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CONDITION OF THE NATURAL RESOURCES OF BISCAYNE NATIONAL PARK



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CONDITION OF THE NATURAL RESOURCES OF BISCAYNE NATIONAL PARK

A STATE OF THE PARKS TECHNICAL REPORT

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Executive Summary

Biscayne National Park (N.P.), located in the heart of a shallow sub-tropical lagoon in south Florida known as Biscayne Bay, embodies the greatest aspirations and deepest challenges faced by the National Park Service. On the one hand, the 173,000-acre park—the largest marine park in the United States—represents a bold attempt to preserve an ecosystem that is unique in America. Biscayne N.P. protects the northernmost extent of the third-longest chain of coral reefs in the world, contains the longest patch of coastal mangroves left in eastern Florida, and harbors a diverse array of marine and tropical fauna and flora, including commercially and recreationally important fish, crustaceans and shellfish, and many rare and endemic species. On the other hand, Biscayne N.P. is bordered by Miami, a rapidly-growing city that anchors the sixth-largest metropolitan area in the United States, with more than five million people. Urban, industrial, and agricultural land uses in south Florida have given rise to a wide array of threats to the park's natural resources. Because the ecological health of the park—95% of which is water—depends upon the natural flow of freshwater into Biscayne Bay, the chief threats to these resources are: 1) drainage, dredging, and water diversion projects that have altered the timing, distribution and quantity of freshwater inputs into the bay, and 2) habitat loss and disturbance to the coastal wetlands that these waters once flowed through. These changes have transformed the estuary from a system characterized by periodic and pulsed inputs of freshwater from surface waters, overland sheet flow, and more gradual, diffuse groundwater flows, into an artificially pulsed system that is driven by freshwater inputs from man-made canals.

In this report, we assess the condition of Biscayne Bay's natural resources using the methodology developed by the National Parks Conservation Association (NPCA) for its State of the Parks Program. This technical report will inform NPCA's State of the Park Report for Biscayne N.P. It should be read together with NatureServe's related report on Florida Bay, an adjacent body of water. Our assessment consists primarily of a thorough review and summary of existing published scientific research, supplemented by expert input from natural resource professionals and scientists familiar with the issues affecting Biscayne Bay. For each of several key natural resources, we review its current condition within a historic context, describe its role and importance within the bay ecosystem, summarize the threats to the resource, and consider opportunities for restoration and management. In this report, we document the extent to which the natural resources of Biscayne N.P. are showing signs of ecological stress and the degree to which this stress is caused by natural versus anthropogenic (i.e. human-caused) forces. Below we highlight key findings related to water resources, terrestrial ecosystems, marine ecosystems, and marine species.

Water Resources

- In the last 100 years, **salinity levels** within Biscayne Bay have risen and become more steady. It is not clear how much of this change can be attributed to man-made alterations to freshwater flows versus natural rises in sea level.
- Though precise, quantitative information is lacking, it is clear that drainage and water diversion projects have altered the timing, distribution and quantity of **freshwater flows** into the bay. Surface water flow has been restricted to flow out of mainly artificial canals. Overland sheet flow has been completely eliminated in the part of the watershed that feeds northern Biscayne Bay, and the historic groundwater flows into the bay have probably diminished.

- Water quality within the park is generally good, though effluents with high nutrient loads and contaminants can lead to periodic declines in water quality, especially in northern Biscayne Bay (outside of the park), and the western margins of the bay.
- There is some evidence that groundwater within the Biscayne Aquifer that underlies and feeds the Bay is contaminated from various land uses, including agricultural fields, landfills, and septic tanks. It is not known to what extent and at what rate this pollution is delivered to waters and habitats of Biscayne N.P.

Terrestrial Ecosystems

- The structure and function of the **coastal wetland communities** that form the western edge of Biscayne N.P. have been fundamentally changed from their natural conditions. Coastal wetlands are already greatly diminished in extent outside of the park boundaries by urban and agricultural land uses. In addition, the ecological boundary between freshwater and marine systems has shifted inland, as marshes recede and mangroves encroach. The rate of this inward shift (from 3 to 30 meters annually) is dramatically greater than the background rate (one-half meter annually) from sea level rise alone.
- **Tropical hardwood hammocks** that occur on islands within the park are a habitat type found in few places in the United States. Harboring many rare and endemic species, hammock on two of the larger islands in Biscayne N.P. have historically suffered significant habitat destruction, and their limited extent and isolation make them vulnerable to further damage from both natural and anthropogenic disturbances.

Marine Ecosystems

- **Coral reef** cover in the park declined from 1984-2000, both for terrestrial bank-barrier reefs (from 29% to 11%) and patch reefs (from 26% to 17%). Diversity within coral reefs declined by 13-29% from 1989 to 1991. Only short-term trend data are available, however, and should be viewed with caution.
- **Threats and stressors to coral reefs** are poorly understood and need to be further investigated, but there is some indication that a combination of natural forces (hurricanes) and anthropogenic disturbances (coral bleaching, white banding disease) have led to declines in coral species. These include two *Acropora* species that were historically the primary framework reef builders in the region.

- **Seagrass communities** within the park, unlike the disturbed communities in northern Biscayne Bay, are relatively stable and healthy. Seagrasses can be negatively impacted on a local scale, however. Direct impacts include damage from boat groundings and boat propellers. Indirect impacts are due to stresses derived from changes in salinity, turbidity, water temperature, and nutrients.

Marine Species

- Recent studies suggest that 27 of 35 **fish species** populations examined in Biscayne N.P., including three fishes selected as representative species for this report, may be overfished. Thirteen of these species can be legally fished at sizes below their size of sexual maturity, indicating that individuals may be harvested before they can replenish populations.
- Due to changes in hydrology and perhaps sea-level rise, fish assemblages in the park and in Biscayne Bay resemble those found in a freshwater-pulsed lagoon, rather than those found under more estuarine conditions. For example, populations of **estuarine fish species**, including red drum and other drums, have declined in the bay, most likely due to loss and degradation of nursery mangrove and oyster bar habitats.
- Populations of **spiny lobster**, an abundant and commercially valuable fishery, are relatively stable, but changes to salinity or nutrient regimes may harm these populations, both through direct and indirect means.

Introduction

Origins and Orientation

With the major portion of its 173,000 acres under marine waters, Biscayne National Park (herein referred to as "Biscayne N.P." or "Park") is one of the largest marine parks in the National Park Service, protecting the northern extent of the third largest coral reef system in the world and the longest stretch of mangrove forest remaining on Florida's east coast, providing habitat and nursing grounds for most of the important commercial and recreational fish, shellfish and crustaceans in the region, and harboring many endangered species, including the West Indian Manatee (NPS 2005a, BBPI-PDC 2001, Lidz 2002). Biscayne N.P. resides in the central portion of Biscayne Bay (Figure 1), located along the southeastern margin of the Florida peninsula. It has been described as a body of water containing crystal clear waters variously colored by the benthic communities underneath it, teeming with fish and wading birds, a place that increasingly became a site to seek solace and refuge amidst the burgeoning growth of Miami (BBPI-PDC 2001). In fact, the establishment of Biscayne National Monument in 1968, expanded in 1974 and again in 1980 to become Biscayne National Park (Cantillo et al. 2000), was driven in large measure to preserve the unique resources within the bay from the development of Miami, a city whose development had already engulfed northern Biscayne Bay, changing its natural physical structure, ocean circulation, bathymetry and turbidity, and salinity patterns (BBPI-PDC 2001).

It is the fact that Biscayne N.P. is one of the few National Parks with significant natural resources in close proximity to a major metropolitan area that characterizes the threats to the health and condition of plants, animals and communities within the Park. As with other natural areas in southern Florida, most notably Everglades National Park, the advent of major water diversion, drainage, and canalization projects throughout the 20th century have altered the natural hydrologic flows and ecological processes that once characterized the region. The bay itself has changed from a functioning estuary driven by the relative balance of freshwater and marine water inputs, to a pulsed system, punctuated by point-source discharges of freshwater from canals (BBPI-PDC 2001). Under the umbrella of this landscape scale change in structure and function, we evaluate the condition of the following ecosystems: coral reefs,

seagrasses, and coastal wetlands; as well as the following representative marine species: spiny lobster (*Panulirus argus*), red grouper (*Epinephelus morio*), red drum (*Sciaenops ocellatus*), and gray snapper (*Lutjanus griseus*). We evaluate the following threats that impinge upon the condition of these natural resources: change in quantity, quality, timing and distribution of freshwater delivery, direct destruction of habitats (benthic vegetation, coral reefs and coastal wetlands), alterations of function caused by anthropogenic disturbance, saltwater intrusion of the Biscayne Bay aquifer, and contamination of water and sediments in areas directly adjacent to canals and creeks that drain into the bay.



Figure 1. Map of Biscayne National Park, located in southern Florida. Sources: NPS 2005b, National Atlas 2005.

Park Location and Size

The map displays the geographical layout of Biscayne Bay, divided into North, Central, and South Biscayne Bay. It includes labels for surrounding areas: Broward to the north, Miami-Dade to the west, and Monroe to the south. A legend in the bottom right corner defines symbols for Broward Bay, Biscayne Bay, North Biscayne Bay, Central Biscayne Bay, South Biscayne Bay, and various water bodies. A scale bar and a north arrow are also present.

The north bay area extends from Broward County and Dumbfoundling Bay southward to Rickenbacker Causeway, constituting about 10% of the total area of the bay. This sector is the most heavily populated and impacted within the Bay. Only two islands in the north bay, Belle Isle and Virginia Key, are natural, whereas the majority of islands in this region have been created artificially by dredge and fill projects. The central bay is the largest section of the main bay, extending from the Causeway southward to Sands Key. This area forms a good portion of Biscayne Bay National Park. The south bay extends from the Featherbed Bank to Card Bank, and harbors the least developed, and best preserved natural habitats in the Bay. There are two sounds in southern Biscayne Bay, Card Sound and Barnes Sound, connected to the Bay by restricted openings at Card Sound which permit limited exchange between the two. There are a number of natural keys in this part of the Bay (SFWMD 1995) much of which also lies within Biscayne National Park.

South Florida has a tropical climate characterized by two seasons: a wet season from May to October and a dry season from November to April (Duever et al. 1994). The average precipitation, which has remained relatively constant for the past 100 years, is 60 inches (152 cm) per year (Buchanan and Klein 1976, Duever et al 1994).

Other than relatively high rainfall and mild temperatures, the region experiences extreme climate events, including freezes, drought and tropical cyclones (e.g. tropical storms, hurricanes). These events vary over time and space, but can have a large effect on the abiotic and biotic processes (Duever et al 1994). Hurricanes have received recent attention, given the occurrence of four hurricanes in Florida in 2004. From 1871-1986, at least one tropical storm or hurricane has impacted ENP every year, with a high of 21 events in 1933

(Duever et al. 1994). These storms can generate storm surges in the coastal areas and heavy rains and winds in the non-coastal areas. Hurricane Andrew, for example, laid bare a 50 km swath of vegetation, where damage was greatest in areas of hardwood vegetation and less so in pine and cypress lands (Duever et al. 1994).

Geology, Landforms and Bathymetry

Approximately five thousand years ago, sea water inundated a limestone depression and formed present day Biscayne Bay (BBPI-PMC 2001, Wanless et al. 1994). This geologic substrate, the Miami oolite formation, is a limestone of varying porosity that formed during the Pleistocene (BBPI-SST 2001, Gleason and Stone 1994). It is underlaid by the easternmost extent of the Biscayne Aquifer which extends into the neighboring Everglades watershed and thus connects Biscayne Bay with the hydrologic processes of that region (BBPI-SST 2001). The Biscayne Aquifer, in turn, is underlaid by the Tamiami formation, substrate laid during the Pliocene.

The Miami formation also forms the substrate of the mainland bordering the western edge of Biscayne Bay. The Atlantic coastal ridge, a mound of cross-bedded oolite limestone (Gleason and Stone 1994), emerges several miles inland to heights of up to twenty-five feet above sea-level, forming the only topographic relief in the region, and a natural geological barrier of water flow between the Everglades watershed and the Biscayne Bay watershed (BBPI-SST 2001). The mainland was also characterized by emergent springs where freshwater was driven to the surface by blockages or areas of low permeability in the limestone (BBPI-SST 2001).

The eastern boundary of Biscayne Bay is formed by a coral limestone ridge that is submerged in the northern reaches of the bay and emergent in the southern portions, forming the following bay islands: Sands Key, Elliott Key, Old Rhodes Key and Key Largo (Figure 3, BBPI-SST 2001). In contrast, the islands in northern Biscayne Bay represent the southernmost extent of the sandy barrier islands (BBPI-SST 2001). Three-quarters of the substrate on these islands is carbonate skeletal sand developed locally, while one-quarter is quartz sand deposited from the north (BBPI-SST 2001). Biscayne N.P. encompasses examples of both the sand and coral islands.

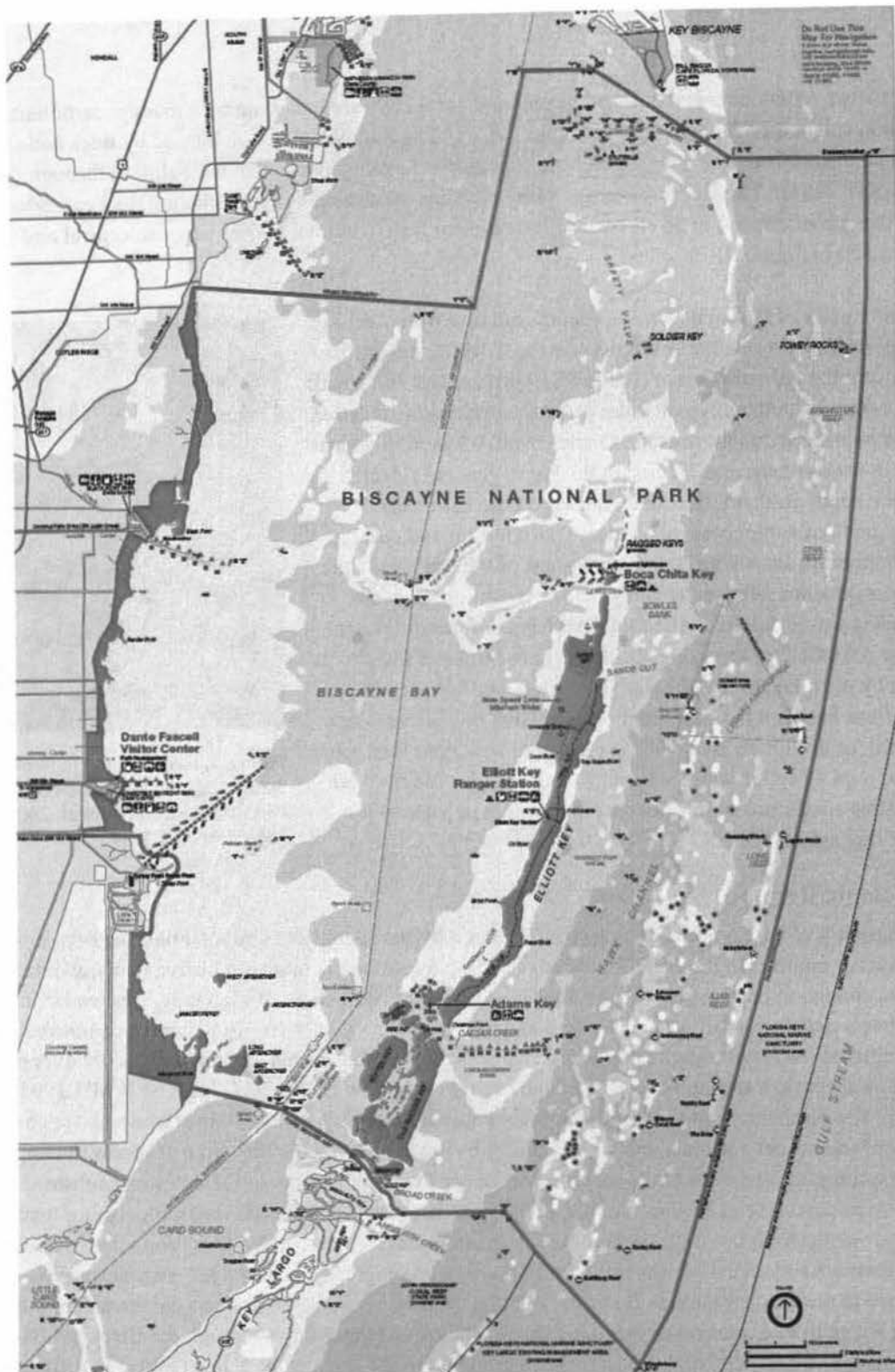


Figure 3. Schematic map of Biscayne National Park, showing islands and landforms within the Park, and adjacent land uses. Source: NPS 2005c.

Open marine waters between the sand barrier and coral keys are underlain by a muddy, carbonate shoal formation called the "Safety Valve" (Figure 3 & 4). The Safety Valve was formed by tides and storms that deposited materials on the submerged limestone ridge, forming canals that have shifted through the years (BBPI-SST 2001). The floor of Biscayne Bay contains other mud banks, including the Featherbed banks, banks that are orientated in an east-west direction and form a natural barrier between central and southern Biscayne Bay (Figure 4).

The bathymetry of Biscayne Bay has depths ranging from 1 to 3 m, sloping from shallows adjacent to the coast to a deeper central bay area toward the Atlantic Ocean (BBPI-SST 2001). Bars and shoals create a complicated bathymetry and present barriers to circulation at some points. Sediment thickness varies from 4-5 m in the north to 1 m in the southern end. Sediment thickness generally decreases along the depth gradient, having an impact on the kinds and rooting depth of submerged vegetation. Hardbottom and coral reef communities appear toward the eastern areas of the bay where the carbonate structures cause the bathymetry to shoal up. Several large inlets permit relatively free tidal exchange of marine water with the Atlantic Ocean through passages between keys and shoals created by the tidal flow. Although restricted, hydrologic connections between the bay and the ocean have not been sealed off by fill, as in Florida Bay. The exchange of Biscayne Bay water with the ocean through these tidal inlets reduces the tendency for hypersaline conditions to develop as often occurs in parts of the Florida Bay estuary.



Figure 4. Aerial photograph of the Safety Valve in Biscayne National Park. After: Cantillo et al. 2000. Source: NOAA 2000.

Hydrologic Regime

The hydrology of Biscayne Bay can be characterized by the spatial and temporal balance between fresh and marine water inputs into the Bay. Knowledge of Bay hydrology is more qualitative than quantitative but we do know enough to paint a general picture of historic patterns of flow. Historically, freshwater inputs came from three sources: rainfall, groundwater, and surface waters. Under pre-management conditions, surface waters entered the Bay through naturalized channels, creeks and spring, and more diffusely over a greater area of land, as sheet flow through coastal wetlands and into the Bay (BBPI-SST 2001, SFWMD 1995).

Groundwater discharged into the Bay as groundwater seepage and through subsurface leakage channels. A number of freshwater springs, both surface and subsurface, entered the Bay from groundwater sources, the surface springs being driven to the surface by areas of low permeability in the limestone substrate (BBPI-SST 2001). Anecdotal stories of ships docked in the western margins of the Bay and replenishing their freshwater supplies directly from the Bay, support the supposition that these groundwater spring inputs were substantial. The Biscayne Bay watershed was historically linked hydrologically to the larger neighboring Everglades watershed to the west by surface flows through the tranverse glades, natural cuts and breaks in the Atlantic Coastal Ridge that separates the two watersheds, and groundwater flows through the Biscayne Bay Aquifer. From a temporal perspective, historic freshwater inputs to the Bay can be characterized by diffuse and prolonged inputs of freshwater from groundwater sources, especially in the dry season, punctuated by sporadic pulse inputs from natural drainage ways during the rainy season.

Historic marine water entered the Biscayne Bay from the Atlantic Ocean through a series of natural breaks and inlets between the eastern barrier islands, including two natural inlets in the northern bay, and the transitional zone separating sandy barrier islands from the coral reef keys. Together, the mixing of fresh and marine waters are believed to have created a Bay characterized by a gradient in salinity increasing from west to east, where an estuarine zone was maintained in its western margins, moderated by natural freshwater inputs, and a more marine environment existed in the central and eastern portions of the Bay.

As is detailed in other portions of this report, modification to the natural environments of Biscayne Bay in the 20th century, including land use changes and major water management projects, have fundamentally altered the hydrology of the region. Major draining and canalization projects, especially those developed under the Central and South Florida Project begun in 1948 (Light and Dineen 1994), have altered the volume, distribution, and timing of freshwater inputs into the Bay (BBPI-PMC 2001). Modifications to the Biscayne Bay itself, especially the northern portions of the Bay closes to Miami, including the construction of two artificial inlets, dredging of bay bottoms by up to 40 feet, the construction of many artificial islands and causeways, and the destruction of coastal wetlands bordering the bay, have led to alterations in marine water inputs and circulation within the Bay (BBPI-SST 2001). In sum, alterations to the natural flows of both fresh and marine waters into Biscayne Bay have created an artificially driven hydrologic system characterized by pulse point source inputs of freshwater into the Bay.

Hydrologic Regime: Sea Level Rise

Sea levels have risen along the south Florida coastline beginning 15,000 years ago, after the end of the last ice age (Wanless et al. 1994). This rate of sea level rise has varied throughout this time period, from 23 centimeters every 100 years from 5,500-3,000 before present to 4 centimeters per year until recent times. In the last seventy years, beginning in the early 1930s, the rate of sea level rise once again increased to 20-40 centimeters every 100 years (Wanless et al. 1994, Maul and Martin 1993), a six to ten-fold increase from the previous period. If sea level rise continues at this rate, or even increases as predicted by some global climate models, then ecosystems in south Florida and Biscayne N.P. will undergo transition and change. These impacts have been recorded in previous times of rapid sea level rise and include: erosion of coastlines, recession of freshwater wetlands inland, encroachment of mangroves or open water environments, saltwater intrusion into the mainland and aquifer, and development of a deeper, more saline bay (Wanless et al. 1994).

Ecological and Habitat Classifications

Several marine, freshwater and terrestrial ecosystems within Biscayne Bay are significant to ecological function in the region, and, in addition, provide habitat to a rich and productive fauna. The principal habitat types in the bay include: the coastal wetlands (including mangroves), the seagrass community, the hardbottom community and the coral reef community. The distribution of benthic communities in Biscayne Bay is shown in Figure 5. Below we describe the classification of these ecosystems according to standard classification schemes developed by NatureServe for marine (Madden and Grossman 2004) and terrestrial (Grossman et al. 1998) communities and ecosystems.

Ecological and Habitat Classifications: Marine Ecosystems

As a framework for organizing ecological information associated with Florida Bay, we utilize an emerging NatureServe habitat classification, called the Coastal Marine Ecological Classification System (CMECS) (Madden and Grossman 2004). CMECS is an ecosystem-oriented, science-based framework for the identification, inventory, and description of coastal and marine habitats and biodiversity. The CMECS is designed to provide a framework for developing a consistent and universally recognized inventory of all habitats of the North American coasts and oceans. The flexibility of this classification supports a variety of local and regional applications.

Consisting of eight nested levels, the CMECS is hierarchical, extending from ecological regions at the largest spatial scale to habitat and associated biotopes at the smallest scale, within the following structure:

- | | |
|----------------|---|
| Level 1 | Ecological Region: 26 large regions of the coasts and oceans of North America and its possessions, defined by similar physical and/or biological characteristics |
| Level 2 | Regime: two coastal and marine types defined by the presence or absence of fresh water |
| Level 3 | System: six defined types that include semi-enclosed estuaries, estuarine-influenced waters, and marine waters of shallow (0-30m), deeper (30-200m) or very deep (>200m) water columns |
| Level 4 | Hydroform/Geoform: large scale physical entities that are formed by either water or solid substrate, such as lagoons, gyres, and large islands |
| Level 5 | Zone: the water column, littoral or bottom zones of the hydroforms and geoforms |
| Level 6 | Macrohabitat: large physical structures that contain multiple habitats |
| Level 7 | Habitat: specific combinations of physical and energy characteristics that creates a suitable place for colonization or use by biota |
| Level 8 | Biotope: the ecological unit including a typical biology associated with its specific habitat |

Linkages between levels of the hierarchy are defined by ecosystem processes and by spatial relationships. The classification was designed to articulate with existing national fresh water and terrestrial classification standards.

The Biscayne Bay ecosystem can be classified at the upper levels of the CMECS as follows: (1) Floridan-Bahamian ecological region; (2) partly Fresh water influenced and partly Marine; and (3) Estuarine and Nearshore Marine systems. Within each of the two *system* divisions at level 3, several *geoform* (level 4) units exist in Biscayne Bay, including Island, Reef, Estuary and Marine Lagoons. Each of these geoforms contains one or more of the following *zones* at level 5: Littoral, Benthic and Water Column Zones. Each of the large geoforms and their zones in the bay can be further classified into the following *macrohabitats* at level 6:



Figure 5. Distribution of the bottom communities in Biscayne Bay (USGS 1995).

Mangrove Swamp, Submersed Bed, Softbottom, Hardbottom, and Coral Reef Macrohabitats. Each of these macrohabitats contains one or multiple *habitats* (level 7) and their *biotopes* (level 8).

The major marine communities within Biscayne Bay that are relevant to this assessment are macrohabitats within Level 6 of the hierarchy: *the Sub-Tropical soft-bottom seagrass community* and *the Coral Reef community*.

Ecological and Habitat Classifications: Coastal Wetlands

Egler (1952) called the coastal plain on the southeastern tip of Florida the Southeast Saline Everglades (SSE) incorporating in this term the flat expanses of herbaceous marsh south and east of the Atlantic Coastal Ridge extending coastward to the saline mangrove forest. Included in the SSE were four marsh belts sandwiched between the uplands and the closed-canopy "fringing" mangrove forests along the coast. Egler's first marsh belt, nearest the uplands was his "upper saline Everglades" occupied by sawgrass marsh. The adjacent belt which he called the "lower saline Everglades", was a narrow belt with sparse vegetation dominated by sawgrass, but also with spikerush (*Eleocharis cellulosa*) and stunted red mangrove. The third belt, called "mangrove-sawgrass vegetation", consisted of a mosaic of sawgrass patches, mixed mangrove forest (mostly red and black mangrove) and areas of open water. The final marsh belt impinged on its shoreward boundary upon the coastal mangrove forest. In the marshes, sawgrass was replaced by salt-tolerant species such as salt grass, *Batis maritima* (saltwort) and *Juncus roemerianus* (needlerush). Mangroves were locally dominant.

The vegetation belts described by Egler (1952) can be related to alliances developed in NatureServe's ecological system framework (Grossman et al. 1998), recognizing that even in 1940, the hydrological balance of the SSE was already markedly altered. Thus the vegetation was probably already in a disturbed condition that differed from the areas prior to disturbance by pre-European man. An alliance is defined as "...a physiognomically uniform group of plant associations sharing one or more dominant or diagnostic species, which as a rule are found in the uppermost stratum of the vegetation." (Grossman et al. 1998). The "upper saline Everglades," the first (interior) marsh belt of Egler (1952), is equivalent to the *Cladium mariscus* ssp. *jamaicense* Seasonally Flooded Tropical Herbaceous Alliance. However, wetter areas may well have supported the *Eleocharis cellulosa*-*Rhynchospora traceyi* Seasonally Flooded Alliance because there are large areas of this ecosystem type today in the nearby southern Taylor Slough marshes that lie north of the mangrove forests bordering Florida Bay.

The adjacent "lower saline Everglades," partially resembles two associations falling within the previously mentioned *Cladium* alliance, specifically the *Cladium-periphyton* and the *Cladium-Fimbristylis castanea*-*Symphyotrichum tenuifolium* Herbaceous associations. In the SSE, the presence of stunted red mangrove reflects the proximity of the coast and is not represented in the *Cladium-periphyton* association. Thus, the *Cladium-Fimbristylis castanea*-*Symphyotrichum tenuifolium* Herbaceous Vegetation association (though defined only as occurring in the Florida Keys) also is similar given the inclusion of woody salt-tolerant species in some variants.

The "mangrove-sawgrass" belt of Egler (1952) resembles most closely the *Rhizophora mangle* Semipermanently Flooded Shrubland Alliance, a non-tidal ecosystem with freshwater components in the herbaceous layer and a stunted tree layer. The marsh belt, nearest the coast, the "mangrove-tidal marsh", shares much in common with the *Rhizophora-Conocarpus* Seasonally Flooded Forest Alliance given its composition and non-tidal conditions.

Ecological and Habitat Classifications: Terrestrial Upland Communities

Most of Elliott Key is covered by dry tropical hardwood forest typical of the Upper Florida Keys. Old Rhodes, Totten and Sands Key also have well developed but smaller hardwood forests. These islands and many of the other, smaller ones support mangrove forest, and some include some coastal strand and beach vegetation. The hardwood forests are classifiable as Southeast Florida Coastal Strand and Maritime Hammock (Grossman et al. 1998).

Little is known of the nature of these forests prior to human disturbance. The hammock forests would fit into ecological site units 11 and 12 in the classification of Keys terrestrial habitats developed by Ross et al (1992). These two units occur on the highest land elevations with canopy heights of 6-10 m and relatively open understories. Based on fine litter production, they have, with the exception of tall mangrove forest, the highest productivities of the terrestrial habitats (Ross et al 1992).

Native and Introduced Species

Biscayne N.P. habitats are renowned for harboring many commercially and recreationally important fish and shellfish, and for providing nursery grounds for many coral reef species (Ault et al. 2001). At least 325 species of fish and macro-invertebrates occur in Biscayne N.P., representing 77 families (Ault et al. 2001). Bradley et al. (2004) documented the occurrence of 454 plant taxa within the Park, 70% of which are native. In addition, there are at least 200 birds, around 30 mammals and reptiles, and 6 amphibians that have been seen in the Park (NPS 2005a).

