FLORIDA BAY CONCEPTUAL ECOLOGICAL MODEL

A. Model Lead

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B. Introduction

A simple conceptual model of the Florida Bay ecosystem is presented here. This model is consistent with our effort to assess the current understanding of south Florida's ecosystems, identify the most important human effects on these ecosystems, identify restoration goals and success criteria, and identify the minimum measurements required to determine whether these criteria are being met. The structure of the model is largely based on the expert opinions of scientists who have focused their attention on Florida Bay during the past several years. During this time, detailed reviews of our understanding of the Florida Bay have been presented (Boesch et al. 1993, Boesch et al. 1995, Boesch et al. 1997, Fourqurean and Robblee 1999). Detailed plans that identify quantitative information needs for environmental management decision making, as well as strategies to provide this information, have also been presented (Armentano et al. 1994, Armentano et al. 1997). While the conceptual model presented here is largely consistent with the body of knowledge described in the reviews and plans noted above, some details or omissions of this model may not be consistent will the opinions of some contributors to the interagency Florida Bay research program.

Florida Bay Primer

Florida Bay is a triangularly shaped estuary, with an area of about 850 square miles, that lies between the southern tip of the Florida mainland and the Florida Keys. About 80% of this estuary is within the boundaries of Everglades National Park. A defining feature of the bay is it's shallow depth, with a mean depth of about 1 meter (Schomer and Drew 1981). This shallowness allows light to penetrate through the water to the sediment surface in almost all areas of the bay and results in the potential for the bay to sustain seagrass beds as a dominant habitat and source of productivity. The shallowness of the bay also affects the circulation and salinity regime of the bay; with a complex network of shallow mud banks, water exchange among the bay's basins and between these basins and the Gulf of Mexico is restricted (Smith 1994, Wang et al. 1994). With a long residence time and shallow depth, the salinity of Florida Bay water can rapidly rise during drought periods. Salinity levels as high as twice that of seawater have been measured (McIvor et al. 1994). Another defining feature of the bay is that the sediments are primarily composed of carbonate mud, which can scavenge inorganic phosphorus from bay waters (DeKanel and Morse 1978).

Until the 1980s, Florida Bay was perceived by the public and environmental managers as being a healthy estuary, with clear water, lush seagrass beds, and productive fish and shrimp populations. By the mid 1980s, however, catches of pink shrimp had declined dramatically (Browder et al. 1999) and in 1987, the mass mortality of turtle grass (*Thalassia*) beds began (Robblee et al. 1991). By 1992, the ecosystem appeared to shift from a clear water system, dominated by primary production on the sediment (benthic production) to a turbid water system, dominated by algae blooms in the water column and resuspended sediment. The conceptual model focuses on these changes in seagrasses and water quality as the central issues to be considered by environmental managers.

Reality Check

The simple model presented below does not address the spatial complexity of Florida Bay. Florida Bay is, indeed, not so much a singular estuary, but a complex array of basins, banks, and islands that differ across a set of regions. The mosaic of seagrass habitat and mangrove habitat, as well as water quality and ecosystem processes, vary distinctly with this spatial variation. Nevertheless, only a single, generic model is described and this model is intended to summarize the main characteristics and trends of the bay. While the structure of this model is appropriate for most areas of the bay, the relative importance of the model's components differ considerably among the bay's sub-regions. Any application of this model (for example, recommendations for a specific set of monitoring parameters and guidelines) must take the spatial variability of the bay into account.

C. External Drivers and Ecological Stressors

It has often been assumed that a direct cause of Florida Bay's ecological changes is a long-term increase in the Bay's salinity that resulted from the diversion of freshwater away from Florida Bay via SFWMD canals. However, recent research has indicated that the Bay's changes are not attributable to a single cause - while decreased freshwater inflow and resultant increased salinity have been part of the problem, it appears that other human activities, as well as natural forces, have also contributed to the problem (Armentano et al. 1997, Boesch et al. 1993, Boesch et al. 1995, Boesch et al. 1997, Fourqurean and Robblee 1999). The conceptual model thus includes both natural and human derived sources of stress.

Altered Salinity Regime

The salinity regime of an estuary is a primary determinant of the species composition of communities, as well as strongly influencing functions of these communities (Sklar and Browder 1998). Salinity is a direct stress on biota; all estuarine biota have adapted to a given salinity range and a given degree of salinity variability. For a given organism, changing salinity beyond this range or too quickly within this range can result in poor health or death. Thus long-term changes in salinity *level* or *variability* are detrimental to some species, but favorable for other species.

