaluating the salinity history of Florida Bay as reflected in molluscan assemblages throughout the past 5,000 years. If we are to understand the present and attempt to predict the future, we need ways to track the evolution of the Bay sediments and the salinity signal they may convey from the isotopic record. Swart (111) examined isotope ratios in a long-lived coral to decipher changes in salinity and carbon quality. The importance of causeway construction on water exchange with Hawk Channel was emphasized, but increasingly hypersaline conditions do not seem to bereflected in this record. However, the site at Lignumvitae Key would seem to be influenced by exchange through the nearby inlet and not to be particularly susceptible to the development of hypersaline conditions. A better place to test the idea may be Cotton Key Basin, south of Cross Bank, where conditions are much more likely to reflect salinity variations in more restricted waters. Continued sampling and further analyses of corals from other sites are needed and encouraged.

Paleoecological approaches are also proving valuable in reconstructing past conditions both in terms of salinity in the Bay and freshwater flow through the Everglades. Wingard's (118) exhaustive analysis of marine biota, pollen, geochemistry, and sedimentology in two cores provides very provocative results which suggest cycles of low and variable and high and more stable salinities. At present, this work suffers from the fact that only two cores form the basis for the conclusions reached. More cores from more widely spaced localities with some internal time-correlative datum is needed for this research to be utilized to its fullest. Winkler's (121) research provides a valuable land-based corollary for comparison with cores from the marine setting of Florida Bay. The paleoenvironmental implications may provide a method for correlating events recorded in two quite different stratigraphic settings. The sections, however, are greatly compressed and may be permeated with discontinuities related to subaerial exposure.

Sediment transport and deposition are critical issues for understanding Florida Bay's past, present and future. As reported only in an abstract, Halley (106) and colleagues are assessing the importance of the balance of sea level rise and sedimentation on water depth and, thus, salinity in Florida Bay. They suggest that sedimentation has not matched sea level rise, thus the Bay is becoming deeper and less subject to dilution from freshwater runoff. As demonstrated in Stumpf's (110) poster presentation, remote sensing is a very valuable approach to assessing turbidity in the Bay which shows considerable promise for continued research and monitoring. The influence and importance of wind wave-induced turbidity in the western and northeastern part of Florida Bay separated by a "clear water" zone (which may coincide with the characteristic salinity maximum in the center of the Bay) was readily apparent. Remote sensing applications should be considered important components of future studies. Wanless (114) reported on two studies which dealt with geomorphic changes, the sedimentary record and erosion and sediment transport processes. Their work on the long-term effects of short-lived catastrophic events (i.e. hurricanes) is very significant and calls attention to the fundamental question of which, in the long run, is more important in the evolution of the Bay: 1) the daily sediment additions and/or redistributions or 2) bursts of energy that rapidly alter the environment and impart major changes in the environment that are long-lived.

Studies of the hydrology and geochemistry of the interior of mangrove mud-islands by Kramer (107) suggested that hypersaline pore waters in the island interiors are formed primarily by isolation and entrapment of sea water behind elevated levees (or "beach ridges") and are not influenced by ambient Bay salinity. The hypersaline condition of these salinas plays a role in excluding mangroves from the island interiors, but the relevance of this study to understanding the mortality of fringing mangroves is unclear. This work needs to be better linked with that of Carlson (227) who speculated that soil ion concentration and balance ($Cl^-$ and $S0_4^=$) was responsible for mangrove mortality. Otherwise the relevance to this research—although of high quality—to understanding and managing the degradation of the Bay is not apparent.

Overall, the quality of sedimentology and paleoecology research was high, the workers competent, contemporary techniques were being utilized and the work seemed capable of being accomplished within the necessary time-frame.

While most of the research presented during this brief conference was related to the sediment/water interface and the water-column environments, there is a need to integrate these data with the Holocene sedimentary record and the overall sea level rise in order to evaluate whether the present day problems found in Florida Bay are human-induced or have a recorded history in the stratigraphic sequence of Florida Bay sediments. The interaction of groundwater within the Pleistocene bedrock and Florida Bay environments needs also to be addressed in greater detail.

Even more importantly, relatively little effort is directed to understanding the processes of sediment resuspension and transport, which have become important ecological processes affecting nutrient availability, light limitation and, quite possibly, mortalities of corals and other sessile epibiota in the Florida Keys Marine Sanctuary. This represents a major deficiency.

