EXHIBIT 7

WETLANDS, Vol. 25, No. 4, December 2005, pp. 854–869

BISCAYNE BAY CONCEPTUAL ECOLOGICAL MODEL

Joan A. Browder[1], Richard Alleman[2], Susan Markley[3], Peter Ortner[4], and Patrick A. Pitts[5]

[1] *National Marine Fisheries Service/National Oceanic and Atmospheric Administration*
75 Virginia Beach Drive
Miami, Florida, USA 33149

[2] *South Florida Water Management District*
3301 Gun Club Road
West Palm Beach, Florida, USA 33406

[3] *Miami-Dade County Department of Environmental Resources Management*
33 SW 2nd Ave.
Miami, Florida, USA 33130

[4] *National Oceanic and Atmospheric Administration*
4301 Rickenbacker Causeway
Miami, Florida, USA 33149

[5] *U.S. Fish and Wildlife Service*
1339 20th St.
Vero Beach, Florida, USA 32960

Abstract: Biscayne Bay is a naturally clear-water bay that spans the length of Miami-Dade County, Florida, USA. It is bordered on the east by barrier islands that include Miami Beach and is an almost completely urban bay in the north and a relatively natural bay in the south. Planned water management changes in the next few years may decrease freshwater flows to the bay from present sources, while offering reclaimed wastewater in return. In addition, a project is planned to restore the former diffuse freshwater flow to the bay through many small creeks crossing coastal wetlands by redistributing the water that now flows into the bay through several large canals. To guide a science-based, adaptive-management approach to water-management planning, a conceptual ecological model of Biscayne Bay was developed based upon a series of open workshops involving researchers familiar with Biscayne Bay. The CEM model relates ecological attributes of the bay to outside forcing functions, identified as water management, watershed development, and sea-level rise. The model depicts the effects of these forcing functions on the ecological attributes of the bay through four stressors. The hypothesized pathways of these effects include salinity patterns, water quality, sediment contaminant concentrations, and physical impacts. Major research questions were identified with regard to uncertainties explicit in the model. The issues addressed include, for example (1) the quantitative relationship between upstream water management, rainfall, and flow into Biscayne Bay; (2) the salinity gradient required to restore the historical estuarine fish community; (3) the potential effect of freshwater inputs on benthic habitats; (4) the effect of introduced nutrient and contaminant loads, including the effects of reclaimed wastewater.

Key Words: Biscayne Bay, seagrass, dolphins, manatees, fish, pink shrimp, water quality, coastal wetlands, freshwater inflow

BACKGROUND

Biscayne Bay (Figure 1) is a naturally clear-water bay with tropically enriched flora and fauna. Prior to the development of Miami-Dade County, Florida, USA, much of the bay was bordered by mangroves and, otherwise, with herbaceous wetlands. The bay was once connected to the Greater Everglades ecosystem hydrologically through tributaries, sloughs, and ground-water flow. It possessed not only a marine habitat and fauna but also a substantial area of estuarine habitat and associated fauna. Because of the bay's shallow depths and naturally clear waters, its productivity is largely benthic-based (Roessler and Beardsley

EXHIBIT 7

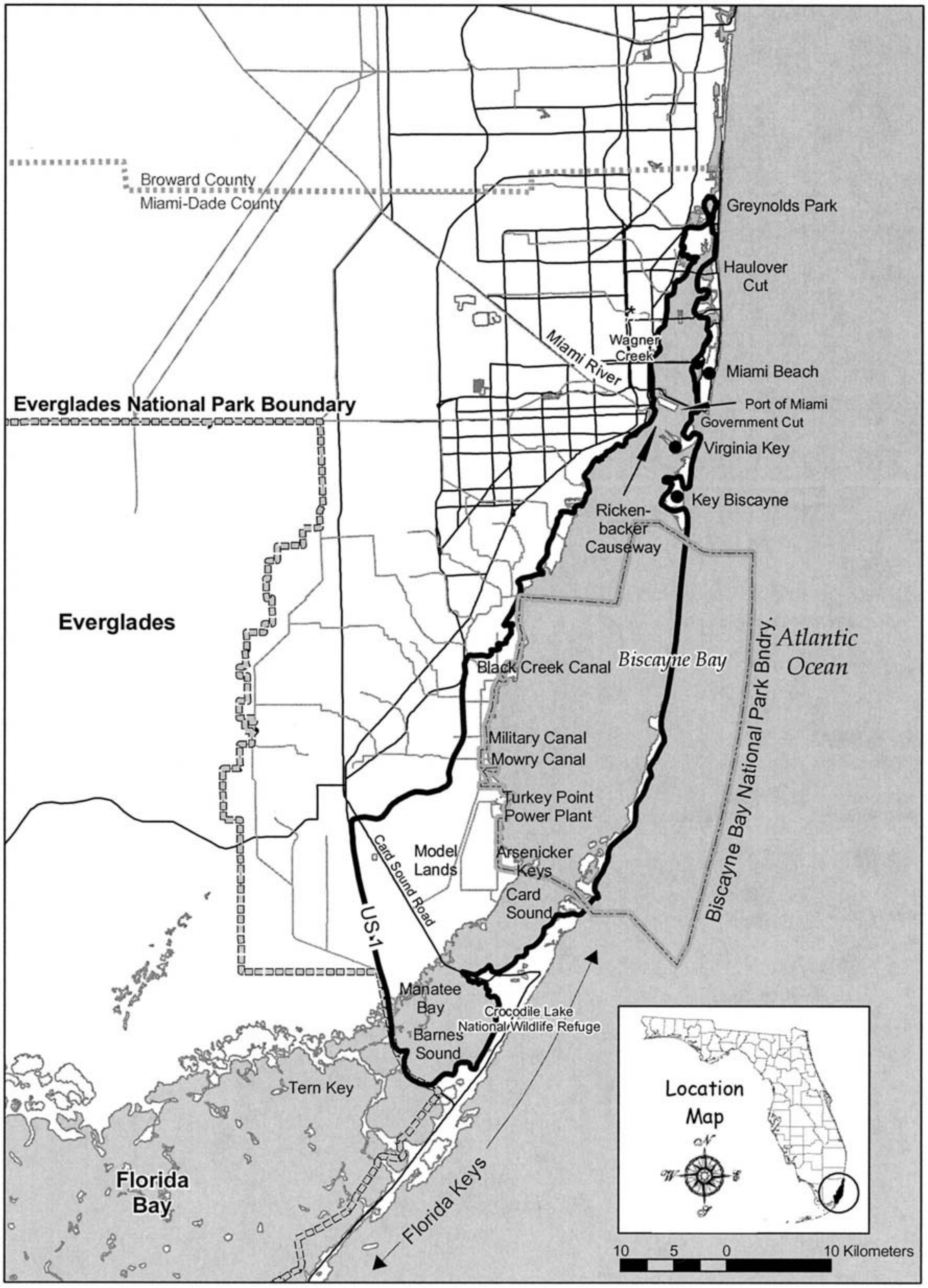

Figure 1. Boundary of the Biscayne Bay Conceptual Ecological Model.

EXHIBIT 7

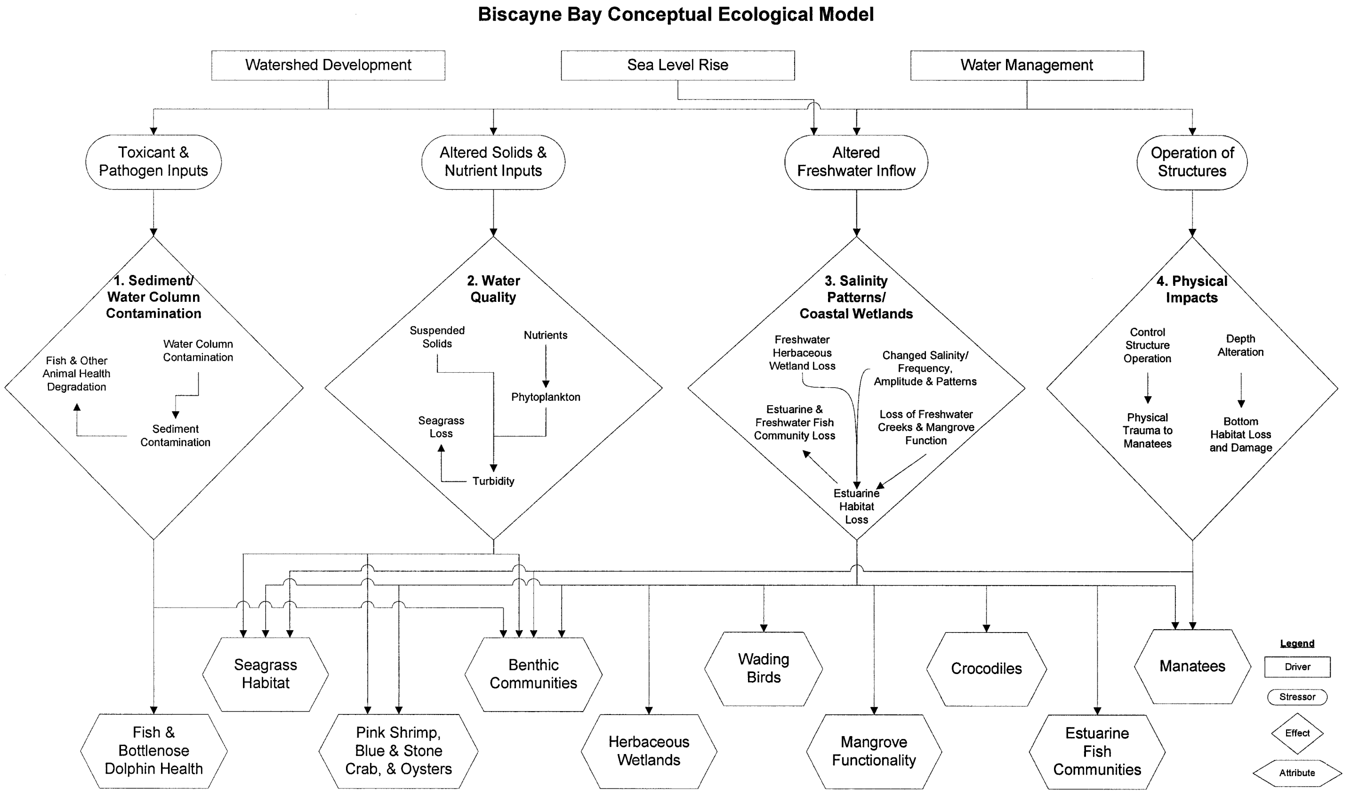

Figure 2. Biscayne Bay Conceptual Ecological Model Diagram.