Though some non-native fish species have been documented to occur in the south Florida Everglades region, including Biscayne N.P. (Loftus et al. 2003), plant species represent the largest number of non-native species found in Biscayne N.P.. Over 130 taxa of non-native (naturalized exotics or cultivated species) plant species occur in Biscayne N.P. (Bradley et al. 2004). Fourteen of these are listed on the Florida Exotic Pest Council's list of most invasive species, including: Brazilian pepper (*Schinus terebinthifolius*), Australian pine (*Casuarina equisetifolia*), sisal hemp (*Agave sisalana*) and seaside mahoe (*Thespesia populnea*) (NPS 2005a).

Imperiled Species

Biscayne Bay and the coastal wetlands and uplands that surround it support over 172 species of concern, species that are listed on at least one state or federal protection list (BBPI-SST 2001). This includes all coral species. In Biscayne N.P. proper, there are sixteen federally endangered or threatened species that occur within Biscayne N.P. (Table 1, NPS 2005d). An additional three species are candidates for listing. Of the threatened and endangered species, five are birds, six are reptiles, three are mammals, one is an invertebrate, and one is a vascular plant. Several high profile species, including the West Indian Manatee and the American Crocodile, occur on these lists, along with several lesser known but equally imperiled species, like *Schaus's* swallowtail, Florida's semaphore cactus, and two species of *Agropora* corals, the once dominant reef-building coral in Biscayne N.P. The largest threats to the manatee, the most endangered species in the Park, are human-caused, including damage in water control flood gates, damage by boat prop propellers, poaching and habitat destruction (BBPI-SST 2001).

Scientific Name	Common Name	G-RANK	S-RANK
Endangered			
<i>Chelonia mydas</i>	green sea turtle	G3	S2
<i>Crocodylus acutus</i>	American crocodile	G2	S1
<i>Eretmochelys imbricata</i>	hawksbill sea turtle	G3	S1
<i>Heraclides aristodemus ponceanus</i>	Schaus swallowtail butterfly	T1	S1
<i>Jacquemontia reclinata</i>	Beach jacquemontia	G1	S1
<i>Mycteria americana</i>	wood stork	G4	S2
<i>Neotoma floridana smalli</i>	Key Largo woodrat	T1	S1
<i>Peromyscus gossypinus allapaticola</i>	Key Largo cotton mouse	T1	S1
<i>Sterna antillarum</i>	least tern	G4	S3
<i>Sterna dougallii dougallii</i>	roseate tern	T3	S1
<i>Trichechus manatus</i>	West Indian manatee	G2	S2
<i>Pristis pectinata</i>	Smalltooth Sawfish	G2	-
Threatened			
<i>Caretta caretta</i>	loggerhead sea turtle	G3	S3
<i>Charadrius melodus</i>	piping plover	G3	S2
<i>Drymarchon corais couperi</i>	eastern indigo snake	G3	S3
<i>Haliaeetus leucocephalus</i>	bald eagle	G5	S3
<i>Alligator mississippiensis</i>	American alligator	G5	S4
<i>Halophila johnsonii</i>	Johnson's seagrass	G2	S2
Candidate			
<i>Acropora cervicornis</i>	staghorn coral	G3	SNR
<i>Acropora palmata</i>	elkhorn coral	G3	SNR
<i>Consolea corallicola</i>	Florida semaphore cactus	G1	S1

Table 1. List of species occurring in Biscayne National Park and on the federal endangered species list. Source: NPS 2005d.

Unique Designations

Ninety-five percent of Biscayne N.P. is a marine environment, making it the largest marine park in the National Park Service (NPS 2005a). Recognizing the significance of the Biscayne Bay to preserve marine and coral reef resources within the region, the Florida legislature has designated Biscayne Bay as one of its Outstanding Florida Waters which affords it the highest water quality protections in the state (SFWMD 1995, BBPI-SST 2001).

Regional and Historical Context

The waters of Biscayne Bay are contiguous with the Florida Bay system via a complex series of sounds and small bays that link the two. Biscayne Bay, the Everglades, and Florida Bay are part of a larger, once hydrologically inter-connected system of wetlands and coastal lagoons, with Biscayne Bay serving as the principal eastern outlet of Everglades flow into the Atlantic Ocean (Davis, 1943, Parker et al. 1955). Historically, the bay received significant fresh water input from that part of the Everglades lying east of a

coastal ridge separating the eastward flows from the north-south flow in the main sloughs of the Everglades, Taylor and Shark River. (Davis 1943, Smith 1898, Buchanan and Klein 1976, Kohout and Kolipinski 1967). Fresh water flowed through natural sloughs and rivers (Buchanan and Klein 1976, Kohout and Kolipinski 1967, Parker et al., 1955). As part of the larger Everglades system, the water that Biscayne Bay received prior to the mid-20th century was clear, low in particulates and oligotrophic, having been filtered through fresh water marshes via slow, diffuse sheetflow. There was also considerable groundwater flow through the Biscayne Aquifer into the bay as the large hydrologic head in interior marshes drove subsurface flows eastward from the Everglades (Parker et al. 1955, Kohout 1960, Kohout and Kolipinski, 1967). Beginning at the turn of the 20th century, the development of south Florida has transformed Biscayne Bay from a subtropical estuary where salinity was controlled by seasonal balances of freshwater and marine water inputs to a pulsed system driven by point-source inputs of freshwater from man-made canals and marine water inputs that have been altered due to physical alterations within and on the eastern margin of the bay (BBPI-PMC 2001). Once bordered by sawgrass plains and mangrove fringe forests on the mainland and a series of discontinuous islands and shoals to the east, land use has graded from agricultural practices in the early part of the century to urban uses thereafter (BBPI-PMC 2001, Cantillo et al. 2000). In order to promote agricultural and urban uses, a series of massive water diversion and drainage projects in south Florida (Light and Dineen 1994) have been undertaken that have transformed the natural hydrology of the region from process driven by diffuse sheet flow to those now driven by pulsed releases of water (BBPI-PMC 2001). Alterations to the bay are most severe in northern Biscayne Bay which is closest to Miami, but are also notable in the central and southern portions of the bay (BBPI-PMC 2001).

Land Use History

In the first half of the 20th century, development of Biscayne Bay area was spurred by the construction of the Flagler railroad and of the Royal Palm Hotel both completed in Miami around the turn of the century (Cantillo et al. 2000). Regional economic booms in the late 1920s and again in the 1940s followed. Developments occurred both within the bay itself and also on the neighboring mainland coastal regions. On the mainland, drainage activities commenced in the late 1800s when Hamilton Disston, a Philadelphia businessman who was granted four million acres by the state of Florida, drained 50,000 acres, connected headwater lakes, canalized the Kissimmee river for navigation, connected Caloosahatchee river to Lake Okeechobee, and completed a preliminary canal, eleven miles long, in the direction of Miami (Sklyar et al. 2002, Light and Dineen 1994). By the late 1920s, the Miami canal was completed, linking waters drained from Lake Okeechobee and Biscayne Bay.

Within the Bay itself, two inlets (Government Cut in 1905 and Baker's Haulover in 1925), several artificial islands and at least four causeways (bridges across the bay) were constructed. In addition, an Intracoastal Highway, 8 feet deep and 75 feet wide, was cut through a north to south direction in the bay (Michael 1976). Raw sewage was dumped directly into the bay from the 1930s until the late 1940s until the construction of a sewage treatment plant was completed (Cantillo et al. 2000). Environmental effects of these early developments included: disruption of freshwater and marine water inputs into the bay, saltwater intrusion of Biscayne Bay aquifer (due to drainage), loss of benthic and coastal habitat, loss of marine life within the bay, degradation of water quality, and increased turbidity (BBPI-PMC 2001).

In the second half of the 20th century, continued water management and drainage activities and the explosive growth of Miami led to further degradation of the Biscayne Bay environment (Cantillo et al. 2000). The Central and Southern Florida Project for Flood Control and Other Purposes (C&SFP) passed by the U.S. Congress in 1948 led to landscape scale alterations to the freshwater flows entering Biscayne Bay (Light and

Dineen 1994). On the bay itself, two more causeways were constructing (bringing the total to six), and eighty hectares of mangrove forest in southern Key Biscayne were destroyed for developments that later failed. More troubling, contamination of bay waters and sediments were noted, especially in the areas around release points from the Miami canal and the Military Canal (Cantillo et al. 2000).

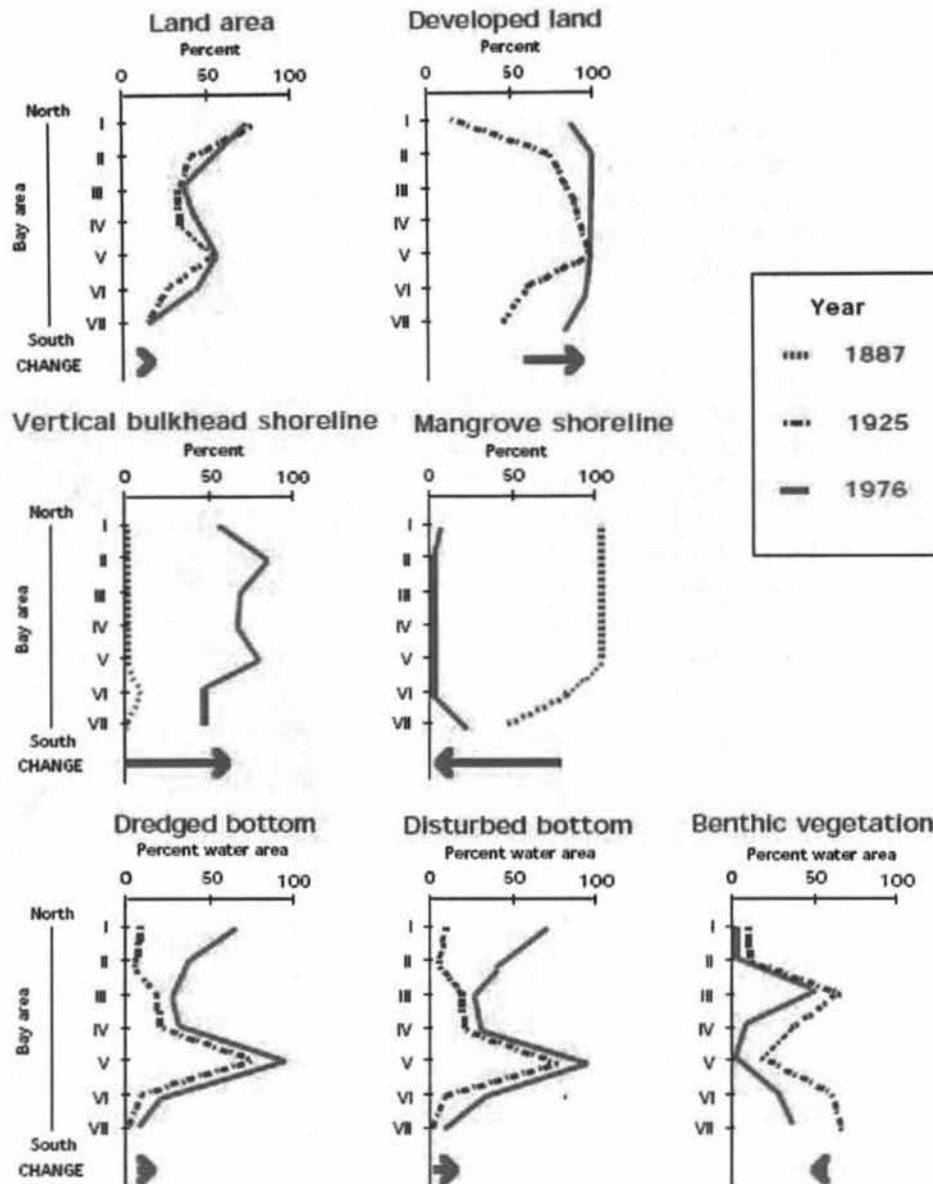


Figure 6. Anthropogenic change (%) in Biscayne Bay from 1887 to 1976. After: Cantillo et al. 2000. Source: Harlem 1976.

By 1925, seventy-five percent of the land bordering northern Biscayne Bay (Figure 6, from Broad causeway to Rickenbacker causeway) had been developed (Harlem 1979). Nearly 100% of these lands had been

developed by 1976. The majority of the shoreline to Biscayne Bay had been bulkheaded by 1976, leading to almost a complete loss of mangroves in northern Biscayne Bay. Within the bay itself, approximately seventy-five percent of the bay bottom between Venetian Causeway and Rickenbacker Causeway had been dredged or disturbed by 1925 (Figure 6 & 7). This figure approached 100% by 1976 leading to a large scale loss of benthic vegetation in this region of the bay (Figure 6).

Adjacent Land Use

Biscayne N.P. is situated within a complex matrix of urban, agricultural and natural land uses (Figure 8, BBPI-PMC 2001). In general, a north to south gradient in land use exists in coastal areas adjacent to the western margin of Biscayne Bay, grading from highly developed urban and industrial uses in Miami, to a mixture of agricultural and suburban developments, giving way to undeveloped coastal wetlands in the south (Figure 9, SFWMD 1995). As noted above, the most pervasive and dominant land use in the area is the city of Miami, where over 2 million people now live (USCB 1995). But Biscayne N.P. is also surrounded by natural lands under some form of protection, including marine waters and lands managed by the state of Florida (John Pennekamp Coral Reef State Park, Bill Baggs Cape Florida State Park, Biscayne Bay Aquatic Reserve) or the federal government (Florida Keys National Marine Sanctuary).

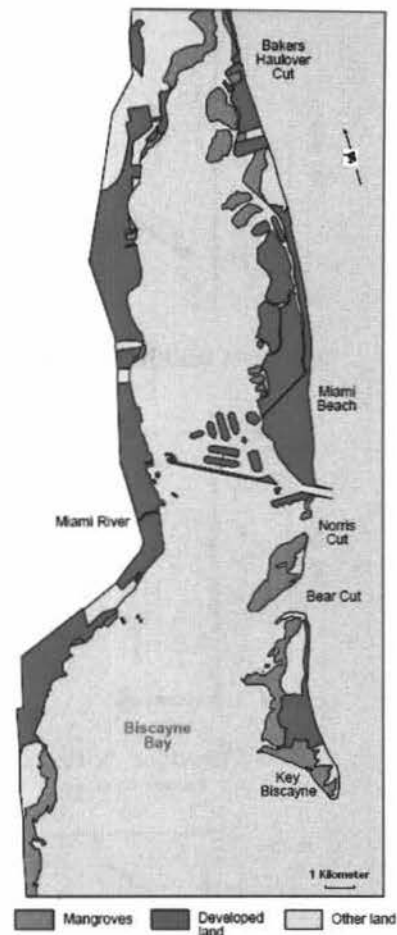


Figure 7. Development of northern Biscayne Bay by 1925. After: Cantillo et al. 2000. Source: Harlem 1976.

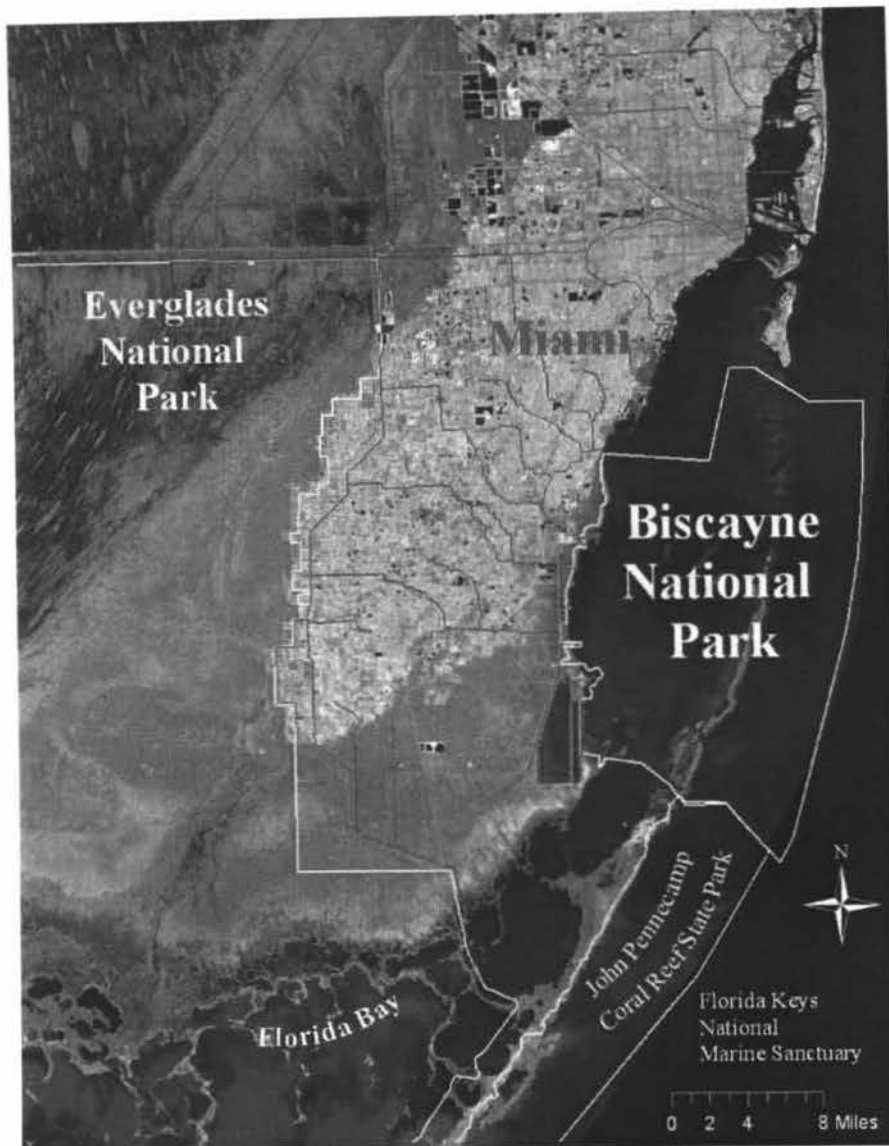


Figure 8. Satellite image of adjacent land use of Biscayne Bay. Sources: SFWMD 2005a, NPS 2005b, FGDL 1999.



Figure 9 (a). Adjacent land uses of northern Biscayne Bay. Source: SFWMD 1995.

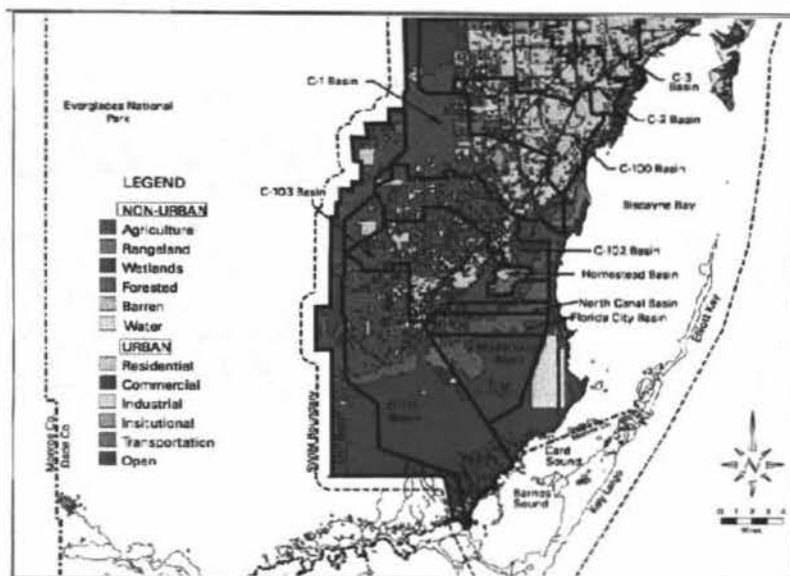


Figure 9 (b). Adjacent land uses of southern Biscayne Bay. SFWMD 1995.

Adjacent land use, in turn, plays an important role in the quantity and quality of waters entering the Bay. In general, fresh water flows from urban uses occur more rapidly and over a shorter period of time than flows from vegetated or wetland areas (Figure 10), leading to “flashier” systems with pulsed surface water inputs and reduced groundwater inputs (SFWMD 1995). Overland flow inputs into Biscayne Bay have been

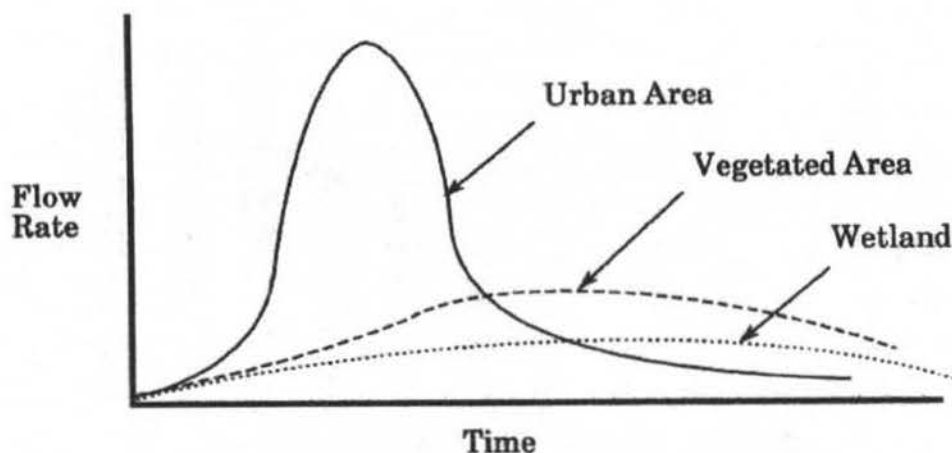


Figure 10. Flow rates from various land uses. Source: SFWMD 1995.

virtually eliminated in the north Bay, but are still prevalent in the extant coastal wetlands bordering the southern Bay. Land use also effects the water quality of freshwater inputs into the Bay. Urban and industrial complexes in the North Bay can contaminate freshwater sources with chemicals and sewage, whereas agricultural can add nutrients and pesticides to the system (SFWMD 1995).

Adjacent Land Use: Urban

Biscayne N.P. is bordered on the Florida mainland by the major urbanized areas that encompasses the Miami metro region. Human populations in south Florida have exploded in the last century, especially in Miami-Dade County, where county population estimates after the 1900 census were under 5,000, growing to over 2 million people by 2000 (Figure 11, USCB 1995). The population of Miami-Dade county is projected to reach nearly three million people by 2020 (BBPI-PMC 2001).

As demands on water supply and point and non-point water and air pollution continue to rise and as groundwater recharge continues to decline, human development around Biscayne N.P. will continue to adversely impact natural resources within the park. Two examples below illustrate that as the south Florida human population has bloomed, so have human impacts to natural resources. From 1964 to 1998, the recreational fishing fleet has increased by 444% with concomitant impacts on fish resources (Ault et al. 2001). Miami-Dade County is one of the country's fastest growing counties, exhibiting many signs of urban sprawl, and also containing lands and habitats that support 58 imperiled and critically imperiled species (Ewing et al. 2005).

Adjacent Land Use: Protected/Natural Areas

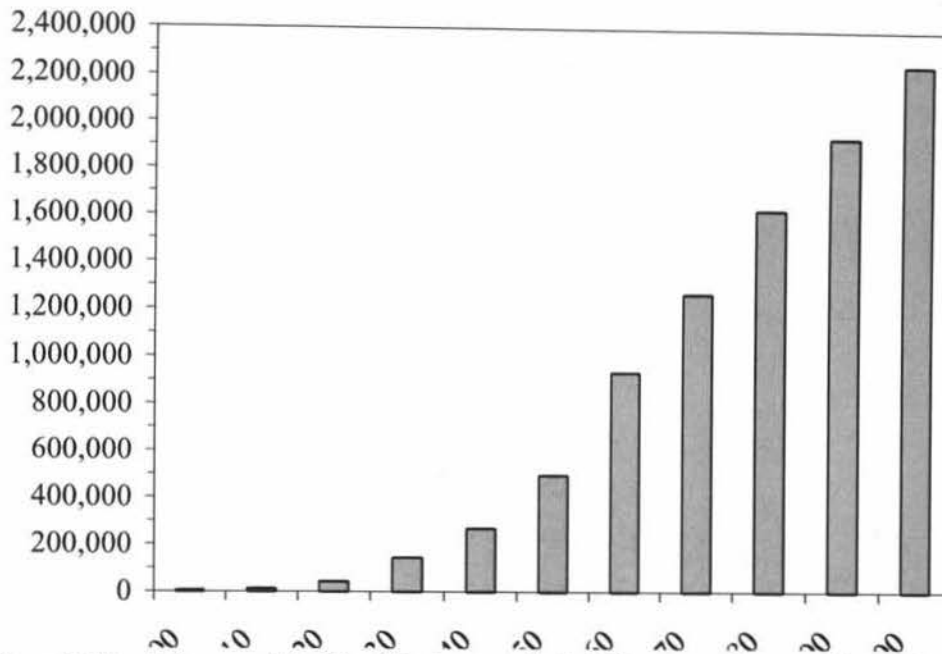


Figure 11. Population growth in Miami-Dade county in the 20th century. Source: Adapted from USCB 1995.

About 60 percent of the land use in Miami-Dade county is under some form of federal, state or local protection (UF-IFAS 2002). The northern and southern extent of Biscayne Bay not protected by Biscayne N.P. are part of the Biscayne Bay Aquatic Preserve, which was established in 1974 and encompasses 69,000 acres (Figure 8, FDEP 2004a). Within this preserve are two water bodies that comprise southern Biscayne Bay, Card Sound and Barnes Sound, which are also part of and protected by the Florida Keys National Marine Sanctuary. These sounds contain important and critical habitats for the survival of Florida populations of a number of threatened and endangered species. Areas bordering Card Sound and Barnes Sound and portions of southern Dade County have been designated as critical habitat for the American crocodile, the West Indian manatee and the snail kite. Card and Barnes Sounds represent one third of all American crocodile nesting in the continental United States. The wetland and tropical hammock areas bordering these sounds contain the Schaus' swallowtail butterfly, Key Largo wood rat, Key Largo cotton mouse, the Monroe County population of ospreys, and the eastern indigo snake, rare tree snails and endangered species of orchids. This area also provides habitat for wading birds that are listed as species of special concern by the state.

Other large protected marine environments immediately adjacent or close to Biscayne N.P. include: John Pennekamp Coral Reef State Park (managed by State of Florida-DEP, established 1968, 178 nautical square miles) and the Florida Keys National Marine Sanctuary (encompasses southern Biscayne Bay and John Pennekamp Coral Reef State Park, managed by NOAA – Ocean Service, established 1990, 2,800 square nautical miles) (Figure 8). Protected upland areas include Bill Baggs Cape Florida State Park in southern Key Biscayne, Crocodile Lakes National Wildlife Refuge, and the Key Largo Hammocks State Botanical Site.

A strip of undeveloped coastal wetlands, comprised of the "Model Lands" and C-111 basin, separates Biscayne N.P. from the eastern margin of Everglades National Park. These lands are the subject of acquisition activities as part of the CERP project (Bellmund 2005).

Adjacent Land Use: Agriculture

Approximately eight percent, or 96,000 acres, of Miami-Dade county is occupied by agricultural land uses (Figure 9, UF-IFAS 2002). These areas are concentrated in the southern half of the county, bordering the southern portion of Biscayne N.P. and the central and southern portions of Biscayne Bay. Almost half of the agricultural lands are devoted to "row crops", mostly winter vegetables, with the other half comprised of fruit and nursery crops. In the crop years of 1997-1998, agricultural revenues in Miami-Dade county totaled over one billion dollars, with again, almost half of the revenue generated by the sale of vegetable crops. While "best management practices" are promoted by several state and watershed groups, there is a history of nutrient and pesticide contamination from these lands uses into Biscayne Bay (SFWMD 1995).

Park Science and Resource Management

Restoration Plans

The Comprehensive Everglades Restoration Plan (CERP) is the overarching regional restoration program designed to accomplish ecosystem restoration in south Florida while providing flood control and water supply services to the burgeoning human population (CERP 2005a). Although the project is not yet approved, the Biscayne Bay Coastal Wetlands Project is among the 68 planned CERP projects. Encompassing 13,600 acres including all of mainland Biscayne N.P., the project is designed to restore estuarine function and provide habitat for fish and wildlife in the bay by redistributing water flow to the bay (Figure 12, BBPI-SST 2001, CERP 2005b). Specific objectives include: re-establishing the oyster reef community and productive nursery habitat for the many fish, shellfish, and crustaceans that use the bay. It will employ various structures including pump stations, spreader swales, stormwater treatment areas, flowways, levees, culverts, and backfilling canals to divert canal flow through coastal marshes and creeks (CERP 2005b). Diversion of canal discharges into coastal wetlands is expected not only to re-establish productive nursery habitat all along the shoreline but also to reduce the abrupt freshwater discharges that are physiologically stressful to fish and benthic invertebrates in the bay near canal outlets.