***Marine Endangered Species***

Robertson (134) demonstrated that breeding populations and success of bald eagles and osprey seemed to be unrelated to variations in the changing environmental conditions in Florida Bay. Consequently, it does not appear to the Panel that this element continues to be of strategic importance to the Florida Bay Research Program. Crocodile reproductive success appears, according to Mazzotti (131) be improving, however he did point out the importance of the brackish transition zone for American crocodiles. This suggests that continued monitoring and studies of crocodiles at least be coordinated with the Program. On the other hand, Brodwer's (127) spatial analysis of wading bird populations in Florida Bay lacks a *prima facie* case for concern that these organisms are being affected by environmental degradation in Florida Bay. If this is the case, one would question its priority as a component of the Program.

### *Algal Blooms and Zooplankton*

The 1993 panel noted the appalling lack of information about the characteristics, much less the causes and dynamics, of the algal blooms proliferating in the Bay (Boesch, et al., 1993). Most "explanations" were, at best, hypotheses based on inferences rather than evidence. Within the past two years the research projects supported by the Florida Bay Research Program have produced fundamental new information about plankton populations and their role in these ecosystems. Most of this information is useful as descriptions of patterns of variability, a requisite first step toward the development of hypotheses about the mechanisms of plankton fluctuations (including blooms). Notable contributions are as follows:

1. Analysis of the 1985-1995 water quality data set to extract the principal modes of variability in Florida Bay by Fourqurean (13) shows a clear change in the nature of the phytoplankton population (chlorophyll) variability around 1991. Prior to that year, chlorophyll concentrations were relatively low and stable in Florida Bay. Since that time, phytoplankton biomass variability has been characterized by a series of episodic blooms—events of high chlorophyll concentration, occasionally reaching levels that we associate with eutrophic waters.
2. Further analyses of this, and more recent data from other projects including those of Steidinger (152) and Phlips (145), suggest that the pelagic zone of Florida Bay is a spatial mosaic, divided into distinct domains that have their own characteristic phytoplankton communities, biomass, and bloom dynamics. This spatial mosaic implies that conceptual models of Florida Bay will require consideration of the possibility that blooms have different mechanisms in the different spatial domains.
3. Nutrient concentrations in Florida Bay, as described by Fourqurean (13), are very different from those typically measured in temperate estuaries or shallow coastal waters. Most of the dissolved organic nitrogen is in the reduced form $NH_4^+$; phosphate concentrations are unusually low; and silicate concentrations are often very high. The evolving conceptual model should be directed to explain why the nutrient chemistry is unusual, and the implications of this chemistry for phytoplankton production and population growth. This might lead, for example, to focused measurements of individual processes of nitrogen cycling, including nitrification and denitrification.
4. The measurements of Gardner (16) provide the first quantitative observations on rates of nutrient cycling processes; they suggest that the rates of pelagic and benthic N

regeneration are of comparable magnitude. This kind of information, although based so far on only two visits to Florida Bay, will be critical in the evolution of the conceptual model of coupled phytoplankton-nutrient dynamics.

5. Similarly, observations of Gardner (16) that most of the inorganic phosphorus uptake occurs in the bacterial size class is another key observation that should be pursued because of its implications concerning bacterial and algal competition for the limited P resource.

6. Several different approaches have been used to reveal spatial patterns of chlorophyll variability. These approaches all suggest that phytoplankton distributions are influenced by the large scale circulation patterns in Florida Bay.

7. Estimates have been made by Steidinger (152) of the phytoplankton contribution to total seston concentration, and the spatial variability of this index of algal versus inorganic sources of turbidity.

8. Fundamental new information on the zooplankton communities of Florida Bay have been provided by Ortner (143). This measurement program has given some surprises, including the observations that meroplankton constitute a large fraction of the macrozooplankton community.

The Science Plan identifies a set of key questions that must be answered as steps toward refining our understanding of bloom dynamics and reducing the uncertainties of the potential effects of different water management scenarios. These questions address two fundamental unknowns: (1) what are the **patterns** of bloom dynamics in Florida Bay (spatial patterns, temporal variability, species composition), and (2) what are the **mechanisms** that give rise to bloom variability? Considerable recent progress has been made toward resolution of the first issue. The second, more challenging issue, will require more time, study and analysis, but also different approaches than those presently being taken. We suggest here one approach that might facilitate progress toward the resolution of this challenging problem of how blooms develop in Florida Bay.