Florida Bay's salinity regime varies greatly over time and space. This variation ranges from coastal areas that can be nearly fresh during the wet season, to large areas of the central bay that can have salinity levels near 70 ppt during prolonged droughts, to nearly stable marine conditions (about 35 ppt) on the western boundary of the bay. The main forces that determine salinity regime in the bay are the inflow of freshwater from the Everglades, rainfall over the bay, evaporation from the bay, and exchange with seawater from the Gulf of Mexico and the Atlantic Ocean. Both freshwater inflow and seawater exchange have changed drastically in the past hundred years, resulting in an alteration of the bay's salinity regime.

Freshwater inflow to Florida Bay decreased in volume and changed in timing and distribution during this century because of **water management**. Hydrologic alteration began in the late 1800s, but accelerated with the construction of drainage canals by 1920, the Tamiami Trail by 1930, and the C&SF Project and South Dade Conveyance System from the early 1950s through 1980 (Light and Dineen 1994). With the diversion of freshwater to the Atlantic coast and Gulf of Mexico coast, the bay's mean salinity inevitably increased. The extent of this increase and how the variability of salinity changed is not known, but is the subject of current research.

Results from this research indicate that another important development that altered the salinity regime of Florida Bay was construction of the **Flagler railway** across the Keys from 1905 to 1912 (Swart et al. 1996, Swart et al. 1999). It appears that in the last century, prior to railway construction and water management, Florida Bay had a lower mean salinity and more frequent periods of low (10 ppt - 20 ppt) salinity than during this century. The extent and frequency of high salinity events does not appear to have changed between centuries. The bay's salinity regime changed abruptly around 1910 because passes between the Keys were filled to support the railway. Thus, water exchange between Florida Bay and the Atlantic Ocean was decreased and water circulation throughout the bay was probably altered.

Two important natural controls of salinity, **sea level rise** and the frequency of **major hurricanes** must also be considered. Florida Bay is a very young estuary, the product of sea level rising over the shallow slope of the Everglades during the past 4000 years. With rising sea level, the bay not only became larger but also became deeper. With greater depth, exchange of water between the sea and the bay probably increased, resulting in a more stable salinity regime with salinity levels increasingly similar to the sea. However, a factor that has counteracted the rising sea is the accumulation of sediment, which makes the bay more shallow. Most sediment that accumulates in Florida Bay is carbonate that is precipitated from water by organisms that live in the Bay. The extent to which these sediments accumulate is a function of the biology of these organisms, the chemistry of the water, and the physical energy available to transport some of these sediments from the Bay. **Major hurricanes** are thought to be important high energy events that can flush the bay of these sediments. However, since 1965, no major hurricane has directly affected Florida Bay. Florida Bay's ecological changes during the past decade may thus be indirectly influenced by changing circulation patterns and resultant changing salinity regimes because of changing water depth in the bay.

Nitrogen and Phosphorus Inputs

The productivity and food web structure of all ecosystems is strongly influenced by patterns of nutrient cycling and the import and export of these nutrients. Throughout the world, estuarine ecosystems have undergone dramatic ecological changes because they have been enriched by nutrients derived from human activity. These changes have often been catastrophic, with the loss of seagrasses and the occurrence of algal blooms and lethal low oxygen or anoxic events. The input of nitrogen and phosphorus (N and P) to estuaries is thus a potentially important stressor of estuaries.

The importance of N and P as stressors in Florida Bay is unclear. In general, the bay is rich in N and poor in P, especially towards the eastern region of the bay (Boyer et al. 1997). There is little evidence that nutrient inputs to the bay have increased during this century, but with expanding agriculture and residential development in south Florida through this century, and particularly development of the Keys, nutrient enrichment almost certainly has occurred (Lapointe and Clark 1992, Orem et al. 1999). Anthropogenic nutrients that enter Florida Bay are derived not only from such local sources (fertilizer and wastes from agriculture and residential areas), but also from remote sources. It is likely that remote contributions to the Gulf of Mexico, such as from the phosphate fertilizer industry of the Tampa-Port Charlotte area and residential development from Tampa to Naples, are the most important external sources of nutrients (Rudnick et al. 1999). This enrichment from external sources, however, may be less important to the bay's ecology than it's own internal sources and cycling. It is, nevertheless, a reasonable hypothesis that a chronic increase in nutrient inputs has occurred in Florida Bay in this century and this increase has contributed to ecological changes. Ongoing research will provide information to test this hypothesis. Development of a water quality model will also help us understand the effects of past nutrient inputs and predict the effects of future management scenarios.

In the conceptual model, **water management** is listed as a source of stress because the canal system can transport nutrients through the wetlands toward the bay, decreasing nutrient retention by the wetlands and possibly increasing nutrient inputs to the bay. Nutrient inputs from the Everglades and the Gulf of Mexico are affected not only by changes of freshwater flowing from Taylor Slough and Shark River Slough, but also by changes in bay circulation. Nutrient retention within the Bay is certainly sensitive to these changes in circulation, which have been caused by **Flagler railway** construction and the balance of sea level rise and sedimentation or sediment removal by **major hurricanes**. The influence of hurricanes may be particularly important, as nutrients (particularly P) accumulate in the bay's carbonate sediment and the absence of major hurricanes may have resulted in an accumulation of nutrients during the past few decades.