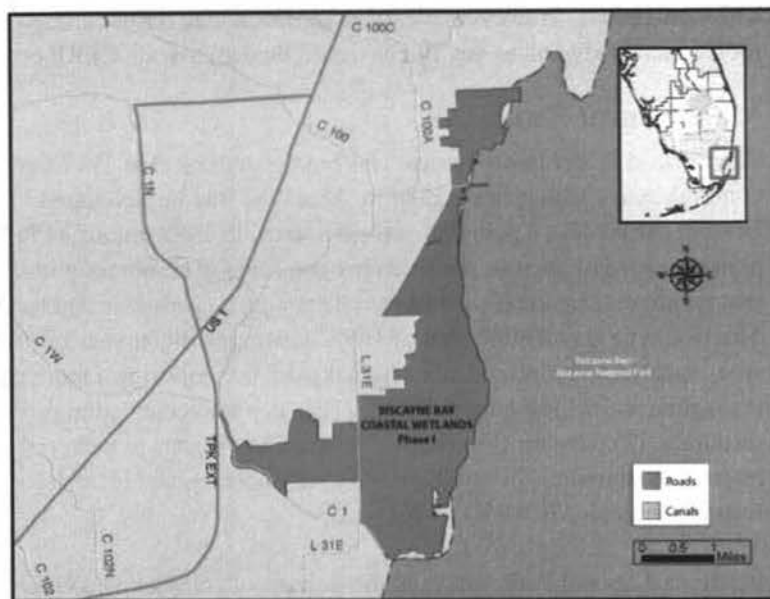


Figure 12. Schematic of Biscayne Bay Coastal Wetlands Restoration Project Area. Source: SFWMD 2005b.

Both CERP and the Lower East Coast Regional Water Supply Plan (LECRWSP) will establish minimum freshwater flows and levels into Biscayne Bay (BBPI-PMC 2001). At this time, these flows have not been established. In fact, it is anticipated that it will be difficult to obtain the water supply necessary to support ecosystem restoration. As such, the project includes a proposed expansion of the South District Miami-Dade Wastewater Treatment Plant to provide treated waste water to the bay (BBPI-SST 2001). Given the risk associated with a major component of the freshwater inputs into the bay composed of treated waste water, the project stipulates that "...other potential sources of water to provide required freshwater flows to the southern and central Biscayne Bay should be investigated before pursuing the reuse facility" (CERP 2005b).

Another approach to restoration is more modest yet perhaps more likely to bring about ecological changes that can be detected over the period of a decade or less. Removal of internal ditches along with other actions, such as plugging of selected small canals and backfilling of some canals within mangrove forest, has been proposed for northern reaches of the Biscayne N.P. coastal wetlands (Ruiz and Ross 2004). Evaluation of aerial photographs from 1928 and related information shows this portion of the park, including the Black Point area and four smaller sites north of the visitor center, to have consisted mostly of sawgrass marsh and a narrow mangrove forest fringe before major changes occurred (Ruiz and Ross 2004). Since then, drainage and other disturbance created conditions very much like what is found in the 13 sub-basins studied by Gaiser and Ross (2003). However, even this approach may trigger unexpected ecosystem responses as did the redirection study and as very likely would the larger scale CERP project.

Management Plans

The Surface Water Improvement and Management Act of 1987 (amended in 1991) mandated that the first comprehensive management plan for Biscayne Bay be developed by the South Florida Water Conservation District (SFWMD), a plan that was completed in 1988 (modified in 1989) (SFWMD 1995). This original plan consisted of an assessment on the condition of resources within the bay and proposed remedial actions that would reverse the course of past management activities that had been detrimental to natural resources. The Biscayne Bay SWIM plan of 1995, encompassing almost 1400 mi² of Biscayne Bay and coastal mainland area, updated and replaced this original plan, by proposing a more rigorous planning approach for bay management, including the following five step implementation process: (1) assess condition of natural resources, (2) develop control and remediation projects to meet restoration goals, (3) conduct remediation and restoration activities, (4) monitor and assess actions, and (5) redesign activities as necessary to achieve restoration goals (SFWMD 1995).

Biscayne National Park staff is in the process of completing a General Management Plan (GMP) for the Park, to replace the last plan that was developed in 1983 (NPS 2003). So far, two steps in the development of this plan, setting the stage for planning and developing a preliminary list of management alternatives, have been completed, and the third step, developing a draft GMP, should be completed by fall of 2005 (Clark 2004). This draft will include five alternative management plans, alternatives that range from no changes to current management, to alternatives that enhance the visitor experience, to alternatives that maximize protection of fragile natural resources (NPS 2003). Alternative four (Figure 13), currently the preferred alternative, strikes a balance between resource protection and visitor experience by expanding use of nature observation, sensitive resource and non-combustion engine use zones while still providing public access to the majority of areas within the park (NPS 2003). This alternative includes establishing part of the reef tract as a *Nature Observation Zone*. This designation would provide protection for part of the park's coral reefs, as well as mangrove shorelines on the keys, with minimal disturbance or impacts from human use.

Low-impact recreational activities, including fishing, would be allowed in Nature Observation Zones, whereas visitors would not be permitted in expanded Sensitive Resource Zones in order to protect important habitat for birds and reptiles.

Concurrently, the Park in conjunction with the Florida Fish and Wildlife Commission is also developing a Fisheries Management Plan (NPS 2004), scheduled for completion in summer 2005 (Clark 2004). The FMP is envisioned as template to guide fisheries management activities for the next 10-15 years, by evaluating management actions that will lead to "desired conditions" of fish populations and habitat and provide for continued recreational fishing opportunities (NPS 2003).

Research and Monitoring

Compared to the efforts undertaken to understand resource conditions, trends and threats of Everglades National Park, similar efforts in Biscayne N.P. have been modest. The

University of Miami sponsored a symposium in 1976 that is the first comprehensive assessment of resource conditions occurring within Biscayne Bay (Thornhaug et al. 1976). The SWIM legislation of 1987 mandated a similar assessment of resources within the bay, a process that was completed in 1995. The Florida legislature also funded a similar state of the Bay assessment in 1999, conducted by the Biscayne Bay Partnership Initiative (BBPI-PMC 2001). In fact, one of the recommendations of this effort was to appoint a Science Committee, integrated with the Science Committee of the South Florida Restoration Task Force, to coordinate and identify scientific research, monitoring and restoration activities required to ensure the health of the Bay (BBPI-PMC). Finally, the CERP program, and specifically the Biscayne Bay Coastal Wetlands project is identifying minimum levels of fresh water flows to the Bay that will support the flora, fauna, and functioning of the Bay (CERP 2005).



Figure 13. Preferred alternative of the Draft General Management Plan of Biscayne National Park. Source: NPS 2003.

Estuarine, Marine, and Terrestrial Ecosystems

Water Resources

Salinity is a water parameter that integrates the influence of hydrologic processes on the structure and function of Biscayne Bay (BBPI-SST 2001), including plant and animal productivity, distribution, abundance, and competitive interactions. Salinity, in turn, is governed by the natural and anthropogenic variability of hydrologic fluxes, including precipitation, evaporation, and freshwater inflows (Nuttie et al. 2003). Human perturbations which can alter the natural patterns of salinity, include high rates of ground water withdrawal and diversions of fresh and marine waters from natural flow paths through the Biscayne Bay watershed.

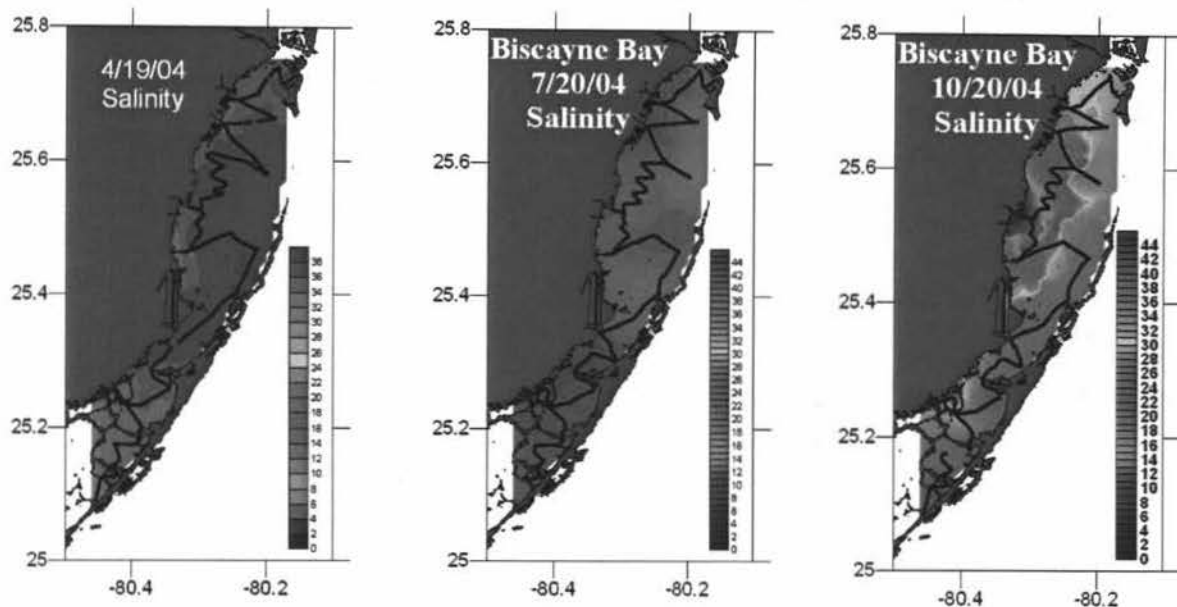


Figure 14. Biscayne Bay salinity patterns form 2004. Source: NOAA 2005.

Given that freshwater inputs are from the west and marine inputs are from the west, salinity with distance away from the western coast of the Bay (Figure 14, Boyer 2003). The freshwater influence is greatest in the wet season (Figure), an influence that has more than likely been diminished through drainage activities.

Changes in Salinity

By examining the distribution and abundance of faunal organisms in bay sediments, and relating these patterns to current relationships of environment and fauna, a salinity record of Biscayne Bay has been constructed. Using these techniques, several investigators from USGS have found that salinities have increased in Biscayne Bay in the 20th century (Wingard et al. 2003, Stone et al. 2000, Ishman et al. 1999). The latest of these studies found that salinities have increased and become more stable in the last 100 years, indicating a rising influence of continental shelf and marine waters (Wingard et al. 2003). Other investigators have found that the faunal assemblages now present in Biscayne Bay resemble those found over 500 years ago when the bay was also under a greater marine influence (Stone et al. 2000). As faunal groups, like foraminifers and mollusks respond to changes in salinity (documented by these studies), so do other species, suggesting that these historic salinity changes have altered the distribution of plants and animals throughout the bay.

It is noteworthy that many of these shifts in the salinity regime occurred during an era when major water management activities led to changes in hydrology in south Florida (Light and Dineen 1994). These studies, however, do not examine the extent to which these changes in salinity can be attributed to anthropogenic change versus sea level rise. Perhaps because they are more closely linked to hydrologic change within the mainland, changes in fauna, vegetation and salinity within the coastal wetlands of Biscayne Bay provide stronger evidence of the chain of events linking drainage to salinity increases and subsequent shifts in species distributions.

Changes in Freshwater and Groundwater Flows

It is without question that drainage and water management activities have changed the quantity, timing and distribution of freshwater inputs into Biscayne Bay (BBPI-PMC 2001, BBPI-SST 2001), but given the paucity of historic data, it is not clear the degree to which these flows have changed. All three of the historic pathways of freshwater flow into the bay, surface flow, overland flow, and groundwater flow, have been altered. Overland flow has been restricted to the coastal wetlands of southern Biscayne Bay, and even there, has likely been reduced due to the construction of the L-31E levee that restricts sheet flow from the Everglades to Biscayne Bay (Meeder et al. 2001). Surface water delivery from natural waterways, including springs derived from groundwater sources, have been concentrated into point source discharges from the 19 canals that drain fresh water into the bay currently (BBPI-SST 2001). Leach et al. (1972) reported a decline of 20% in freshwater flows from the mid 1950s to the mid 1970s, but these reductions were noted after many of the water management structures had already been constructed.

Amidst a drop in the water table in Miami-Dade County of four to six feet (Parker et al. 1995), groundwater inputs into Biscayne Bay have also diminished by some unknown but significant amount. The saltwater intrusion line of the Biscayne Bay Aquifer has continued moved inland for decades, beginning in the 1940s, though this trend has been somewhat ameliorated with enhanced control structures (Cantillo et al. 2000, BBPI-SST 2001). Groundwater inputs play a significant role in replenishing freshwater supplies in the bay in the dry season when surface inputs are minimal. If groundwater inputs have declined, then it is this decline in freshwater inputs during the dry season that would have the greatest effect on the biota.

Evidence of hydrologic change can be inferred from changes in the distribution and abundance of organisms that depend upon the coastal marine environment that border Biscayne Bay, especially those organisms that are sensitive to changes in the salinity regime. Changes in the vegetation pattern, periphyton communities, and assemblages of oysters and mollusks in the coastal wetlands of Biscayne Bay have been documented and are detailed in the section "*Coastal Wetlands – Anthropogenic Disturbance*" of this report. Together, these studies provide evidence of the rising influence through time of marine waters, a diminishment of the freshwater influence, rising salinities in the coastal environment, and a shift inland of the ecotone between freshwater and marine habitats.

Water Quality

In general, water quality within Biscayne Bay is relatively high, though there are some specific areas of concern (BBPI-SST 2001, SFWMD 1995). Most of the water quality trends in the past thirteen years of monitoring have improved, including turbidity, dissolved oxygen, and total coliform bacteria (SFWMD 1995). Declining trends are evident for ammonia and nitrate/nitrite, especially in two drainages that fed Biscayne Bay, the Miami River in the northern Bay and Black Point Canal in the central Bay (SFWMD

1995). High ammonia concentrations in both surface and ground waters, coming from sources that include landfills and dumps, are at a level that threatens natural resources (BBPI-SST 2001). In a laboratory test of toxicity, the most sensitive indicator suggested that bay sediments are toxic throughout the bay (Long et al. 1999).

The impact of these water quality issues on the biota will be covered more in depth in other parts of this assessment, but it is likely that contaminants are adversely affecting plants and animals in the Bay. Fish with external abnormalities have been observed in the Bay (Cantillo et al. 2000). Investigation of this issue has found a spatial correlation between incidence of abnormality and presence of aliphatic hydrocarbons in the water (Gassman et al. 1994). In addition, deformities of benthic forams have been found in the Bay, especially around Black Point Landfill, indicating possible leaching of contaminants from this source into the Bay (Lidz 2002).

In a pattern that becomes familiar upon studying water quality in the region, water quality tends to be poorer in the drainage ways that fed the Bay, in the western margin of the Bay that is in closest proximity to these freshwater sources, or in the North Bay, where a high level of modification has taken place (BBPI-SST 2001, Boyer 2003, Carnahan 2005). This pattern of diminished water quality in the north and western portions of the Bay is evident for nutrient related parameters, Chl A, dissolved inorganic nitrogen, and total phosphorus (Boyer 2003, BBPI-SST 2001), and for heavy metal contaminants (Carnahan 2005). Water quality patterns can also be related to land use (Lietz 2000), where concentrations in canal waters and adjacent Bay waters tend to be higher in nitrate/nitrite in the southern Bay, areas that drain agricultural fields, higher in ammonia and total phosphorus in the urbanized northern Bay, and higher in total organic nitrogen in the areas of the southern bay that drain wetlands (Lietz 2000).

In the north Bay, turbidity and phytoplankton blooms are of concern, results of dredging, loss of benthic vegetation, and bulkheading (BBPI-SST 2001). The Miami river and other tributaries that drain into the north Bay contain levels of total coliform bacteria that exceed state standards, sometimes by several orders of magnitude, and concentrations of heavy metals that are the highest measured in the state of Florida (BBPI-SST 2001). In the central and southern portions of Biscayne Bay that comprise Biscayne N.P., the highest level of concerns for water quality include nitrate/nitrite loads coming from agricultural practices (Lietz 2000), and contaminated waters flowing from Military Canal (BBPI-SST 2001), a canal that directly connects Biscayne N.P. with Homestead Air Force Base.

Water Quality: Heavy Metals

Carnahan (2005) found elevated concentrations for a suite of heavy metals to be prevalent in northern Biscayne Bay sediments between Miami River and Key Biscayne, and also in muds along the periphery of the southern bay, especially from Black Creek Canal to Turkey Point. Concentrations in heavy metals were highest in northern Biscayne Bay near Miami, with moderate levels in southern Biscayne Bay near Turkey point, and lower still in south-central Bay near Black Creek Canal. Further, she found that three foram assemblages co-varied with these patterns in heavy metals, suggesting that contamination may have influenced the distribution of these species. Specifically, she found stress tolerant taxa to predominate in the north Bay, contrasted with a more diverse open-bay assemblage, including a significant component (~10%) of symbiotic forams, an indicator of normal marine conditions. These results are supported by other finding (Lidz 2002, Long et al. 1999). Conducting laboratory toxicity tests on bay sediments, Long et al. (1999) noted, among other things, the prevalence of moderate to acute toxicity effects on sites bordering Black Creek Canal and Turkey Point for at least one of the four parameters measured. A sixty year trend of the declining

prevalence of forams with algal symbiotes and the increased prevalence of stress-tolerant symbiotes are indicative of declining water and sediment quality in the Bay in regards to heavy metal contamination, especially in the north Bay and western boundaries of the Bay (Carnahan 2005).

Water Quality: Biscayne Bay Aquifer

The Biscayne Bay aquifer is vulnerable to the anthropogenic change that has occurred in the region. Other than the aforementioned decline in the water table and saltwater intrusion, the high degree of connectivity of the aquifer with the surface canals and lands that fed it (due to the high permeability of the limestone substrate) has led to potential direct contamination of aquifer waters with nutrients and other contaminants (Klein and Hull 1978, Pitt et al. 1975). The aquifer is vulnerable to the following sources of contaminants: (1) direct infiltration from runoff from buildings, yards, etc., (2) infiltration from septic tanks, (3) infiltration from canals, (4) solid waste disposal areas, (5) sewage treatment plants, (6) wells used to drain storm waters, and (7) wells used to dispose of industrial waste (Klein and Hull 1978). By 1970, nearly 175,000 septic tanks discharged domestic water waste directly to the aquifer in Dade County (Klein and Hull 1978, Pitt et al. 1975). Beginning in 1972, secondary treated sewage has been directly injected into deep wells below the aquifer to a depth of 3,000 meters. Landfills are prevalent in the area, including the Northwest 58th Street landfill (closed), and two landfills that directly on Biscayne Bay, the South Dade landfill at Black Point and Munisport Landfill (inactive, Superfund site) (SFWMD 1995). Sewage treatment plants also occur in the vicinity, including the Virginia Key Sewage Treatment Plant, which receives raw sewage from the mainland through the Cross Bay Line, a pipe that sits directly under the Bay surface and has developed leaks in the past (Cantillo et al. 2000). Though more studies need to be conducted regarding the water quality of the aquifer in south Miami-Dade county, high concentrations of nitrate in wells associated agricultural practices and high concentrations of ammonium, phosphorus and fecal coliform bacteria in areas close to septic tanks have been noted (Klein and Hull 1978, Pitt et al. 1975). In addition, areas of the aquifer that are in close proximity to the Munisport landfill have been found to have high concentrations of ammonia, and low levels of trace metals, pesticides, and volatile organics (Cantillo et al. 2000).

Representative Estuarine Ecosystems

Coastal Wetlands

The mainland coastal areas within Biscayne National Park (Biscayne N.P.) comprise a narrow strip of land less than 2 km wide that fringe the shores of Biscayne Bay (Figure 15). When the area was reserved by the federal government as Biscayne National Monument in 1968 (authorized as a national park in 1980), extensive alteration of the coastal wetlands had already occurred in conjunction with attempts to convert the coastal area east of the Atlantic Coastal Ridge into agricultural enterprises and to regulate flooding and mosquito

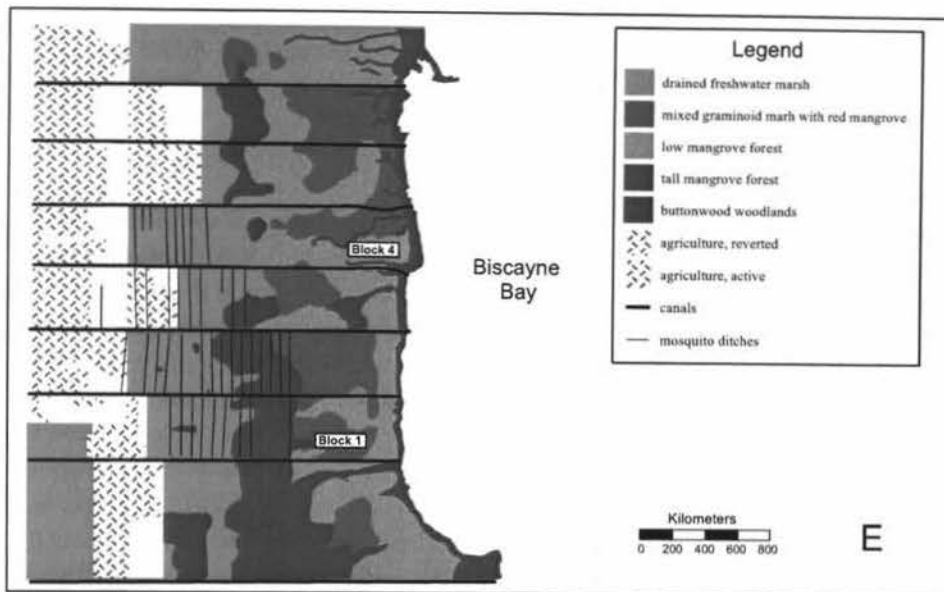


Figure 15. Vegetation and canals in part of the Biscayne coastal wetlands in 1940. The eastern part of this image was later included in Biscayne National Park. The present Visitor Center is located on the tip of the easternmost land area at the bottom of the image. Note that large freshwater marshes were already drained for agriculture and mosquito control and agricultural areas closest to the coast were already apparently abandoned. Source: Gaiser and Ross (2003).

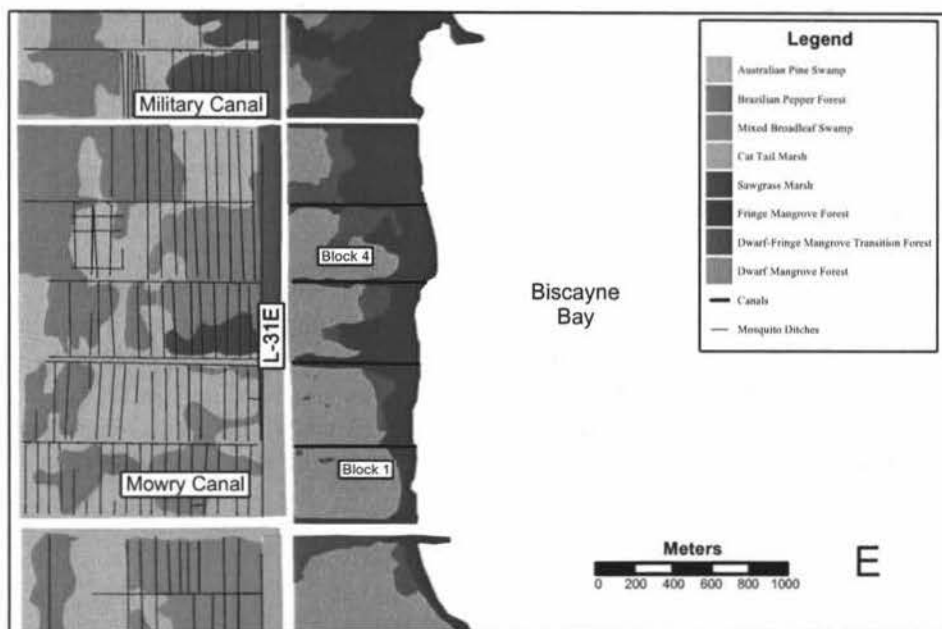


Figure 16. Vegetation and canals in the Biscayne coastal wetlands in 1992. The areas within Biscayne National Park occupy portions east of the L-31E levee extending inland from the Biscayne Bay shoreline a distance varying from about 0.4 to 1.0 km. Note how the tall mangrove fringe forest had expanded westward, dwarfed mangrove scrub had become far more extensive, exotics proliferated and freshwater systems nearly eliminated. Source: Gaiser and Ross (2003).

populations (Ruiz and Ross 2004). The wetlands of southeastern Florida have been relatively little studied compared to the Everglades to the west and to Biscayne Bay and other estuarine areas to the east and south. However, it is evident from inspection of maps and photographs that the coastal wetlands must have been components of the larger system that included Biscayne Bay and the coral reefs, played a role in conveying fresh water to the nearby marine waters, and thereby influenced salinity patterns within the bay.

Before the era of artificial drainage, herbaceous marsh, dominated by sawgrass is believed to have extended nearly to the coast line of Biscayne Bay, separated from it by a narrow fringe of mangrove forest (Egler 1952). Given the relatively low salinity tolerances of sawgrass (Rejmankova et al. 1996), it is apparent that the areas inland of the mangroves were largely freshwater in nature and bore considerable resemblance to sawgrass stands further west in the Everglades. However judging from the report by Tabb et al. (1967) on the coastal wetlands located on the south side of the C-111 canal (in the extreme southeastern corner of Everglades National Park), periodic incursions of salt water, driven inland by storms, raised salinities and affect coastal freshwater communities differently than interior freshwater marshes. In 1965, for example, Hurricane Betsy forced salt water into the coastal communities south of the C-111 canal, near the southeastern tip of the peninsula, killing off sizable areas of sawgrass, and favoring the somewhat more salt-tolerant *Eleocharis cellulosa* (spikerush), with *Distichlis spicata*, (salt grass) a salt-tolerant grass replacing *Eleocharis* closer to the coast (Tabb et al. 1967).

Besides the vascular plants such as mangroves and sawgrass, periphyton communities, composed of algal and bacteria species, play an important role in the ecosystems of the coastal wetlands. Just as in the Everglades, the low phosphorus levels, alternation of surface water flooding and drawdown, and presence of a limestone substrate near the surface have provided conditions favorable for development of thick mats of calcareous algae on the surface of the marsh, or where flooding is deep enough, in floating masses. The algae and other biotic components are embedded in a layered polysaccharide matrix formed by the algae. The calcareous algae components include many species of filamentous and non-filamentous green algae, diatoms, and cyanobacteria (blue-green algae). Dinoflagellates (protozoa) and bacteria living within or on the surface of the polysaccharide matrix also can be important. Diatoms are an especially diverse group and hundreds of taxa occur in the coastal areas, many sorting out along the salinity gradient (Gaiser and Ross 2003). Of equal or greater ecological importance, however, are several genera of the cyanobacteria, especially *Schizothrix* and *Scytonema*, which are responsible for the incorporation of calcium carbonate crystals into the matrix. This function is the key first step in the formation of calcitic marl that accumulates as one of the principal soil types of the south Florida marshes.

We selected the coastal wetland communities as representative communities of Biscayne N.P. because of their key role in influencing the inshore areas of Biscayne Bay and because they constitute a large proportion of the terrestrial area of the park. In addition, they comprise one of the few remaining tracts of coastal wetlands in southeastern Florida. The Biscayne N.P. wetlands are highly altered from their natural condition as a result of disturbance of the natural hydrological cycle yet have the potential for recovery of the natural structure and function through hydrological restoration.

Coastal Wetlands: Historic Conditions

Egler's observations (1952) were centered on the areas a few km southwest of the shoreline of Biscayne N.P., but conditions in the flat marshes east of the Atlantic Coastal Ridge that extend to the mangrove-lined fringe along Biscayne Bay would have had much in common with the Southeast Saline Everglades (SSE). Figure 16 shows that in 1940 the natural vegetation pattern within current Biscayne N.P. resembles that of the SSE with a tall shoreline mangrove forest, an intermixed marsh-mangrove area and freshwater marshes further from the coast. Egler noted that within the SSE appeared a rather narrow band of high reflectance that is visible from aerial photographs and parallels the north shorelines of Florida Bay. This "white zone" continues along the tip of the peninsula extending north and east of the Turkey Point power plant that forms part of the extreme southwestern boundary of Biscayne N.P. Ground inspection shows that the reflection comes from the marl substrate, visible through sparse vegetation with additional reflection from calcite-encrusted periphyton (Ross et al. 2000). Egler placed the interior boundary of the "white zone" at the transition of the upper and lower saline Everglades, demarcating the furthest inland extent of "invasion by *Rhizophora* propagules sufficient to form a complete coverage" (Egler 1952). This transition zone may very well have continued further north along the shores of Biscayne Bay, but the pattern is not discernable, perhaps because the wetlands have been highly disturbed.

The pattern of declining mangrove tree size (basal area and canopy height) with increasing distance from the coast seen in Biscayne N.P. occurs widely in south Florida and elsewhere in the tropics (Feller 1995). A broad band of scrub mangrove is found along the entire extent of the mangrove forest zone along the Gulf Coast and Florida Bay, and extends eastward into the C-111 Basin and Model Lands area that lie between ENP and Biscayne N.P. (Craighead 1971). Heights of the trees are always <5 m and usually much less, and productivity is far lower than in the tall fringing mangrove zone (Ross et al. 2002). The scrub areas always lack direct tidal flows and are flooded for long periods with, however, completely dry-out in droughts. In many places, the scrub mangroves occur intermixed with herbaceous marsh comprised mainly of freshwater species and abundant periphyton. Considering that Harshberger (1914) in his classic early treatise on the vegetation of south Florida already mentions the dwarfing of mangroves north of Florida Bay and its intermixing with sawgrass marsh, it is likely that the scrub mangrove zone has been present for untold centuries in the same relative location between the shifting interfaces of the mangrove forests and the interior freshwater marshes.

Numerous factors probably interact to explain the apparent long-term persistence of the dwarfed mangrove stands in the interior areas including, tropical storms, occasional freezes and fires. Phosphorus occurs in very low amounts in the calcitic marl soil and phosphorus availability is known to limit red mangrove growth in scrub environments (Feller 1995). Salinity is undoubtedly involved. It varies from near 0 ppt following the heavy rains of summer or in tropical storms to levels above ocean salinity in droughts, particularly if tide water was forced into the zone in a hurricane in the preceding autumn Tabb et al. 1967, Ross et al. 2002).