Phytoplankton blooms can be viewed simply as events in which the production rate of algal biomass exceeds losses to grazers and transport processes, such that the population increases. In the process phytoplankton consume inorganic (and organic) nutrients. Bloom dynamics are closely related to nutrient dynamics (the sources, sinks, and cycling of those elements in shortest supply). Phytoplankton blooms often occur as responses to change in the physical structure of the water column, so they are linked to hydrologic, climatic, and tidal variability. Blooms often occur when grazing losses to filter feeding animals (both zooplankton and benthic forms) are small, so they are linked to changes in the abundance and activity of consumer animals. And, blooms can often occur as responses to changes in the patterns of horizontal circulation and mixing. Therefore, we can view the question of bloom mechanisms as a theme around which we can develop an integrated conceptual model of the linkages between the geologic, hydrologic, climatic, hydrodynamic, geochemical, and biological variability of Florida Bay. This conceptual model could be pursued through the organization of a small workshop, of the type suggested in the concluding Recommendations, designed specifically to: (1) synthesize existing information about linkages referenced above; (2) consider what is known about these linkages in other shallow tropical coastal waters; (3) identify the key **processes** that remain to be measured in Florida Bay; and then (4) develop a strategic plan for measuring key unknowns and integrating these processes into numerical models

As the Florida Bay Research Program evolves, its managers should search for ways to address the following issues:

1. There appears to be a fair amount of duplication or redundancy among the different projects. Four projects include elements to measure zooplankton grazing on phytoplankton (but none include elements to measure benthic macrofaunal grazing). Perhaps 8-10 different projects include measurements of water quality—in particular salinity, temperature, chlorophyll, and turbidity. There appears to be little coordination among these projects, each having its own sampling network and timetable. Here, as elsewhere, resources are limited and efforts should be made to minimize this measurement redundancy and optimize coordination among the different sampling programs.
2. It is also clear that investigators working on closely related topics have not all established working relationships with exchanges of data and ideas. The Science Conference was an important step to initiate the process of information exchange, but the process should be accelerated and made continuous by the formation of small working groups charged with specific tasks of data synthesis and integration.
3. During the Science Conference we saw numerous cases of either contradictory interpretations of data or inconsistencies among different measurements. We heard from one investigator that remineralization of dead seagrass biomass provided the nutrients which stimulate plankton blooms and that land-based nutrient inputs were not important, while another speculated that the recent algal blooms were triggered by nutrient delivery following periods of heavy precipitation and runoff. Furthermore, the role of mangrove detritus following Hurricane Andrew in furnishing nutrients to the Bay remains to be assessed with the above sources in a quantitative framework. One theory of seagrass die-off has been the lack of recruitment because of light limitation caused by algal blooms, yet the spatial zones of intense blooms and most rapid seagrass die-off are not coherent. Results of some nutrient bioassays are difficult to interpret and certainly not consistent with the hypothesis that phytoplankton are nutrient limited. These kinds of inconsistencies are not unusual; they are symptomatic of a research program in its infancy. However, these inconsistencies should be resolved through focused debate. These debates would logically be included in the process of developing a conceptual model of the Florida Bay ecosystem which would extend analyses beyond stoichiometry toward budgets, with concurrent experimentation on nutrient fluxes and transformations. The relative importance of internal versus external sources of nutrients remains a question, despite considerable new information.

### *Molluscs and Crustaceans*

The work of Herrnkind (166) on spiny lobsters was an excellent demonstration of the linkages between landscape-level considerations of changing habitat and focused hypothesis testing. The linkages between modeling efforts, field experiments and large-scale surveys were clear and carefully thought out.

Browder's (161) research on pink shrimp is in its first year, so it is difficult to judge whether this ambitious project will succeed. The organization of the investigations around hypotheses about recruitment, growth and suvivorship and the use of both modeling and experimental approaches appear as major strengths, but most of the work to date has been statistical correlations of existing data. The investigations of genetics does not seem to be well integrated with the rest of the project and does not seem to address central questions for the Florida Bay Research Program.

Surveys of mollusc by Lyons (167) and sponges by Stevely (173) appeared to be competently executed and provide useful descriptive information. Future investigations of these biotic components should be more directed to an understanding of the effects of seagrass die-off and blooms on benthic organisms and the consequences of these effects on the ecosystem. Further wide-spread surveys are not warranted, at least not on an annual basis. Future emphasis should be focused on species which are ecologically important because of their roles in food webs or in influencing ecosystem processes.