1974). Benthic communities in the central and southern bay (i.e., south of the Rickenbacker Causeway) consist of several species of seagrasses, a mix of soft and hard corals, attached macroalgae and sponges, and coral-algal bank fringes that alternate in dominance in different areas. Benthic communities in northern Biscayne Bay are dominated by seagrasses intermixed in some cases with calcareous green algae. Parts of the bay are afforded various levels of state or federal protection, being designated or contained within Miami-Dade County Aquatic Park, Florida Aquatic Preserve, Outstanding Florida Water, Outstanding National Resource Water, Florida Surface Water Improvement and Management Priority Water Body, Biscayne National Park, Florida Keys National Marine Sanctuary, and Crocodile Lake National Wildlife Refuge.

Biscayne Bay is one of several south Florida estuaries that will be affected by the Comprehensive Everglades Restoration Plan (CERP) and its 68 individual projects. The selected plan, as described in the 1999 document (USACE and SFWMD 1999), contains provisions that will affect the sources, amount, and therefore quantity and quality of fresh water that Biscayne Bay receives, as well as the timing and location of flow. The specific projects likely to affect the bay most directly are the Biscayne Bay Coastal Wetlands Project, the C-111 Spreader Project, the South Dade Waste Water Reuse Project, the L31-N Seepage Management Project, and Lake Belt Storage Projects. The Coastal Wetlands Project has the objective of restoring the historic water supply patterns through wetlands to the southern Biscayne Bay. Wastewater reuse has the potential to affect bay water quality. The remaining projects listed all directly affect the amount of fresh water available to Biscayne Bay.

To guide a science-based, adaptive-management approach to water-management planning, a conceptual ecological model of Biscayne Bay was developed based upon a series of open workshops involving researchers familiar with Biscayne Bay. Since the adaptive management process for CERP is the context in which this conceptual model was developed and will be used, the emphasis of the Biscayne Bay CEM is on the relationship between the bay ecology and the mainland shoreline and freshwater sources.

EXTERNAL DRIVERS AND ECOLOGICAL STRESSORS

In the Biscayne Bay Conceptual Ecological Model (Figure 2), the two principal drivers applicable to the Comprehensive Everglades Restoration Plan (CERP) are watershed development and water management. They exert their effects through four principal stressors: toxicant and pathogen inputs, altered solids and nutrient inputs, altered freshwater inflow, and operation of physical structures, particularly water-control structures and maintenance of infrastructure. Altered freshwater flow is the stressor that CERP will most directly affect and includes flow volume, velocity, timing and spatial distribution. CERP may indirectly affect the input of solids, nutrients, toxicants, and pathogens.

Construction of the major canals through the Everglades and dredging of natural tributaries and transverse glades that carried fresh water to Biscayne Bay resulted in lowered regional and coastal water tables (Parker et al. 1955), reduced water storage in the watershed, decreased ground-water flow to the bay, and the elimination of many tributaries. Drainage of the watershed greatly affected the natural salinity gradients and ecotones from the Everglades through coastal wetlands and tidal creeks into the bay, and reduced or eliminated critical estuarine habitat for bay species requiring low-to-moderate salinity waters. In addition, constructed drainage systems result in pulsed, point-source discharge degrading estuarine habitat near canal mouths by creating biologically damaging zones of bottom scouring and rapid salinity fluctuations. Departures from natural salinity patterns are ecologically damaging to many species because salt concentration affects growth, survival, reproduction, and other critical physiological processes in both plants and animals (see, for example, Kinne [1971]). The general lowering of the water table on the east-coast ridge and diversion of both surface and ground water into canals has degraded not only estuarine habitats within the bay, but also adjacent coastal wetland communities, including herbaceous freshwater marshes and coastal mangrove wetlands that were once functionally connected to the estuarine habitats. The few coastal tropical hammocks that remain have also been detrimentally affected by the lowered water table (M. Roessler, pers. comm.).

The bay has also been significantly affected by the watershed development made possible by water management (Alleman et al. 1995). Before drainage of the watershed, urban and agricultural development was restricted to the highest ground along the Atlantic Coastal Ridge, consisting of hammocks and pinelands (University of Miami and SFWMD 1995). As land was drained, development encroached into lower lands and former wetlands. Today, most new development is occurring in former wetlands.

Development has had many detrimental consequences. The continued loss of open, pervious land increases stormwater runoff velocity and pollutant loads and reduces the quantity of water storage in the watershed. Other dramatic changes occurred in northern Biscayne Bay as a result of dredging and filling. Bottom dredging resulted in the loss of seagrass beds in northern Biscayne Bay and has affected the stability of bay sediments and the capacity to assimilate nutrients and trap particulates. Stormwater runoff from urban development has increased the bay's exposure to contaminants and excessive nutrients. At the same time, the filling and destruction of coastal wetlands has eliminated natural filtering capacity. The dredging of inlets at Haulover and Government Cuts significantly increased salinity in northern Biscayne Bay (Wanless 1969, Wanless et al. 1984), changing much of it from an estuarine to a more marine system.

Biscayne Bay's water quality has improved substantially in the past 30 years because of the elimination of direct discharge of sewage into the bay and other pollutant-control measures (McNulty 1970, Alleman et al. 1995, DERM 2005a). Parts of North Biscayne Bay now support substantial seagrass beds. Extensive seagrass beds have always been characteristic of South Biscayne Bay. In recognition of its exceptional values, the State of Florida has designated the bay and its natural tributaries as Outstanding Florida Waters, and as such, they receive the highest level of state protection from degradation. Present water quality generally meets or exceeds federal, state, and local standards for recreational use and propagation of fish and wildlife. Nonetheless, the bay still receives dissolved nutrients, trace metals, organic chemicals, and suspended sediments via stormwater runoff, sewage overflows, discharges from industrial facilities or vessels, and canal discharges. Canal water typically has lower dissolved oxygen and clarity and higher concentrations of contaminants than receiving waters of the bay.

ECOLOGICAL ATTRIBUTES

Ecological attributes of the overall health of the Biscayne Bay ecosystem include four types of habitat: seagrass meadows, mangrove forests, herbaceous wetlands, and benthic faunal communities (both soft bottom and hard bottom). Ecological attributes that have been defined because of their special relevance and utility for monitoring and reporting the state of the bay include pink shrimp (*Farfantepenaeus duorarum* Burkenroad), blue crabs (*Callinectes sapidus* Rathbun), stone crabs (*Menippe mercenaria* Say), oysters, estuarine fish communities, fish and bottlenose dolphin (*Tursiops truncatus* Montagu) health, crocodiles (*Crocodylus acutus* Cuvier), West Indian manatees (*Trichechus manatus latirostris* Linnaeus), and wading birds.

Seagrass Habitat

Large areas of the bay bottom support seagrass communities because sediment depth and nutrients are sufficient, water depths are shallow, and water clarity is high. Seagrass has been documented to cover up to 64% of the bay bottom (DERM 1985). There is very little area of bare bottom with sufficient sediment to support seagrass except where there has been a physical disturbance such as dredging. Seagrass beds function as vital habitat to support critical life stages of a variety of ecologically important and commercially or recreationally valuable species. At least seven species of seagrasses occur in Biscayne Bay: turtle grass (*Thalassia testudinum* Banks & Soland. ex Koenig), shoal grass (*Halodule wrightii* Aschers.), manatee grass (*Syringodium filiforme* Kuetz.), three species of *Halophila*, including *H. johnsonii* (Eiseman), which is a federally-listed protected species, and *Ruppia maritime* (Linnaeus). Distribution of seagrass species is generally related to water clarity and quality, substrate, salinity levels, and variability. *Syringodium filiforme* and *H. wrightii* are common in the northern bay, where salinities are lower and water clarity is diminished due to high freshwater discharge combined with a low flushing rate. Significant mixed *Thalassia/Syringodium* beds also exist in North Biscayne Bay. *Thalassia* is most prominent in central and south Biscayne Bay where salinities are higher and more stable and nutrient levels are lower overall.

The distribution of seagrass species and other benthic flora and fauna in the western nearshore area of central and southern Biscayne Bay is influenced by both canal discharges and submarine ground-water seepage (Kohout and Kolipinski 1967, Meeder et al. 1997, 1999). Presence or absence of *Thalassia* often is an indication of distinct zones where ground-water influence is substantial (*Thalassia* absent) or insignificant (*Thalassia* present). Along a transect from 25 to 300 m from shore, Meeder et al. (1997, 1999) found the maximum ground-water seepage about 200 meters from shore. The amount of ground-water seepage and its influence has been diminished by the general lowering of the water table in Miami-Dade County (Parker et al. 1955) to facilitate development in wetlands. Sea-level rise also reduced ground-water seepage to Biscayne Bay by reducing the hydraulic gradient, or difference between the water table and sea level at the coast, which, according to Darcy's Law, drives ground-water flow in an unconfined aquifer (Chow 1964).