Coastal Wetlands: Community Extent

The coastal wetlands of Biscayne N.P. form a narrow strip bordering Biscayne Bay. The mostly varies in width from about 0.2 to 0.6 km, extending about 29 km from north to south. In the vicinity of the visitor center and along the southern boundary adjacent to Turkey Point Power Plant, the mainland park area is up to 1-3 km wide. In a park in which the land area of 1770 ha is only 2.5% of the total (NPS 1995), the mainland wetlands occupy less than half of the total land area of the park. Stalter et al. (1999) report somewhat different figures. They estimate that mangroves cover 2794 ha in the park, or 3.8% of the park area. This figure,

however, includes island mangrove forests as well as the coastal strip. In either case, an area well under 2.5% of the park total appears to apply to the coastal strip.

Coastal Wetlands: Community Composition

Plant species diversity tends to be low in most of the coastal wetlands communities in southeastern Florida. This trend may have been reinforced by the profound alternation of the natural hydrological cycle through drainage, and construction of canals, levees and roads throughout the area. No information appears available on the diversity of the coastal ecosystems before these interventions. Egler's (1952) report which describes conditions in the 1940s is perhaps the earliest scientific report but by the time of his observations, significant changes had occurred in the Everglades as a whole and in the southeastern Florida wetlands in particular. Egler himself, for example, accessed his sampling sites via highway U. S. Rt. 1 so the attendant hydrological disruptions already probably were in effect. He also commented on the presence of *Casuarina equisetifolia*, the invasive Australian pine that colonizes sandy coastal sites, and noted its potential to disrupt natural communities.

Some insight into species diversity may be found from a 4-km transect established in the mid 1990s just south of Turkey Point Power Plant and therefore just south of the southern boundary of Biscayne N.P. (Ross et al, 2002). The tally of species found only 11 species of vascular plants. It is reasonable to assume that the species encountered also would be found a few km north within Biscayne N.P. today. The species along the transect followed a pattern similar to what Egler found. Red mangrove was dominant near the shore, while black and white mangrove, and the halophytic needlerush and salt grass were common in the interior areas. These species yielded to sawgrass, spikerush and a few associated freshwater species only in the last few tenths of a kilometer. Undoubtedly this pattern reflects the continued isolation of these areas from freshwater inputs that Egler already noted in the 1940s. Evidence based primarily on analysis of sediments suggests that the changes that Egler detected more than half a century ago, continued in the following decades, leading to a withdrawal inland of the freshwater communities and expansion of the low diversity saline communities at a rate that was greater than would have occurred as a result of sea level rise alone (Meeder et al. 1996). In much of the park's coastal wetlands where the width of the land is narrower than at the southern end of the park, there are no remaining freshwater marshes and the few tree islands have been overtaken by mangroves and *Casuarina* (Ross et al. 2003), thus patch or beta-diversity also is likely to have declined following disturbance.

There appear to be few plant species of the coastal strip that can be considered as being of special concern. Stalter et al. (1999) report none. Gann et al. (2002) mention *Pavonia palludicola*, a malvaceous swamp shrub as occurring in several sites including the mainland mangroves. Although they included this species as "critically imperiled" in the U.S., substantial numbers have been recently discovered in Everglades National Park, making it likely that the species will be downgraded in status.

No historical information appears to be available on the role of the SSE marshes as habitat for animal species. One can hypothesize that in the predisturbance era when freshwater flow supported sawgrass marshes nearly up to the narrow mangrove fringe forest bordering Biscayne Bay, the wetlands functioned similarly as did other coastal wetlands as foraging habitat for wading birds. In marshes near northeastern Florida Bay, for example, spoonbills and other wading birds once nested in the estuarine ecotone before degradation by drainage of the Everglades. Wading birds of coastal affinity, such as Roseate Spoonbills and Great White Heron may have foraged in the coastal marshes along Biscayne Bay as they still do in reduced numbers north of Florida Bay. The nearest nesting site for Spoonbills today is Tern Key in northeastern Florida Bay.

Individuals from that colony have been tracked to coastal wetlands on the east side of the C-111 but still over 12 km from the nearest boundary of Biscayne N.P. (Lorenz et al., 2002). Crozier and Gawlik (2003) present results of the annual South Florida wading bird nesting survey. Their map of the locations of south Florida nesting colonies shows nothing for the area of the SSE or Biscayne Bay coastal wetlands. Another animal that may have occurred in the coastal wetlands is the American Alligator which is known to use tidal creeks and surrounding marshes in habitats north of Florida Bay (Craighead 1968) that resemble those near Biscayne Bay before their complete hydrological isolation.

The periphyton occur in both freshwater and marine areas and were historically quite distinct. In the marshes, periphyton was organized into thick mats having a surficial calcareous, non-photosynthetic layer over a green photosynthetic layer (Gaiser and Ross 2003). In contrast, within the shaded habitat of the mangrove forest, the periphyton consisted of a thin, green film attached to roots and leaf litter. Phosphorus content of the freshwater periphyton was lower by an order of magnitude than the periphyton of the saline areas, consistent with patterns seen in the Everglades where calcifying marl dominates only in highly oligotrophic seasonally dry marshes (Browder and Swift 1994). Within the marsh periphyton mats were the filamentous cyanophytes that are found elsewhere in the freshwater Everglades- dominant species belonging to the genera *Scytonema* and *Schizothrix*. Microscopic examination reveals these taxa to be coated with calcite crystals that are the main ingredient in marl formation as in the Everglades (Browder et al. 1994). Closer to the coast the calcareous taxa are replaced by non-calcite (precipitating cyanophytes before yielding dominance to filamentous chlorophytes) (Gaiser and Ross 2003).

The diatom component of the periphyton, comprising 405 taxa in all, was the most diverse algal group. About 20% of the taxa are apparently not identifiable from manuals or the algal literature, perhaps illustrating the uniqueness of the southern Florida periphyton flora if not simply to the lack of extensive study. The diatoms separated out as either freshwater or marine in composition. Indicator species were reliably associated with the following community types: mangrove forest, freshwater marsh, dwarf mangroves, and transitional mangroves (Gaiser and Ross 2003). The overriding factor controlling periphyton diatom composition was salinity. Other algal taxa co-occur with the diatoms, including cyanobacteria (coccoid and filamentous), desmids, dinoflagellates and chlorophytes. The non-diatom component also could be distinguished based on freshwater or marine environments. Given the known rapid response times of periphyton algae to small shifts in water quality and salinity (Gaiser and Ross 2003), there is considerable potential for these species to serve as indicators of subtle environmental change that would not be demonstrable with larger organisms.

Coastal Wetlands: Natural Disturbances

Mangrove forests like other ecosystems of south Florida develop and persist in an environment replete with natural disturbances. Damaging hurricanes are frequent, freezes are believed to help determine the northern limits of mangrove and other tropical species, drought occurs on decadal scales, and destructive fires may accompany the droughts. The fringe and dwarf forests of Biscayne N.P. were affected very differently by Hurricane Andrew in 1992 which passed directly over the coastal wetlands. The tall fringe forest was badly damaged with major canopy loss and mortality. Contrastingly, the scrub forest showed little effect other than foliage loss. Undoubtedly the low stature and location downwind of the tall, dense fringe forest provided some protection. In one site, studied by Ross et al. (2001), three years following the storm, fringe forest aboveground biomass, taken up almost entirely in a new recruitment cohort, averaged 18 Mg/ha, and in just two more years, soared to 56 Mg/ha (Table 2). Ninety percent of the trees were red mangrove. The biomass was apportioned into 64% wood (stem plus branch), 14% foliage and 22% in prop roots. The above-ground

biomass of the dwarf forest was 16 Mg/ha in 1995, but increased to only 22.3 Mg/ha in 1997. Interestingly, the biomass apportionment was almost identical- 66%, 16% and 18% for wood, foliage and proproots respectively. Annual biomass production was several times greater in the fringe forest and apportionment was much different. Fringe forests channeled only 47% of growth to foliage leaving most of the rest to wood as stems grew taller. In the dwarf scrub, 73% of the production was measured as foliage, and relatively little was seen as wood, perhaps not surprisingly given that the scrub averaged under 1 m in height in 1997 (Ross et al. 2001).

Parameter	Community type			
	Dwarf forest		Fringe forest	
	mean	± S.E.	mean	± S.E.
Basal area ($\text{m}^2 \cdot \text{ha}^{-1}$)	—	—	13.54	3.44
Density (#/ha)				
stems > 1m	8,800	8,800	57,800	9,000
stems ≤ 1m	608,200	122,100	107,200	42,900
Total Biomass ($\text{Mg} \cdot \text{ha}^{-1}$)	22.28	5.18	56.02	11.96
Biomass apportionment by tissue (%)				
Stem	55.3	—	42.7	—
Branch	10.7	—	21.6	—
Leaf	16.1	—	13.6	—
Proproot	17.8	—	22.1	—
Biomass apportionment by species (%)				
<i>R. mangle</i>	96.3	—	90.5	—
<i>L. racemosa</i>	3.6	—	8.2	—
<i>A. germinans</i>	0.1	—	1.3	—
Maximum stem height (m)	0.97	0.05	4.04	0.52

Table 2. Structural characteristics of fringe and dwarf mangrove stands in the coastal wetlands of Biscayne National Park in 1997, five years after Hurricane Andrew struck. Source: Ross et al. 2001.

Coastal Wetlands: Anthropogenic Disturbance

The mainland fringe of Biscayne N.P. as well as coastal areas immediately to the south has been deprived of freshwater for decades as a result of drainage of the adjacent interior areas for agriculture and housing development, and the more general lowering of the water table in the southeastern Florida (Craighead 1971). Public works projects dating back to the early 1900s compartmentalized the Biscayne Bay coastal wetlands for control of mosquitoes, storm surges and water levels. Ditches and small canals dug to drain lands for agriculture were already well underway when the Dade mosquito control district was formed in 1933 (Ruiz and Ross 2004). By the mid-1940s, the cumulative effect of all the drainage activities plus a drought worsened soil salinization leading to abandonment of much of the agriculture (Craighead 1971, Egler 1952). These lands, once freshwater marsh, were colonized after abandonment by woody plants including red mangrove, and the exotics, Australian pine (*Casuarina equisetifolia*) and Brazilian pepper (*Schinus terebinthifolius*).

The mainland portion of Biscayne N.P. is bounded on the east by the L-31E canal and levee and includes large canals (e.g., Mowry and Princeton canals) that run due east through the coastal wetlands to the Bay. In addition, there are a parallel series of smaller internal ditches cut through the property that run parallel to Mowry and Princeton canals. The four large canals discharge most the overland freshwater flow originating to the west directly into Biscayne Bay and act as a barrier to exchange of water between freshwater and saline wetlands (Gaiser and Ross 2003). Many tidal creeks observable in a 1940 aerial photograph no longer were present in 1995. As a result of these gross hydrological changes, salt-tolerant species, especially but not limited to mangroves, have expanded inland reducing the area of freshwater marsh. (Gaiser and Ross 2003).

Coastal Wetlands: Anthropogenic Disturbance—Evidence from Vegetation Patterns

Gaiser and Ross et al. (2003) established a study site extending about 7 km long (north to south) between the main canals and used the parallel ditches to demarcate 13 sub-basins between the main canals. This is the first known study of the vegetation of the Biscayne N.P. mainland. The width of the park land holdings in the study site is about 0.3-0.5 km. Each sub-basin was bounded on the west by the L-31E canal and extended east to the Biscayne Bay shoreline. The study sites actually extended further west than the boundary of Biscayne N.P. which for the most part, does not reach the L-31E. Therefore, the full range of habitat types in the coastal wetlands is not found within Biscayne N.P.

Because the present vegetation zones are aligned parallel to the Bay, they cut across all of the sub-basins, forming a sequence of roughly parallel bands. These bands, extending west from the Bay shoreline, are, in order: 1) fringe mangrove forest, with trees > 9 m tall and an overstory predominantly of *Avicennia germinans* and *Laguncularia racemosa*, and an understory dominated by *Rhizophora mangle*, 2), interior mangrove forest, with the same species, but canopy heights are mostly 5-9 m, and sometimes with *Schinus terebinthifolius* (Brazilian pepper), and 3), transitional and dwarf mangrove forest with the same species as in the fringe and interior forests plus *Conocarpus erectus* (buttonwood) as the overstory dominant in some blocks and canopies < 5m or < 2m if dwarfed. These three types characterize nearly all of the vegetation falling within park boundaries. There also are small salt marsh areas near tidal creeks where *Juncus roemerianus* and *Distichlis spicata*, a salt-tolerant rush and grass, respectively, share dominance with mangroves. Further west, outside park boundaries yet still east of the highly disturbed lands, additional habitat occurs. These types include sawgrass marsh, some of it mixed with red mangrove scrub or the exotic tree, *Casuarina equisetifolia*, swamp forest, small mangrove tree islands and cattail. The sawgrass stands mostly occur west of the L-31N where saline influence has been reduced.

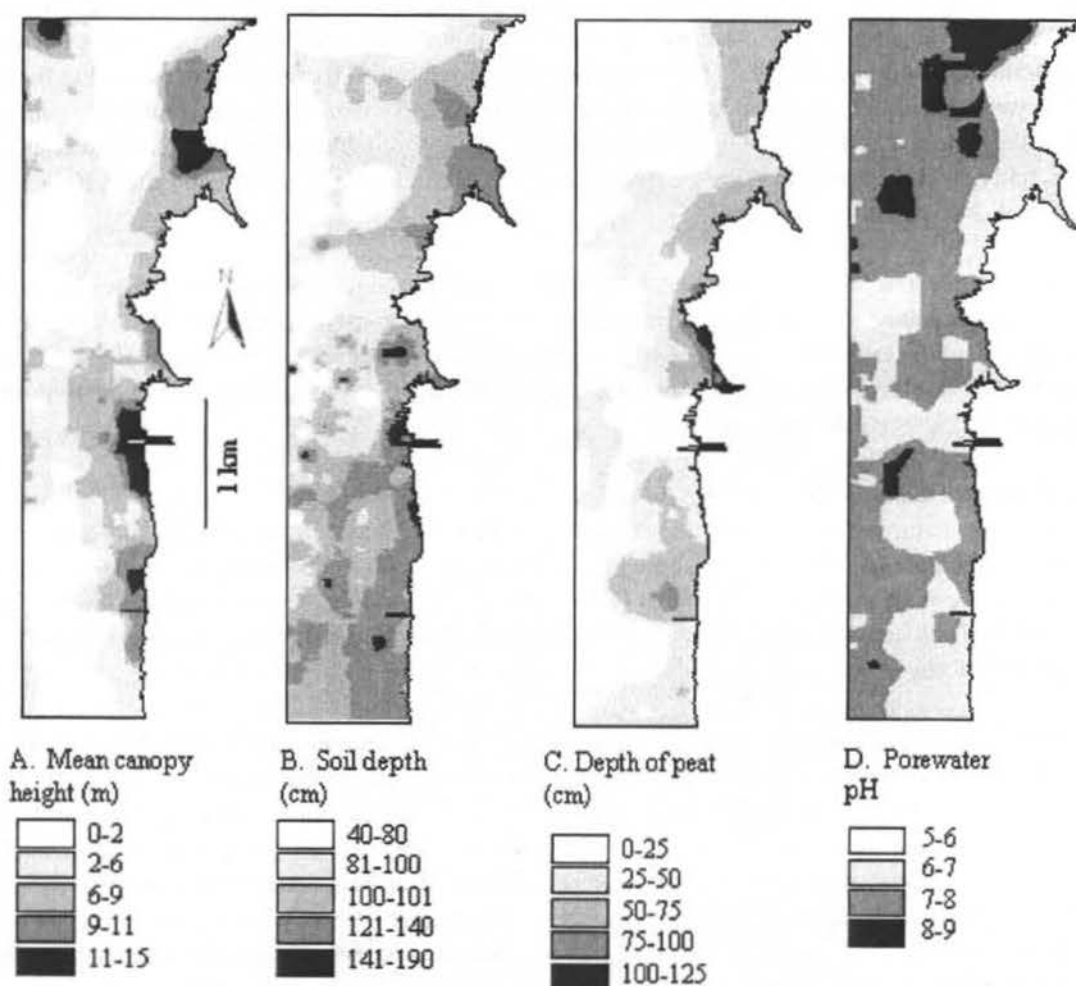
The interior scrub or dwarf forests and the coastal fringe forests in the coastal wetlands of Biscayne N.P. are extremely different in height, biomass, density and other structural measures (Table 1). As mentioned, these differences hold true elsewhere in south Florida such as in the mangrove forest and scrub zone on the north shore of Florida Bay and in the interior of the Gulf Coast forests in Everglades National Park.

Despite the inability to know in detail what the pre-disturbance coastal wetlands were like, it is evident that the wetlands of today differ greatly from their pre-drainage state. The immediate shoreline of Biscayne Bay is still occupied by tall mangrove forests with dominance by red mangrove. However, behind the fringing forest, marshes have been overcome by scrub mangrove, and mixed marsh-mangrove stands still present in 1940 have mostly lost their herbaceous component. Freshwater marshes which even by 1940 had been degraded in its easternmost portions relative to 1928 aerial photographs (Ruiz and Ross 2004) were further degraded by the 1990s. Remaining freshwater marsh has shrunk westward outside the park boundaries.

Tidal creeks which provided habitat for various woody species, for tall mangrove forests, have been filled or disturbed and support instead exotic trees and shorter mangroves. Tidal flows now penetrate the interior much less often.

Coastal Wetlands: Anthropogenic Disturbance—Evidence from Soils

Present soils in Biscayne N.P.'s mainland area are either deep peat in the mangrove forest fringe extending down to bedrock, or, inland of the mangrove forest, a calcitic marl deposited by periphyton as part of freshwater marsh (Figure 17). Where mangroves have extended into marsh areas, supplanting the freshwater vegetation, a thin layer of peat occurs on top of the marl. The surficial peat layer was formed from mangrove



root biomass

Figure 17. Patterns in canopy height, soil depth, peat depth and porewater pH in the Biscayne Bay coastal wetlands. The image extends from Fender Point to just south of Mowry Canal, west to the L-31E levee and east to the shores of Biscayne Bay. From Gaiser and Ross (2003).

within mangrove stands that have spread inland in response to diminished fresh water supply (Zafiris et al. 2004). Radioisotope dating confirms that the surficial peat was deposited in 1950s and 1960s, the period when major drainage operations associated with the large canals became active. Inspection of Figure 17 shows fringe or tall mangrove forest indicated by canopy heights exceeding 9 m occur in areas where peat is deep and pH relatively acidic. The deep peat is associated with higher productivity and absence of calcareous periphyton. Where pH is basic, there is abundant calcium, and marl soils indicative of high periphyton activity and sparse macrophyte vegetation.

The presence of abundant mollusk shells in mainland within Biscayne N.P. permitted a paleoecological reconstruction of ecological trends from soil cores (Figure 18, Zakiris et al. 2004). Soils were 0.5 to 1.5 m deep and were deposited beginning from 2000 to 3000 yr BP. The following trends could be elucidated: 1), increasing salinity levels along the coast and into the adjacent interior coastal marshes, 2), replacement of mixed graminoid-mangrove vegetation by dense scrub mangrove, and, 3), restriction of remaining freshwater systems between the saline zone and the levees, canals and roads. Similar trends and results are found when looking at the historic distribution of oyster beds, once prevalent throughout tidal creeks in the coastal wetlands, and now restricted to mangroves along the shoreline and to tidal creeks inland about 100 meters (Meeder et al. 2001, Meeder et al. 1999).

Lateral encroachment of the mangrove-freshwater ecotone accelerated greatly since the 1950s, although it was proceeding at a much slower rate in the past few millennia as a consequence of Holocene sea level rise. The inland shift of the saline-freshwater ecotone is estimated to have increased from a rate of about 0.5 m/yr as a result of sea level rise with a marked increase to a rate of 3 to 30 m/yr as a consequence of the drainage beginning in the 1950s (Gaiser et al. 2003).

Coastal Wetlands: Current Restoration Efforts

Given the highly disturbed nature of the current system and its importance to the economically and ecologically important marine ecosystems to which it is hydrologically linked, there is considerable interest in achieving some level of ecosystem restoration (CERP 2005b). In addition, because there are few precedents for restoration of any ecosystem type in south Florida, especially at this scale, much interest is focused on the success of the efforts.

In the early 1990s, a freshwater redirection project was planned as a demonstration of the feasibility of delivering water in a restoration context from existing water management structures to the Biscayne coastal wetlands (Ross et al. 2003). The goals of the project were to: (1), reverse some of the damage caused by decades of drainage and salinization, (2), explore field measurement and monitoring protocols, (3), and develop techniques for evaluating ecosystem responses that would be both feasible and scientifically sound (Ross et al. 2003). The wetland areas selected to receive canal water inflows were part of the coastal wetlands within Biscayne N.P.. Water from the Mowry Canal was delivered to the wetlands through two three foot diameter culverts that conveyed water to two spreader canals located on the eastern base of the L31E levee. Water flow was tied to canal operational criteria such that the majority of flow occurred in the summer wet season. The sites chosen for the demonstration were located within the same wetland where Gaiser and Ross et al.

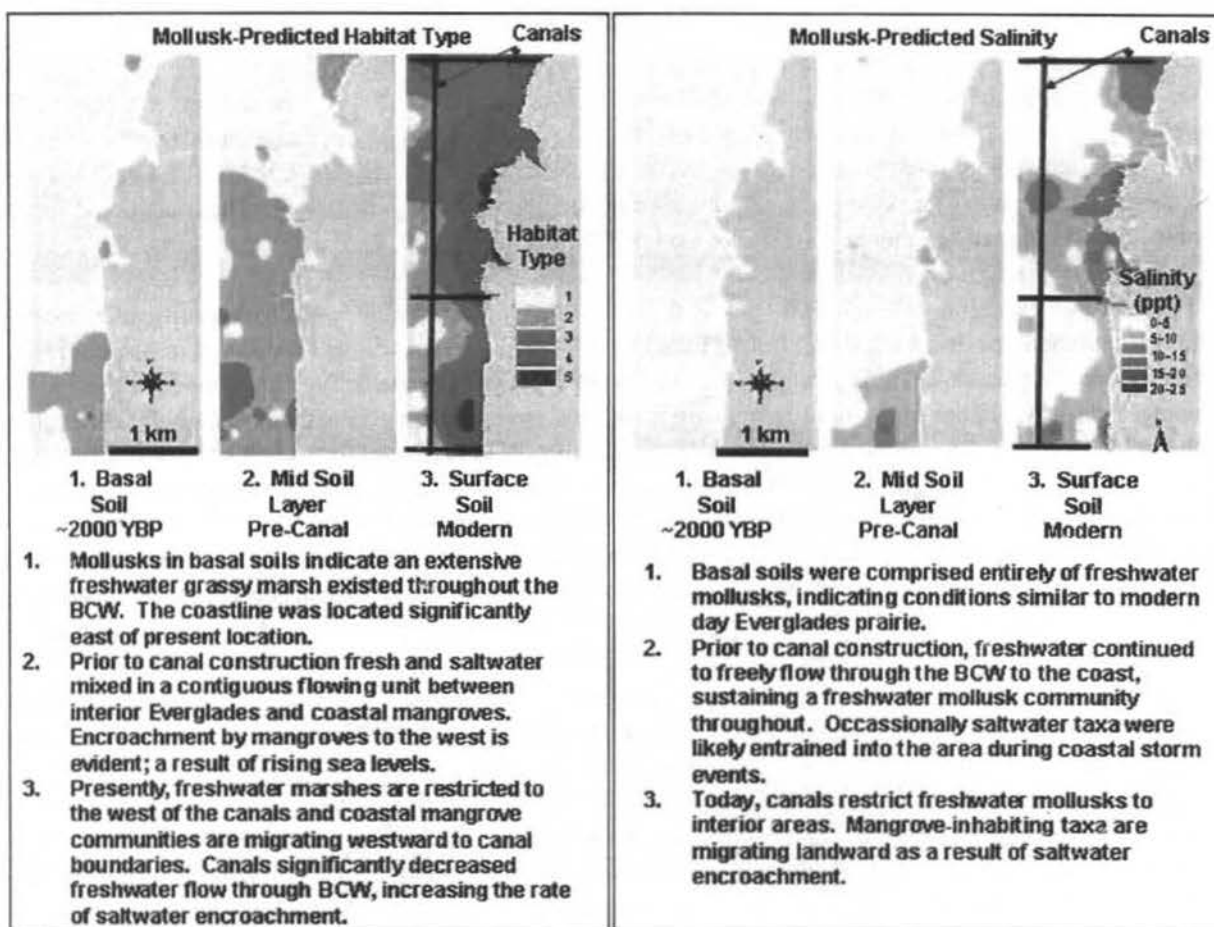


Figure 18. A reconstruction of past environments in the Biscayne Bay coastal wetlands using species composition of mollusk shells recovered from soil cores as indicators of salinity and habitat. From Gaiser and Ross (2003).

(2003) conducted baseline ecological studies. Two of the 13 blocks delimited by east-west canals were selected as a control and a treatment block, both containing the full suite of community types, ranging from mangrove fringe forest to scrub mangrove (Ross et al. 2003).

Freshwater deliveries began in August 1997 and continued irregularly through the sampling period that extended from 1995 to 2002 (Ross et al. 2003). The blocks also received natural tidal inputs, which influenced primarily the mangrove fringe forest. In contrast, the interior dwarfed mangroves received seasonally varying freshwater inputs from the canals and from precipitation and in the fall, tidal water influences that are not detectable in other seasons. There also was a large difference in total phosphorus with the fringe mangroves having over five times the pore water phosphorus levels of the interior scrub (dwarf) mangrove, an effect unrelated to the experimental treatment.

Water levels and flooding were higher in the treatment than in the control mangrove scrub (Ross et al. 2003). There was also some reduction in salinity in the treatment block in the wet season, but only close to the L-31E canal (on the far west of the block). No response of the mangrove communities to the hydrological and salinity effects could be detected from the field measurements, something that might have changed if the experiment were run longer. Rather, the ecosystem trends in the control and treatment blocks were complex and heavily related to external factors operating differentially in the two blocks. These factors included: a hurricane, two freezes, differences in initial vegetation conditions, a probable difference in nutrient supply to

scrub areas, and other unidentified, non-hydrological factors (Ross et al. 2003). The site was in a mode of recovery from Hurricane Andrew which, in 1992, caused 95% tree mortality in fringe forests, extensive damage in transitional forests, but only minor effects in the dwarf forest. By 2002, the fringe forest had recovered its pre-hurricane basal area and species composition remained unchanged. The transitional forest, however, was denser and more diverse a decade later.

The freezes occurred in 1996 and 2000 during the hurricane recovery period, causing mortality and canopy injury in the interior dwarf scrub but little effects in the forests. Mangrove species differed in response to the freezes and the hurricanes, with effects at the stand level dependent on the relative importance of the mangrove species in the sites. White mangrove is the most vulnerable to freeze damage and black mangrove the least. In contrast, white mangrove has the greatest capacity to resprout following hurricane damage to existing trees, black mangrove is intermediate, and red mangrove has a very limited resprouting capacity. These species differences are reported by other observers (e.g., Baldwin et al. 2001). There also were differential initial growth conditions. The control fringe forest had higher basal area than the treatment fringe forest before the experiment began and competitive exclusion in the control forest appears to have caused mortality of large red mangroves that had survived the hurricane. For an unexplained but non-hydrological reason, the mean above ground biomass in the treatment dwarf scrub was double that of the control dwarf scrub at the end of the experiment and even greater at the onset. Despite these differences, the two blocks did not differ in annual production during the 1996-2000 period, indicating that there was no detectable treatment effect in the mangrove ecosystems.

Two biological changes were documented that can be interpreted as a response to the treatment. An effect of treatment upon the periphyton community was clearly demonstrated, based on the classification of the diatom flora into marine, brackish and freshwater components from the literature. The freshwater component of the diatom taxa was larger, as expected, in the interior of both blocks, but in addition, was greatest in the treatment block indicating an early response to freshwater flows (Ross et al. 2003). Secondly, in the treatment block closest to the L-31E levee, colonization by sawgrass and spikerush was detected in low numbers in 2002. Although still a minor component of the plot vegetation, the appearance of these unambiguously freshwater indicator species suggests a vegetation response to the freshwater deliveries. However, whether or not these species would continue to increase in importance with continuing freshwater deliveries was beyond the scope of the study.

Overall, the effects of the treatment were seen primarily in the vicinity of the L-31E levee in terms of salinity, periphyton and sawgrass response as described above. Otherwise, it must be concluded that the volume of freshwater associated with the treatment may have been too small or been provided over too short a time period to cause measurable ecosystem responses that could be distinguished from the effects of non-treatment independent variables.

Coastal Wetlands: Recommendations

The following conclusions and observations can be gleaned from the various studies reviewed here and from the results of other areas. Removal of mosquito ditches could be an important first step in reestablishing hydrologic connections between the artificially created sub-basins. However, this step probably will trigger a number of changes that should be investigated and well understood. These changes might be erroneously interpreted as undesirable or as an indication that hydrological restoration was failing. For example, mosquito populations may increase if isolation of wetlands is reduced. The increased freshwater flow will reduce soil salinities, and if the change is significant enough, bring about vegetation change. This might involve a

transition period when mangroves are stressed or killed as other species colonize the sites. For example, because the mangrove fringe forest has migrated inland in response to salinization, freshening of hydrologic status may trigger retraction of the boundary through mortality of the western portions of the expanded forest.

Exotics also might increase where they previously were limited by salinity levels, requiring intervention by managers to eliminate them. There is no guarantee that hydrological restoration alone will eliminate the exotics even if their colonization was facilitated by drainage.