Pesticides and Mercury

With the widespread **agriculture and residential development** of south Florida, the application and release of pesticides and other toxic materials has increased. Mercury is of particular concern because of high concentrations of methylmercury in upper trophic level species. However, it is unclear whether anthropogenic mercury inputs to the Everglades or Florida Bay have increased or whether, perhaps more importantly, mercury cycling and methylation rates have changed. Pesticides and mercury are of concern because they can affect human health after the consumption of fish or other biota with high concentrations of these toxins, and because other species may be adversely affected by these compounds. To date, there is no evidence the main ecological changes in Florida Bay are in any way linked to inputs of toxic compounds. Water management affects the distribution of these toxic materials and potentially their transport to Florida Bay. Controlling water levels in wetlands may also influence the decomposition of pesticides and mercury methylation rates because both of these processes are sensitive to the presence of oxygen in soils, which is affected by water levels.

Fishing Pressure

For any species that is the target of recreational or commercial fisherman, fishing pressure directly affects population dynamics and community structure. Within Everglades National Park, commercial fishing has been prohibited since 1985, but populations that live outside of ENP boundaries for at least part of their life cycle, which includes most of Florida Bay's sport fish species, are nevertheless affected by fisheries (Tilmant 1989).

D. Ecological Attributes

A set of Florida Bay's attributes that are either indicators of the health of the ecosystem or intrinsically important to society are given in the conceptual model. These attributes in most cases are biological components of the ecosystem, including seagrass, mollusks, shrimp, fish and birds, but also an aggregated attribute (water quality condition) that includes phytoplankton blooms and aspects of the Bay's chemical and physical condition. While the list of biological components is broad, it is clear from the links to stressors that are presented that these attributes are not equally weighted within the model; the central attribute of this conceptual model of Florida Bay is the seagrass community. Details of each attribute and linkage are given below.

Seagrass Community

The keystone of the Florida Bay ecosystem is its seagrasses (Zieman et al. 1989, Fourqurean and Robblee 1999). These plants are not only a highly productive foundation of the food web, but are also the main habitat of higher trophic levels and a controller of the bay's water quality. Understanding how seagrasses affect water quality is essential for understanding the current status and fate of the bay.

Seagrasses affect water quality by three mechanisms: nutrient uptake and storage, binding of sediments by their roots, and trapping of particles within their leaf canopy. With the growth of lush seagrass beds, these mechanisms drive the bay towards a condition of clear water, with low nutrients for algae growth in the water and low concentrations of suspended sediment in the water. During the 1970s through the mid-1980s, lush *Thalassia* beds grew throughout central and western Florida Bay and the water was reported to be crystal clear. We hypothesize that with the onset of a *Thalassia* mass-mortality event in 1987 (Robblee et al. 1991), these mechanisms reversed, initiating a cycle that causes continued **seagrass habitat loss** and propagates persistent turbid water with algae blooms (Stumpf et al. 1999).

The cause of the 1987 mass-mortality event is not known, but thought to be related to earlier changes in two stressors, the salinity regime and nutrient availability. These changes caused *Thalassia* beds to grow to an unsustainable density by the mid 1980s. It is also likely that a decrease in shoal grass and widgeon grass (*Halodule and Ruppia*) occurred with the *Thalassia* increase. *Thalassia* "overgrowth" may have occurred because the species thrived when the salinity regime of the bay was stabilized, with few periods of low salinity. Nutrient enrichment also may have played a role, with a chronic accumulation of nutrients caused by increased inputs over decades or decreased outputs because of the absence of major hurricanes or closure of Keys' passes. The factors that conspired to initiate the mass-mortality event in 1987 are also unknown, but thought to be related to the high respiratory demands of the dense grass beds and accumulated organic matter. During the summer of 1987, with high temperatures, sulfide levels may have risen to lethal concentrations. Low concentrations of dissolved oxygen in hypersaline bottom water may have been a critical component of this die-off scenario.

Regardless of the cause of the mass-mortality event, once this event was initiated, the ecology of Florida Bay changed. The cycle causing continued seagrass habitat loss, which characterizes the present Florida Bay, is illustrated in the model. Continued seagrass mortality results in increased sediment suspension (Prager and Halley 1999) and increased nutrient release from the sediments (>N & P), stimulating the growth of phytoplankton in the water column. The presence of both phytoplankton and suspended sediment result in decreased light penetration to the seagrass bed. In this cycle, it is this decreased light that stresses the seagrasses and sustains the feedback loop. Light penetration is thus an essential aspect of the attribute, water quality.