Where sediment depths and currents are appropriate, seagrass species generally follow a pattern of zonation from west to east (*Ruppia*, *Halodule*, *Thalassia*, *Syringodium*) correlated with general salinity gradients and salinity fluctuation (Lirman and Cropper 2003). The freshwater inflows (surface and ground) occurring along the shoreline are critical in maintaining this zonation and benthic diversity. The altered salinity patterns that resulted in concentration of surface-water inflows into canals and reduced ground-water seepage likely affected competition among seagrass species, changing this zonation and making it less defined. Results from a hydrodynamic simulation model comparing canal inflows versus distributed inflow indicate that the canal scenario produces higher overall salinity in the nearshore zone than the distributed inflows (i.e., to simulate flow through the historical creeks (Brown 2003). Channelization of the Miami River might have had a similar effect as construction of the South Miami-Dade canals that shortcircuited the historic creeks. Analysis of sediment cores from southern Biscayne Bay indicates that it has become more saline and less variable in the last 100–200 years (Wingard et al. 2003). Seagrass composition in these areas has been documented to vary between *Ruppia*, *Thalassia*, and *Halodule*, or mixtures of *Halodule* and *Ruppia* or *Halodule* and *Thalassia*, depending on salinity regime.

Mangrove Functionality and Herbaceous Wetlands

Coastal wetlands are highly productive habitats that provide nursery, foraging, and refuge areas for many bird, fish, and invertebrate species. In addition, these coastal wetlands help maintain water and habitat quality by filtering sediments and nutrients from inflowing waters. Biscayne Bay's remaining mangroves and associated herbaceous wetlands, including nearshore freshwater wetlands, have lost much of their ecological function because fresh water has been diverted away from coastal feeder streams and creeks into drainage canals. Restoration of both brackish and freshwater wetlands and coastal creeks on the western shore of Biscayne Bay is important to the success of bay restoration and, therefore, is defined as an indicator of success. In the southern part of the western bay, water management and watershed development activities to date have caused saltwater intrusion and led to an encroachment of scrub mangroves on former freshwater wetland. Freshwater wetlands are a vital component of the coastal wetland system, and their loss is undesirable, even when replaced by salt-tolerant species like mangroves. The presence of a system of coastal wetlands integrated by the inflow of freshwater from upstream and, to varying degrees, by tidal exchange, is essential to the restoration of a fully functional Biscayne Bay ecosystem.

Benthic Communities

Benthic organisms such as mollusks, attached fauna, and infauna provide essential ecological and biological functions in the bay and can influence the quality of the environment. The benthic community is the basis for development of high quality habitat that will support diverse fish and motile invertebrate populations. Degradation or loss of benthic communities will diminish the ability of the bay to maintain the mosaic of conditions that support high habitat diversity and productivity. Benthic communities are depauperate within the dredged canals and channels of the drainage system that empty into the bay. These channels provide poor habitat because of their depths, near vertical banks, low dissolved oxygen, and reduced water transparency (DERM 2005b). In addition, they are frequently redredged, disturbing the bottom sediments, and are regularly sprayed with herbicides. The present operation of water-control structures (opening and closing automatically according to upstream and downstream water level) causes discontinuous freshwater flows that result in localized extreme salinity variability that is unsuitable habitat even for estuarine organisms (Serafy et al. 1997).

Pink Shrimp, Blue Crabs, Stone Crabs, and Oysters

Juvenile pink shrimp immigrate to Biscayne Bay from offshore spawning grounds each year and settle in the seagrass beds close to the mainland shoreline near freshwater inputs. Pink shrimp seem to prefer a salinity range of 20–35 parts per thousand (ppt) (Pattillo et al. 1997), but survival and growth have been tied to temperature and salinity (Browder et al. 1999), with an optimal salinity for juvenile growth at 30 ppt (Browder et al. 2002). This species would be expected to benefit from an expansion in estuarine habitat in the western bay. Pink shrimp's ecological characteristics and economic value, together with the background of knowledge about this species in South Florida, make it an appropriate biological indicator of change in freshwater inflow quantity, timing, and distribution. Furthermore, pink shrimp constitute the most significant commercial fishery in Biscayne Bay (Berkeley 1984). A commercial pink shrimp live-bait fishery has operated in Biscayne Bay for many years, and a more recent commercial fishery harvesting pink shrimp from the bay for human consumption is expanding. The distribution of juvenile pink shrimp in Biscayne Bay has been measured and modeled (Campos and Berkley 1986, Ault et al. 1999a, b). Spotted pink shrimp (*Farfantepenaeus brasiliensis* Latreille) also is present in Biscayne Bay but in very low number compared to *F. duorarum*).

The blue crab resides in the south-central area of Biscayne Bay and also supports a commercial fishery. An average of 50,768 kilograms of blue crabs was taken annually from Biscayne Bay from 1996 to 2000 (Murphy et al. 2001). Optimum blue crab egg hatching occurs at salinity between 23 ppt and 28 ppt, and juveniles prefer a seagrass habitat with salinity between 2 and 21 ppt (Pattillo et al. 1997).

The eastern or American oyster is not currently harvested in south-central Biscayne Bay but is present nearshore in small numbers where conditions are suitable. The species was apparently more abundant in the past when surface water drained through a series of small creeks into the bay (Meeder et al. 2001, 2002) and provided a salinity regime more conducive to oyster growth and survival. Growth rates of oysters are reported to be best at 14–28 ppt (Shumway 1996); however, at the higher salinity range, mortality can increase as a result of infection by *Perkinsus marinus* (Mackin, Owen, and Collier), a parasite (Burreson and Ragone-Calvo 1996, Soniat 1996, Chu and Volety 1997). The oyster is important ecologically for several reasons. The accumulation of shells provides physical habitat structure for a variety of other species, their organic rich deposits are a food source for benthic feeders, and they filter particulates from the water, improving water quality (Pattillo et al. 1997). Other estuarine species have some dependence on oyster reefs; for example, 24 species were found associated with oyster reefs in the Caloosahatchee Estuary (Volety et al. 2003).

Estuarine Fish Communities

Several estuarine fish species known to have occurred in Biscayne Bay in the past (Smith 1896, Siebenaler 1953, Udey et al. 2002) contributed to the bay's commercial and recreational fisheries but appear to be scarce or absent in the bay today. The opportunity for anglers has changed and, according to longtime residents, has diminished, possibly as a result of the loss of the estuarine component of the fauna. The estuarine fish community could make an important contribution to the recreational fishing experience in the bay if its abundance and diversity were restored. An increase of the bay's estuarine habitat would be expected to lead to greater abundance and diversity of estuarine fishes, including those desired by anglers.

An increase in the distribution and abundance of fish in the fresh to brackish water wetlands adjacent to Biscayne Bay would be an indication of restored functionality of the coastal wetland-estuarine nearshore habitat that is important to the bay's diversity and productivity.

Freshwater fish communities that spread into oligohaline (0–5 ppt salinity) environments seasonally can reach high densities and provide abundant prey to pisciverous estuarine fish, as well as to wading birds (Lorenz 2000).

Fish and Bottlenose Dolphin Health

The health of fish communities and the health of a resident bottlenose dolphin group are valuable attributes of the Biscayne Bay ecosystem. Externally visible abnormalities such as scale and skeletal deformities have been observed to occur in a number of Biscayne Bay fish (Browder et al. 1993) and are more prevalent in fish sampled from human-impacted sites (Gassman et al. 1994). This is consistent with Fournie et al. (1996) for Gulf of Mexico estuaries and Sanders et al. (1999) for Ohio rivers. The prevalence of abnormal fish is being used as part of a biological integrity index in a growing number of state and national monitoring programs (Simon 1999).

Bottlenose dolphins in Biscayne Bay include permanent residents and nearshore migrants. National Oceanic and Atmospheric Administration (NOAA) Fisheries conducts a photo identification program in Biscayne Bay that can potentially distinguish residents from migrants. Through the Southeast Fisheries Science Center, the NOAA Fisheries Miami Laboratory has been conducting health assessments of other bottlenose dolphin in the southeast to obttain baseline information on marine mammal contaminant levels, associated diseases and incidence, and impacts of human-related pollution on marine mammal populations. The program conducts current and retrospective evaluation for the accumulation of toxicants in various tissues of bottlenose dolphins and other marine mammal species in relation to their health, as reflected in histopathology, blood profiles, and other medical diagnostics (Sweeney 1992, Worthy 1992, Hansen and Wells 1996, Reddy et al. 2001, Schwacke et al. 2002). Biopsies of small amounts of subcutaneous blubber can be taken from living animals for contaminant analysis during low-level monitoring activities. Health assessment profiles of dolphin populations for comparison to regularly monitored and assessed ''reference'' populations can be developed in this manner. The bottlenose dolphin and other marine mammals are protected species under the Federal Marine Mammals Protection Act of 1972. Opportunistic biopsy sampling of the Biscayne Bay resident dolphin population began in February 2000 as a pilot study by the NOAA Fisheries Miami Laboratory.

Crocodile

The American crocodile is an endangered species that is known to range throughout southern Biscayne Bay. Historically, the range of the American crocodile extended north to at least Miami Beach (Kushlan and Mazzotti 1989). It nests primarily at the Florida Power and Light Turkey Point Power Plant cooling canals and Crocodile Lake National Wildlife Refuge. Recent studies indicate an increase in the number of nests occurring in the cooling canal area of the Turkey Point Power Plant since the early 1980s, while nest numbers at the Crocodile Lake National Wildlife Refuge have remained relatively stable (Mazzotti et al. 2002). Nesting success at the Turkey Point Power Plant may be responsible for an increase in the number of crocodile sightings occurring north of the plant and may indicate an expansion of the animal's range. Crocodiles have been sighted as far north as Key Biscayne and the Miami River (M. Cherkiss, University of Florida, pers. comm.). Although nest numbers have remained relatively stable at the Crocodile Lake National Wildlife Refuge, the population in this area may be increasing, based on an increase in the number of crocodile sightings throughout the Florida Keys and an increase in the number of road kills occurring along U.S. 1 and Card Sound Road over the past several years (S. Klett, Crocodile Lake National Wildlife Refuge, pers. comm.).