The experience with the L-31E redirection demonstration project provides conclusions that are useful for other restoration efforts that involve manipulating ecosystems. Clearly, the definition of a field site as a “control” cannot achieve the ideal concept of controlling all factors other than the treatment. Despite the best efforts to select similar sites for experimental treatments, external factors can sometimes influence outcomes in unexpected ways, overwhelming treatment effects. Besides unanticipated natural events like hurricanes and freezes, underlying drainage patterns, sea level rise, as well as vegetation type and status can influence timing and trajectory of outcomes. The kinds of changes envisioned by planners (Figure 19) are idealized in that there is little precedence for bringing about such major ecosystem-level changes through engineering redesign, and the ecological database from which to project the feasibility of such major changes is limited.

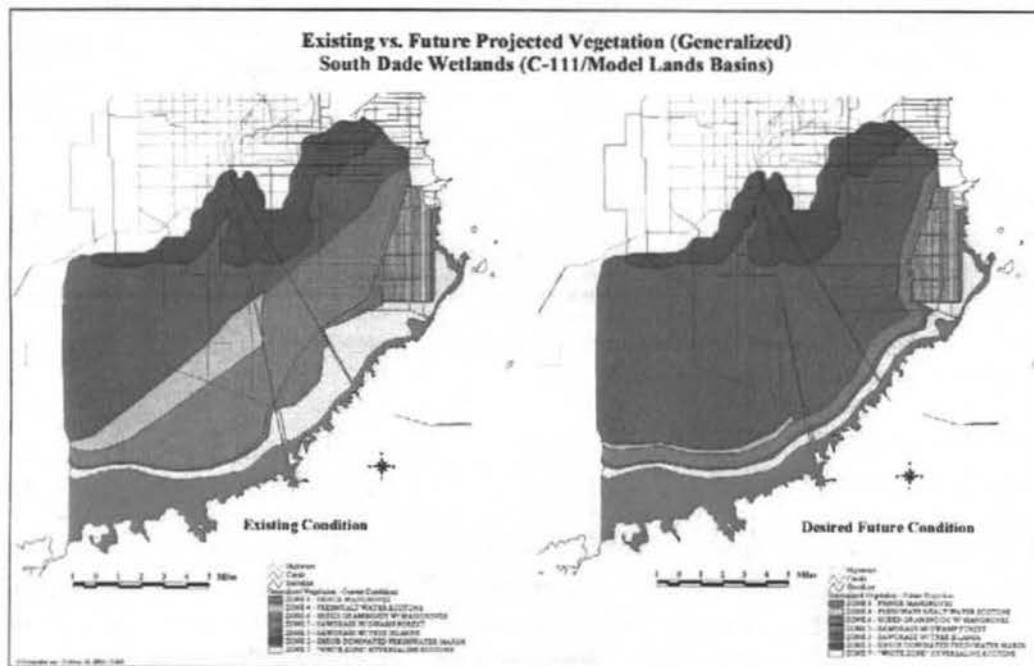


Figure 19. Vegetation maps of the coastal wetlands in the area between southern Biscayne National Park and southeastern Everglades National Park (C-111-Modal Lands basins). Zonation is equivalent to that of Egler (1952) and Ross et al. (2000), with some changes in terminology. The left map depicts current conditions with the freshwater-salt water ecotone (zone 4) displaced well inland, and the “white zone” widened in areas subject to elimination of freshwater supply by roads and canals. The right map depicts a desired future condition at an unspecified time, assuming that hydrological restoration is successful. The overall goal is to expand freshwater systems towards the coast, and to shrink the white zone in east where it has expanded at a rate greater than expected from sea level rise alone.

The experience from the redirection project argues for a focus on sensitive indicators such as periphyton to gauge success, at least initially, and for research into the identifying other sensitive ecosystem indicators. Also important is the question of what magnitudes of hydrological “improvements” are needed to bring about the desired major landscape-level responses, given climatic variability and the ability of external (and often unmeasured) factors to create unanticipated outcomes. Creating achievable goals is essential for sustaining public support for what must be a long-term commitment to ecosystem restoration.

Representative Marine Ecosystems

Coral Reefs

Coral reefs are among the most diverse and complex ecosystems in the world. While coral reefs cover 0.2% of the ocean area, they are estimated to provide habitat to 33% of all marine fish species, thousands to millions of other species, and enormous fish catches annually. Coral reefs are often considered the rainforests of the oceans, harboring a wealth of biodiversity and chemicals, which may have importance for human health. They provide physical and biological habitat for a complex community, support economically fisheries, attract tourism dollars for the diving, fishing, and boating industries and provide a natural breakwater for protection of shorelines from erosion by physical processes.

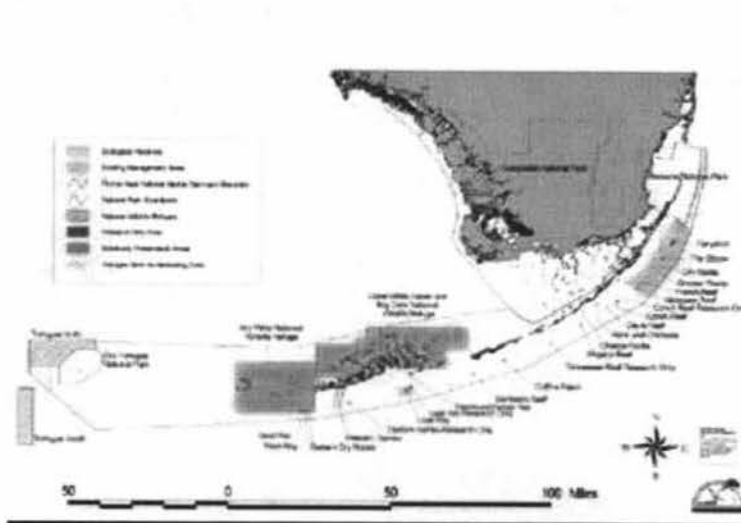


Figure 20. Coral reefs of south Florida and the Florida Keys. Source: FKNMS 2004.

Massive reef structures are formed by the CaCO_3 skeleton produced by scleractinian (stony) corals. Most scleractinian coral polyps are small, but colonies are the major framework builders of coral reefs. Hermatypic corals contain symbiotic algae called zooxanthellae within their gastrodermal cells. The coral provides the algae with a protected environment and the nutrients necessary for photosynthesis. The algae supply the coral with organic products of photosynthesis. In some coral species, these carbon compounds account for most of the coral's nutrition, and are necessary for coral calcification. The mutual exchange of algal photosynthates and cnidarian metabolites is the key to the high rates of biological productivity and calcification in reef building corals.

Coral reefs are found throughout tropical and subtropical oceans, and coral reef development is influenced by such abiotic factors as light, substrate, circulation, sediment, salinity and temperature. Reef development begins by settlement of reef framework builders and construction of a limestone foundation in shallow, warm, well-lit water. Breakdown of skeletal material by physical and biological processes provides carbonates

sediments which are recycled or cemented to the reef framework by biogeochemical processes. The result is accretion of the carbonate framework with an increase in reef habitat complexity and biological diversity.

Coral Reefs: Reefs of South Florida and the Florida Keys

The reefs of the Florida Reef Tract are the only living tropical coral reef system in the continental United States. Maximum coral reef development extends from Fowey Rocks on the northern boundary of Biscayne National Park (Biscayne N.P.) to Loggerhead Reef on the western boundary of Dry Tortugas National Park (Figure 20, FKNMS 2004). The two dominant types of coral reefs in the Florida Keys are patch reefs and bank-barrier reefs (Jaap 1984). In Biscayne N.P. there is a north-south and east-west gradient in patch reef morphology. The patch reefs near the northern boundary of the Park and close to Hawk Channel are dome patch reefs, roughly circular, from 20-400m diameter and often occurring in clusters. They usually consist of large coalesced coral heads and are dominated by the reef-building corals *Montastrea* spp., *Porites* spp., *Siderastrea siderea*, *Colpophyllia natans* and *Diploria clivosa* (Jaap 1984, Jones 1977, Marszalek et al. 1977). Linear patch reefs are more prevalent in the southern part of the Park and near the edge of the reef platform. They consist of elongated reefs perpendicular to the prevailing currents and wave energy. *Acropora palmata* and *Acropora cervicornis* are often found on the linear patch reefs.

Bank-barrier reefs occur offshore at the edge of the reef platform. In Biscayne N.P., these are mostly relict reefs characterized by the absence of well defined zones (back reef, reef flat, fore reef). These reefs have a low topography and are depauperate in reef corals compared to patch reefs (Jaap, 1984).

The reef tract of Biscayne N.P. is a complex assortment of approximately four thousand patch reefs located on a shallow Holocene platform on the eastern edge of Hawk Channel (Jaap 1984, Figure). Hawk Channel is a shallow (12-15 feet), narrow (less than one half mile) channel that extends from Miami to Key West following the seaward edge of the Florida Keys. Within Biscayne National Park the patch reef platform is separated from the slightly deeper banking reefs to the east by a narrow (one quarter mile wide), contiguous, "sand channel" similar in depth to Hawk channel to the west. This sand channel is less discernable, and in some southern areas, non-existent. It is significant in that it directs Florida Current water onto the coral reef platform, the only place in the Florida coral reef system where this happens. The banking reefs to the east of the "sand channel" isolate the patch reef platform from the Florida Straits.

The physical processes that regulate the flow of oceanic and nearshore waters through the coral reef ecosystem include tides, coastal and deep ocean currents, and wind driven surface currents (Wolanski 1994). In Biscayne N.P., the protected shoreline is dominated by mangroves, rocky intertidal or sedimentary environments. The substrate from the intertidal zone out to Hawk Channel is a mosaic of seagrasses, sediments, hardbottom and some patch reefs. Seaward of Hawk Channel, patch reefs are more abundant, and bank reefs begin at the edge of the reef platform.

Coral Reefs: Hydrology

The Florida Current dominates the environment of the outer banking reefs and much of the patch reef platform. The prevailing currents and the time of year determine the source and character of plankton, nutrients (both particulate and dissolved), salinity, and temperature of water flowing over the reefs (Lee 1986). Circulation in the upper Florida Keys is significantly different from that observed in the lower Keys, consisting of two flow regimes. The water in Hawk Channel has a net northerly flow in summer and a slight net southerly flow in winter modified by the passage of atmospheric fronts (Lee et al. 1992). The particulate character and organic load are strongly affected by water flowing out of Florida Bay. Water flows to the

north year round in the "sand channel." These two water masses mix over the patch reef platform. To complicate the coral reef platform hydrology, frequent eddy currents spin off the Florida Current and move southwest over the patch reef platform, loosing their integrity near the middle of the Park.

Coral Reefs: Importance in Biscayne National Park

The coral reef platform covers approximately one half of Biscayne N.P. Of the different ecosystems found in the park, it is the most threatened by known and unknown anthropogenic pressures (Curry 2005), and its functional processes are the least understood. The hard coral cover within Florida reefs has declined from 25-30% to less than 2% on some reefs over the last 20 years and this precipitous rate shows no sign of slowing (Porter and Meier 1992). Loss of the coral reef ecosystem, or major components of the coral reef community, will have a cascading affect on mangrove, seagrass and hardbottom ecosystems found in the Park because they are all highly interconnected and interdependent.

Several interacting factors have contributed to the consideration of this ecologically, economically, and aesthetically unique system as an "ecosystem at risk". The geographical location of Florida reefs near the northernmost limit of reef development and adjacent to a large and rapidly growing urban center makes this system especially vulnerable to coral disturbances like eutrophication, sedimentation, and pollution commonly associated with coastal development. Southeast Florida has considerable industrial and agricultural activities that are important sources of pollution in nearshore waters. The Florida Reef Tract and adjoining Biscayne Bay are sites of extensive recreational and commercial fishing, an activity that has a large impact on coral reefs.

Understanding essential coral reef processes is a priority within Biscayne N.P.'s General Management Plan. From another perspective, understanding environmental processes which affect coral reefs is critical when litigating ecosystem damage, or threats, associated with ship groundings, coastal pollution, and other forms of disturbance.

Coral Reefs: Community Structure

Community structure on coral reefs can be characterized by species recruitment, species population dynamics and species interactions on the reef. Studies of coral recruitment in the Florida Keys suggest recruitment rates are highly variable (Chiappone and Sullivan, 1996), with low recruitment rates for the large frame-building corals (e.g. *Montastrea* spp., *Acropora* spp., *Diploria* spp.; Szmant, 1986). Porter and Meier (1992) consider recruitment important in determining community structure in both bank-barrier and patch reefs in Biscayne N.P. The bank-barrier reefs have generally lower relief and less coral cover while many of the patch reefs have greater coral cover and species diversity (Miller, et al., 2000; AGRRA, unpublished data). Post-settlement mortality due to biological and physical processes is also an important factor in structuring coral communities in Biscayne N.P. (Miller et al., 2000).

Coral Reef: Community Productivity

The most important ecosystem processes on coral reefs are trophic interactions and bioconstructional processes (Done et al 1997). Reefs are characterized by high rates of primary production relative to the surrounding areas (Hatcher 1988). Estimates of gross primary production range from 1250 – 7300 gC/m²/yr (see Lewis, 1981). The outstanding trophic characteristics are: 1, dominant role of endosymbiotic zooxanthellae and benthic algae to primary production and the relatively minor role of phytoplankton (Hatcher 1988, 1990); 2, sensitivity of benthic production to nutrient inputs and sedimentation (Hallock and Schlager 1986; Birkeland 1987); and 3, large number and high diversity of trophic levels in food webs (Grigg

et al. 1984). The outstanding bioconstructional processes are the high biogenic production of limestone and calcareous sediment, and the balance of cementation processes that bind the reef framework versus processes of physical destruction and bioerosion that break down the framework into sediment.

Coral Reefs: Current Condition

Early studies of coral reef ecology were generally limited to reefs in clear waters far from human or continental influences (Hatcher 1999). The typical coral reef was often described as a diversity oasis in an oceanic desert, with the prevailing opinion that reefs were closed, fragile climax systems found in areas with only small environmental fluctuations (Hatcher 1997). Over time, this view changed and coral reefs are now seen as dynamic systems subject to natural disturbances. Disturbance at an intermediate level has been suggested to be important for the high species diversity of reefs (Connell 1978) and much research has focused on the ability of reefs to recover to their original state before disturbance (Pearson 1981). During the past few decades, not only has our understanding of the role of disturbance in determining community structure change, but also the nature of disturbances themselves and the ability of many reefs to recover from them have changed (Hughes and Connell, 1999; Wilkinson, 1999). A major contribution to this change is the increased human dominance of ecosystems (Vitousek 1997; Nystrom et al. 2000). In addition to human use (e.g. fishing and recreation) and abuse (e.g. destructive fishing and uncontrolled tourism), coral reefs have also been indirectly affected by environmental impacts caused by upstream stressors, e.g. by global warming, eutrophication, overfishing, pollution and land use change. This has resulted in a global decline in the health of coral reef communities (Sebens 1994, Hough-Guldberg 1999, Pandolfi et al. 2003, Gardner et al. 2003, Bellwood et al. 2004).

The decline in reef health in southeastern Florida and the Keys is well documented. For example, live coral cover in the Florida Keys National Marine Sanctuary decreased by 38 percent from 1996 to 1999, and observations of coral disease increased (Porter et al., 2002). Over the past several decades, the areal coverage and species abundance on coral reefs within Biscayne National Park and the South Florida reef tract have declined (Dustin and Halas, 1987; Porter and Meier, 1992). Jaap (1984) measured coral cover on transitional bank-barrier and patch reefs in Biscayne N.P. at 29% and 26% respectively. Nearly two decades later, Miller et al., (2000) reported coral cover at 2% on offshore bank-barrier reefs, 11% on transitional bank-barrier reefs and 17% on patch reefs in the Park. From 1989 to 1991, both bank-barrier and patch reefs in Biscayne N.P. experienced a decline in coral diversity (number of species) between 13% to 29% (Porter and Meier 1992).

A recent survey of the Florida reefs using the Atlantic and Gulf Rapid Reef Assessment protocol (AGRRA 2003) focuses on the condition of major reef-building corals on both patch and bank-barrier reefs in Biscayne N.P. The AGRRA methodology is designed to rapidly assess the health of coral reefs by assessing multiple indicators, including coral mortality, coral condition (bleaching/disease), coral cover and algal cover. These indicators are used to provide a status report on the state of the reefs across reef to regional spatial scales. They can also be used as a baseline to determine the effects of anthropogenic disturbances over time.

Coral Reefs: Status of *Acropora* Species

Biscayne National Park, the University of Miami, and NOAA are monitoring the distribution and growth of Acroporids, or branching corals, throughout the Park. The monitoring program is in conjunction with ongoing work at Virgin Islands National Park. The goal of the program is to compare key ecological coral reef processes through the quantification of the distribution and abundance of Acroporid coral populations in Florida. In the 1960s and 1970s, *Acropora palmata* (elkhorn coral) and *A. cervicornis* (staghorn coral) were two of the primary framework builders in Florida and the coastal margins of the Virgin Islands. In the mid

1970s and 1980s, white band disease (WBD) and hurricanes caused dramatic declines in *A. palmata* (Gladfelter 1982, Aronson and Precht 2001). In Biscayne N.P., *A. palmata* coverage at Ball Buoy reef, an intermediate offshore reef, increased in area from 1989- 1991 (Porter and Meier 1992). After the passage of Hurricane Andrew in 1992 and Tropical Storm Gordon in 1994, *A. palmata* was studied extensively with regard to storm damage and extensive fragmentation on Ball Buoy reef and Elkhorn reef, an inshore patch reef with widespread *A. palmata* thickets (Fong and Lirman 1994, Lirman and Fong 1995, 1996). In 1992, *A. palmata* was present to a limited extent on some other Biscayne N.P. reefs studied (Szmant *et al.* 1997).

These studies suggested a strong connection between *A. palmata* population survivorship and persistence with asexual reproduction by fragmentation (Lirman 2000). Recovery from storm damage was slowed by coral bleaching in 1993 (Lirman and Fong 1995). In late 1998/early 1999, *A. palmata* at Elkhorn Reef declined dramatically presumably due to a severe coral bleaching event and possibly white band disease (Lirman 2000). This trend was also seen in other *A. palmata* populations at other reefs in the Park and in Looe Key (Miller *et al.* 2002.) The loss of abundance and distribution was so extensive in some areas of Florida and the Virgin Islands that they could be classified as "local extinctions." For some reason, there has been a remarkable recovery of *A. cervicornis* over the last five to six years along the south central Florida coast north of Biscayne National Park. This recovery of *A. cervicornis* is slowly moving south and a limited recovery is occurring in Biscayne National Park (Dickman 2004). Unfortunately, the abundance of *A. palmata* continues to decline in Biscayne National Park, and highly localized extinctions are already obvious. Complicating the recovery of these two major reef builders are the occurrence of coral diseases (white band), hurricanes and increased densities of the coralivorous snail, *Coralophilia* sp., damselfish and the fire worm, *Hermodice carunculata*.

Coral Reefs: Anthropogenic Disturbance

A number of environmental parameters have been hypothesized as factors responsible for the observed decline in the health of coral reef communities. These include: anthropogenic nutrient loading (cf. Szmant and Forrester, 1996), increased sedimentation (Telesnicki and Goldberg, 1995), climate-related increases in surface temperatures (Brown and Ogden, 1993), physical abuse (groundings, coral and live rock harvesting), and other activities that have adverse affects on coral reef communities. Although observations of nutrient concentrations, suspended sediment concentrations, and water temperatures have been closely monitored on the Florida reef tract, no single, or combination of factors has been conclusively identified as a primary driver of degradation within reef communities. A recent report by the World Resources Institute (Burke and Maidens, 2004) identifies several anthropogenic impacts on South Florida reefs and their potential risks to reef health (Figure 21). Potential risks are indicators of reef condition and threats from: 1, coastal development (i.e., pressures from sewage discharge, urban runoff, construction, and tourism development); 2, watershed-based sediment and pollution (i.e., pressures related to soil erosion and runoff of fertilizers and pesticides from farmlands); 3, marine-based pollution and damage (i.e., pressures from shipping and boating, including dumping of garbage, oil spills, discharge of ballast, and physical damage caused by groundings and

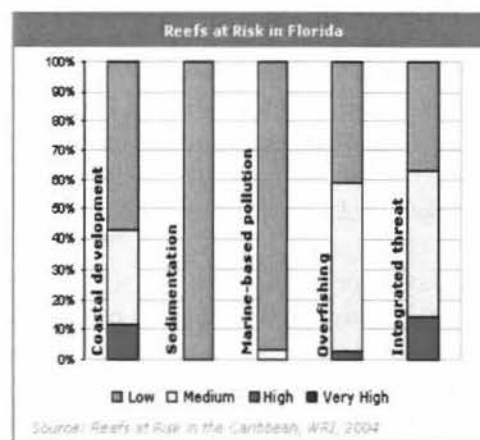


Figure 21. Analysis of relative risks associated with coral reefs in Florida. Source: Burke and Maidens 2004).

anchors); and 4, overfishing (i.e., pressure from unsustainable levels of fishing). The level of these threats varies among locations throughout the Caribbean and provides the basis for assessing potential risks. Rather than trying to identify a specific cause, Pandolfi et al. (2005) suggest that the only way to reverse reef decline is to simultaneously reduce all threats.

Coral Reefs: Anthropogenic Disturbance–Eutrophication

As an urban park, Biscayne N.P. is affected by the rapid development occurring in Miami-Dade County. Biscayne N.P. encompasses a large tract of the only undeveloped mangrove shoreline remaining in Miami-Dade County. Biscayne Bay and the reef tract are buffered from the direct effects of coastal development by an urban development boundary established in the mid-1970s to slow the incursion of urban development onto agricultural and ecologically sensitive areas adjacent to the Biscayne N.P. boundary.

Agricultural lands adjacent to the Park are a source of nutrients discharged directly into Biscayne Bay by a series of flood control canals draining the area. Recent evidence suggests that nutrient loading in the Florida Keys may lead to eutrophication of coastal waters resulting in algal blooms, changes in the community structure, and decreased biological diversity. The presence of algae on substrate can inhibit colonization by larval recruits, thereby initiating a decrease in live coral cover and an increase in algal or other vegetative cover.

Hydrological and physical forcing mechanisms, including rainfall, tides, water management, and wind transport agricultural runoff from the mainland Everglades watershed to the coral reefs of the Lower Florida Keys (Lapointe et al. 2004). This is a significant source of nitrogen supporting eutrophication and algal blooms in seagrass and coral reefs there. Changes in water management practices that affect inflow of fresh water into Florida Bay, and physical transport of warm, hypersaline water onto the reef tract are also potential stressors contributing to the recent decline in coral cover on some reefs of the Florida Keys (Porter et al. 1999).

The reefs in BNP may also be influenced by changes in water quality in Biscayne Bay. When Biscayne Bay water is flushed out on the coral reefs during storms or passing fronts, the nutrient, salinity and temperature gradients may extend to the offshore waters on the reef tract causing episodic increases in turbidity and declines in water quality. The remaining coastal wetlands adjacent to Biscayne Bay serve as important buffers that reduce storm runoff and sediment loading directly into Biscayne Bay. Further development of these coastal wetlands could cause cascading effects that would eventually impact the offshore reefs.

Coral Reefs: Anthropogenic Disturbance–Vessel Groundings

Vessel groundings within seagrass habitats were quantified for the years 1995 to present based on towboat reports (Figure 22, Table 3, Bourque 2005). Catastrophic grounding events, those in excess of an acre or

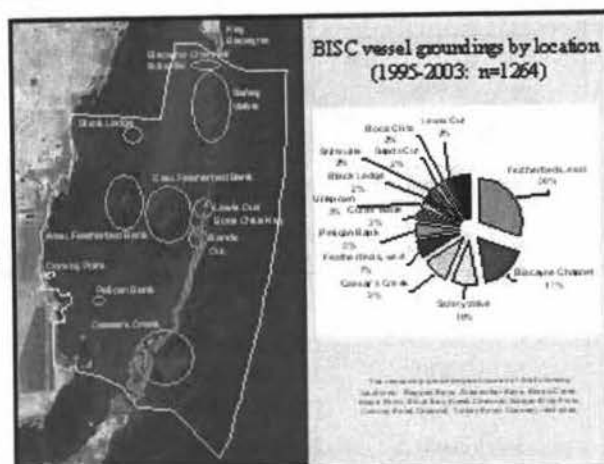


Figure 22. Vessel groundings occurring in Biscayne National Park from 1995-2003. Source: Bourque 2005.

more, occur within NPS areas once or twice a decade. Smaller groundings, or reef damaging events are more frequent. At Biscayne N.P., there have been five major groundings in twenty-five years, and there are more than twenty documented groundings (e.g. vessels stuck on the reef long enough to be observed or that required commercial assistance to get off) and an unknown number of undocumented groundings every year, damaging approximately 5 to 150 m² per event, and most require some sort of rehabilitative action to stabilize the broken coral colonies, salvage coral fragments, and minimize further damage from wave surge.

DATE	VESSEL NAME	VESSEL SIZE	VESSEL TYPE	LOCATION	TOTAL DAMAGE (m ²)
4/3/2004	Gayler	60' Hatteras	Power	Dome Reef	107.75
12/4/2002	Evening Star	49' Hyundai	Power	Anniversary Reef	146.4
7/26/2000		34' Luhrs	Power	Long Reef	
6/26/2000	Cookie Monster	55'	Sail	Hawk Channel	34.98
4/17/2000	Darid Smith	19'	Power	Ajax Reef	
3/10/2000	Debbet	64' Halmatic	Power	Ajax Reef	161
3/5/2000	Familia	50' Viking	Sail	Legare Anchorage	
1/1/2000	Haitian	60'	Power	Long Reef	8.55

Table 3. Vessel Groundings on Coral Reefs in Biscayne N.P. 2000-2004. Source: Bourque 2005.

Coral Reefs: Anthropogenic Disturbance—Fishing

Overfishing is the predominant direct threat to the coral reefs in Biscayne N.P. Serial overfishing throughout the Keys has dramatically altered reef fish populations (Ault et al., 2001). Pressure comes not only from commercial fishing but also from recreational fishing in South Florida, which has grown exponentially since 1964, with no set limits on the number of boats allowed to fish. Several, mostly very small, no-take zones have been established in the Florida Keys National Marine Sanctuary to conserve dwindling fish stocks, and early results show improvements (Causey et al., 2002). To date, the National Park Service has set aside no-take reserves within the Biscayne N.P. boundary. Overfishing not only affects the size of harvestable stocks but can lead to major shifts, direct and indirect, in community structure, both of fish species and reef communities as a whole. Specific ecological services provided by the reef ecosystem can also be affected: aesthetic quality, shoreline protection, fisheries production and carbonate production (McClanahan 1995). In the competition for space between corals and algae, herbivorous fish help to control algae, thus favoring the growth and recruitment of corals. When the herbivores are removed, algae can flourish and coral cover is reduced. Overfishing can lead to short-term losses in biodiversity, the loss of species with critical roles in the ecosystem, and may also lower the resilience of the reef to other threats. The status of fisheries in Biscayne N.P. is covered elsewhere in this report. However, protection of the Parks's coral reef fisheries resources is essential to the long-term health of the reefs.

Coral Reefs: Anthropogenic Disturbance—Disease

In recent decades, an unprecedented array of new diseases has emerged, severely affecting coral reefs. Most observations of coral reef disease reported across the globe have come from the Caribbean region (Green and

Bruckner 2000). Prominent among these reports have been the Caribbean-wide die-off of the long-spined black sea urchin *Diadema antillarum* (Lessios et al., 1984); widespread losses of major reef-building corals (staghorn and elkhorn) due to white band disease (Gladfelter 1982, Aronson and Precht 2001a,b) and numerous outbreaks of white plague (Porter et al., 2002). Before 1980, the Acroporid corals, *Acropora palmata* and *A. cervicornis* were the dominant framework builders at shallow and moderate depths on Caribbean coral reefs. Both species played an important roll in the maintenance of healthy and productive reefs by providing critical habitat for the high diversity of fish and other organisms. White band disease is thought to be the primary cause of the decline in Acroporas in Florida and elsewhere in the Caribbean (Aronson and Precht 2001b).

Coral Reefs: Climate Change

The rapid buildup of greenhouse gases in the atmosphere during the past century has already altered the global climate. Green house gas concentrations have grown by more than a third since pre-industrial times and, without significant policy intervention, are expected to reach double preindustrial levels by the end of the twenty-first century (IPCC 2001). The average temperature of the Earth has risen by 0.6°C to 0.8°C in the last 100 years, and the global average sea level has risen some 18 centimeters (IPCC 2001). The impacts of these basic changes have not been fully determined, but could alter patterns of surface currents and upwellings, the location and intensity of extreme climatic events, and chemical processes in the oceans, associated with elevated levels of dissolved carbon dioxide (Buddemeier et al. 2004).

Coral Reefs: Climate Change - Coral Bleaching

The most direct evidence of the impact of climate warming on Caribbean marine biodiversity has been widespread bleaching of reef-building corals. Coral bleaching occurs when the symbiotic zooxanthellae (single celled algae) are expelled from the host coral organism due to stress, leading to a bleached white appearance. Over the past 20 years, coral bleaching has become more frequent, lasted longer (Hough-Guldberg, 1999), and been responsible for some of the dramatic declines in coral cover on Florida coral reefs since 1997 (Causey, et al., 2002). Bleaching can be a response to many different stresses, including salinity changes, excessive light, toxins, and microbial infection, but increases in sea surface temperature (SST) are the most common cause of bleaching over wide areas (Glynn 1996, Hough-Guldberg 1999). Coral bleaching in the Caribbean is usually triggered by an increase of at least 1.0°C in SST above the normal summertime maximums with a duration of at least 2 to 3 days. In mild events, bleaching is transient, and corals regain their color (algae) within months with little apparent mortality. In more severe cases, many of the corals die. Postbleaching surveys have shown that some coral species have higher rates of mortality than others. Repeated bleaching events in the Caribbean over the past decades have caused widespread damage to reef-building corals and contributed to the overall decline in reef condition (Glynn 1996).