***Seagrass Ecology***

Seagrass research in Florida Bay currently consists primarily of monitoring seagrass coverage and species composition throughout the Bay, including the studies of Durako (177), Hefty (181), Morrison (191), Sargent (194), Zieman (196) and Zimba (198). This extensive effort will be important to detecting future changes, recovery or spread of die-off. Concurrent monitoring of physical data should be useful for multivariate analyses of factors potentially controlling seagrass abundance. *Thalassia* turnover rates have measured at fewer stations across the Bay. An expanded disease monitoring program has been initiated. Communication and coordination regarding sampling strategies apparently is good. Many of the investigators have good track records in seagrass ecology.

Progress toward understanding the cause of seagrass die-off has progressed more slowly. As one example of many, it is still unknown whether high sediment sulfide levels are the cause, as suggested by Durako (177), or result of, seagrass stress. Systematic tests regarding the control of seagrass distribution and abundance have been limited, despite the existence of conceptual models of the die-off and consensus that physiological stress initiated the die-off. Researchers are encouraged to consider the complexity and interactions of factors affecting seagrass health. Although building conceptual models is a critical step in understanding complex ecological problems, such models can be seductive in their simplicity when not accompanied by rigorous hypothesis testing. Appeal to a simple "unifying" model of seagrass distribution may obscure understanding of causes of mortality in a specific case. Without such understanding, informed management decisions cannot be made, nor can predictions of when to expect future declines in seagrass-associated animal communities.

Particularly important is the role of hypersalinity in initiating seagrass mortality and of salinity fluctuation in controlling seagrass biomass and species distribution, because salinity is one of the few environmental factors than might be addressed by management action. The importance of nutrient enrichment in controlling species distribution and biomass remains unresolved. Experimental evidence (Fourqurean, 179) exists that species distribution and density is controlled by nutrients, yet nutrient enrichment has not been incorporated into the conceptual models for seagrass die-off. The degree to which the initial die-off was anthropogenically induced is still unclear but a newly-emerging viewpoint, as articulated by Zieman (196), is that seagrasses in Florida Bay are returning to some pre-1980 'natural' state. These remain as hypotheses, and it will be difficult if not impossible to reconstruct historical seagrass coverage. This again points to the need for predictive understanding of the controls of seagrass distribution and abundance.

A monitoring program is valuable but not a substitute for experiments and other studies directed to test hypotheses directly. Are there suites of questions around which the monitoring has been designed? For example, what is the effect of increased precipitation on *Thalassia* abundance and what is the correlation between increased flows down Taylor Slough and seagrass coverage bay-wide?

The Program Management Committee and investigators are urged to reconsider carefully the recommendations of the 1993 panel (Boesch, et al., 1993), which in the view of this Panel are still appropriate. Specifically, the Panel recommends integrating monitoring efforts with experimental hypothesis testing directed to understanding seagrass dynamics in Florida Bay. To help prioritize research hypotheses, existing conceptual models for die-off should be refined and used to generate testable hypotheses, determine the most effective allocation of research resources, and move toward consensus on the most likely critical factors and management implications. Multivariate analyses of existing data sets should also be performed to guide experimental hypothesis testing (e.g., is salinity more likely to be a stressor than temperature, do salinity and temperature interact in controlling seagrass distribution, and which levels of factors should be included in experiments?). A modeling effort should also be included to provide a means of simulating environmental conditions and guiding management decisions, e.g., whether freshwater diversion will make a change in seagrass dynamics, or perhaps did so in the past. Sensitivity/elasticity analyses are critical to the utility of such models. This research should have important relevance for other seagrass dominated systems both locally (Biscayne Bay) and elsewhere (Texas bays). A seagrass dynamics model should focus on *Thalassia* and be community-based. Several existing models for seagrasses (e.g., Chesapeake Bay, New England) perhaps could be modified. Physiological models based on single leaves or shoots, although available, are not likely to be useful for predicting seagrass dynamics or for Bay-wide management questions.

Improved light, sulfide, rhizome status, and disease data are probably required for modeling. Prioritization of these needs should be addressed by the investigators through a coordinated approach, such as discussed above.

Seagrass dynamics need to be placed in the context of the Bay as a system. To this end, it will be critical to determine the relationship between the phytoplankton blooms and seagrasses. It is unclear whether this is being systematically considered, i.e., have hypotheses been generated that drive monitoring programs, are seagrass researchers communicating with plankton biologists? Likewise, information on sediment resuspension and its control of light to the seagrasses is important. Attention should be directed to what is limiting seagrass recovery; these factors may well differ from the ones that initiated the die-off. Defining what constitutes "recovery" is prerequisite to setting management goals.