The dynamics of this feedback loop are probably not independent of the salinity regime. A disease of seagrass, caused by a slime mold infection, seems to be more common at salinities near or greater than seawater (= 35 ppt) than at low (15 to 20 ppt) salinities (Landsberg et al. 1996). This may have played a role in either the initial seagrass mass mortality event, but more likely has served to continue seagrass mortality since that event. The incidence of this disease may be directly affected by water management actions.

If the state of the seagrass community is to be used as a criterion to decide the success of environmental restoration efforts, environmental managers must specify the desirability of alternative states. The consensus among scientists is that the Florida Bay of the 1970s and early 1980s, with lush *Thalassia* and clear water, was probably a temporary and atypical condition. From an ecological perspective, restoration should probably strive for a more diverse seagrass community, less dominated by *Thalassia* than during that period.

Water Quality Condition

Water quality condition reflects not only obvious characteristics, such as salinity, but also the light field, algal blooms in the water column, and the availability of nutrients in the ecosystem. All of these characteristics are closely related to the condition of seagrasses and the food web structure and dynamics of the bay. While these characteristics have been monitored and researched since the early 1990s, earlier information is scarce for salinity and even less available for other characteristics. Thus, at the present time, we do not know whether nutrient inputs to the bay have actually increased in recent decades or whether periods with sustained algal blooms and high turbidity occurred in the past.

Salinity has frequently been suggested as a primary restoration target. However, establishing salinity success criteria, such as those used in the Restudy's evaluation of the effects of hydrological alternatives on coastal salinity, depends on the development of a model of the "natural" salinity distribution of Florida Bay in time and space. This requires a both a water budget for the bay (monitoring rainfall, evaporation, and freshwater flow, groundwater flow, water level, and salinity) and a hydrodynamic model, which is now under development. With modeled salinity variability for a wide variety of target sites in the Bay, the fit of observed salinity fields to modeled fields could serve as the basis of deciding levels of success.

The magnitude of nutrient inputs to the bay and their relationship to freshwater inputs is under investigation. Success criteria based on water column nutrient concentrations are probably less meaningful than criteria based on nutrient loading. Preliminary results indicate that phosphorus loads to the bay do not greatly increase with increased freshwater inputs (Rudnick et al. 1999), but Florida Bay is probably very sensitive to any increase in P availability. Unlike phosphorus, nitrogen loads probably do increase with more freshwater flow and algae blooms in western and central Florida Bay appear to be stimulated by increased N (Tomas 1996). The potential thus exists for hydrological restoration to increase N loading and stimulate phytoplankton blooms (Brand 2000). Because most of the N that is exported from the Everglades to the Bay is in the form of organic compounds (Rudnick et al. 1999), the fate of these compounds within the bay is a critical unknown; if these compounds are easily decomposed and their N is available to algae, then increased freshwater flow could stimulate algal growth. However, internal losses (denitrification) of this N may compensate for any increased N supply.

Finally, as emphasized earlier, the penetration of light through Florida Bay waters is a key to the health of seagrasses. An important success criterion should be light penetration, which is largely a function of turbidity from algae and suspended sediment. Light penetration should be sufficient to support a viable seagrass habitat. Such light-based criteria have been used successfully in other estuaries.

Mollusks and Benthic Grazers

Consumption of phytoplankton cells by mollusks and other benthic filter feeders and suspension feeders may have a significant impact on the distribution, magnitude, and duration of algal blooms. The long-term abundance and biomass of these grazers may increase such that blooms decrease. However, some grazers may be negatively affected by the blue-green algae [*Synechococcus* sp., the dominant species in central Florida Bay's algal blooms (Phlips and Badylak 1996)] and loss of seagrass habitat loss. Mollusk abundance, biomass, and distribution should be monitored because of their functional link with phytoplankton blooms and also because their shells provide information on historical community structure. The composition and activity of the mollusk community is a function of salinity, seagrass and other habitat availability, and food supply. Studies of long-term changes in the composition of this community (by analyzing shells in the sediment) have indeed found changes that reflect the large-scale changes of the bay's salinity regime. Furthermore, because mollusks can be important as grazers of phytoplankton, the trophic status of the bay is reflected by mollusk community composition. It is also important to monitor other major invertebrate groups that could control phytoplankton blooms, such as sponges and tunicates. With increased phytoplankton blooms, benthic filter feeders and other grazers may increase such that they decrease these blooms.