Coral Reefs: Climate Change-Sea-Level Rise

Over the next century, mean global sea level is predicted to rise about 3 to 10 cm per decade (Brown 1997). Healthy reef ecosystems have the potential to respond to a rising sea through reef accretion (Neumann and MacIntyre 1985). However, the situation is less clear for reefs already degraded by or under stress from other threats (Brown 1997).

Coral Reefs: Climate Change-Reduced Calcification Potential

Rising levels of atmospheric carbon dioxide (CO₂) are beginning to alter the chemistry of the shallow ocean. Higher concentrations of dissolved CO₂ increase the acidity of this surface water, in turn affecting the solubility of CaCO₃. (Kleypas et al, 1999). Since the growth of coral reefs represents a balance between

calcification and bioerosion, a small shift in the rate of calcification due to elevated CO₂ could hold serious consequences for the future of coral reefs. Curbing excessive CO₂ emissions is essential to reducing the long-term threat (Reaser et al., 2000).

Coral Reefs: Research Needs—Groundwater Monitoring

Most of the reefs in Biscayne N.P. more than 4 km offshore of the islands separating the reef platform from Biscayne Bay and thus are not directly affected by surface runoff (Szmant and Forrester 1996). There is increasing evidence that groundwater moving through the porous limestone substrate may be a source of nutrients on the reef platform. The United States Geological Survey (USGS) is monitoring wells in Biscayne N.P. to measure groundwater discharge in the Bay and out on the reef platform. (Quinones-Aponte 1996). Groundwater discharged along the shoreline has elevated levels of nitrogen and phosphorous, similar to nutrient concentrations in adjacent tributary canals. Groundwater flows make up only a small part of the total water budget, however, the elevated nutrient concentrations suggests groundwater discharges may influence benthic community zonation. The contribution of nutrient subsidies via groundwater discharge on the reef platform is not well understood.

The prevailing currents through the channels connecting the Bay with the offshore reef tract and the time of year determines the source and character of plankton, nutrients (both particulate and dissolved), salinity, and temperature of water flowing over the reefs. Biscayne N.P. is currently monitoring water quality parameters in Biscayne Bay as part of the Comprehensive Everglades Restoration Plan. Extending this monitoring effort to identify the movement of water masses from the Bay to the reef tract through time-series observations of physical, chemical, and biological properties at the reef during summer and winter will provide a record of the local environment in the two seasons of subtropical latitudes. Quantifying changes in water quality parameters and planktonic community structure and abundance will provide information on the long term health of the resident filter feeding component of the coral reef community. How the coral reef nutritional story has changed over the last 40 years will be established through the comparison of current conditions to the historical data from the Florida Current and, if information exists, Hawk Channel, Florida and Biscayne Bays.

Coral Reefs: Inventory and Monitoring

Since 1989, NPS and the U.S. Geological Survey (USGS) have jointly conducted coral reef monitoring programs for the Atlantic-Caribbean, focusing on natural and human disturbance to reefs around the U.S. Virgin Islands. The program has recently been expanded to include Biscayne N.P. A key component of this effort, known as Park Vital Signs Monitoring, is long-term monitoring program for key indicators of change. Vital signs are measurable, early warning signals that indicate changes that could impair the long-term health of natural systems (NPS 2005e). Early detection of potential problems allows park managers to take steps to restore ecological health of park resources before serious damage can happen. Vital signs monitoring in Biscayne N.P. will serve to establish a baseline for coral reef monitoring, but as of now, monitoring efforts have only recently been instituted and are too preliminary to indicate any long term trends in reef health.

Coral Reefs: Restoration Planning

Biscayne N.P. is currently developing a Restoration Plan/Programmatic Environmental Impact Statement (RP/PEIS) to address coral reef restoration activities in the Park. The purpose of the plan is to aid managers in determining appropriate restoration actions for coral reefs based on the restoration goal statement:

The goal of coral reef restoration actions is to create a stable, self-sustaining reef environment of similar topography and surface complexity to that which existed prior to injury, such that natural recovery processes, enhanced through mitigation, will lead to a fully functioning coral reef community with near natural complexity, structure and makeup of organisms.

The plan will focus on geologic (altered topography, rubble) and biological injuries (loss of living organisms on reef structure, tissue toxicity/water quality) damage, and potential restoration actions for each.

Coral Reefs: Nursery in Biscayne National Park

Coral reef restoration projects have largely focused on areas mechanically damaged during vessel groundings, and rarely involve more than the stabilization of the remaining reef framework and transplanting a large number of hard coral colonies into the area. Some restoration efforts have been more creative, reconstructing the topography in an effort to restore habitat complexity. A few projects have transplanted other coral reef organisms from the area being rehabilitated. Transplanted corals used for rehabilitation typically come from one of two sources: the damaged area itself through the recovery of larger colony fragments and dislodged soft corals, or by harvesting material from the surrounding intact reefs.

Biscayne N.P. has established an innovative restoration program focused on restoring damaged reefs with corals grown in a field nursery (**Figure 23**, Curry 2005). The nursery is seeded by rescuing coral fragments from grounding sites and growing them out in protected areas for eventual transplantation back on the damaged reef. On average, each boat grounding damages between 1 to 10 coral heads. Much of this material can be salvaged by reattachment at the grounding site, but many fragments are too small to survive even if reattached. These are recovered for stocking the nursery. Collected fragments range in size from several cm^2 to about 700 cm^2 . The larger fragments are cut into 2 cm^2 removing much of the underlying coral skeletal material and leaving the healthy coral over a skeleton about 1.5 cm thick. The corals are then epoxied to PVC stakes and passive integrated transponders (PIT Tags) are embedded in the coral fragment to give each fragment a unique 12-digit identification number that can be electronically read in the water and out. This allows researchers to follow the history of the coral fragment throughout its life in the nursery.

Coral Reefs: Recommendations

Given the pressure on Biscayne N.P. resources and based on their effectiveness as a management tool, the Park should consider designating protection zones for coral reefs and establishing no-take zones prohibiting commercial and recreational fisheries as part of its general management plan and fisheries plan. Improved enforcement of existing fisheries laws, and increased visitor outreach efforts to educate park users about responsible fishing and boat use would also help relieve some of the stressors affecting the coral reefs. The State, County and Army Corps of Engineers should consider the environmental impact on Biscayne N.P. before carrying forth development plans that would destroy wetlands before it is known whether these areas are needed in the future to restore the water flows into the park. The Biscayne Bay Coastal Wetlands project of the Everglades restoration plan must proceed with the utmost flexibility for ensuring restoration of the coastline and bay.



Figure 23. Coral nursery in BNP. Photo courtesy of Richard Curry, NPS.

Seagrasses

The seagrass community of Biscayne Bay plays a central role to the functioning of systems within the Park, including: providing habitat and food sources to commercially and recreationally important fish and shellfish, acting as a nutrient and sediment trap, stabilizing the bottom substrate, and contributing to high rates of primary and secondary productivity (Zieman 1982, Lirman and Cropper 2003). Because of the shallow depths (ranging from 1-3 m) and relatively clear waters in the central and southern portions of Biscayne Bay, where Biscayne N.P. is located, light generally penetrates to the bottom of Biscayne Bay (Zieman 1982, Kenworthy and Schwarzschild 1995). This environment is conducive to primary production by benthic macrophytes, the submersed vascular vegetation (SAV), and macroalgae. In this portion of the bay, phytoplankton contribute much less to production. In contrast, the natural depths of many areas in the northern bay have been altered in recent decades by extensive dredge and fill activities around the urban center of Miami (Harlem 1979, Kohout and Kolipinski 1967). Decreased light penetration and nutrient enrichment in these areas have led to a diminishment in the seagrass contribution to production and function, and a more dominant phytoplankton community.

The distribution, composition and health of the SAV community in Biscayne Bay are determined by several factors, both natural and anthropogenic. Sediment depth, water depth and natural precipitation cycles play important roles in zonation and composition of the seagrass community by determining salinity and light regimes (Day et al. 1989). Hurricanes and storms can cause periodic mechanical damage to the rooted plants and macroalgal populations (Wanless et al. 1995). Altered hydrology, changes in water quality and propeller scarring are important recent human perturbations that impact the survival and dynamics of the seagrass community (Zieman 1976, Sargent et al. 1995). The relatively small watershed of the bay (932 mi²), with its large urban and agricultural density tends to concentrate the intensity of anthropogenic impacts on the bay ecosystem. These impacts include consumptive water use, reduction in groundwater flow to the bay, contaminated runoff, boat groundings and blockage of natural sheetflow via causeways and canals. The many flood control canals that cut through the watershed discharge strong pulses of fresh water directly into Biscayne Bay that can stress plant communities adjacent to canal outflows by abruptly changing salinity (Thomas et al. 1961). Thermal stress is a unique impact on part of southern Biscayne Bay by discharge from the cooling canals of the Turkey Point nuclear power plant (Bader 1969, Thorhaug et al. 1973). Local water temperatures there can be elevated by as much as five degrees C.

Seagrass Communities: Community Extent and Habitat Characteristics

The flora of Biscayne Bay is dominated by seagrass beds on the bay bottom and mangrove wetlands on the surrounding coasts and islands. The contiguous subtropical seagrass communities of the Biscayne Bay and the Florida Bay systems together cover an estimated 5,500 km² of southern coastal Florida and form one of the largest seagrass systems in the world (Figure 24, Zieman 1982). The major seagrass species in

Biscayne Bay are turtlegrass, *Thalassia*

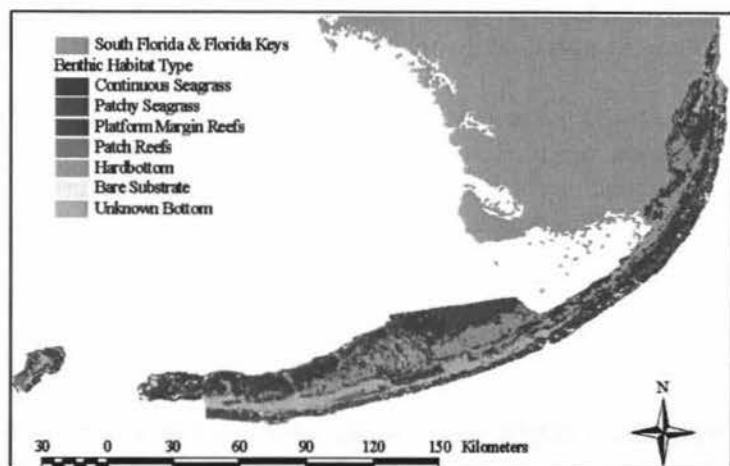


Figure 24. Benthic habitats of the Florida Keys National Marine Sanctuary and Biscayne Bay. Source: Modified from Benthic Habitats of the Florida Keys, FMRI/NOAA 1998.

testudinum (Figure 25a), shoal grass, *Halodule wrightii* (Figure 25b), and Manatee grass, *Syringodium filiforme*, together covering 64% of the total area of the bay (Figure 5, Miami DERM 1985). Widgeon grass, *Ruppia maritima*, occurs in the mouths of canals and rivers where salinity is lower. Johnson's seagrass, *Halophila johnsonii*, is found in small patches in central Biscayne Bay, its southern limit along the Florida Atlantic coast. This species was first recognized as a separate species 1980 and has been federally protected since 1998 under the Endangered Species Act (NMFS 2002). The National Marine Fisheries Service considers Johnson's seagrass to be threatened due to its limited distribution. Johnson's seagrass can tolerate large fluctuations in salinity and because it also tolerates a wide range of water clarity, it is often found in deeper waters than other seagrass species.



Figure 25a. *Thalassia* bed in Biscayne Bay. Source: NPS 1999a.



Figure 25b. *Halodule* bed in Biscayne Bay. Source: FDEP 2004b.

Seagrass Communities: Species Composition, Distribution, and Abundance

Seagrass habitat in Biscayne Bay is most extensive in the central bay, where 75% of the bottom is rooted vascular vegetation, and least extensive outside Biscayne N.P. in the northern bay (Figure 26). Beds of *Thalassia* range throughout the bay. In the central bay, mixed stands of *Thalassia* and *Halodule*, or dense monotypic stands of *Halodule* are found (Lirman and Cropper 2003). Large *Halodule* and *Syringodium* beds are found in areas of the northern bay and some sections of the central and south bay. There is a natural spatial zonation of seagrasses in undisturbed areas, grading from a band of *Halodule* in the nearshore and intertidal zone, shifting with distance from shore to *Thalassia* interspersed with *Halodule* and *Syringodium* in the deeper sublittoral waters and grading to green algae, sand bottom or hardbottom towards mid-bay (Miami DERM 1995, Lirman and Cropper 2003). The northern bay has been heavily impacted and normal seagrass communities are not observed north of the Port of Miami. In some areas of the western bay near canals, grasses are impacted by turbidity and salinity fluctuations that cause stunting and low density (Lirman and Cropper 2003).

In addition to the several seagrass species mentioned in the previous section, seagrass communities in Biscayne N.P. support many other organisms (Ault et al. 1999, Lirman and Cropper 2003). These include: the pink shrimp (*Penaeus duorarum*), spiny lobster (*Panulirus argus*), and several species of recreationally and commercially important fishes including the spotted sea trout (*Cynoscion nebulosus*), red drum (*Sciaenops ocellata*), snook (*Centropomus undecimalis*), and mangrove snapper (*Lutjanus griseus*). These organisms use the seagrass habitat directly during at least some part of their life cycles. Biscayne Bay is an important refuge for juvenile spiny lobster (*Panulirus argus*) (Brook 1975, Bellmund et al. 1999) and a large

portion of the Bay is designated as a Lobster Sanctuary. The West Indian manatee (*Trichechus manatus latirostris*), listed as an endangered species in 1967, thrives in the bay, and depends on aquatic plant communities, particularly *Syringodium*, as its food source (Ashton 1992).

Seagrass Communities: Ecosystem Processes

Seagrasses and their associated epiphyte consortium provide food to higher organisms within the ecosystem in at least three pathways: (1) directly via herbivory, (2) inputs to detrital food webs within seagrass beds, and (3) inputs of detrital material exported out of seagrass beds (Zieman 1982). Direct herbivory on seagrass leaves is not common, but green sea turtles and the West Indian manatee graze on them directly. The detrital food web is a more important pathway for trophic energy transfer as seagrass blades die and break down. The physical breakdown and reduction in particle size of decaying seagrasses facilitates its assimilation by filter feeders and deposit feeders, which in turn, are fed upon by higher consumers (Odum and Heald 1975, Odum et al. 1982).

The thick sediment layer in the western and eastern areas of the bay is partially responsible for higher seagrass biomass there (Lirman and Cropper 2003). The sediment thickness to bedrock varies from zero to a few cm in the eastern bay to several meters in the western and northern bay (Wanless et al. 1994). Fourqurean et al. (1993) hypothesized that in Florida Bay greater sediment volume provides increased porewater nutrients and allows the development of extensive below ground biomass of *Thalassia*. Christian et al. (2004) found that as sediment depth decreased in the southern Biscayne Bay, seagrass densities also decreased, coinciding with increases in calcareous green algae, green algae, and red algae. Green algae dominated where sediment was shallowest or where there was hard bottom. Similar trends in benthic composition were observed when moving from inshore to offshore, as the water depth got progressively deeper.

Seagrass Communities: Historic Conditions

Using palaeoecological methods, Wingard et al. (2003) examined the salinity history and benthic habitat types in Biscayne Bay through time. Results of an analysis of six cores taken in the central and southern bays showed that SAV has been present in Biscayne Bay throughout the period examined, 1450 to the present. Fluctuations in abundance and species composition were noted. *Thalassia* became most abundant after the 1700s, peaking between 1900 and 1950. This peak coincided with a period when the salinity regime of the bay became more marine and increasingly stable, as fresh water was withdrawn from the upstream system. Additional changes to bay hydrology were initiated by landscape alterations such as road and railroad construction that began in the early 20th century (Light and Dineen 1994). In upcore sequences after 1950, SAV indicators begin to decline in some areas, suggesting a recent decrease in *Thalassia* density in parts of the central and southern bays, with the central bay showing the largest decline. A large area in the middle of the central bay is known to have become denuded of seagrasses between the 1940s and 1970s (Fourqurean 1995), likely because the 5 m depths of this area, coupled with reduced water clarity, may have reduced light at canopy height to below threshold levels for *Thalassia* survival. In this period and continuing today, there has been a concomitant but slight increase in macroalgal indicators for species such as *Brachidontes*, *Bittium* and *Xestoleberis*. In sum, these patterns indicate that there was a substantial increase in seagrass habitat throughout central and southern Biscayne Bay between 450-250 years ago, culminating in a peak in abundance from 100-50 years ago. In the central bay, this was followed by a moderate decline that has stabilized in recent years, while southern Biscayne Bay seems to have maintained healthy seagrass communities throughout the period.

Seagrass Communities: Current Conditions

Unlike Florida Bay, which experienced a catastrophic loss of 30% of its *Thalassia* community in 1987 (Robblee et al. 1991), the Biscayne Bay seagrass community has not undergone a similar die-off event. Rather, some areas of the bay have been subjected to a slow decline in seagrass biomass, while other areas near canal outputs or in actively dredged areas have lost their seagrass cover entirely or shifted species composition to fresh water forms, such as *Ruppia* (Christian et al. 2004). Seagrasses in Biscayne Bay appear to be more impacted by nutrient enrichment from adjacent urban and upland areas (Miami DERM 2002), a pattern that is consistent observations in other systems such as Chesapeake Bay (Kemp et al. 1983) and Narragansett Bay (Kopp et al. 1995, Bricker et al. 1999), but lies in contrast to the main threats to seagrasses in neighboring Florida Bay. SAV is slowly overcome by epiphyte overgrowth, and the maximum depth gradually decreases due to reduced water transparency. Greater circulation and exchange with ocean water and reduced hypersalinity in Biscayne Bay may be an underlying reason for the continued relative health of Biscayne Bay's seagrass community compared to Florida Bay.

Seagrass Communities: Current Conditions of the North Bay

Seagrass distribution in northern Biscayne Bay is heavily influenced by both dredge and fill activities and canal flows from urban areas (SFWMD 1995). Seagrasses are at their lowest extent in the northern bay, covering only 25% of the bottom (Figure 26). Phytoplankton are the principal autotrophs in this section of the bay (SFWMD 1995). Dredged bottom is the most predominant bottom type (40%) and macroalgae and bare bottom account for only 10% and 15% of the bottom. Although many areas of the benthic substrate are

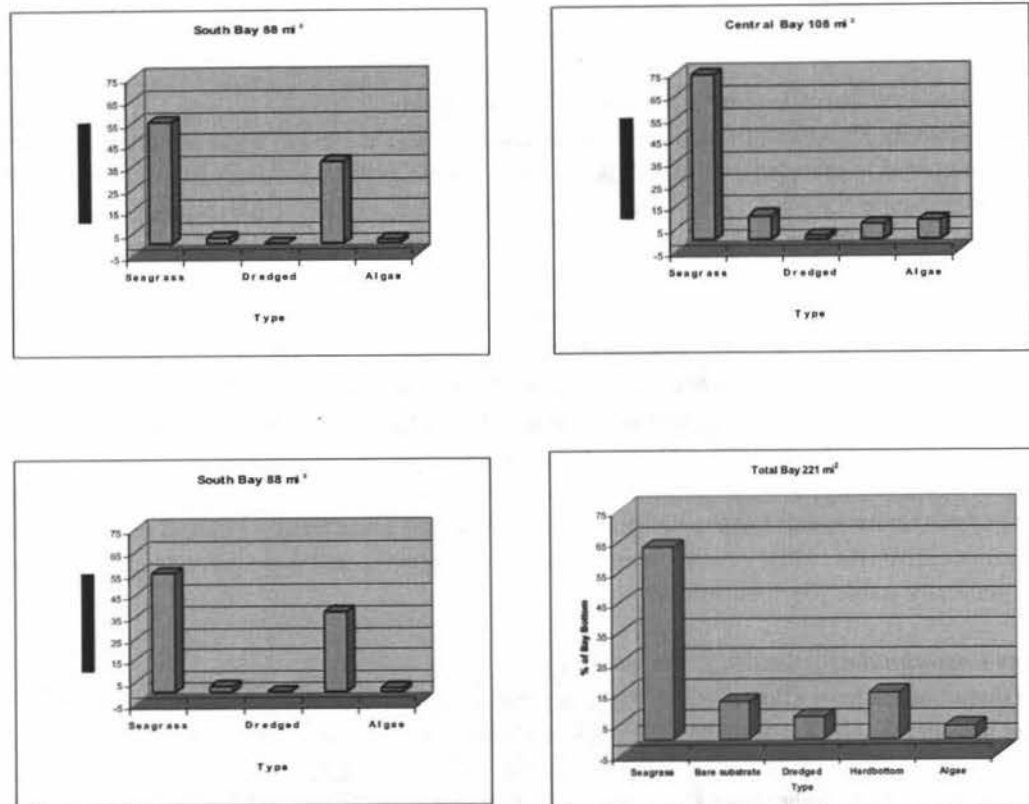


Figure 26. Distribution of bottom types, in per cent cover, in north, central, south Biscayne Bay and average for entire bay. The area of each section of the bay is given above the figure. (Adapted from Markley and Milano 1985).

bare, approximately 3000 acres of healthy seagrasses flourish in the central area of the north bay, despite being surrounded by a highly urbanized environment (DERM unpublished data). Near the mouth of the Miami River, seagrass communities are impacted by reduced water quality, reduced water transparency, and nutrient enrichment (Zieman 1982, Kenworthy and Schwarzschild 1995). As the effect of the river diminishes with distance from the river mouth, extensive seagrass beds are found toward the central part of the bay. Parts of the north bay that have not been impacted by dredging have beds containing sparse to moderate *Thalassia* (SFWMD 1995), but *Halodule* dominates in much of the undredged areas, owing to its tolerance for reduced light (Gallegos et al. 1991). *Syringodium* is prevalent in the easternmost reaches of the north bay, where salinities are greatest (Lirman and Cropper 2003).

Seagrass Communities: Current Conditions of the Central Bay

The benthic habitat in the central bay is dominated by the SAV community. Nearly 75% is inhabited by seagrasses, mostly *Thalassia*. About 7% of the bay bottom is green algae, while 5-7% is bare sand or hardbottom community (Christian et al. 2004). Central Biscayne Bay, largely within Biscayne N.P., is characterized by fresh water canal inflow, groundwater seepage, and exchange with the open ocean through tidal passages and is fairly well-flushed (Wang and Van de Kreeke 1984, Van de Kreeke and Wang 1984). Salinity patterns in this area are dynamic due to the alternating influence of pulsed canal discharges of fresh water and tidal exchange with the ocean (Miami DERM 1985). Some of the denser seagrass beds have experienced propeller scouring due to heavy boat activity in localized areas (Sargent et al. 1995). Deeper areas in the middle of the central bay that were denuded of seagrass in the mid-20th century have recovered and as water transparency has improved, seagrasses have recolonized other formerly barren bottom areas (BBPI-SST 2001).

Seagrass Communities: Current Conditions of the South Bay

Seagrasses (mainly *Thalassia*) predominate in the southern bay, and green algae are found in their lowest densities compared to other regions of the bay (Miami DERM 1995). Southern Biscayne Bay comprises the majority of Biscayne N.P. and is characterized by extensive seagrass beds, hardbottom, and coral communities. Over 50% of the benthos is seagrass habitat, while coral and hardbottom account for 35% of the bay bottom in this region, the largest extent of this bottom type anywhere in the bay. Macroalgae and bare substrate represent only 1-2% of the bottom in this area. In recent mapping surveys of the western area of south Biscayne Bay, Mir et al. (2005) found interesting zonation of the seagrass community. *Thalassia* was distributed with greatest density at some distance from shore, while *Halodule* was densest fringing the shallow areas along the shore. *Ruppia* was found at the mouths of fresh canal discharges.

This sector of the bay has tidal connection with the ocean, circulation that is restricted by banks and keys, a high rate of evaporation, and fresh water input from canals that drain the agricultural region of south Miami-Dade county (SFWMD 1995). Owing in part to the vast seagrass resources here, fisheries within the southern bay are generally stable (Bartone and Wilzbach 1997).

Seagrass Communities: Natural Disturbances

Natural disturbances have affected submerged vegetation in Biscayne Bay periodically during the period of recorded history (Wanless et al. 1995). These disturbances include hurricanes, tropical storms, and sea level rise. Sea level rise is relevant to Biscayne Bay seagrasses because there are areas of the bay that are deep enough that they can be light limited, causing loss of habitat or shifts from high-light species, such as *Thalassia*, to low-light species, such as *Halodule*. This impact is somewhat controllable by management, since water column clarity is a function of phytoplankton blooms and terrigenous inputs of turbid water.

Tropical storms primarily impact the seagrass community as water discharge events, abruptly pulsing fresh water into the system. These storms can occur several times annually, and do not represent grave threats to the seagrass community. Hurricane impacts are much stronger, impacting the community by wave scour, sediment redistribution, storm surge and fresh water pulses.

Hurricane Andrew scored a direct hit on Biscayne Bay in 1992, causing a resuspension and redistribution of sediments in the bay and shearing and uprooting seagrasses (Wanless et al. 1995). Wanless et al. (1995) observed that the passage of Hurricane Andrew caused much more damage to the Biscayne Bay ecosystem and seagrasses than originally thought. The migration of sediment covered large areas of hardbottom and seagrasses, particularly close to the eastern boundary of the bay, where storm currents were strongest. Large fields of "blow-out" holes, areas where all seagrass was completely gone, were prevalent. Those areas were not recolonized even several years after the hurricane. Currents were sufficiently strong near tidal inlets (90 cm/sec) that there was complete stripping of *Thalassia* blades in some areas. Massive amounts of sediment were redistributed, covering existing seagrass beds to depths as great as 30 cm and preventing recovery of those areas. Beds on the eastern side of south Biscayne Bay suffered the most damage and local losses in the grassbeds of up to 80% were observed in places (Miami DERM 1995).

After 13 years, however, damage to seagrass habitat on the ecosystem scale, was minimal (Christian et al. 2004). According to the Miami-Dade Department of Environmental Resources Management (DERM), much more damage was done to mangrove shorelines, and the sponge and coral communities (Miami DERM 1995). Seagrasses survived largely intact and fish stocks remained unaffected in the long term. Fishing and water clarity even improved during the 1990's following the storm, due to several factors, one being the continued presence of seagrass habitat. One of Hurricane Andrew's impacts, in fact, was to create an opportunity to improve the ecosystem. The removal of exotic vegetation by the storm led to the replanting of denuded areas with native species. At least one million mangrove trees were planted along Biscayne Bay, and 100 acres of wetlands were restored or created (Zaneski, 1995).

Other slower moving storms have had a dramatic impact on the seagrass beds of the reef tract (Wanless et al. 1995). The Great Labor Day Hurricane of 1935 removed seagrass cover from a large portion of the southern bay. Hurricanes Donna (1960) and Betsy (1965) caused stripping of large portions of the seagrass cover in Biscayne Bay and the reef tract. Thomas et al. (1961) noted that the abrupt salinity change with the input of massive amounts of fresh water from Hurricane Donna in 1960 did more damage to seagrasses than the physical impact caused by the waves and currents themselves. Most recently, tropical storm Gordon caused similar damage on a smaller scale. Hurricanes Frances and Jeanne in 2004 had very little impact on Biscayne Bay.

Seagrass Communities: Anthropogenic Disturbances

The central and southern portions of Biscayne Bay occupied by Biscayne N.P. have vast seagrass beds, hard bottom and other healthy marine and estuarine communities (Miami DERM 1995, Lirman and Cropper 2003). These habitats, in turn, serve as nursery areas for many estuarine and marine organisms (USFWS 1995). Yet, they are also fragile and depend on good water quality and good light penetration through the water column to maintain their integrity. Biological communities in southern Biscayne Bay have been impacted by degraded water quality, interruption of overland flow of freshwater to the wetland fringe, unnatural amounts and timing of freshwater releases from canals, propeller scouring on bottom communities in shallow areas, and destruction or perturbation of coastal wetlands (Browder and Ogden 1999).

Seagrass Communities: Anthropogenic Disturbances—Propeller Damage

Boating impacts are the most common and pervasive form of physical damage to seagrasses, especially in the populated areas of northern Biscayne Bay but also within Biscayne N.P. (Sargent et al. 1995). Sargent et al. (1995) analyzed the entire south Florida coast and mapped the impact by prop scars (Figure 27). In Biscayne Bay, where the areal extent of boating impacts was not as great as in other areas, the concentration of boating activities in small areas of the northern and central bays led to local areas of moderate to severe prop scarring. In populated areas outside of Biscayne N.P., "prop dredging," the intentional dredging of the sediments using boat propellers to permit greater navigation access, is increasing, but it has been difficult to enforce the stricter regulations against this activity.



Figure 27. Grounding and prop scars, Featherbed Shoal, Biscayne National Park (1996). Source: Cantillo et al. 2000. Photo by Karen Battle, Biscayne National Park.