A habitat suitability model for crocodiles has been developed based on salinity levels (Mazzotti and Brandt 1995). The model targets juvenile crocodiles because studies indicate that this life stage requires lower salinities due to osmoregulatory limitations (Mazzotti and Dunson 1984). This model shows that salinity between 0 and 20 ppt provides the most suitable habitat, 20–40 ppt provides intermediate suitability, and 40 ppt is least suitable. Applying the model to Biscayne Bay suggests that restoring freshwater flow to the coastal wetlands would benefit crocodiles, especially along the western shore in the central and southern regions. Most of this area is currently unsuitable for juvenile crocodile habitat. Restoration efforts will include redirecting flow from conveyance canals through coastal mangrove wetlands and maintaining flow into the beginning of the dry season.

Manatee

Endangered West Indian manatees occur throughout Biscayne Bay but are most frequently observed in tributaries and nearshore seagrass beds. Manatees are present year-round and are most abundant in winter, when more than 130 have been counted on a single day (Mayo and Markley 1995). Biscayne Bay seagrass meadows provide important foraging habitat for manatees wintering at warm water discharges (power plants) in Broward County, and the bay is a significant seasonal migratory corridor. Thus, the total number of

EXHIBIT 7

animals using the Biscayne Bay area is likely to be greater than the maximum number observed on any given day.

Manatees utilizing the bay are part of the larger Atlantic region ''subpopulation,'' which includes those animals ranging along the Atlantic coast from southern Georgia to the Florida Keys and including the lower St. John's River. Atlantic coast manatees undertake seasonal, intraseasonal, and daily migrations or movements (Deutsch et al. 2003). Radio-telemetry studies and tracking or resighting of known scarred individuals have shown that manatees may travel hundreds of kilometers seasonally, moving to southeast Florida or unnatural sources of warmer water. Tracking studies of animals in the Biscayne Bay area also suggest a general diurnal pattern, with animals resting in canals and sheltered basins during the daytime and moving into bay areas to feed in late afternoon and evening (C. Beck, United States Geological Survey, pers. comm.). Although wide-ranging, manatees demonstrate a high degree of site fidelity, yet they also show individual patterns, flexibility, differential use of sites over time, and adaptation to changing conditions, moving among warm water refuges, freshwater sources, and feeding sites. The general distribution of manatees is strongly linked to fresh water; they more frequently occupy areas where freshwater sources are readily available (O'Shea and Kochman 1990, Mayo and Markley 1995, LeFebrve et al. 2001, Deutsch et al. 2003). Changes in timing and volume of freshwater delivery could affect manatee distribution, particularly in south Biscayne Bay.

Adult annual survival rates for manatees in the Atlantic subpopulation have been estimated at 88.7–92.6%, a lower rate than has been estimated for other regions (Langtimm et al. 1998). Due to uncertainty in population model estimations, it is not possible to determine with statistical confidence whether the Atlantic population has been stable, decreasing, or increasing in recent years; however, annual manatee mortality in the Atlantic region remains high and appears to be increasing at a greater rate than optimistic estimates of population growth (USFWS 2001). Although many manatees have been killed or injured in Biscayne Bay by vessel collisions, the leading known cause of manatee in death in Miami-Dade County is crushing or entrapment in water-control structures (Mayo and Markley 1995). Thus, changes in operation of these structures may directly affect survival of individuals using the Biscayne Bay area and stability of the Atlantic subpopulation.

Wading Birds

Wading birds are being used as biological indicators throughout the region because of their close association with hydropattern. The islands, tidal flats, and coastal wetlands of Biscayne Bay provide valuable habitat for wading birds. Frequently used nesting sites occur at Greynold's Park near the northern bay, in the Arsenicker Keys in the southern bay off Turkey Point, and on small islands off Key Biscayne and Virginia Key (Browder personal observation). Tidal flats and coastal wetlands of the bay provide important feeding habitat for wading birds that nest nearby. For example, roseate spoonbills (*Ajaia ajaja* Linnaeus) that nest in the Tern Keys of northeastern Florida Bay feed in mangrove creeks and herbaceous wetlands of southern Biscayne Bay (Card and Barnes Sound areas), as well as those of Florida Bay. Wood storks (*Mycteria americana* Linnaeus) that nest in the southern Everglades also feed in wetlands of southern Biscayne Bay. The natural pattern of seasonal variation in water stages alternately produces and concentrates forage fish for wading birds. A more natural seasonal variability in water stages in relation to the rainfall pattern will not only produce and concentrate fish for wading birds but also support favorable salinity conditions for estuarine fish and macroinvertebrates downstream in Biscayne Bay.

ECOLOGICAL EFFECTS: CRITICAL LINKAGES BETWEEN STRESSORS AND ATTRIBUTES/ WORKING HYPOTHESES

In the Biscayne Bay Conceptual Ecological Model (Figure 2), relationships between the five stressors and the ecological attributes discussed above are depicted in the four diamond-shaped modules representing pathways of effects. Most of the ecological attributes are directly affected by salinity patterns/coastal wetlands, water quality, or sediment/water column contamination. These are determined by the stressors according to the relationships depicted in the ''effects pathways'' modules (the diamonds in Figure 2). The discussion of these effects pathways is followed by a discussion of hypothesized linkages between the ecological attributes and these effects pathways, including physical impacts (depicted in its own ''effects pathways'' module, fourth diamond in Figure 2). Physical impacts include effects of dredging, water-management control structures, and fishing gear.

Salinity Patterns/Coastal Wetlands

The ecological effects and interrelationships associated with salinity patterns and coastal wetlands are depicted in the third diamond in Figure 2. Data and historic accounts document that, in the past, freshwater inflows to Biscayne Bay were more diffuse and continuous via surface sheet flow, ground water, and

EXHIBIT 7

freshwater 'springs' within the bay (Kohout 1967, Kohout and Kolipinski 1967). These conditions generated a diverse salinity regime, with general gradients near 0 ppt close to the mainland, to 35 ppt or greater in the open areas of the bay in the southeast. These conditions apparently extended to Manatee Bay off Barnes Sound at the extreme southern end of Biscayne Bay (Ishman et al. 1998). Prior to drainage, several small rivers that flowed into the semi-enclosed northern part of the bay made it brackish. Natural patterns of salinity distribution and fluctuation were major determinants of habitat development, composition of biological communities within these habitats, and their overall productivity. Therefore, restoration of more natural freshwater inflows and associated salinity patterns and coastal wetlands are necessary prerequisites to restoration of the bay's natural estuarine diversity and productivity.

Relationship between Salinity Patterns and Freshwater Inflows. Both flow rate and distribution of freshwater inputs to Biscayne Bay have been altered by construction and operation of the present water-management system (Buchanan and Klein 1976). The system of canals and water-control structures provides a means to manipulate and control virtually all inflow to the bay. Altering the historical distribution of freshwater inflow in time and space has had an effect on patterns of salinity distribution and salinity variability. Routing freshwater flow to the bay through canals and away from coastal creeks and wetlands has resulted in a loss of estuarine habitat. The salinity gradient resulting from large, point-source discharges is very different from that resulting from more diffuse flow through tidal creeks and wetlands and ground-water seepage resulting from higher overall water tables. Inflows distributed through coastal wetlands resulted in a positive salinity gradient from interior wetlands and a broader mesohaline zone along the shoreline prior to drainage. Diversion of freshwater runoff into canals (i.e., point sources) short-circuits coastal wetlands and does not create positive gradients from interior wetlands outward. Although the general relationship between freshwater inflow and salinity is well known in Biscayne Bay, this relationship has not been rigorously quantified within the critical western nearshore zone and associated wetlands, where the greatest effect of changes in freshwater inflow patterns can be expected.

Relationship between Freshwater Inflow and CERP. Changes in upstream water-management practices will cause changes in freshwater inflow to Biscayne Bay. Modeling results with the South Florida Water Management Model (SFWMM) indicate that CERP's proposed changes to water-management features and practices in Biscayne Bay's watershed will substantially affect freshwater delivery patterns. Exact relationships between rainfall in the watershed, freshwater delivery patterns, and planned changes to the water-management system are difficult to define quantitatively. For example, model estimates of daily discharge rates through coastal canal structures bear little relationship to daily rainfall, suggesting highly unnatural flow patterns. Furthermore, present methods of estimating discharge rates at structures can introduce significant error (Swain et al. 1997) and will need to be improved to fully investigate rainfall-runoff relationships.

Water Quality

Relationship of Biscayne Bay Water Quality to Water Quality in Ground Water, Storm Water, and Canal Discharge. The term ''water quality'' includes both abiotic and biotic characteristics; therefore, water quality both influences and embodies major aspects of the ecological functioning of Biscayne Bay. The processes that link ecological attributes in Biscayne Bay to stressors are depicted in diamond 2 of Figure 2. In general, water clarity in Biscayne Bay is high, except where and when bottom sediments are disturbed by wave action or boat traffic. Inorganic nutrient concentrations are naturally low, and phytoplankton in the water column is not an impediment to light penetration. Open waters of Biscayne Bay are generally characterized by high dissolved oxygen concentration, low nutrient and chlorophyll concentrations, and high clarity. Sewage-related bacteria, trace metals, and other toxicants typically occur at low concentrations in Biscayne Bay waters. A primary controlling factor of water quality in Biscayne Bay is the quality of water discharged into the bay. Water quality in a number of canals and rivers that discharge to the bay is poor in comparison to the open waters of the bay. Surface waters in some canals in south Miami-Dade County that discharge into Biscayne Bay contain high levels of inorganic nitrogen.

Water quality can also be affected by ground-water inputs. In some areas, ground water contains elevated levels of ammonia nitrogen from landfill leachate and nitrate-nitrogen from agriculture (DERM 1987, Alleman 1990, Markley et al. 1990, DERM 1993, Alleman et al. 1995, Lietz 1999, Meeder and Boyer 2001). Submarine ground-water discharge into shallow nearshore waters is a source of elevated nutrients (Meeder et al. 1997); nutrient concentrations in shallow ground water (beneath the nearshore bay between Mowry Canal and Military Canal) are higher than in bay or canal waters or deep ground water. The structure and operation of water-management systems, land uses and urban and agricultural practices, and sea-level rise all affect ground-water input (and nutrient loading) to Biscayne Bay.