Pink Shrimp

Pink shrimp are intrinsically important to society as an economic asset. They are also ecologically important, serving as a major component of the diet of game fish and wading birds; pink shrimp are an indicator of the bay's productivity. Florida Bay and nearby coastal areas are a primary nursery ground for pink shrimp - a nursery that supports the shrimp fishery of the Tortugas Grounds (Ehrhardt and Legault 1999). Hydrological and ecological changes in the Everglades and Florida Bay may have impacted this fishery, which experienced a decline in annual harvest from about 10 million pounds per year in the 1960s and 1970s to only about 2 million pounds per year in the late 1980s (Ehrhardt and Legault 1999). This decline may have been associated with seagrass habitat loss or high salinity (50 to 70 ppt) during the 1989-1990 drought; experiments have shown that pink shrimp mortality rates increase with salinities above 40 ppt (Browder et al. 1999). Shrimp harvest statistics indicate that shrimp productivity increases with increasing freshwater flow from the Everglades (Browder et al. 1999).

Fish Populations

The health of Florida Bay's fish populations is of great importance to the public; the sport fishing is a major economic asset to the region. It is clear from recent studies that seagrass beds and the mangrove zone are important habitats for fish, but no dramatic baywide decreases in fish abundance have been observed along with seagrass mass-mortality (Thayer et al. 1999). Rather, a shift in the species composition of this upper trophic level has occurred as a result of the cycle of seagrass habitat loss and sustained algae blooms. While some fish species have declined, fish that eat algae in the water, such as the bay anchovy, are thriving. Thus the stressors, such as altered salinity, not only affect upper trophic level animals directly, but also affect them indirectly through food web changes.

Another important stressor that needs to be considered with regard to fish populations is the impact of pesticides and mercury. As concentrations of mercury and some pesticides greatly increase in upper trophic level animals, such as sport fish, (via the process of bioaccumulation), and if people eat such fish, a human health issue potentially exists. Pesticides and mercury can also have ecological impacts by physiologically stressing organisms (particularly reproductive functions). The extent of any existing problem with these toxic compounds in Florida Bay is being investigated, but they currently do not appear to significantly impact human health or ecological health in the bay. The possible impact of future restoration efforts on these issues, however, must still be considered.

Among the many fish species that could be used as indicators of the health of the ecosystem's upper trophic level, there is consensus among scientists that spotted sea trout is a key species. This is the only major sport fish species that spends its entire life-span in the bay. Population changes and toxic residues in this species thus reflect the specific problems of the bay and should also reflect the restoration actions that we take. For northeastern Florida Bay, the abundance of snook, red drum, crevalle jack, and mullet should also be considered.

Birds

Florida Bay and its mangrove coastline is an important feeding ground and breeding ground for water fowl and wading birds. Conceptual models for other regions of the Everglades, particularly the mangrove - estuarine transition zone conceptual model, present more detailed descriptions of the use of bird populations as ecological indicators and consider a wide variety of birds. For the Florida Bay conceptual model, we consider only fish-eating birds, such as osprey, brown pelicans, and cormorants. These birds are important predators of fish in the bay and are potentially impacted by any stressors that affect their prey base, including salinity changes, nutrient inputs, toxic compounds, and fishing pressure. As with other top predators, these bird species are the most vulnerable members of the ecosystem with regard to pesticide and mercury effects.

E. Ecological Effects

Critical Linkages Between Stressors and Attributes/Working Hypotheses

Unlike the previous text of this narrative, the following description of hypotheses is preliminary and, as of January 2001, has not been reviewed by members of the Florida Bay scientific community or the interagency research program's peer review panels. More detailed descriptions and reviews of many of the ideas presented below, as well as this narrative as a whole, can be found on the web page of the Florida Bay and Adjacent Marine Systems Science Program (www.aoml.noaa.gov/flbay/; see "Science Program" and then "Documents").

Estuarine Geomorphology and Water Circulation

Relationship of Mud Bank Dynamics and Accretion to Sea Level Rise

The mud banks and associated seagrass beds of Florida Bay will accrete sediments at rates comparable to predicted rates of sea level rise, which are estimated to be roughly two feet during the next 100 years. Persistence of the mud banks will sustain patterns of banks and basins, and related circulation patterns much as they are today, even with the occurrence of future major hurricanes.

Level of Certainty – moderate

Relationship of the Exchange and Circulation of Gulf and Atlantic Water

Predicted rates of sea level rise during the next century will increase the exchange and circulation of Gulf and Atlantic water in Florida Bay, shifting the Bay from an estuarine to a more marine system. Construction of the Flagler Railway and Keys Highway decreased water exchange between the Bay and Atlantic, increasing water residence time in the Bay and changing circulation and salinity patterns.