### *Fisheries*

Concerns about fisheries production in Florida Bay stem from declines in population levels of some living resources indicating the Bay's capacity to support them is declining or from observed degradation of habitats deemed important to these resources. Focused questions outlined in the research plan (Florida Bay Research Program, 1995) are

1. Have recruitment, growth and survival been affected?
2. Has habitat degradation or loss caused a reduction in fisheries production?
3. Have the distribution and reproductive success of fish been altered?

Fisheries research in Florida Bay consists primarily of monitoring species abundance and composition throughout the Bay using a variety of sampling techniques, including trawls, drop nets and seines. Most studies assess the community of fishes and motile crustaceans, most of which are not harvested, rather than species of direct importance in commercial or recreational fisheries *per se*. Of the seven fish-related projects, six were surveys of standing stock [Colvocoresses (203), Hoss (209), Lorenz (211), Matheson (215), Schmidt (217), and Robblee (170)]. Only two of these, Robblee (170) and Lorenz (211), framed their investigations as direct tests of hypotheses about what controlled community composition. Several studies focused on comparisons with historical data from surveys conducted in the mid-1980s prior to the seagrass die-off and came to similar conclusions, namely that the fish and crustacean community is significantly altered by the loss of seagrass beds. This result is not surprising given the broad background of information available on the relationship between fishes and seagrass beds. Monitoring is an important element in developing a management plan and dectecting long-term changes, however it should not be the only approach used. The most valuable monitoring programs are those which are designed around specific hypotheses and coordinated with focused experiments and modeling (National Research Council, 1990).

The importance of hypersaline or extreme temperature conditions on the fish and crustacean community is not very well addressed in the present studies. Existence of seagrass is not the only habitat factor that influences fish distribution and abundance. Both salinity and temperature are thought to be major controlling factors in fish habitat selection and distribution, growth and survivorship of most and invertebrates are affected by high salinities. Only Elledge's (207) study is attempting to correlate changes in spotted seatrout growth and fecundity with salinity.

Patterns of fish community change need to be better integrated at the ecosystem and landscape levels. An obvious approach would be to link observed changes in the community associated with the loss of seagrass habitat to the changes in total seagrass habitat available. Only Matheson's (215) study made any attempt to "scale up" the changes in the fish community beyond individual sites. Linkages between other landscapes connected with Florida Bay also need to be considered. Fishes often undergo extensive and predictable migration among mangroves, seagrasses and offshore areas for feeding, spawning, refuge, and development. For example, the loss of mangrove areas on fish that use both mangrove and seagrasses needs to be considered. Recruitment of many species is determined by hydrodynamics that is governed by freshwater discharge, tidal circulation and wind forcing. Examples are described by Hoss (209). Alterations in tidal circulation as a result of the building of the railroad causeway have been suggested to alter this circulation, as have changes associated with reduced freshwater inputs. No studies appear to be addressing the linkages between hydrodynamics (and changes thereto) and recruitment of fishes.

Documenting the patterns of fish abundance was a logical starting point, however it is time to address more directly the mechanisms responsible for the observed distributions. Recruitment, growth and mortality are three critical processes which determine standing stock. Understanding the relationships between these processes and changes in habitat, primary producers and hydrodynamics will require different approaches that those currently used. Very little effort has been directed on these processes thus far. Only Elledge’s (207) study evaluates growth and mortality of a fish, the spotted seatrout. Although this study looks promising, it is too early to evaluate to whether the approach employed will provide information at the appropriate scale. Enough is known about correlations between salinity, temperature and seagrass structure, on one hand, and fish growth and survival, on the other, to develop clear and testable hypotheses, which could be addressed using a combination of observations, experiments and models. These would guide strategic studies of the effects of changing hydrodynamic conditions, salinity, temperature and habitat structure on growth and mortality of key organisms.