Biscayne Bay is vulnerable to nutrient loading, especially from phosphorus, the limiting nutrient to phytoplankton growth in Biscayne Bay (Brand 1988). Water-column inorganic and organic nutrient concentrations, turbidity, photosynthetically-active radiation (PAR), bacteria, plankton taxa, size, and composition of plankton, as well as phytoplankton biomass, as reflected in chlorophyll and other pigments, can all be influenced by solids and nutrients received via canal discharge, stormwater runoff, and ground water.

CERP's proposed changes in freshwater delivery, particularly in south Miami-Dade County, may affect nutrient concentrations and loading to Biscayne Bay. On the one hand, plans to reroute canal discharge through coastal wetlands could reduce nutrients reaching Biscayne Bay; on the other hand, wastewater reuse may increase nutrient or other contaminant loading. While water-quality targets for wastewater reuse have been proposed that would protect open waters of south Biscayne Bay from degradation, it is not yet clear that achieving these targets is technically and economically feasible. This will pose problems since the water from wastewater reuse is a substantial part of total inflow to the bay provided under CERP (USACE and SFWMD 1999).

Sediment/Water Column Contamination

Processes linking ecological attributes to stressors are depicted in the first diamond in Figure 2. Community composition, distribution, and health of macrobenthic, infaunal, and demersal organisms can be affected by the presence of toxic substances in sediments. Potentially toxic pollutants, such as metals and organic chemicals, usually have low water solubility and tend to bind to particulate material and accumulate in sediments (Seal et al. 1994, Long et al. 2000). Most contaminants in Biscayne Bay sediments occur in highest concentrations in conveyance canals, rivers, streams, and marinas, and the lowest concentrations are along the central north-south axis of the bay (Corcoran et al. 1983, Alleman et al. 1995). Trace metals and synthetic organic contaminants, such as some pesticides and polychlorinated biphenyls (PCBs), are found in higher concentrations in Miami River and Wagner Creek sediments than in any other area in the State of Florida (Schmale 1991, DERM 1993, Seal et al. 1994). Other canals that have high levels of sediment toxicity include Little River (C-7), Black Creek (C-1), and Military Canal (USEPA 1999, Miami-Dade County Department of Environmental Resource Management, pers. comm.).

Relationship of Sediment/Water Column Concentration to Toxicity. Recent studies (Long et al. 2000, 2002) showed that contaminant levels in Biscayne Bay sediments were slightly below the national average, but toxicity levels (based on biological assays) were slightly above. These studies supported earlier findings that contamination and toxicity were most severe in several conveyance canals and a few natural tributaries, and that sediments from the open basins were less toxic than those from the adjoining canals and tributaries. In more open waters of the bay, chemical concentrations and toxicity were generally higher north of Rickenbacker Causeway than south of it. However, a section of southern Biscayne Bay showed remarkably high toxicity that could not be attributed to any of the substances analyzed in sediments. Evidence suggests that mixtures of some metals and synthetic organic chemicals were likely contributors to toxicity observed in the lower Miami River. For example, an amphipod survival test showed a high degree of correspondence with a gradient of general chemical contamination in the river and adjoining reaches of the bay. Because contaminants are conveyed to the bay through tributaries and ground-water flux, changes in distribution or sources of fresh water or ground-water stages may affect the fate, amount, and pattern of contaminants introduced. This could increase water- column and sediment contaminant levels (or toxicity), increase ecological exposure, and ultimately affect sensitive species and, perhaps, overall secondary productivity or diversity.

Seagrass Habitat

Relationship of Seagrass Abundance and Distribution to Salinity Patterns and Water Quality. Processes linking the bay's ecological attributes to stressors are depicted in the second diamond in Figure 2. Seagrass and benthic communities require a consistent (both in range and variability) salinity regime and appropriate water quality (sufficient but not excessive nutrients and sufficient light for photosynthesis). Abundance, distribution, and composition of seagrasses will be determined, in part, by modifications of salinity patterns and water quality. Changes in composition and areal coverage of seagrasses will affect habitat quantity and quality with respect to breeding, refuge, and feeding areas available for dependant invertebrate and vertebrate species. Diversion of part of the canal flow from a 'point source' to more 'diffuse' delivery through coastal wetlands and creeks will approximate reconstruction of freshwater flow to the bay from the Everglades through historic pathways (i.e., the historic freshwater coastal creeks, as many as 40 of which interdigitated with tidal creeks prior to development).

This is expected to reduce sediment resuspension and nutrient concentrations in the water delivered to the bay and improve water clarity. This could lead to expansion of seagrass cover in the nearshore areas where sediment depths are adequate and may improve local water clarity by inhibiting sediment resuspension.

Mangrove Functionality and Herbaceous Wetlands

Relationship of Freshwater Inflow and the Boundary between Mangrove and Herbaceous Wetlands. The relationship of mangrove functionality to stressors is depicted in the third diamond of Figure 2. Diversion or reduction of freshwater inflow has caused a loss of the many small creeks that furnished freshwater to the bay and has diminished the degree to which mangroves support a healthy, diverse epiphytic community and provide habitat for both sport fish and their prey. Alteration of freshwater inflow has caused a shift in the boundary between the mangrove and herbaceous wetland and the inland migration of the landward boundary of the ‘‘white zone’’ (Ross et al. 2000). The white zone is a band of low productivity at the ecotone between brackish and freshwater wetlands. Recent studies in the wetlands of Barnes and Card Sounds (see Figure 1 for location) indicate that the boundary of the white zone has moved inland by an average of 1.5 km since 1940, and the white zone is expanding (Ross et al. 2000). The most significant changes to the white zone boundary and width occur in areas cut off from freshwater sources by canals or roads (especially east of U.S. Highway 1). Low productivity of the white zone may be primarily the result of wide seasonal fluctuations in soil salinity and moisture content due to reductions in freshwater inputs from upstream sources (Ross et al. 2002). CERP's restoration of a more natural freshwater flow across the coastal wetlands should reduce the areal extent of the white zone and shift its inland boundary seaward. Reestablishing flow across a broader front through re-created coastal freshwater creek systems should also restore full mangrove functionality. Exotic vegetation has replaced the white zone in some areas but is not a substitute for natural herbaceous wetland, and the exotics may have to be addressed with specific remedies to restore coastal wetlands.

Sea-level rise has to be considered in wetland restoration. For one, it influences the location of the ecotone between the mangrove and herbaceous wetland and the boundary of the white zone, and sea-level rise might shift them inland over coming decades. For another, hydrostatic pressure from increased sea level might further retard ground-water inflows already diminished by a lowered water table.

Benthic Communities

Relationship of Bottom Habitat to Freshwater Inflow Volume and Variation. Benthic communities are related to stressors as depicted in the third diamond of Figure 2. Benthic communities are directly impacted by the volume and intensity of freshwater inflow and the range and rapidity of its variation. Point-source discharges of fresh water into the bay via conveyance canals result in large, but ephemeral, salinity fluctuations that deleteriously affect benthic communities (Montague and Ley 1993, Irlandi et al. 1997). The bay bottom in the vicinity of canals often is devoid of benthic organisms. Miami-Dade Department of Environmental Resources Management documented destruction of established benthic sessile communities in Manatee Bay in the extreme south Biscayne Bay by sudden and prolonged high-volume releases of fresh water. Recovery is dependent upon the duration of appropriate salinity regimes between events. Benthic communities are also directly affected by trawling, which can significantly disturb bottom habitat and benthic organisms.

Pink Shrimp

Pink shrimp are related to stressors primarily through diamonds 2 and 3 in Figure 2. These relate suitability of habitat for pink shrimp to salinity pattern and water quality and catches in the fishery to abundance of juvenile pink shrimp.

Relationship of Suitable Pink Shrimp Habitat to Salinity Pattern and Water Quality. Changes in water management in relation to CERP are expected to expand the area of optimal habitat for juvenile pink shrimp both directly and indirectly. Salinity, which affects many physiological processes, is a major environmental factor directly influencing pink shrimp. Like many species, pink shrimp have an optimum salinity range (Browder et al. 2002). Although the species may be found outside of this range, survival, growth, and reproduction may not be as great. As for many species, optimum salinity for shrimp must occur in conjunction with suitable bottom habitat (e.g., seagrass) to be supportive, and salinity patterns and water quality will directly affect seagrass distribution, composition and density, thus affecting shrimp indirectly (Browder et al. 2005).

Relationship of Juvenile Pink Shrimp to Shrimp Harvests. High densities of juvenile pink shrimp can be expected to enable high catch rates in fisheries. A close link between juvenile densities and catch rates in bay shrimp fisheries would be expected because nursery and fishing grounds overlap or are in close proximity.

Fishing effort may affect juvenile density on fishing grounds, but trawls cannot operate in waters less than one meter deep, where the nursery grounds in Biscayne Bay are located (Diaz 2001). The relationship of pink shrimp juveniles in Biscayne Bay to offshore spawning or fishing grounds is unknown. The nearest known spawning and fishing grounds are near the Dry Tortugas, and the relationship between the spawning grounds and the Biscayne Bay nursery has not been determined.

Estuarine Fish Community

Relationship of Estuarine Fish Communities to Salinity Pattern. The estuarine fish community is related to stressors through diamonds 2 and 3 in Figure 2. Abundance and biomass of estuarine fishes has been reduced and species diversity has changed due to a loss of estuarine habitat along the bay's western shoreline (Serafy et al. 2001). Much of this habitat loss stems from changes in freshwater inflow that have disturbed the natural correspondence of favorable salinity with favorable bottom and shoreline habitat for estuarine species (Browder and Moore 1981). These species need a persistent positive salinity gradient extending from coastal wetlands, freshwater coastal creeks, and shallow nearshore waters into the bay. Flow from canals rather than through coastal wetlands prevents development of a positive gradient from interior wetlands into the bay. Unnaturally high salinity fluctuations caused by canal discharges further reduce suitable habitat for estuarine fish communities (Serafy et al. 1997). Presently, the rate of freshwater inflow fluctuates in a much more pronounced way than it did prior to the construction of the water-management system. Fluctuation is because of the shortage of storage for stormwater runoff in the watershed and manipulation of the little storage that exists. For example, at the end of wet season and during dry season (generally November to May), water may be discharged to artificially maintain low ground-water elevations in the watershed to promote agricultural activity, even though no rainfall has occurred; contrarily, sometimes no water is discharged after storm events because water stages are still below optimum. Spatial and temporal patterns of freshwater delivery that radically depart from the natural pattern of flow in relation to rainfall do not provide optimal habitat for estuarine species. Many species that can withstand gradual changes in salinity are vulnerable to the abrupt lowering of salinity caused by freshwater pulses (Serafy et al. 1997).