Level of Certainty - moderate

Hydrologic Restoration and Water Quality Condition

Linkage of Everglades Hydrology to Freshwater Inflow, Circulation and Water Quality in Florida Bay

Water quality and circulation of coastal systems are linked to inland, freshwater wetlands through a combination of diffuse overland flow, creek and river flow, and groundwater seepage. The salinity regime of Florida Bay, as well as many other aspects of the Florida Bay ecosystem (water residence time, stratification, nutrient loading, etc.) depend upon the quantity, timing, and distribution of freshwater inputs to the Bay. Planning and implementation of ecosystem restoration requires the capability to link, through a predictive model, changes in hydrology of Everglades wetlands and consequent changes in Florida Bay and adjacent coastal ecosystems. These linkages have yet to be modeled and this is perhaps the highest priority need for Florida Bay restoration.

Level of Certainty - low

Relationship of Phytoplankton Blooms to Nutrient Sources, Seagrass Die-off, Sediment Resuspension and Circulation Pattern

The spatial extent, duration, density and prevalence of *Synechococcus* in phytoplankton blooms in central Florida Bay are controlled by the combined and inter-related effects of external N loading, internal P cycling, seagrass die-off, sediment resuspension and water residence time. Seagrass die-off results in increased phytoplankton growth because of increased sedimentary nutrient mobilization, reduction in competition for water column nutrients, and decreased grazing pressure because of the loss of habitat for benthic filter feeders. Sediment resuspension due to seagrass die-off supplies additional water column nutrients via both porewater advection and desorption of surface-bound nutrients from resuspended particles, which is salinity dependent. The latter process may be an important P source for phytoplankton.

Level of Certainty – low

Relationship of Phytoplankton Blooms to Dissolved Organic Nutrients

Dissolved organic nutrients are available to phytoplankton and support phytoplankton blooms in Florida Bay. Increased inputs of dissolved organic nitrogen from the restoration of natural water inflows from the Everglades will thus increase the prevalence of phytoplankton blooms in Florida Bay.

Level of Certainty – low

Relationship of Salinity to Nutrient Cycling and Availability

Reduced incidence of hypersalinity will yield greater P retention within the Bay sediments. With this greater retention, the extent of P limitation in the Bay will increase and algal growth will decrease.

Level of Certainty - moderate

Functional Importance of Florida Bay as Source and Sink for Nitrogen

There is a net loss of nitrogen in Florida Bay because of rapid denitrification. Both nitrogen fixation and denitrification occur within Bay sediments and seagrass beds and the rates of these processes are likely to greatly exceed the rate of N input from the Everglades watershed. The impact of any change of N loading to the Bay that is associated with hydrologic restoration will depend upon the relative magnitude of these rates. Internal N cycling rates (and the balance of nitrogen fixation and denitrification) will also change with restoration, because of changing salinity and seagrass community structure.

Level of Certainty - low

Seagrass Community

Relationship of Seagrass Community to Light Penetration, Nutrient Availability, Salinity Sulfide Toxicity, Epiphyte Load, and Disease

The spatial coverage, biomass, production and taxonomic composition of seagrass beds in Florida Bay are controlled by the combined and inter-related effects of light penetration, epiphyte load, nutrient availability, salinity, sulfide toxicity, and disease. Decreased salinity caused by increasing freshwater flow will have a direct effect on seagrass communities through physiological mechanisms, resulting in greater spatial heterogeneity of seagrass beds, a decrease in the dominance of *Thalassia testudinum*, and an increase in coverage by other seagrass species. Decreased salinity will also decrease the importance of slime mold infection of *Thalassia*. Light availability will depend upon phytoplankton growth and sediment resuspension, which depend both on nutrient availability, grazing, and seagrass bed binding of sediments.

Level of Certainty – moderate

Estuarine Fish Communities and Fisheries

Seagrass Habitat and Salinity as Determinants of Fish Community Structure

Seagrass habitat loss and sustained algae blooms have resulted in a community shift from demersal to pelagic fish species, including increased abundance of fish that eat algae in the water, such as the bay anchovy. Elevated salinity has resulted in a community shift from euryhaline to marine fish species.

Level of Certainty - moderate

Relationship of Spotted Seatrout Populations to Salinity

Juvenile density and sport catch of spotted seatrout in Florida Bay reflect the suitability of estuarine habitat and nursery grounds as influenced by salinity. Density of post-larvae are highest at an intermediate salinity range of 20-30 ppt, and density drops when salinity exceeds 35 ppt. Juvenile density is expected to increase due to the resumption of natural volumes and timing of freshwater flow into the Bay, in response to a reduction in the frequency and duration of hyper-salinity events. Adult abundance and distribution based on sport CPUE should reflect juvenile growth and survival, although that relationship is not presently known.

Level of Certainty – moderate

Relationship of Pink Shrimp Juvenile Density and Adult CPUE to Salinity and Freshwater Flow

Juvenile density of pink shrimp in Florida Bay reflects the suitability of estuarine nursery grounds as influenced by salinity. Optimal salinity conditions for survival appear to be somewhat below that of seawater (35 ppt). Pink shrimp juvenile density is expected to increase in Florida Bay in response to the restoration of estuarine salinity ranges and the reduction of the frequency and duration of hyper-salinity events. Beneficial conditions in Florida Bay will contribute to increased annual catch per unit effort in the Tortugas fishing grounds.