Grounded vessels are a severe threat to benthic communities in Biscayne N.P., including seagrasses (Sargent et al. 1995). Over 700 groundings have been recorded since 1995, a number thought to comprise only 10-20% of all groundings (NPS 1999b). When a vessel runs aground, the propellers normally cut or uproot seagrasses, leaving a "scar." The damage can take years to recover and in areas of high currents, the seagrass may never grow back (Holmquist 1992). Several estimates of the recovery time from prop scarring have been made. Zieman (1976) estimates that 12-15 years is required for full recovery. One of the most damaging aspects of the prop scar is that the physical setting of the sea bed itself is changed by the impact- a trench is cut that can be as shallow as a few cm to as deep as 35 cm. Generally, the cuts are about 25 cm wide. Multiple engine vessels or larger ships grounding can cause commensurately more damage.

Rhizomatous growth by seagrasses occurs horizontally, and so upon encountering a prop scar, the apical meristem of the rhizome will turn back and grow in a different direction or cease growing (Zieman 1976). Natural sedimentation, in-filling and consolidation of the scar with new sediment substrate are required before the site is again suitable to sustain rhizome incursion. This process alone can take years. Zieman (1976) noted that

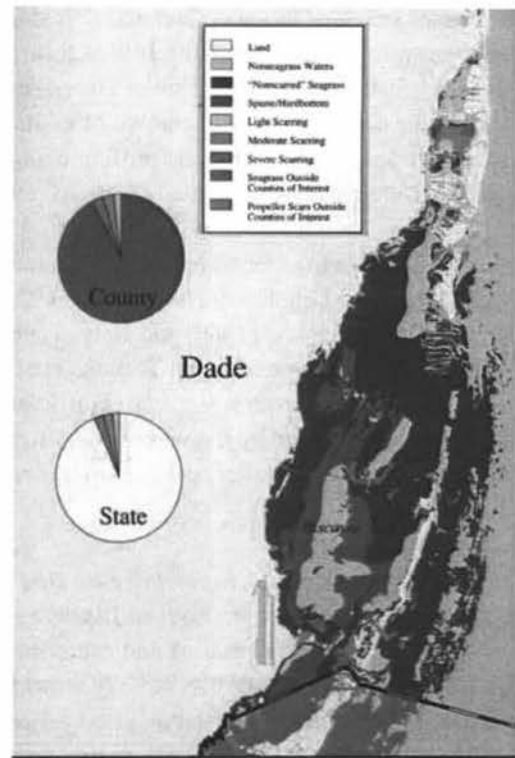


Figure 28. Bottom cover and incidence and intensity of prop scarring in seagrass habitats of Biscayne Bay. (Modified from Sargent et al. 1995).

infilling generally can take more than two years, and even then alterations to the sediment characteristics in the scar can inhibit growth. pH was found to be lower in prop scar sediments after infilling. More acidic waters may create a less favorable environment for rhizome growth (Zieman 1976). This growth is generally slow at any rate, especially in *Thalassia*. *Halodule* is known to recover more rapidly from scar damage, with generally more rapid vegetative propagation and less below ground biomass.

The density of prop scarring is a function of the boat traffic patterns in the bay and the bathymetry of the bay (Zieman 1976). Several sites in Biscayne Bay are highly susceptible to damage prop scars, as depicted in GIS maps of scarring density (Sargent et al. 1995). Damage in Biscayne Bay is concentrated in the northern bay near Miami due to the density of recreational boat traffic, and in the central bay in popular fishing and traffic in areas that have complicated and/or shallow bathymetry (Figure 28).

Seagrass Communities: Anthropogenic Disturbances—Eutrophication and Turbidity

Human activities in the Biscayne Bay watershed and in the bay itself, have led to a decline in water quality as compared to historical descriptions (McNulty 1970). These perturbations, in turn, have impacted seagrass distribution. Water quality in the northern part of the bay ranges from slightly to heavily degraded due to reduced water transparency and high loads of nutrients (McNulty 1970). Turbidity limits light penetration and inhibits the growth of seagrass, particularly in the northern bay outside Biscayne National Park. Dredging in the northern bay impacts the seagrass community by resuspending sediments and increasing turbidity, in addition to direct physical impacts of removal and burial. Dredged areas act as sources of fine particulate materials. During the 1980s, fine suspended material was identified as a major problem in Biscayne Bay by Wanless et al. (1984). Even after initial resuspension subsides, because dredged sediments are looser and unconsolidated, they are frequently resuspended, even with low energy input. Currents, wave action, boat wakes, and reflected wave energy can resuspend fine particulates and contribute to turbidity.

Action was taken to reduce suspended material and turbidity by exercising better control over dredging activity and the concentration of suspended solids decreased from 1979 to 1983 (Miami DERM 1985). However, efforts to restore seagrasses in the 1980s failed in many areas due to continuing high turbidity because increasing nutrient inputs were causing phytoplankton growth (SFWMD 1995). Influxes of dissolved nutrients from stormwater, canal discharges, and direct land runoff have enriched parts of Biscayne Bay, particularly in the northern bay. The areas of the northern bay with the healthiest seagrass beds were those that were flushed by clear ocean water through tidal passes and had high salinity.

Nutrient enrichment can cause phytoplankton blooms that increase turbidity and further reduce light penetration in the water column (Kenworthy and Schwarzschild 1995). Plankton turbidity is particularly problematic because the chlorophyll in plankton absorbs exactly the wavelengths of light required by seagrass plants for photosynthesis (Kirk 1983, Kenworthy and Schwarzschild 1995). Peak chlorophyll concentrations in Biscayne Bay occur following the first large rainfall at the end of the dry season, suggesting flushing of nutrient rich groundwater and surface runoff (Miami DERM 1995). There is a strong negative correlation between chlorophyll concentration in the bay and salinity, indicating that most nutrients in Biscayne Bay are associated with freshwater flow from land (SFWMD 1995).

Through the 1990s and more recently, continued efforts to improve water quality in the Biscayne watershed have been successful (SFWMD 1995, Christian et al. 2004). Water quality data have shown statistically significant decreases in turbidity and chlorophyll, and indicate that water column transparency is increasing. Watershed land use changes have resulted in concurrent changes to the water quality of the surface and

groundwater flows to Biscayne Bay. Improvements have been reported in many constituents, although turbidity continues to be a problem in some areas. Despite urbanization and other development in north Biscayne Bay, however, water quality in much of the remainder of the estuary is good (Fourqurean 1995). Since controls on direct discharge and sewage outfalls were implemented in the latter half of the 20th century, the seagrass community within the Biscayne N.P. is relatively unaffected by blooms or epiphyte growth from nutrient loading to the north bay and is in generally good condition.

Seagrass Communities: Anthropogenic Disturbances—Thermal Stress

The conventional units of the Florida Power and Light Turkey Point Power Plant in South Bay began operations in 1968, and the effects of thermal pollution on the seagrass community were noticed almost immediately (Bader 1969). Surveys of the area around plant outflows showed water temperatures to be elevated by as much as 6°C. *Thalassia* does not survive in temperatures more than 4°C above ambient (or about 35°C), and a decline in density of 50% was measured in waters 3-4°C above ambient temperature (Thorhaug et al. 1973). In a mapping study by (Bader 1969), an area devoid of vegetation around the Turkey Point Cooling Canal mouth extended for up to 30 acres. The zone of influence of the canal outflow, where *Thalassia* was found to be affected by thermal stress, covered 200 acres, and extended up to 1 km from the mouth of the canal. Even outside of this zone of obvious impact, it is thought that environmental stress caused by elevated temperature may make *Thalassia* more susceptible to other stresses and disease.

Seagrass Communities: Anthropogenic Disturbances—Salinity Stress

While salinity, either high or low, is not a major stress overall in Biscayne Bay, local impacts of fresh canal discharge can change or even harm the SAV community. Long-term, a gradual trend of increasing salinity in the 20th century due to human alteration of input and circulation patterns has resulted in community transitions, as seagrasses in some areas of Biscayne Bay have shifted species composition to more salt-tolerant species (BBPI-SST 2001). Historically, northern Biscayne Bay was isolated from the ocean by barrier islands; fresh water from land was trapped more easily in the bay and conditions were more estuarine. Large areas of the bay were freshwater or low salinity ecosystems (Wanless and Browder 2001). Since about 1900, the opening of various inlets, construction of the Intracoastal Waterway, construction of salinity control structures and lowering of ground water levels to provide flood protection have altered the amount and timing of freshwater flows and the rate of tidal exchange. These changes have resulted in higher salinity conditions throughout Biscayne Bay and a more marine seagrass species composition.

Stress in the direction of reduced salinity is not as ubiquitous as hypersalinity, but is more damaging. Although water quality parameters have improved, inputs from canal operations to all parts of the bay continue to produce extreme pulses on an irregular schedule of fresh water input. This impact was recognized as a major community structuring force as early as the 1960's (Kohout and Kolipinski 1967). Marine and estuarine communities are affected by event-related salinity reductions. Currently, water is primarily conveyed into the Bay as point source discharge through canals and through groundwater inflows. The timing, volume and method of delivery of canal discharges can cause acute effects. Seagrasses can tolerate somewhat reduced salinity, but photosynthetic rates are affected (Koch 2003). Fresh water plugs discharged from canals have done severe damage to Biscayne *Thalassia* beds following storm events (Thomas et al. 1961).

Canal flows result in abnormal freshwater distribution and water movement. Because fresh water flowing into the Bay acts as a coherent and discrete stable low salinity water mass, it does not immediately mix with marine water due to the density difference (Chin Fatt and Wang, 1987). This maintains the extreme salinity

disparity when it impacts the benthos. The extreme and rapid reduction in salinity as these water masses discharge into the bay severely impacts or kills attached or rooted benthic organisms and plants as well as impacting fish communities (Serafy et al. 1997; Irlandi and Serafy 1997; Lorenz 1997; Montague and Ley, 1993). Generally, bottom areas around canal discharge points are either devoid of seagrasses (Christian et al. 2004), or have stunted morphologies and sparse distributions. Macroalgae is often killed as well and rooted plants often shift to fresh-tolerant species, such as around the C111 Canal, Model Land Canal, and discharge areas around Black Point (Christian et al. 2004).

Seagrass Communities: Conclusions

Despite natural and anthropogenic pressures, the seagrass community is relatively healthy throughout much of Biscayne Bay. Large expanses of *Thalassia*, *Halodule* and *Syringodium* thrive, and *Halophila*, the threatened Johnson's seagrass, is under a management plan (NMFS 2002). Continued improvements to water quality, hydrologic restoration efforts, and regulation of boat traffic and dredging are required for continued improvement in the seagrass community of Biscayne National Park.

Representative Terrestrial Ecosystems

Tropical Hardwood Hammocks

There are forty-two islands in Biscayne National Park (Biscayne N.P.), some of which form the northern end of the Florida Keys (derived from coral substrates) while the others form a transition to the sand barrier islands immediately to the north (Hoffmeister 1974). The Biscayne N.P. islands occur as a narrow chain about 12 to 16 km east of the mainland shoreline on the eastern side of Biscayne Bay. Only a few islands are large and elevated enough to provide habitat for upland hardwood forests. These forests tend to be inundated by sea water only in severe hurricanes. Elliott Key, at 13 km long and less than a km wide, is the park's largest island and is considered the first of the true Florida Keys which extend in a 210 km long chain to Key West. The area of the largest islands, in order, are: Elliott, 668 ha, Old Rhodes Key, 259 ha, Sands Key, 169 ha, Totten Key, 154 ha, and Little Totten Key, 80 ha (Stalter et al 1999). The islands to the north of Elliott Key, from Sands Key to Soldier Key, are considered "transitional" in that they share features of both the hard rock coral keys to the south and the sand barrier islands to the north (Hoffmeister 1974).

The tropical hammocks of the Biscayne Bay islands represent an ecosystem type that in the United States is restricted to south Florida. Within this ecosystem type, the island forests represent a subset of the U.S. tropical hardwood forests confined primarily to coastal areas of eastern Miami-Dade County, the Florida Keys and the coastal areas within Everglades National Park that are on or near the northern shore of Florida Bay. A few small hammocks preserved in parks in Broward and Palm Beach County also can be considered as belonging to the coastal sub-type. However islands north of Key Biscayne on the east coast, hammocks of the Atlantic Coastal Ridge in Miami-Dade County and in Everglades National Park, and the dry hammock forests of the lower Florida Keys do not occur on the Key Largo Limestone as do the island forests of the upper two-thirds of the Florida Keys. Thus the Biscayne N.P. island forests represent a distinctive forested ecosystem type found in a limited area. The principal areas of this ecosystem type that are secure from the rampant development that has transformed south Florida are in Biscayne N.P. and in the nearby Key Largo a few km to the south. A few smaller tropical forest preserves found further down the chain of Florida Keys islands on Key Largo Limestone are very similar to the Biscayne N.P. hammock forests. These forests, however, are lower in stature and productivity than the northern Florida Keys forests (Ross et al 1992). Very little if any of

the coastal tropical forests have escaped human disturbance and all have been, and continue to be susceptible to, damage by hurricanes. As late as the 1970s, for example, Elliott Key, the largest islands in Biscayne N.P. was subjected to severe damage by clearing for road construction and agriculture undertakings of varying success have affected many of the forests throughout its U.S. distribution. The Biscayne N.P. hammocks provide essential habitat for the buccaneer palm (*Pseudophoenix sargentii*), the semaphore prickly pear cactus (*Opuntia corallicola*), both rare plant species, the Schaus's swallowtail, a federally endangered butterfly, and the state endangered eastern indigo snake.

Tropical Hardwood Hammocks: Community Extent

The land area of Biscayne N.P. is about 1770 ha, or about 2.5% of the entire park area (NPS 1995). The land area includes the mainland portion which, besides developed areas, is mostly mangrove forest, and brackish wetlands, as well as the islands. The island forests occupy considerably less area than the mainland terrestrial communities. Stalter et al (1999) suggest that the aggregate hammock area in the park is 40.5 ha.

Tropical Hardwood Hammocks: Community Composition

Although the Upper Keys forests resemble those of the mainland hammocks such as in Long Pine Key in Everglades National Park, of the 35 species occurring on 3 or more plots in 23 northern Key Largo sites, 37% are principally or entirely coastal in distribution, and do not occur on Long Pine Key (Table 4). The coastal contingent includes some of the common tree species such as *Piscidia piscipula*, and *Pithecellobium keyense*, but mostly species of secondary importance like *P. unguis-cati*, *Exostema caribaeum*, and *Reynosa septentrionalis*. The coastal species are well distributed among stands of differing ages, and not concentrated among older or younger stands (Table 5). For the most part the most important species like *Bursera simaruba*, *Eugenia axillaris*, *Metopium toxiferum* and *Coccoloba diversifolia*, also are important species on Long Pine Key.

Stand Age	Species	Opt/Tol. n	Canopy Position/ Leaf Phenology	LPK
<50 yr	<i>Solanum bahamense</i>	14/-	1 C	N
	<i>Guettarda scabra</i>	38/27	7 S	Y
	<i>Bourreria ovata</i>	43/30	10 S/D	N
	<i>Lysiloma latisiliqua</i>	47/22	10 C/D	Y
	<i>G. elliptica</i>	46/35	17 S/D	Y
50-75 yr	<i>Swietenia mahogani</i>	55/22	16 C/D	Y
	<i>Ficus</i> spp (2)	56/21	15 C/D	Y
	<i>Sideroxylon salicifolia</i>	57/22	19 M/E	Y
	<i>Pithecellobium keyense</i>	57/18	12 S/E	N
	<i>Ardisia escallonioides</i>	58/24	19 S/E	Y
	<i>Metopium toxiferum</i>	58/18	23 C/D	Y
	<i>Piscidia piscipula</i>	60/22	22 C/D	N
	<i>Pithecellobium unguis-cati</i>	60/-	1 S/E	N
	<i>Zanthoxylum fagara</i>	60/29	9 S/E	Y
	<i>Bursera simaruba</i>	61/25	22 C/E	Y
	<i>Eugenia axillaris</i>	62/26	23 S/E	Y
	<i>Exostema caribaeum</i>	63/8	6 M/E	N
	<i>Reynosia septentrionalis</i>	63/6	4 S/E	N
	<i>Guapira discolor</i>	65/27	9 C/E	Y
	<i>Eugenia foetida</i>	65/9	10 S/E	N*
	<i>Canella winterana</i>	67/20	4 S/E	N
	<i>Coccoloba diversifolia</i>	71/26	23 M/E	Y
	<i>Ximenia americana</i>	73/23	4 S/E	Y
>75 yr	<i>Colubrina elliptica</i>	77/24	6 M/E	N
	<i>Amyris elemifera</i>	78/23	11 S/E	N
	<i>Gymnanthes lucida</i>	79/26	21 S/E	Y
	<i>Nectandra coriacea</i>	83/28	8 S/E	Y
	<i>Krugiodendron ferreum</i>	84/20	15 M/E	Y
	<i>Exothea paniculata</i>	84/26	4 C/E	Y
	<i>Eugenia confusa</i>	85/28	3 M/E	N
	<i>Sideroxylon foetidissimum</i>	86/20	4 C/E	Y
	<i>Drypetes laterifolia</i>	87/18	5 S/E	Y
	<i>D. diversifolia</i>	96/16	7 M/E	N
	<i>Calypttranthes pallens</i>	96/15	10 S/E	Y
	<i>Simarouba glauca</i>	100/6	4 M/E	Y

Table 4. Successional age optima of 35 tree species found on 23 hammock sites on Key Largo. Species optima (opt) are abundance-weighted means of occurrences in stands of differing age and tolerance (tol) is the weighted standard deviation. n is the number of sites. Methodology is that of Birks et al (1992). Canopy position is denoted by C (upper canopy), M (mid-level) and S (subcanopy). Leaf phenology is either E (evergreen) or D (deciduous). LPK refers to whether or not the species also occurs on Long Pine Key in Everglades National Park. * = rare on LPK. Nomenclature follows Wunderlin (1998). Source: Ross et al (1998) and Armentano et al (2002).

Tropical Hardwood Hammocks: Rare Plant Species—Semaphore Prickly-Pear Cactus

In 2001, it was discovered that the rare semaphore prickly-pear cactus, *Opuntia corallicola*, a species that exists only in South Florida, occurs within the park. The cactus is critically imperiled at the global scale (G1) and within the state of Florida (S1), and is a candidate for the federal endangered species list (NatureServe 2005). Botanists found 570 of the plants in 2001 on an island in southern Biscayne Bay, a number that is more than 80 times greater than the other known population. Major threats are hurricanes and *Cactoblastis cactorum*, a South American moth which is expanding its range in Florida. The other population is in an area subject to development pressure, even though the population occurs within a preserve (Torchwood Key in the lower Florida Keys) (Gann et al. 2002). Another population on Big Pine Key was extirpated in the 1960s. Thus, Biscayne N.P. has a critical role to play in the conservation of this species.

The species' occurrence within a national park should protect it against habitat destruction and, to a lesser extent, poaching, but the cactus still is potentially vulnerable to the exotic moth, *Cactoblastis cactorum*, that is expanding its range in the U.S. and has become a genuine threat to cacti of the genus *Opuntia* in the Florida Keys and elsewhere in Florida (Stiling and Moon 2001). Larvae of the moth live and feed within the cactus pads making them invulnerable to traditional control methods. Hand removal of infected pads has been the main approach to reducing the problem. Although this was practical in the small lower Keys population through the dedication of volunteers, it would be much more difficult in the larger population. Fortunately, although the moth has reached the Big Pine Key population, it had not, as of 2001, been detected in the Biscayne N.P. population. Given that the pest is already in the Dry Tortugas (Armentano, personal observation) and on Cape Sable in Everglades National Park, it probably will appear in Biscayne N.P. Based on the effects of Hurricane Georges, a relatively weak storm, which crossed the Florida Keys in 1998, hurricanes also are a threat to the cactus. The stems of a large proportion of the Big Pine Key population were broken and stripped of pads by the force of the winds from Georges.

Tropical Hardwood Hammocks: Rare Plant Species—Sargent's Palm

The Sargent's Palm (*Pseudophoenix sargentii*), recognized as an endangered species by the state of Florida (Coile and Garland 2003), also occurs in Biscayne National Park. Considered to be the rarest palm native to Florida, it is critically imperiled within the state (NatureServe 2005). It is a drought-tolerant coastal species growing on alkaline sand and shell material with some organic matter (Lippincott 1992). It was initially found on Elliott Key and Sands Key within Biscayne N.P. and on Long Key in the Florida Keys, but collectors in the late 1800's began to harvest them for ornamental use. By 1920, it was considered nearly extirpated on Elliott Key. A single tree remained on Sands Key in 1922 (Lippincott 1992). A thorough survey in 1958 turned up 28 *P. sargentii* on Elliott Key, apparently progeny of the palms seen in the 1920s, and three on Long Key. In 1991, only 50 *P. sargentii* were found on Elliott Key, but the species was apparently extirpated from Long Key (Lippincott 1992). Many were also damaged in Hurricane Andrew. Today there are about 16 plants on Elliott and 123 on Long Key thanks to efforts undertaken to reintroduce palms on three of the original islands.

Threats to *P. sargentii* include: saltwater flooding (although the species is tolerant of some exposure to salt); hurricanes (Hurricane Andrew caused some losses (Fairchild Tropical Garden, n.d.); and exotic plants. In particular, *Colubrina asiatica*, (latherleaf), a problematic invasive species in Biscayne N.P., has been known to suppress palm seedlings in the Keys. Herbivory, possibly by rodents or "marsh rabbits", also occurs and has led to managers outfitting some palms with protective cages.

Species	Life Form	BNP Status	USA Status
<i>Nevrodium lanceolatum</i>	Epiphytic fern	extirpated	extirpated
<i>Salvia micrantha</i>	Terrestrial forb	extirpated	extirpated
<i>Spiranthes polyantha</i>	Terrestrial orchid	extirpated	extirpated
<i>Aristolochia pentandra</i>	Unconfirmed sighting	1 station-Elliott Key	No other sites
<i>Phoradendron rubrum</i>	hemiparasite		
<i>Caesalpinia major</i>	Leguminous liana	1 station-Elliott Key	2 other sites
<i>Guaiacum sanctum</i>	Canopy tree	On 2,maybe 3 keys	9 other sites
<i>Rhynchosia swartzii</i>	Leguminous vine	On Elliott Key	5 other areas
<i>Eugenia rhombea</i>	Small Tree	On 2 keys	6 other areas
<i>Vallesia antillana</i>	Shrub	Total of 3 plants	

Table 5. Vascular plant species of special interest that occur, now or historically, on the islands of Biscayne National Park. *Pseudophoenix sargentii* and *Opuntia corallicula* are discussed in the text. Biscayne N.P. Status refers to the present known occurrence of the species in Biscayne National Park and USA Status refers to the present known occurrence of the species in the United States. Source: Adapted from Gann et al. 2002.

Tropical Hardwood Hammock: Rare Plant Species—Other Rare Plants

Other rare species are summarized in Table 5. All of these are considered as “critically imperiled” in south Florida by Gann et al (2002); most are also ranked as critically imperiled within the state of Florida (NatureServe 2005). In Gann et al. (2002), “critically imperiled” is defined as species that occur in five or fewer locations or comprise fewer than 1000 individuals. Species may also be critically imperiled because of extreme vulnerability to extinction due to some factor. The list provides some insight into the conservation problems and opportunities before Biscayne N.P.’s natural resource managers. Gann et al (2002) recommend consideration of reintroduction of the three extirpated species. Some knowledge of habitat requirements, demography and life history would increase the probability of success.

The ribbon fern (*N. lanceolatum*), for example, was found at most only a few times, or perhaps only once on Old Rhodes Key many decades ago. It is currently extirpated within Biscayne N.P. and the state of Florida (NatureServe 2005). No information is available on habitat or biology of the plant in the United States. To determine whether suitable habitat for this species still exists on Old Rhodes Key or any other key, information is needed on habitat characteristics in healthy populations found outside the U.S. and in potential reintroduction sites on Old Rhodes Key. The site for *A. pentandra* is a coastal berm on Elliott Key. Sites of this kind are intrinsically unstable due to storms and in addition are often colonized by latherleaf and other exotics. More information is needed on whether the species can be augmented by establishing them in less vulnerable habitat.

P. arboretum, the mahogany mistletoe, is dependent on large trees of the mahogany, *Swietenia mahogany*. Also mistletoes depend on certain bird species for propagule dispersal, although it is possible for man to artificially disperse them to appropriate hosts. A management question that needs to be addressed is whether these bird species inhabit the Biscayne N.P. islands that support appropriate mahogany populations.

C. major is a large thorny leguminous liana that is easily confused with the common *C. bonduc*, grey nickerbean. Also the nomenclature of the taxa is inconsistently presented leading to possible misinterpretation of the status of the rare species. Its habitat is subject to expansion of aggressive exotic plant species like latherleaf and *Thespesia populnea*, and to damage by storms. *E. rhombea* is critically imperiled in the wild but is planted as an ornamental. This may or may not suggest that reintroduction would likely be successful. *G. sanctum*, *lignumvitae*, is a tree of special interest because of appearance, wood quality and history. It also grows very slowly. An exceptional stand has existed on Totten Key and may include the largest known individual tree in the U.S. (Duever et al., 1982). Its response to Hurricane Andrew has not been described. Given its occurrence at nine other sites, a public-private cooperative program of monitoring of populations and habitat, determination of U.S. status and range-wide consideration of reintroductions is desirable.

R. swartzii is a herbaceous vine that is easily overlooked, and may be confused with other small, trifoliate vines, of which there are at least a half-dozen potentially sharing habitat. The U.S. populations are almost entirely confined to Elliot Key and nearby north Key Largo, suggesting vulnerability to large destructive hurricanes. It is a hammock-edge species susceptible to exotics, herbicides and trimming according to Gann et al (2002). Only three individuals of *V. antillana* are known for Biscayne N.P. A population in Everglades National Park may have been extirpated by a hurricane, which must be considered as a distinct future possibility in Biscayne N.P. Further surveying is needed to determine the true population size. If the number is not much larger than three, the species should be considered at great risk of extirpation and the park should consider reintroduction after determination of habitat requirements.

Tropical Hardwood Hammocks: Rare Animal Species

The animal species of special interest in Biscayne N.P. are primarily aquatic, such as the West Indian manatee (*Trichechus manatus*) and several species of sea turtle. However, the park's hammocks are habitat for Schaus's swallowtail (*Papilio aristodemus ponceanus*) which is federally endangered and critically imperiled at the global scale (T1) and within Florida (S1) (NatureServe 2005). Schaus's swallowtail is dependent on trees of the citrus family (Rutaceae) as a host plant for its larvae. Two native rutaceous species that are common in Biscayne N.P. hammocks are *Amyris elemifera* and *Zanthoxylon fagara* (Loftus and Kushlan, 1984). The swallowtail has not been seen on the Florida mainland since 1924. Habitat destruction, mosquito spraying and hurricanes are believed to be the main limiting factors. Presumably the first two of these are under control in the park. Natural or human forces that affect the host plants directly and indirectly (by damaging host plants) threaten the butterfly.

In 1992, Hurricane Andrew reduced the known population of Schaus's swallowtail to only 70 adults, but fortunately, eggs were collected prior to the storm. These were successfully reared and then reintroduced successfully in Florida Keys habitats (Daniels and Emmel 2004). These efforts have increased the population size of the species. In addition, beginning in 2002, new butterfly habitat is being established through planting of host plants in 20 Florida Key hammock locations suitable for the butterfly (NWF 2005). By expanding the number of egg-laying sites, it is hoped that the species will occur in a sufficiently wide area that a destructive hurricane or fire in Biscayne N.P. will not threaten the species as a whole (Daniels and Emmel 2004).

Hammock within Biscayne N.P. probably also provide habitat for the Eastern Indigo Snake (*Drymarchon corais couperi*) which is federally threatened and vulnerable at the global scale (G3) and within Florida (S3) (NatureServe 2005). This species is considered as "casual" by the National Park Service (NPS 1999) signifying that it may only be occasionally encountered and may not have a stable population in the park. Although the indigo snake is restricted to Key Largo and Biscayne N.P. keys in the upper keys, it also occurs on the mainland in terrestrial habitats such as in Long Pine Key and there is a disjunct population in the lower keys (Steiner et al 1983). Its range is given as north to southeast Georgia and west to Alabama although it may be extirpated in Alabama (Steiner et al 1983). Hurricanes and fires would have to be considered as threats within the park although only the former is frequent. Exploitation by the pet trade and human destruction of habitat are problems elsewhere but presumably not in the park. It is limited by appropriate habitat for denning sites.

Tropical Hardwood Hammocks: Soils

Elliott and the keys to the south occur on Key Largo limestone, formed by coral reefs in the Pleistocene as was most of the Florida Keys. Soils in the dry upland tropical forests of the Keys, are organic, yet well-drained, distinguishing them from the typical organic soils of wetlands (Ross et al. 2003). The soils form directly on the limestone bedrock. Because of its high permeability, Key Largo Limestone does not retain freshwater in a subsurface lens as does the Miami Limestone which prevails in most of the Dade County uplands and the Lower Keys (Halley et al 1997). The ecological importance, if any, of this substrate difference is not well known, but drought is a recognized environmental stress occurring in south Florida upland forests. Hammock species appear to be limited to obtaining water from soils rather than being able to tap moisture trapped in the porous limestone as can slash pine (Ish-Shalom-Gordon et al., 1992). The soil volume available to the upland hardwood forests is very limited in terms of moisture and nutrient availability and to a considerable extent, species sort out along a gradient of soil volume, across the terrestrial habitats of the Keys (Ross et al. 1992).

Soils in upland forests within the keys are shallow, generally <20 cm and overlain by a thin litter layer <5cm deep (Ross et al. 2003). Nutrients are tightly held in the soils and are promptly and efficiently recycled through the shallow root systems and litterfall. Despite the organic nature of the soil, organic matter is decomposed rapidly (turnover time <2 yr), but is rapidly replaced by fresh material (Ross et al. 20003). Less than half of the litterfall winds up as soil carbon (Ross et al 2003).