Fish and Bottlenose Dolphin Health

Contaminants present in Biscayne Bay's sediments and water column at various locations, including the Miami River mouth, may affect faunal health and development in the bay. Fish and bottlenose dolphin were selected to help monitor potential adverse effects of contaminants because a relatively high prevalence of morphological abnormalities has been found in fish from some locations in Biscayne Bay, and bottlenose dolphin are a long-lived species in which contaminants are known to accumulate, according to studies in other estuaries. Fish and dolphin health are related to stressors through diamond 1 in Figure 2.

Relationship of Fish Abnormalities to Human Influences. The relationship between exposure to anthropogenic inputs and morphological abnormalities observed in Biscayne Bay fishes needs evaluation in view of the higher prevalence of fish with abnormalities in areas of the bay directly exposed to human inputs. The most common abnormalities in Biscayne Bay fish are scale disorientation and deformed or missing dorsal fin spines, which are found in a number of species (Browder et al. 1993). Limited data from selected locations showed significant correlations between combined abnormalities and aliphatic hydrocarbons in sediments and between abnormalities in bluestriped grunt (*Haemulon sciurus* Shaw) and copper in sediments (although not with other sediment contaminants) (Gassman et al. 1994). Other factors can also influence fish health and development, including, according to some reports, previous encounters with fishing gear.

Relationship of Bottlenose Dolphin Toxicant Body Burden to Toxicants in the Sediments. The body burden of toxicants in the Biscayne Bay resident bottlenose dolphin population may reflect their degree of toxicant exposure. Body burdens could be correlated with various health-assessment indices that describe the status of population health. Through NOAA and its collaborators, a program is gradually evolving that characterizes toxicant body burdens and blood profiles of dolphin populations in various estuaries of the southeastern United States. Information from the resident Biscayne Bay dolphin population could therefore be used to compare toxicant exposures in Biscayne Bay to other estuaries. Such an effort would be facilitated by the ongoing NOAA project to identify and catalogue resident dolphins of the bay to distinguish them from members of coastal migrant populations and to determine local movements.

Manatees

The relationship of manatees to stressors is depicted in diamonds 3 and 4 of Figure 2. Manatees are directly

EXHIBIT 7

affected by floodgate closures, a documented cause of mortality. They may also be affected by the way that canals and levees have concentrated the availability of fresh water at a few sites, almost all near floodgates.

Relationship of Manatee Distribution to Timing, Location, and Volume of Freshwater Inflow. Changes in timing, location, and volume of freshwater inflow could affect manatee distribution within the bay and their use of canal habitat. For example, restoration of more natural and stable freshwater creeks and springs may enhance manatee habitat in areas more remote from human threats. However, complete elimination of existing canals (or access to them) or discharge structures may disrupt behavior of individual manatees that traditionally utilize such sites.

Relationship of Manatee Mortality to Water-Control Structure Operations. Water control floodgates are the leading cause of determinable manatee mortalities in Biscayne Bay (Mayo and Markley 1995, FWC 1999, USFWS 2001). Miami-Dade County leads the state in floodgate and other human-related causes of manatee mortality. Manatees are attracted to canals as a source of fresh water and cold-weather refuge. Over the last two decades, water-control-structure operations have been modified, and some gates have been retrofitted with pressure-sensitive devices that are supposed to prevent the gates from closing on an object. Although this has resulted in some improvement, mortalities have continued. Modification of gates or their operation may affect manatee mortality. For example, if water normally discharged through a coastal water-control gate were diverted into a series of creeks, as planned in the Biscayne Bay Coastal Wetlands Project of CERP, then the frequency that the gate opens and closes would be reduced, thereby reducing the risk to manatees. The number of manatees in Biscayne Bay increases during cold weather, increasing vulnerability to human related impacts (e.g., control structures and boats) during that time of year, so gate operations are particularly important then.

Wading Birds

Relationship of Wading Bird Nesting Activity, Nesting Success and Foraging Activity to Water-Management Structures and Their Management. The relationship of wading birds to stressors is primarily through effects expressed in diamond 3 of Figure 2. Lorenz (2001a,b) showed that nesting success of roseate spoonbills in one colony (Tern Key) was detrimentally affected by changes in water stages caused by water-management structures and operations near Florida Bay. Feeding opportunities for roseate spoonbills and other wading birds also have been diminished by the reduction in freshwater flow to Biscayne Bay wetlands resulting from road construction and diversion of water into canals. Modification of the structure and operation of the water-management system in relation to Biscayne Bay wetlands could affect nesting success at the Tern Key site in eastern Florida Bay. Improvements in water management might also affect activity and nesting success of colonies of wading birds that nest on islands within Biscayne Bay.

RESEARCH QUESTIONS

Science issues were identified based on the hypotheses encapsulated in the conceptual ecological model. Those considered most important to address before restoration construction plans are finalized were consolidated into a set of 14 research questions. The selection of the most important science issues was by informal concensus in the workshops organized to develop the model and was based primarily on the degree to which the topic was considered to be fundamental to the success of Biscayne Bay restoration and relative uncertainty. The following 14 research questions, roughly priorized by the authors, were identified.

1. What is the quantitative relationship between upstream water management, rainfall, and flow into Biscayne Bay? 2. How is estuarine habitat affected by quantity, timing, and distribution of freshwater inflow? 3. What salinity gradient from interior coastal wetlands through the nearshore zone would optimize diversity and abundance of oligotrophic and mesohaline fish species in the bay and its coastal wetlands? 4. What is the quantitative relationship between nutrient and contaminant loads and spatial and temporal patterns of water-quality and sediment-quality? 5. Will use of reclaimed wastewater as a significant component of freshwater inflow have ecological, water quality, or sediment quality effects? 6. How is juvenile pink shrimp abundance affected by changes in quantity, timing, and distribution of freshwater inflow, and is there a direct quantitative relationship between juvenile pink shrimp abundance and fishing success? Is the catch per unit of effort in these fisheries affected by freshwater inflow? 7. How might proposed changes in water management affect seagrass distribution, density, species composition, and dominance in the western nearshore area? 8. What are the effects of freshwater inflow change and sea-level rise on the white zone? 9. What is the functional relationship of toxicant concentrations and fish exposure to the types of abnormalities prevalent in Biscayne Bay fish? 10. What is the actual exposure to toxicants of the bottlenose dolphins in Biscayne Bay? 11. Will changes in freshwater volume and delivery affect manatee distribution, particularly in south Biscayne Bay? 12. What effects will changes in

EXHIBIT 7

water management and control structures have on manatee mortality in Biscayne Bay. 13. Will wading bird nesting activity, nesting success, and foraging activity be improved by the reestablishment of more natural hydropatterns in Biscayne Bay's coastal wetlands? 14. Will changes in water management affect the spread of exotic fish and macroinvertebrate species?

ACKNOWLEDGMENTS

The authors appreciate the technical information provided by Ruth Ewing, Peter Harlem, Jerome Lorenz, John Meeder, Joe Serafy and others. They also appreciate the technical editing provided by Kimberly Jacobs and the comments by reviewers.

LITERATURE CITED

Alleman, R. A. 1990. Surface water quality in the vicinity of Black Point, Dade County, Florida. Miami Dade Department of Environmental Management, Miami, FL, USA. Technical Report 90-14.

Alleman, R. W., S. A. Bellmund, D. W. Black, S. E. Formati, C. A. Gove, and L. K. Gulick. 1995. An update of the surface water improvement and management plan for Biscayne Bay, technical supporting document and appendices. South Florida Water Management District, West Palm Beach, FL, USA.

Ault, J. S., G. A. Diaz, S. G. Smith, J. Luo, and J. E. Serafy. 1999a. An efficient sampling survey design to estimate pink shrimp population abundance in Biscayne Bay, Florida. North American Journal of Fisheries Management 19:696–712.

Ault, J. S., J. Luo, S. G. Smith, J. E. Serafy, G. Diaz, and R. Humston. 1999b. A spatial multistock production model. Canadian Journal of Fisheries and Aquatic Sciences 56(S1):4–25.

Berkeley, S. A. 1984. Fisheries assessment. Final report to Dade County Department of Environmental Resources Management, Miami, FL, USA.

Brand, L. E. 1988. Assessment of plankton resources and their environmental interactions in Biscayne Bay, Florida. Miami-Dade Department of Environmental Resource Management, Miami, FL, USA. DERM Technical Report 88-1.

Browder, J. A., D. B. McClellan, D. E. Harper, M. G. Kandrashoff, and W. Kandrashoff. 1993. A major developmental defect observed in several Biscayne Bay, Florida, fish species. Environmental Biology of Fishes 37:181–188.

Browder, J. A. and D. Moore. 1981. A new approach to determining the quantitative relationship between fishery production and the flow of freshwater to estuaries. p. 403–430. *In* R. Cross (ed.) Proceedings of National Symposium on Fresh Water Inflow to Estuaries, San Antonio, TX, USA.

Browder, J. A., V. R. Restrepo, J. Rice, M. B. Robblee, and Z. Zein-Eldin. 1999. Environmental influences on potential recruitment of pink shrimp, *Farfantepenaeus duorarum*, from Florida Bay nusery grounds. Estuaries 22(2B):484–499.