Level of Certainty – moderate

F. Research Questions

Although Florida Bay is one of the most intensively studied ecosystems in south Florida, two key areas of uncertainty hamper our ability to predict ecological responses to the restoration of freshwater flows to Florida Bay. They pertain to: 1) the hydrologic linkage between the Everglades and the Bay, including the relationship of changing upland hydrologic conditions to freshwater flow to the Bay and water circulation and salinity within the Bay; and 2) the fate and ecological consequences of increased nutrient inputs that may accompany restored in flows to the Bay.

Linkage of Everglades Hydrology to Freshwater Inflow

How does Everglades hydrology relate to the inflow and circulation of freshwater in Florida Bay? Develop a validated, predictive model to link changes in Everglades hydrology to consequent changes in the freshwater inflow and circulation of surface and ground water in the Bay. Develop validated hydrodynamic and water quality models of the Bay that can accurately predict water residence times and salinity in the Bay.

Fate and Ecological Consequences of Increased Nutrient Inputs That May Accompany Restored Freshwater Inflows to the Bay

What is the functional importance of Florida Bay as a source and sink of nitrogen? Is there a net loss of nitrogen in Florida Bay via denitrification? Measure quantitative relationships of nitrogen inputs from the Everglades and dentrification and nitrogen fixation rates within the Bay, their relationships to salinity patterns, and model how they will change with restoration of natural freshwater inflows and salinity patterns. Will increased inputs of dissolved organic nitrogen from the restoration of natural water inflows of the Everglades result in an increase in the prevalence of phytoplankton blooms in Florida Bay? Determine the extent to which dissolved organic nutrients in different sources of water, particularly Everglades runoff, are mineralized. Determine the availability of dissolved organic nutrients in different water sources directly to phytoplankton.

Relationship of Phytoplankton Blooms to Nutrient Sources, Seagrass Die-off, Sediment Resuspension and Circulation Pattern.

Are phytoplankton blooms strongly influenced by factors other than nitrogen availability? Measure rates of phosphorus supply, grazing (particularly benthic grazing), and relationships with seagrass cover and sediment resuspension and include these dynamics in a water quality model.

G. Hydrologic Performance Measures

Salinity Pattern

Salinity patterns will be altered as a result of the modification of the volume, timing and distribution of freshwater inflow. The desired alterations include less abrupt and less extreme decreases in salinity in northeastern Florida Bay; a reduction in the frequency, extremity and extent of hypersaline conditions in the central, southern and western bay; an increase in the frequency and extent of low salinity conditions in the central bay; and an increase the frequency and extent of salinities less than that of seawater in the western bay, extending westward along the Gulf of Mexico coastal shelf to Lostman's River. (Text provided by Kim Jacobs, SWMD)

H. Ecological Performance Measures

A list of fundamental measures associated with each of the model's ecosystem attributes is given in **Table A-3**. This list should be considered minimal; interpretation of many of these measures requires a set of associated measures. The list includes not only "structural" variables (for example, pink shrimp abundance), but also dynamic, process variables (for example nutrient fluxes). Note that this list does not reflect the temporal or spatial time scale at which measurements are necessary, but temporal patterns, such as seasonality and interannual variability, and spatial patterns are a central aspect of ecological dynamics. Also note that the power to predict the fate of any ecosystem requires more than monitoring; research and modeling are also essential, with these three interdependent approaches providing the scientific basis for environmental management.

Table A-3. Ecological performance measures for the Florida Bay Conceptual Ecological Model listed by attribute

Water Quality Condition	
Salinity	Phytoplankton
Dissolved Oxygen	Nutrient Concentrations
Freshwater Inflow	Nutrient Fluxes
Water Budget	Sediment Nutrients and Toxics
Light Extinction and Turbidity	
Seagrass Community	
Spatial Heterogen	Coverage
Biomass	Pure Water Sulfide
Productivity	Disease Frequency
Mollusks and Filter Feeders	
Grazing Rates on Phytoplankton	Mollusk Abundance and Diversity
Zooplankton and Benthic Grazer Biomass	
Pink Shrimp	
Abundance	Mortality
Productivity	
Fish Community	
Diversity	**Mortality**
Abundance	Toxic Residues
Productivity	
Fisheating Birds	
Abundance	**Mortality**
Reproduction	Toxic Residues

I. Model

The diagram for the Florida Bay Conceptual Ecological Model is presented in **Figure A-14**. The key to the symbols used in the diagram is presented in **Figure A-13**.