Another aspect which has received little attention is the effect of changing species composition, both plants and animals, on ecosystem processes and trophic pathways. The shift in primary production from rooted macrophytes to phytoplankton should have altered the rates, pathways and distributions of consumer organisms in Florida Bay. Hoss (209) and Colvocoresses (203) both noted the loss of pelagic species and increases in benthic fish species associated with the loss of seagrass. Shifts in the physical location of forage fish from the surface to the bottom can have important consequences for wading birds who are limited in the depth of water in which they can effectively feed. As a result of limited predation by birds, lowered mortality of fishes may result in higher standing stocks. Animals can further influence ecosystem processes by top-down controls or by altering nutrient pathways. Fourqurean’s (179) documentation of the effect of bird fertilization in influencing seagrass community composition is one example of the importance of animals in ecosystem processes. Filter feeders have been shown to control phytoplankton biomass in other estuaries. The loss of up to 90% of the biovolume of sponges documented by Stevely (173) has surely changed the ability of the filter feeding community to influence non-toxic phytoplankton biomass in Florida Bay. Interactions between animals and ecosystem processes need to be considered in future work.

Coordination and communication between researchers could be improved by a workshop that focused on developing a basin-wide fish assessment sub-program and standardizing gears. The lack of communication among groups was evident in the redundancy of the project objectives and the wide variety of gear types being used for assessment. For example, two studies, Colvocoresses (203) and Hoss (209), had as a major goal a re-assessment of the same historical study. In addition, there seemed to be little coordination in gear types among projects sampling in different locations. For example, Matheson (215) and Robblee (170) both used drop traps, however differences in mesh size (3 mm vs. 0.11 mm) and number of sweeps within a trap (minimum of 10 vs. 3) make it difficult to combine these two studies into a bay-wide assessment. To their credit, both Robblee and Matheson chose their gear to exactly match to past studies, however, intercalibration of gears currently being used would seem a logical and not yet considered step. The fish assessments based on trawl and seine studies suffer the same general problem. The results of fish assessment studies are notoriously gear-dependent and specific. Different studies with different objectives often need to use different gear. Sometimes, however, the choice of gear can be adjusted and still meet the project objectives while fitting into a broader scope assessment. Combining the current separate projects into a basin-wide assessment will be problematic unless the use of different gears is addressed.

The Panel's general impression is that little work on fish is being done that significantly advances our understanding of how the changes in Florida Bay are affecting fish production. The documented changes in fish standing stock with loss of seagrass, through well done by competent and knowledgeable workers using classic techniques, were not surprising. Fish have been well studied in Florida Bay and other places and the results were predictable. It is time to move beyond simple assessment of patterns of fish abundance to directed studies of the mechanisms responsible for the patterns and the consequences to important living resources. At this point, we should be able to develop testable hypothesis on the response of fish to alterations in hydrology, temperature, salinity and seagrass habitats. The use of newer techniques in otolith assessments such as Sr/Ca ratio's as indicators of freshwater inputs, or $^{18}O$ isotopes for temperature would help resolve controls on growth. Individual-based modeling approaches would allow predictions of population size and composition using growth and mortality functions linked to temperature and salinity. The Panel suggests eliminating the redundancy in projects documenting changes in fish standing stock and community composition and replacing them with focused field experiments including process measurements coupled with modeling.

### *Mangrove Ecology*

A central question is whether the recent observations of dead and dying mangroves on islands in Florida Bay reflect intrinsic forest stand processes and disturbance interventions independent of human activities or hypersaline conditions in the Bay worsened by freshwater diversion. This issue is being addressed by detailed vegetation surveys from the air and on the ground (Armentano, 225) and by relating environmental records (salinity, water level, temperature, rainfall and evaporation rates) and porewater salinities to temporal patterns of mortality (Carlson, 227). Carlson suggested that inundation of mangrove islands with high salinity water, which then evaporates leaving salinas with very high pore water salinity, caused lethal stress of island interior mangroves. He also suggested that sulfide toxicity may be a factor. Carlson’s results are highly inferential and based on hindcasting pore water salinity. In the Panel's opinion they are not yet conclusive and require physiological measurements to confirm. Furthermore, his results should be compared and reconciled with those of Kramer (107) who found that porewater salinity in salinas is little influenced by ambient water salinity, but is more a feature of evaporation.

## Overall Evaluation and Recommendations

### *Accomplishments*

There has been an impressive expansion of the scientific investigation of Florida Bay since 1993. Some of these investigations are providing information which was has been largely lacking: preliminary hydrological and hydrodynamic models; paleoecological reconstructions of past environmental conditions; the first detailed characterization of phytoplankton and zooplankton communities; and regular aerial surveys of blooms and turbidity. Monitoring programs have been put into place which will be able to detect meaningful changes to the Bay in the future and are already yielding useful results. In addition, it is noted that some of the intense controversies which existed two years ago, while not fully resolved, have been placed in a more productive framework for resolution. Furthermore, it bodes well for long-term capabilities for the application of science to management to see the regional universities and research institutions more actively engaged in Florida Bay research.