Browder, J., M. Robblee, J. Hall, D. Reed, D. Smith, and A. Daniels. 2005. Part I: Faunal density and community composition of the nearshore zone. p. 1–91 *In* Biscayne Bay coastal and nearshore community baseline study to develop biological performance measures. Annual Report to the South Florida Water Management District on Agreement C13401-A02. Southeast Fisheries Science Center, National Marine Fisheries Service, NOAA, Miami, FL, USA.

Browder, J. A., Z. Zein-Eldin, M. C. Criales, M. B. Robblee, and T. L. Jackson. 2002. Dynamics of pink shrimp recruitment in relation to Florida Bay salinity and temperature. Estuaries 25(6B): 1335–1371.

Brown, G. L. 2003. Biscayne Bay feasibility study phase 1 scenario study (presentation of results). U. S. Army Corps of Engineers, ERDCVBG-CHL, Vicksburg, MS, USA.

Buchanan, T. J. and H. Klein. 1976. Effects of water management of freshwater discharges to Biscayne Bay. p. 113–132. *In* A. Thorhaug and A. Volker (eds.) Biscayne Bay: Past/Present/Future. University of Miami, Coral Gables, FL, USA. Sea Grant Special Publication No. 5

Burreson, E. M. and L. M. Ragone Calvo. 1996. Epizootiology of *Perkinsus marinus* in Chesapeake Bay, with emphasis on data since 1985. Journal of Shellfish Research 15:17–34.

Campos, W. L. and S. A. Berkeley. 1986. Impact of the commercial fishery on the population of bait shrimp (*Penaeus* spp.) in Biscayne Bay. Final report to the Dade County Department of Environmental Resources Management, Miami, FL, USA.

Chow, V. T. 1964. Handbook of Applied Hydrology. McGraw-Hill, New York, NY, USA.

Chu, F. L. E. and A. K. Volety. 1997. Disease processes of the parasite *Perkinsus marinus* in the eastern oyster, *Crassostrea virginica*: minimum dose for infection initiation, and interaction of temperature, salinity, and infective cell dose. Diseases of Aquatic Organisms 28:61–68.

Corcoran, E. F., M. S. Brown, F. R. Baddour, S. A. Chasens, and A. D. Frey. 1983. Biscayne Bay hydrocarbon study. Final report to Florida Department of Natural Resources, St. Petersburg, FL, USA from University of Miami, FL, USA.

DERM. 1985. Biscayne Bay today, a summary report on its physical and biological characteristics. Miami-Dade County Department of Environmental Resources Management, Miami, FL, USA.

DERM. 1987. Biscayne Bay and the Miami River: a water quality summary, Biscayne Bay through 1984 and Miami River through 1985. Technical Report. Miami-Dade County Department of Environmental Resources Management, Miami, FL, USA.

DERM. 1993. Miami River water quality plan. Report to the Miami River Water Quality Commission. Miami-Dade County Department of Environmental Resources Management, Miami, FL, USA. DERM Technical Report 93-3.

DERM. 2005a. Biscayne Bay water quality wtatus and trends (C-15864), Final Report to the South Florida Water Management District, Miami-Dade County Department of Environmental Resources Management, Miami, FL, USA.

DERM. 2005b. Evaluation of the low dissolved oxygen levels in Miami-Dade County WBIDS: interaction of ground water with surface water in Miami-Dade County canals. Technical Memorandum to Florida Department of Environmental Protection, Miami-Dade County Department of Environmental Resources Management, Miami, FL, USA.

Deutsch, C. J., J. P. Reid, R. K. Bonde, D. E. Easton, H. I. Kochman, and T. J. O'Shea. 2003. Seasonal movements, migratory behavior, and site fidelity of West Indian manatees along the Atlantic coast of the United States. Wildlife Monographs No. 151.

Diaz, G. A. 2001. Population dynamics and assessment of pink shrimp (*Farfantepenaeus duorarum*) in subtropical nursery grounds. Ph. D. Dissertation. University of Miami, Coral Gables, FL, USA.

Fournie, J. W., J. K. Summers, and S. B. Weisberg. 1996. Prevalence of gross pathological abnormalities in estuarine fishes. Transactions of the American Fisheries Society 125:581–590.

FWC. 1999. Save the Manatee Trust Fund fiscal year 1998–1999 annual report. Florida Fish and Wildlife Conservation Commission, Tallahassee, FL, USA.

Gassman, N. J., L. B. Nye, and M. C. Schmale. 1994. Distribution of abnormal biota and sediment contaminants in Biscayne Bay, Florida. Bulletin of Marine Science 54:929–943.

Hansen, L. J. and R. S. Wells. 1996. Bottlenose dolphin death assessment: field report on sampling near Beaufort, North Carolina, during 1995. National Oceanic and Atmospheric Administration, Center for Coastal Fisheries and Habitat Research, Beaufort, NC, USA. Technical Memorandum NMFS-SEFSC-382.

Irlandi, E., S. Macia, and J. E. Serafy. 1997. Salinity reduction from freshwater canal discharge: effects on mortality and feeding of an urchin (*Lytechinus variegates*) and gastropod (*Astracea tecta*). Bulletin of Marine Sciences 61:869–879.

Ishman, S. E., T. M. Cronin, G. L. Brewster-Wingard, D. A. Willard,

EXHIBIT 7

and D. J. Verardo. 1998. Record of ecosystem change, Manatee Bay, Barnes Sound, Florida. Journal of Coastal Research Special Issue 26:125–138.

Kinne, O. 1971. Invertebrates. p. 821–995. *In* H. Barnes (ed.) Marine Ecology. Volume 1, Part 2. Wiley-Interscience, New York, NY, USA.

Kohout, F. A. 1967. Relation of seaward and landward flow of ground water to the salinity of Biscayne Bay. M. S. Thesis. University of Miami, Coral Gables, FL, USA.

Kohout, F. A. and M. C. Kolipinski. 1967. Biological zonation related to ground-water discharge along the shore of Biscayne Bay, Miami, Florida. p. 488–499. *In* Estuaries: American Association for the Advancement of Science Publication No. 83.

Kushlan, J. A. and F. J. Mazzotti. (1989) Historic and present distribution of the American crocodile in Florida. Journal of Herpetology 23:1–7.

Langtimm, C. A., T. J. O'Shea, R. Pradel, and C. A. Beck. 1998. Estimates of annual survival probabilities for adult Florida manatees (*Trichemus manatus latirostris*). Ecology 79:981–997.

LeFebrve, L. W., M. Marmontel, J. P. Reid, G. B. Rathbun, and D. P. Domning. 2001. Status and biogeography of the West Indian manatee. p. 425–474. *In* C. A. Woods and F. E. Sergile (eds.) Biogeography of the West Indies: New Patterns and Perspectives. CRC Press LLC, Boca Raton, FL, USA.

Lietz, A. C. 1999. Methodology for estimating nutrient loads discharged from the east coast canals to Biscayne Bay, Miami-Dade County, Florida. United States Geological Survey, Tallahassee, FL, USA. Water Resources Investigations Report 99-4094.

Lirman, D. and W. P. Cropper. 2003. The influence of salinity on seagrass growth, survivorship, and distribution within Biscayne Bay, Florida: field, experimental, and modeling studies. Estuaries 26:131–141.

Long, E. R., M. J. Hameedi, G. M. Sloane, and L. B. Read. 2002. Chemical contamination, toxicity, and benthic community indices in sediments of the lower Miami River and adjoining portions of Biscayne Bay, Florida. Estuaries 25:622–637.

Long, E. R., G. M. Sloane, G. I. Scott, B. Thompson, R. S. Carr, J. Biedenbach, T. L. Wade, B. J. Presley, K. J. Scott, C. Mueller, G. Breken-Fols, B. Albrecht, J. W. Anderson, and G. T. Chandler. 2000. Magnitude and extent of chemical contamination and toxicity in sediments of Biscayne Bay and vicinity. Center for Coastal Monitoring and Assessment, National Centers for Coastal Ocean Science, National Ocean Service, National Oceanic and Atmospheric Administration, Silver Spring, MD, USA. Technical Memorandum NOS NCCOS CCMA 141.

Lorenz, J. J. 2000. The impact of water management on Roseate Spoonbills and their Piscine Prey in the coastal wetlands of Florida Bay. Ph.D. Dissertation. University of Miami, Coral Gables FL, USA.

Lorenz, J. J. 2001a. The effects of water management on roseate spoonbills and their piscine prey. Responses to a multiyear high rainfall period: implications for the restoration of Taylor Slough. p. 188. *In* Programs and Abstracts of the 2001 Florida Bay Science Conference, Key Largo, Florida. Everglades National Park, Florida Bay and Adjacent Waters Research Program, Homestead, FL, USA.

Lorenz, J. J. 2001b. The effects of water management on roseate spoonbills and their piscine prey II: water depth and hydroperiod effects on prey availability and spoonbill nesting success. p. 190. *In* Programs and Abstracts of the 2001 Florida Bay Science Conference, Key Largo, Florida. Everglades National Park, Florida Bay and Adjacent Waters Research Program, Homestead, FL, USA.

Markley, S. M., D. K. Valdes, and R. Menge. 1990. Sanitary sewer contamination of the Miami River. Miami-Dade County Department of Environmental Resource Management, Miami, FL, USA. DERM Technical Report 90-9.

Mayo, K. E. and S. M. Markley. 1995. Dade County manatee protection plan. Miami-Dade County Department of Environmental Resource Management, Miami, FL, USA. DERM Technical Report 95-5.

Mazzotti, F. J. and L. A. Brandt. 1995. A Biological assessment of the effects of the C-111 Project on the American crocodile in northeastern Florida Bay, Everglades National Park. Final report to University of Florida, Department of Wildlife Ecology and Conservation, Gainesville, FL, USA.

Mazzotti, F. J., M. S. Cherkiss, G. S. Cook, and E. McKercher. 2002. Status and conservation of the American crocodile in Florida: recovering an endangered species while restoring an endangered ecosystem. Final report to the National Park Service, Everglades National Park, Homestead, FL, USA.

Mazzotti, F. J. and W. A. Dunson. 1984. Adaptations of *Crocodylus acutus* and alligator for life in saline water. Comparative Biochemistry and Physiology 79:641–646.