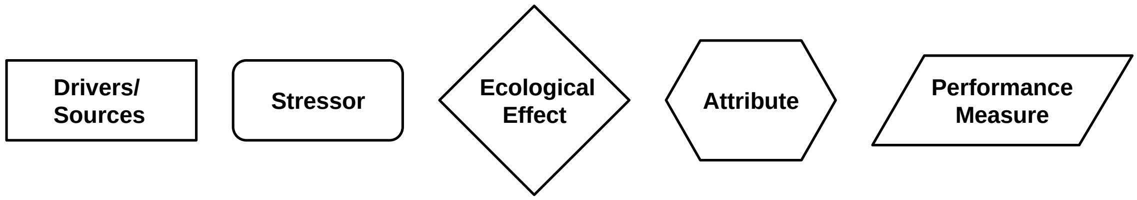

Figure A-13. Key to the symbols used in the following diagram

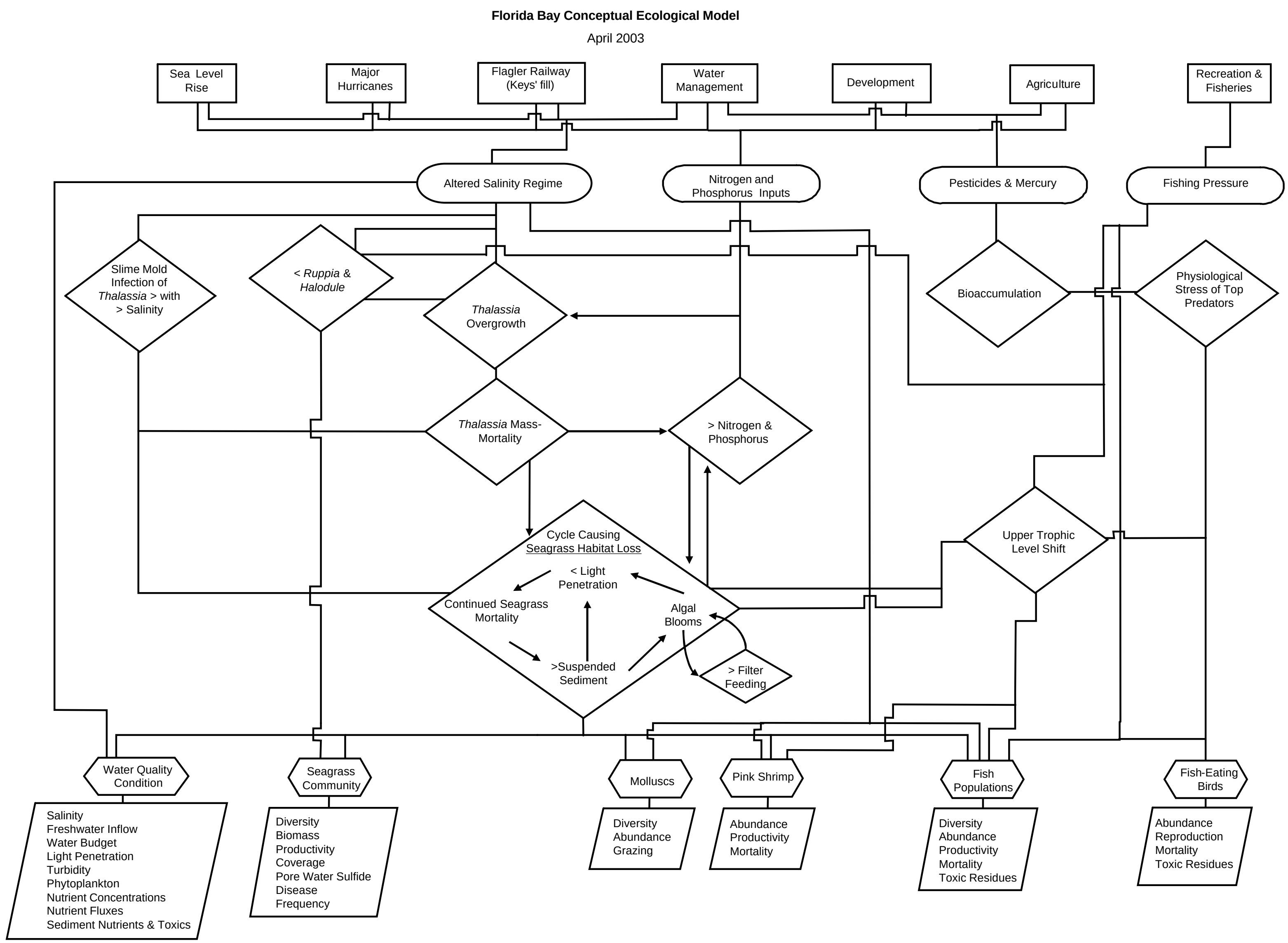

Figure A-14. Florida Bay Conceptual Ecological Model diagram

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