### *Toward Strengthening the Florida Bay Science Program*

1. The large number of projects and investigators, overlap among the projects, and suboptimal coordination among projects gives the impression of a "shotgun" rather than a "rifle" approach. The fact that there are 11 discipline-oriented topic areas is a graphic reflection of suboptimal coherence and focus at this point. In addition to some unnecessary duplication and several projects which do not seem to address critical questions, some key issues are not adequately addressed, e.g., (a) the exact causes of seagrass dieoff, including the role of salinity, sulfide toxicity and light limitation; (b) resuspension, deposition and transport of sediments; and (c) phytoplankton-nutrient dynamics. The program should more tightly focus on the key strategic issues—at the expense of other, less central questions, if necessary—and insure that the most relevant science is adequately supported with appropriate continuity.

2. A very large proportion of the effort consists of surveys and monitoring. Such approaches are unlikely to answer key management questions, at least within an acceptable time frame. While surveys and monitoring are needed to provide background information and document future changes, more of the scientific investigations should be directed to hypothesis testing. This will require more experimentation (e.g. for resolving the mechanisms of seagrass mortality and phytoplankton nutrient limitation) and fewer observations not tied to testing specific hypotheses.

3. Many of the investigators did not demonstrate an understanding of the relationship of their study element to the whole environment and to environmental changes and management options. While this may in part be a result of the early stage of many of the projects, understanding of the context of the investigation by the investigators must be sound from the start. Emphasis should be placed on the development of models which reflect the relationships among physical, chemical, geological and biological components and processes. While physical modeling should appropriately strive to be quantitative and predictive, conceptual and modeling of ecosystem processes should precede numerical model development. In particular, more emphasis should be placed on mass balance approaches to understanding nutrients and carbon as well as salinity.

4. There should be flexibility and resources to allow for a rapid, tactical response to investigate unusual events such as hurricanes and major freshwater inflow events. These provide opportunities for natural experiments which reveal much about important environmental processes. Furthermore, such infrequent events may have major long-lasting effects on the Bay.

5. In general, the boundary relationships of the Florida Bay ecosystem (exchanges with the Everglades, the Gulf of Mexico, Hawk Channel, and the atmosphere) deserve more attention. In particular, transport and transformation processes between the Shark River/Mangrove Coast region and Florida Bay and transport of algal blooms and sediment into Hawk Channel loom important.

6. Although data sharing and collaboration among some projects was apparent, it was clear that for many others such interaction had not yet occurred. An annual meeting is insufficient for this purpose. Rather the Program Management Committee should, as a matter of urgency, foster and facilitate appropriate interaction among investigators to exchange information, resolve key issues and point out the most effective strategic directions. An effective mechanism would be structured workshops focused on critical questions, e.g. nutrient-phytoplankton relationships, seagrass physiology and mortality, and the quantitative importance of material import and export. Workshops should be limited to a small number of participants, including the central investigators and a few outside experts (to keep the process honest), and should develop consensus or identify ways to resolve disagreements. Such small workshops can be successful in linking science and management and resolving or refining scientific questions if they are led by a skilled and knowledgeable facilitator, directed toward a specific goal, and preceded by some level of pre-workshop analysis.

7. Data management systems should be developed in order to facilitate data sharing and accessibility by investigators and to insure data preservation. However, avoid overprescription of formats and centralized databases which become burdensome. Rather, develop networks that link distributed databases. Geographic information systems may be particularly valuable tools to relate diverse spatial data.

8. Science is a human endeavor and cannot simply be prescribed by a science plan or request for proposal. It is important that the Florida Bay Research Program engage experienced, committed, imaginative scientists and keep them involved, while at the

same time bringing in new expertise and ideas. Some scientists who are among the most knowledgeable of and committed to Florida Bay science have not been adequately involved in the Florida Bay Research Program. They should be more effectively engaged not only for the research they can perform but for the knowledge and ideas they can share.

9. Peer review of proposals or project plans seems to have varied widely among agencies. The Program Management Committee should commit to external peer review of proposals and reports and insure that external peer review is applied within the mechanisms available within the sponsoring agencies.

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