McNulty, J. K. 1970. Effects of abatement of domestic sewage pollution on the benthos, volumes of zooplankton, and the fouling organisms of Biscayne Bay. University of Miami Press, Coral Gables, FL, USA.

Meeder, J. F., J. Alvalord, M. Byrn, M. S. Ross, and A. Renshaw. 1997. Distribution of benthic nearshore communities and their relationship to ground water nutrient loading. Final report to Biscayne National Park from the Southeast Environmental Research Program, Florida International University, Miami, FL, USA.

Meeder, J. and J. N. Boyer. 2001. Total ammonia concentration in soil, sediments, surface water, and ground water along the western shoreline of Biscayne Bay with the focus on Black Point and a reference mangrove site. Final report to the National Park Service in response to Project Statement BISC-N-011.000 under National Park Service/Florida International University Cooperative Agreement No. CA5280-8-9038. Florida International University, Southeast Environmental Research Center, Miami, FL, USA.

Meeder, J., P. Harlem, and A. Renshaw. 2001. Historic creek watershed study final results; year 1. Southeast Environmental Research Center, Florida International University, Miami. FL, USA.

Meeder, J., P. Harlem, and A. Renshaw. 2002. Restoration of the Black Creek coastal wetlands and adjacent nearshore estuarine zone of Biscayne Bay. Southeast Environmental Research Center, Florida International University, Miami, FL, USA.

Meeder, J. F., M. S. Ross, and P. Ruiz. 1999. Characterization of historic Biscayne Bay watersheds. First Quarterly Report to Florida Center for Environmental Studies by Southeast Environmental Research Program, Florida International University, Miami, FL, USA.

Montague, C. L. and J. A. Ley. 1993. A possible effect of salinity fluctuations on abundance of benthic vegetation and associated fauna in northeastern Florida Bay. Estuaries 16:707–717.

Murphy, M. D., C. A. Meyer, and A. L. McMillen-Jackson. 2001. A stock assessment for blue crab, *Callinectes sapidus*, in Florida waters. Florida Fish and Wildlife Commission, Florida Marine Research Institute, St. Petersburg, FL, USA.

O'Shea, T. J. and H. I. Kochman. 1990. Florida manatees: distribution, geographically referenced data sets, and ecological and behavioral aspects of habitat use. p. 11–22. *In* J. E. Reynolds, III and K. D. Haddad (eds.) Report of the Workshop on Geographic Infromation Systems as an Aid to Managing Habitat for West Indian Manatees in Florida and Georgia. Florida Fish and Wildlife Commission, Florida Marine Research Institute, St. Petersburg, FL, USA. Research Publications No. 49.

Parker, G. G., G. E. Ferguson, and S. K. Love. 1955. Water resources of southern Florida with special reference to the geology and groundwater of the Miami area. United States Geological Survey, Washington, DC, USA. Water Supply Paper 1255.

Pattillo, M., T. Czapla, D. Nelson, and M. Manaco. 1997. Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries. Volume II: species life history summaries. National Oceanic Atmospheric Administration/National Ocean Service Strategic Environmental Assessment Division, Silver Spring, MD, USA. Estuarine Living Marine Resources (ELMR) program report no. 11.

Reddy, M. L., J. S. Reif, A. Bachand, and S. H. Ridgway. 2001. Opportunities for using navy marine mammals to explore associations between organochlorine contaminants and unfavorable effects on reproduction. Science of the Total Environment 274:171–182.

Roessler, M. A. and G. L. Beardsley. 1974. Biscayne Bay: Its' Environment and Problems. Florida Scientist 37:186–204.

EXHIBIT 7

Ross, M. S., E. E. Gaiser, J. F. Meeder, and M. T. Lewin. 2002. Multi-taxon analysis of the ''white zone.'' A common ecotonal feature of the South Florida coastal wetlands. p. 205–238. *In* J. W. Porter and K. G. Porter (eds.) The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: an Ecosystem Sourcebook. CRC Press, Boca Raton, FL, USA.

Ross, M. S., J. F. Meeder, J. P. Sah, P. L. Ruiz, and G. J. Telesnicki. 2000. The southeast saline everglades revisited: a half-century of coastal vegetation change. Journal of Vegetation Science 11:101–112.

Sanders, T. P., R. J. Miltner, C. O. Yoder, and E. T. Rankin. 1999. The use of external deformities, erosion, lesions, and tumors (DELT anomalies) in fish assemblages for characterizing aquatic resources: a case study of seven Ohio streams. p. 225–246. *In* T. P. Simon Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. CRC Press, New York, NY, USA.

Schmale, M. C. 1991. Effects of historical contaminants on biota in Biscayne Bay, Florida 1991–93. Report prepared by Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL, USA for South Florida Water Management District, West Palm Beach, FL, USA.

Schwacke, L. H., E. O. Voit, L. J. Hansen, R. S. Wells, G. B. Mitchum, A. A. Hohn, and P. A. Fair. 2002. Probabilistic risk assessment of reproductive effects of polychlorinated biphenyls on bottlenose dolphins (*Tursiops truncates*) from the southeast United States coast. Environmental Toxicology and Chemistry 21: 2752–2764. Erratum in: Environmental Toxicology and Chemistry 22:689.

Seal, T. L., F. D. Calder, G. M. Sloane, S. J. Schropp, and H. L. Windom. 1994. Florida Coastal Sediment Contaminants Atlas. Florida Department of Environmental Protection, Tallahassee, FL, USA.

Serafy, J. E., J. S. Ault, P. Ortner, and R. Curry. 2001. Coupling Biscayne Bay's natural resources and fisheries to environmental quality and freshwater inflow management. p. 163–174. *In* Biscayne Bay Partnership Initiative. Science Team Final Reports, Miami, FL, USA.

Serafy, J. E., K. C. Lindeman, T. E. Hopkins, and J. S. Ault. 1997. Effects of freshwater canal discharge on fish assemblages in a subtropical bay: field and laboratory observations. Marine Ecology Progress Series 160:161–172.

Shumway, S. E. 1996. Natural environmental factors. p. 467–513. *In* V. S. Kennedy, R. I. E. Newell, and A. F. Eble (eds.) The Eastern Oyster *Crassostrea virginica*. Maryland Sea Grant College Publication, College Park, MD, USA.

Siebenaler, J. B. 1953. The Biscayne Bay commercial fishery. University of Miami, Miami, FL, USA. Florida Board of Conservation Technical Series No. 6.

Simon, T. P. 1999. Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. CRC Press, Washington, DC, USA.

Smith, H. M. 1896. Notes on Biscayne Bay, Florida, with references to its adaptability as the site of a marine hatching and experimental station. p. 169–186. *In* Report to the U.S. Commissioner of Fish and Fisheries for 1896, Government Printing Office, Washington, DC, USA.

Soniat, T. M. 1996. Epizootiology of *Perkinsus marinus* disease of eastern oysters in the Gulf of Mexico. Journal of Shellfish Research 15:35–43.

Swain, E. D., A. Kapadia, S. Kone, E. Demisse, D. Mtundu, and G. M. Tillis. 1997. Determining discharge-coefficient ratings for coastal structures in Dade County, Florida. United States Geological Survey, Tallahassee, FL, USA. Water Resources Investigations Report 97-4079.

Sweeney, J. 1992. Report summary of the Bottlenose Dolphin Health Assessment Project, Matagorda Bay, TX, USA. Report to the National Marine Fisheries Service.

Udey, L., A. Cantillo, W. Kandrashoff, and J. Browder. 2002. Results of a fish health survey of north Biscayne Bay: June 1976–June 1977. National Oceanic and Atmospheric Administration, Silver Spring, MD, USA (Technical Memorandum NOS N CCOS CCMA) and Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL, USA. Technical Report 2002-02.

University of Miami and SFWMD. 1995. The South Dade Watershed Project planning and support documents. South Florida Water Management District, West Palm Beach, FL, USA.

USACE and SFWMD. 1999. Central and Southern Florida Project Comprehensive Review Study Final Intergrated Feasibility Report and Programmatic Environmental Impact Statement. United States Army Corps of Engineers, Jacksonville District, FL, USA and South Florida Water Management District, West Palm Beach, FL, USA.

USEPA. 1999. Region 4 Military Canal Special Study Homestead Air Force Base, Florida. Final report, United States Environmental Protection Agency, Atlanta, GA, USA. SESD Project No. 98-0062.

USFWS. 2001. Florida manatee recovery plan (*Trichechus manatus latirostris*), third revision. United States Fish and Wildlife Service, Atlanta, GA, USA.

Volety, A. K., S. G. Tolley, and J. T. Winstead. 2003. Effects of seasonal and water quality parameters on oysters (*Crassostrea virginica*) and associated fish populations in the Caloosahatchee River. Florida South Florida Water Management District, West Palm Beach, FL, USA.

Wanless, H. 1969. Sediments of Biscayne Bay: distribution and depositional history. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami. FL, USA. Technical Report 69-2.

Wanless, H., D. Cottrell, R. Parkinson, and E. Burton. 1984. Sources and circulation of turbidity in Biscayne Bay, Florida. Florida Sea Grant and Miami-Dade County, Miami, FL USA.

Wingard, G. L, T. C. Cronin, G. S. Dwyer, S. E. Ishman, D. A. Willard, C. W. Holmes, C. E. Bernhardt, C. P. Williams, M. E. Marot, J. B. Murray, R. G. Stamm, J. H. Murray, and C. Budet. 2003. Ecosystem history of southern and central Biscayne Bay: summary report on sediment core analyses. U.S. Department of Interior, U.S. Geological Survey, Reston, VA, USA. Open File Report 03-375.

Worthy, G. A. J. 1992. Body condition of free-ranging bottlenose dolphins (*Tursiops truncatus*) in the vicinity of Port O'Connor, Texas-July 1992. Contract report to National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, Miami, FL, USA.

Manuscript received 10 January 2005; revisions received 6 September 2005; accepted 27 September 2005.