The location of the tropical hammocks on low elevations close to the sea suggests that some tolerance of salinity is an intrinsic feature of the vegetation. Although this possibility has not been explicitly investigated, Ross et al (2003) found that although primary productivity correlates inversely with soil salinity in Keys upland hardwood forests, many of these stands thrive where ground water salinity is moderately saline, a common situation where the highly permeable Key Largo limestone prevails.

Tropical Hardwood Hammocks: Natural Disturbances

Natural forces influence ecosystems within the Biscayne N.P. keys. Hurricanes play an important role, though freezes seem to be less damaging to islands within the park as they are on the mainland (Loftus and Kushlan 1984). The southern eyewall of Hurricane Andrew passed over Totten and Old Rhodes Keys, and the eye passed over Elliott Key (Figure 29). Storm surges were generally only about 2 m high but this was enough to inundate most of the Biscayne N.P. islands. Effects of the storm on the Biscayne N.P. islands were not quantified soon after the storm but mortality in two study sites in the nearby coastal mangroves following the storm ranged from 85% in red mangrove to 59% in white mangrove (Baldwin et al. 1995). In a coastal hammock just north of the Biscayne N.P. boundary, 52% of the tree had boles broken and 31% were uprooted (Horvitz et al. 1995). These figures are very high, much higher than seen in studies of other south Florida hardwood stands, but are not commensurate with mortality.

As elsewhere in south Florida and the Caribbean, the mean return time of hurricanes, estimated at 27 years in the Florida Keys (Ross et al. 1998), is short enough that older hardwood trees must have experienced at least several strong storms. This suggests that the forests have evolved some adaptations to frequent, strong disturbances. Ross et al (1998) studied hardwood forest recovery and successional status following Hurricane Andrew, focusing on Totten and Old Rhodes Keys which were disturbed less by past human activities than was Elliott Key. Mean canopy heights were 5.8 m and 6.0 m in Totten and Old Rhodes respectively. Light penetration was greater in the more damaged portions of the stands each of which contained areas ranging from light to heavily damaged by the storm. Stand composition data suggest that the Totten Key stand had been more recently disturbed than the one on Old Rhodes.

The mean inferred successional age (MISA) was 114 yr in Totten Key and 81 yr in Old Rhodes Key. MISA is calculated from a weighted average regression of abundance of a given species at sampling sites for which time since disturbance is known from aerial photographs and ancillary information. A difference of about 30 yr in MISA between the islands extended across differing categories of storm disturbance (Figure 30). Greater weighting is given in proportion to the abundance at a given site. The calculation produces an optimum and a tolerance for each species, an outcome that can be obtained for any group of species in relation to an environmental variable (Birks et al 1992). Ross et al (1998) interpret the MISAs of the two

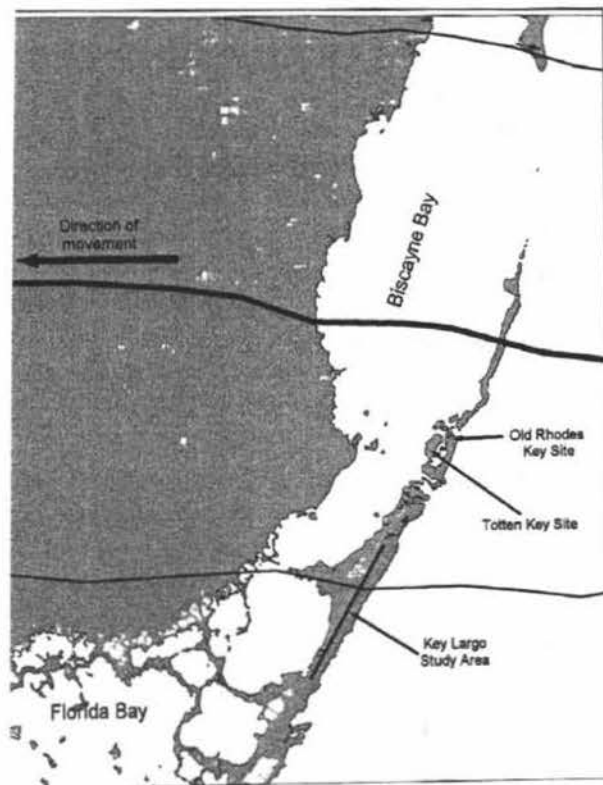


Figure 29. Track of Hurricane Andrew across Biscayne National Park islands. Shown are the central storm track plus the extent of the northern and southern eyewalls. The eye of the storm passed over Elliott Key while Old Rhodes and Totten Keys were within the southern eyewall. Source: Ross et al (1998).

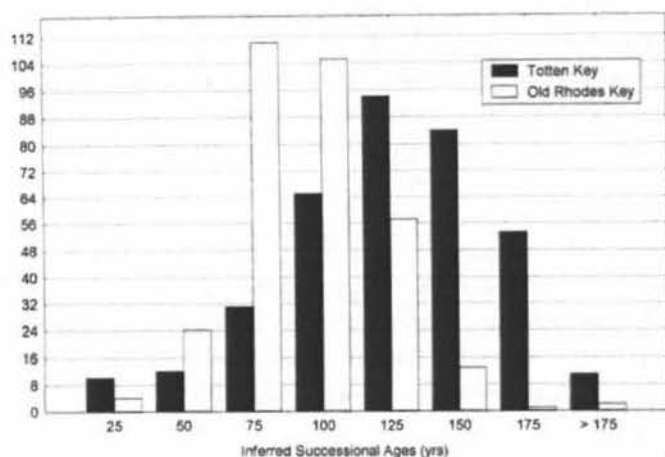


Figure 30. Frequency distribution of inferred successional ages in Totten Key and Old Rhodes Key hammocks in 1997, five years following Hurricane Andrew. Number of sample plots is on the x axis. Source: Ross et al. (1998).

islands as indicating differences in disturbance history. Old Rhodes Key is apparently mostly second-growth, possibly following agricultural disturbance, or has responded to fire or some other stand-initiating disturbance in the last century. Totten Key, where some MISA estimates exceed 200 yr, was probably never cleared for agriculture, and was unaffected by severe disturbance for at least several decades longer than Old Rhodes.

Tropical Hardwood Hammocks: Natural Disturbances & Succession

From data from these and other Keys sites, tree species can be characterized in terms of their successional status. Of the forty-two species encountered in twenty-three hammock sites in northern Key Largo, a few km south of the southern boundary of Biscayne N.P., , thirty-five could be given successional age optima (Table 5). Early successional species like *Bourerria ovata* and *Guettarda scabra* (optimum <50 yr) are primarily deciduous with relatively wide tolerances enabling them to establish rapidly after disturbance and to persist for a few decades in the recovering forest. Late successional trees like *Drypetes diversifolia*, *Calypttranthes pallens* and *Krugiodendron ferreum* (optima >75 yr) are primarily evergreen and unable to colonize stands recently opened by storms or fires except in small gaps. The torchwood, *Amyris elemifera*, one of the two native host plants of the endangered Schaus's swallowtail butterfly, is a late successional tree common on Elliott Key. Often however the most abundant and, or largest trees are those of intermediate optima (e.g., *Bursera simaruba* and mahogany, *Swietenia mahogani*) that may establish relatively early following disturbance yet live indefinitely as canopy emergents (Armentano et al 2002, Ross et al 1998). The second host species of the Schaus's swallowtail, *Zanthoxylum fagara*, is a common species of the intermediate stand-age category.

The high frequency of disturbances in the Upper Keys forests seems to have produced stands with patches differing in structure as a result of time since major disturbance, local differences in disturbance intensity, and varying site factors (Ross et al. 1998). On Totten Key, these patches were expressed finely, at a scale of 5 to 15 m. In this regime of frequent disturbance and adaptable species, change in composition is more conservative across time than is forest structure, given the tendency for relatively low mortality of hammock trees due to strong storms and a high capacity for regrowth.

Heavily damaged hardwood patches with larger canopy openings on Totten Key had MISA's averaged for the species present, below 60 yrs. These larger openings are most favorable for recruitment by early successional species. Plots with fewer heavily damaged sites and smaller openings had less difference in composition between new recruits and canopy. The Ross et al (1998) study missed prompt stand responses to the storm

because it was conducted three years later. But from other work it is known that post-disturbance recovery of leaf area is rapid (partially infilled within a few months, fully expressed in about a year) in sub-tropical forests (Armentano et al 1995). In all but the most disturbed sites, this quick response quickly closes canopies, limiting opportunity for growth and survival of new seedling recruits. In addition, rapid and in places, rampant, vine growth rapidly reduces light penetration reducing seedling recruitment opportunities.

Tropical Hardwood Hammocks: Anthropogenic Disturbance

Since the late 19th century and continuing until establishment of the Biscayne National Monument in 1968, humans have altered the forest habitats on the Biscayne N.P. islands, particularly Elliott Key. For example, a pineapple plantation was already established by 1886 and much of the hammock was cut and burned for pineapple and lime farms by turn of the 20th century (Lippincott 1992, Small 1922). By 1920, Small (1922) reported that farming and collecting drove *Pseudophoenix sargentii*, a rare palm (discussed above) to near extirpation on Elliott Key. Elliott Key and Sand Key were slated for residential and highway developments in 1960 when they still were privately owned. In 1968, an existing road down the middle of Elliott Key was widened to 125' by bulldozer, removing 49 ha of hammock (including a *Pseudophoenix* grove).

Tropical Hardwood Hammocks: Recommendations

The recommended steps needed to fully discharge the responsibility of Biscayne N.P. with respect to the rare species within tropical hardwood hammocks discussed include: 1) full surveys of extant populations, 2) adoption of a population monitoring program that encompasses the many scientific advancements that have been presented in scientific journals of the last decade, 3) effective control of invasive exotic species, and 4) consideration of reintroduction or augmentation of imperiled species, but only following adequate study of the species' habitat requirements.

Sustainability of funding is critical given that most of these actions will take years. The park and agency needs to energetically advance the concept that these actions are part of ecosystem restoration even if hydrological manipulations are not involved. The concept of ecosystem restoration has been captured by advocates of engineering redesign and consequently, ecological objectives not conceptually linked in a direct cause-effect relationship to these traditional approaches become marginalized and consequently unfunded.

With respect to tropical hardwood forests, similar needs exist, but the sparse literature clarifies that at this point, the agency lacks a basic understanding of what tropical hardwood resources (in a stewardship context) exist on the islands of Biscayne N.P. Basic ecological surveys are needed that encompass all the islands and their terrestrial ecosystems, including intertidal and strand systems. A series of long-term plots is needed which will enable scientists to assess the effects of storms including winter storms upon plant and animal components.

Islands have special ecological and biogeographical features and vulnerabilities. For example, tropical storms can modify island configurations and cross-sections, thus fundamentally influencing local ecosystems. Substrates are inherently unstable. Local populations often "wink" in and out (exaggerated role of stochastic events sometimes leading to local extinctions), even without human intervention. This has happened often in the Dry Tortugas, but there is no literature on the extent to which the Biscayne N.P. islands operate as islands rather than as "mainland fragments". Therefore, ecological surveys are needed not only of the various biotic elements (at the population and stand level) but also of the abiotic processes whose influences are intensified on islands.

Marine and Estuarine Representative Species

Marine Fishes

Historical Assessments

Smith's (1896) evaluation of Biscayne Bay—in his capacity as Assistant to the Commissioner on Fish and Fisheries—is the only report conducted prior to the construction of the coastal canal system. He listed a total of 95 taxa of fishes that occurred in the Bay providing detailed annotations for a number of species. Of particular interest is the presence of several species of drum (*Sciaenidae*) which were common or abundant in the more estuarine conditions that occurred within the Bay more than a century ago. Smith (1896) referred to red drum (*Sciaenops ocellatus*) as "Abundant at all seasons". However, only a couple of the eight species of drum that Smith (1896) listed have been reported as common or abundant in recent surveys (i.e. during the last 30 years).

Voss et al. (1969) wrote the first comprehensive synopsis of the geology, hydrology, and biota of Biscayne National Monument. They listed a total of 496 species of fishes and grouped them according to the primary habitats they utilize. This very long species list was formed by combining those of all prior studies. The major shortcoming of this study, for our purposes, is that their list lacked species-specific information concerning relative abundances so there is no indication of which species were rare versus common in the park.

de Sylva (1976) reviewed the current state of knowledge of the fishes of Biscayne Bay as it was known in the early 1970s and noted the general lack of quantitative data on Biscayne Bay's fishes and the fisheries they supported. He suggested that a number of studies (e.g. Roessler 1965, Tabb and Kenny 1969; Bader and Roessler 1971; Low 1973) conducted before and after the Voss et al. (1969) report was published were too limited in scope to be representative of the ichthyofauna inhabiting Biscayne Bay as a whole. In addition, de Sylva (1976) added 17 species of fishes to the list previously compiled by Voss et al. (1969) for a total of 512 species.

Campos (1985), using the database produced by Berkeley and Campos (1984), examined the seasonal variation in juvenile fishes from the southern portion of Biscayne Bay in relation to a number of environmental and biological indicator variables. Species composition and spatial variability was shown to remain relatively constant among seasons and Campos (1985) suggested that the density of seagrass blades and salinity were the most important characteristics of fish habitat. Campos' (1985) work supports the de Sylva (1976) contention that the fishes of Biscayne Bay were largely indicative of a lagoonal rather than an estuarine system.

Ault et al. (2001) performed an assessment of the fishery resources of Biscayne N.P. based on data obtained from three principal sources of previously conducted studies: 1) recreational creel surveys conducted by Biscayne N.P., 2) reef-fish visual census conducted by NOAA/Univ. of Miami, and 3) rollerframe trawl surveys conducted by the Univ. of Miami. A total of 325 fish and macroinvertebrate species were found to occur on Biscayne N.P. after compilation of these data sources.

Mangrove Habitats

Our current understanding of the importance and degree to which mangrove prop-root habitats serve as nursery areas for fishes is limited by the extreme difficulty involved with sampling these habitats (Serafy et al. 2003). Indeed, a number of species of fishes that occur within the Bay as juveniles and on the offshore reefs as adults (e.g. gray snapper) are thought to make ontogenetic migrations from the Bay to the reef through mangrove habitats (Sedberry and Carter, 1993; Ogden, 1997; Ley and McIvor 2002). However, actual migrations through such habitat corridors have never been actually demonstrated (Serafy et al. 2003).

Quantitative assessment of the use of mangrove prop-root habitats by fishes has only recently begun (e.g. Thayer et al. 1987; Laegdsgaard and Johnson, 1995; Ley et al. 1999; Lorenz, 1999). However, most previous studies have focused on temporal patterns on small spatial scales instead of a more ecologically meaningful approach examining the variability of diversity, abundance, and size-structure over larger spatial scales (e.g. Thayer et al. 1987; Rooker and Dennis, 1991; Laroche et al. 1997; Lin and Shao, 1999).

Serafy et al. (2003) quantified the fishes that utilize Biscayne Bay's mangrove-lined shorelines. They restricted their work to the southern portion of the Bay as mangrove-lined shorelines no longer exist in northern Biscayne Bay, except at its northernmost extremes. Visual censuses were conducted comparing leeward keys versus mainland shoreline among seasons (wet and dry). They observed very high densities of juvenile and subadult gray snapper, schoolmaster snapper (*Lutjanus apodus*), several grunt species (Haemulidae) and great barracuda (*Sphyraena barracuda*). They concluded that mangrove-lined shorelines serve as shelter for fishes that have outgrown the protection of seagrass beds but are not yet mature enough to migrate to offshore reefs.

Anthropogenic Disturbances

Anthropogenic Disturbances: Changes in Hydrology and Salinity

The changes to the watershed that have occurred as a result of the canalization of water and construction of oceanic passes in the areas surrounding Biscayne N.P. has altered the salinity of area and has resulted in a loss of the brackish habitats that previously existed. This has led to the loss of estuarine fishes such as the Red Drum that were apparently dependent on the existence of oyster reef that declined after these alterations in the salinity regime (de Sylva, 1976). de Sylva (1976) stated that "Historically, the northwestern shores of the bay were more estuarine, but have become more saline, whereas the southwestern part of the bay has become more brackish". He stated that the Bay is no longer an estuary and so the fishes now present resemble more a stenotypic tropical fish assemblage than an estuarine one. Furthermore, Tabb et al. (1974) stated that with the exception of those in Everglades National Park, south Florida's marshes "...have been converted into part of the marine continuum with short intrusions, often very abrupt and intense, of freshwater influence".

Fish assemblages currently in Biscayne Bay represent those that would occur in a body of water that has changed from estuary to freshwater-pulsed lagoon (Tabb et al. 1974, de Sylva 1976, Campos 1985, Serafy et al. 1997). Serafy et al. (1997) suggested abrupt salinity fluctuations associated with freshwater canal discharge are a source of potential stress on fish communities and generally tend to lower diversity as they are especially stressful for estuarine species. Serafy et al. (1997) used the same methodological approach as Berkeley and Campos (1984) and Campos (1985) for their examination of the juvenile fishes inhabiting Biscayne Bay. They found a general pattern of reduced species richness and lower abundance for several fish species exposed to freshwater canal discharges. Laboratory-based salinity stress trials on field-collected juveniles provided support for a physiological basis for these patterns (Serafy et al. 1997; Harrington and

Serafy 1998). They suggested further laboratory studies to determine the extent to which abrupt salinity changes can affect reproduction, development, feeding, growth, and ability to avoid predators. Ault et al.'s (2001) analysis of rollerframe trawl and reef-fish visual census survey data indicated that the western edge of Biscayne N.P., an area associated with high levels of freshwater canal discharge, was characterized by low species diversity. Levels of species diversity, however, increased along the same west-to-east gradient as salinity, suggesting the major role this environmental factor plays in regulating fish community structure.

Biscayne N.P. has been directly and indirectly subjected to a significant quantity of physical alterations which, in turn, have greatly impacted the quality of fish habitats producing a deleterious effect on fishery resources. A decrease in water quality and the loss of habitat has resulted from urban construction and dredging to support the growing shipping and cruise line fleets of Miami. In addition, breach re-nourishment projects supporting the tourism industry have resulted in an increase in turbidity, siltation, and destruction of essential fish habitat (Lindeman and Snyder, 1999).

Anthropogenic Disturbances: Fishing

Voss et al. (1969) discussed the inshore commercial fishing activities within Biscayne National Monument that may have affected the Bay's fish assemblages at the time. They concluded that the loss of fish as bycatch of the shrimp fishery was very low and recommended that the bait shrimp fishery be allowed to continue. They also believed that the mullet gill net fishery was not detrimental to the Monument and recommended that it be allowed to continue as well.

Berkeley and Campos (1984) published the first and only Bay-wide assessment of the fisheries occurring within Biscayne Bay, which was based upon a creel census sampling program, a fishery-independent rollerframe trawl survey, and a commercial harvest monitoring program. The creel census program provided data on 138 fish taxa. The three most important fish species harvested by recreational anglers for food (not bait) were, in descending order, gray snapper (*Lutjanus griseus*), white grunt (*Haemulon plumieri*) and spotted seatrout (*Cynoscion nebulosus*), which together accounted for approximately 34% of the total recreational finfish harvest.

Based on the data generated by the Berkeley and Campos (1984) study, Berkeley et al. (1985) did an assessment of the Biscayne Bay bait shrimp fishery. They included a list of juvenile gamefishes captured and discarded as bycatch of the shrimp fishery which included 27 recreationally important fishes. Gray snapper (*Lutjanus griseus*) were listed among the five species of fishes that dominated the bait shrimp bycatch. Berkeley et al. (1985) were careful to state that juvenile fish mortality due to capture and handling was generally unknown but suggested that "a high percentage" of gray snapper were likely to survive but that mortality rates for other species such as yellowtail snapper, spotted seatrout and hogfish were probably much higher.

Biscayne Bay's live bait shrimp fleet has been shown to damage hardbottom fish habitat. Berkeley et al. (1985) estimated that approximately 20% Biscayne Bay's bottom is swept four times annually by the commercial bait shrimp fleet. Ault et al. (1997b) detected no significant damage to seagrass habitats but obvious damage to soft corals and sponges. Investigator-controlled trawling increased damage levels to the soft corals and sponges by 12 to 38%. Tilmant (1982) found that 80% of corals, 50% of sponges and 38% of gorgonians were crushed, uprooted, turned over or otherwise damaged by the passage of shrimp roller trawls in the southern portion of Biscayne Bay. This damage was still evident at least 11 months after the passage of

the trawl. Algae were also affected, especially the calcareous species but recovery of these appeared to be faster than that of corals, gorgonians and sponges

Using data for 35 reef fish species from three families (Serranidae, Lutjanidae, and Haemulidae) collected in Biscayne N.P., Ault et al. 2001 found that populations of these species were under heavy fishing pressure. This finding is illustrated by the fact that the mean length of legal sized fish is usually at or near the minimum legal catch size. More importantly, though, was the suggestion that for 27 of the 35 species, where sufficient data was available for detailed examination, were found to be either growth and/or recruitment overfished. The recreational creel survey data also indicated that, at least for some species, a high proportion of the recreational catch was under the legal catch size.

In addition, Ault et al. (2001) found that for 13 of the 35 species examined, the size of sexual maturity was greater than the minimum legal catch size (e.g. spotted seatrout). They suggested such fishery management policies place individuals under fishing pressure before they can contribute to replenishment of the population. Ault et al. (2001), therefore, recommended an increase in the minimum legal catch size for species in which it is currently less than the size at sexual maturity in order to mitigate the level of overfishing.

Anthropogenic Disturbances: Deformities

An apparent prevalence of individuals with external abnormalities has been previously reported for fishes inhabiting the Bay portion of Biscayne N.P. (Skinner and Kandrashoff 1988; Browder et al. 1993; Gassman et al. 1994; SFWMD 1995; Corrales et al. 2000). Experimental fishing and trawl surveys showed that the majority of the observed deformities were characterized by stunted or missing fin rays, scale abnormalities, depressions in the dorsal profile, missing or stunted fin rays, and jaw deformities (Skinner and Kandrashoff 1988; Browder et al. 1993; Corrales et al. 2000). Gray snapper were one of three species in which these abnormalities were found to be particularly evident.

A significant relationship was found to occur among the prevalence of fish deformities and the historical concentrations of aliphatic hydrocarbons occurring in the sediments of Biscayne Bay (Gassman et al. 1994). Aliphatic hydrocarbons are a pollutant produced and introduced into bodies of water mostly as a result of anthropogenic activities such as hydrocarbon production, transportation, and farming. Gassman et al. (1994) emphasized the need for more recent data on the source and distribution of contaminants in order to determine the cause of and solution to deformities found in fishes inhabiting the Bay.

Little attention has been given to determining whether mechanical damage resulting from fishing activities either causes or contributes to the prevalence of abnormalities of fishes in Biscayne Bay. Laboratory experiments conducted by Corrales et al. (2000) suggested that scale disorientation was not caused by mechanical damage alone. It is still unclear, however, the extent to which the observed fin ray and jaw deformities were a direct result from previous contact with rollerframe trawl nets and hook-and-line fishing gear. Physical injury to fish mouth parts and fin ray elements are to be routinely expected with hook-and-line fishing and rollerframe trawl catches, respectively (Gjernes et al. 1993; Albin and Karpov 1998).

Anthropogenic Disturbances: Exotic species

There have been no quantitative surveys of exotic fresh-water fish species that inhabit either the freshwater creeks and canals that enter Biscayne N.P. or that enter the Bay, though there have been a few qualitative distribution studies (Hogg 1976; Loftus and Kuslan 1987). Serafy et al. (2003) observed a group of six Mayan cichlids, *Cichlasoma urophthalmus*, during one occasion during the dry season along the Bay's mainland shoreline. The Mayan cichlid has the potential to disrupt native aquatic communities, particularly through competition and predation (Courtenay and Robins 1989). Of particular interest, the natural coastal habitats of this fish in the Yucatan are very similar to the Florida Everglades (Loftus 1987). This species has a very high salinity tolerance range (from 0 ppt to 40 ppt) (Martinez-Palacios et al. 1990) making it ideally suited to thrive in South Florida's coastal habitats.

Representative Fish Species

At least 20 of the 73 species in the Snapper-Grouper Fishery Management Plan can use Biscayne Bay as juveniles or adults (Lindeman et al. 2000).

We chose three fish species to represent Biscayne N.P. for this assessment, red grouper (*Epinephelus morio*), red drum (*Sciaenops ocellatus*), and gray snapper (*Lutjanus griseus*). This is an important trio of game fishes in Biscayne N.P. from both a historic (e.g. red drum) and current perspective. Game fishes are of major ecological and economic value in South Florida and rely heavily on nursery grounds located within Biscayne Bay. Much of the use of Florida's National Parks by visitors consists of recreational fishing for these species or diving and snorkeling to see them.

Red grouper, red drum, and gray snapper are uniquely dependent on habitats found within Biscayne N.P. Red grouper and gray snapper adults are generally found outside of the bay within the reef habitats of the eastern part of the park. Their early stages are dependent on the mangrove and seagrass environments within the eastern bay sections of Biscayne N.P. as a nursery and far fewer juveniles occur outside of Biscayne Bay than within its boundaries. In fact, Florida and Biscayne Bays appear to be the primary nursery habitat for gray snapper. Red drum used to be abundant in the areas now within the boundaries of Biscayne N.P. with adults occurring offshore and juveniles in the estuarine waters of the bay. They became rare after changes to the watershed occurred and attempts to restock them in the park have failed. We believe this species is an important indicator of the altered or properly restored state of the habitats within the park.

These three species represent a range of life history strategies and thus are susceptible to different pressures (fishing, environmental, habitat degradation) which makes them good indicators of the effects of fishing pressure, habitat loss, environmental variability and the effects of other stressors within the Park.

Red Grouper - Epinephelus morio

Red Grouper: General description

Red Grouper (Figure 31) occur from Massachusetts to Brazil and are especially abundant in the Gulf of Mexico down to the Yucatan peninsula (Bullock and Smith 1991). In southwest Florida adults are found in deep water below 118 feet and juveniles reside on the shallow (10-59 ft) reefs (FMRI, 2003). Genetic studies have been inconclusive in separating stocks from the Gulf of Mexico and the southeastern Atlantic but they are most probably separate stocks (Zatcoff et al. 2004).

Red Grouper: Habitat

Adults.—Adult red grouper are known to excavate soft bottoms and clear sediment from the top of hard bottom areas and maintain these sites for themselves. These cleared hard bottom areas are then colonized by sessile organisms such as corals, anemones, seagrasses and algae, and this in turn provides habitat for a diverse community of animals including, lobsters,

crabs, shrimp, and other species of fishes (Scanlon 2000; Scanlon 2004; Scanlon et al. 2004). Red grouper have been observed to remove sediment lying over solution holes in the Miami Limestone, and in other areas with soft bottoms, they construct large circular pits about 6m wide and 2 m deep (Scanlon 2004). These excavating and sediment mixing activities are extensive and believed to be an important process in changing the character of large areas of the benthos where these fishes are present. Removal of these fishes probably effects changes to the benthos and may be detrimental to other species by altering or eliminating habitat available to them.

Ault et al.'s (2001) examination of rollerframe trawl and reef-fish visual survey data from studies conducted in Biscayne N.P. indicate that both the juvenile and adult stages of red grouper were absent from the Biscayne Bay, occurring only along the inshore patch and platform margin reef habitats.

Juveniles.—Juvenile red grouper can be found in shallow reef areas but there is little specific information on the habitat preferred by juvenile red grouper (Sluka et al. 1994). The patch reefs in Biscayne N.P. that are densely covered by gorgonians may be especially good habitat for small red groupers (Eklund 2005).

Red Grouper: Life History

Red grouper are monandric protogynous hermaphrodites and begin life as female and transition to male at 7 years of age and after reaching 23 inches in length. Females reach maturity at around 4 years and 17-21 inches (Moe, 1969; Brule et al. 1999). Spawning occurs between January and June with peak spawning occurring from March to May (Johnson et al. 1998). Red grouper are not known to form spawning aggregations as other species of grouper do.

Juveniles are believed to feed on shrimp and other small crustaceans (Bullock and Smith 1991) and adults consume small fish, crabs, shrimp, octopus, squid, and larvae of lobsters (Moe 1969).

Red Grouper: Anthropogenic Disturbances - Fishing

Pressure—Total landings for this species in Florida were 8,495,343 in 2001 with the commercial fishery accounting for 82% of the landings. Ninety-nine percent of the landings were from the Gulf coast. Recreational landings are highest in the southwest region (FMRI 2003). Landings in Biscayne N.P. based on its creel census of 28,923 trips between January 1976 and July 1991 showed a total of 3,004 red grouper (Harper et al. 2000). Commercial accumulated landings reported to NOAA SEFSC (April 2005) show total landings of red grouper in Biscayne Bay (National park and non-national park), and adjacent Card Sound and Barnes Sound to have been a mere 31 pounds with a value of \$65 in 1997 and 14 pounds (\$24) in 2003.

Red grouper were declared overfished by the National Marine Fisheries Service (NMFS) in October of 2000. Ault et al.'s (2001) assessment of the reef fish populations inhabiting Biscayne N.P. indicated that populations



Figure 31. Red grouper. Source: FMRI 2003a.

of red grouper were growth overfished. The natural mortality rates of large reef species is very low and implies that in order to sustain the species, annual fishing mortality must be sustained below 10% for these species (Walters and Pearse 1996), which is almost never the case.

Because of the ecological and behavioral characteristics that red grouper share with other large reef species such as snappers and other species of groupers (including slow growth, hermaphroditism, high site fidelity, ontogenetic and reproductive migrations), commonly used fishery management tools are proving ineffective in protecting these long-lived species (Coleman et al. 2000). For example, size limits may protect females and the number of eggs available but may impact males. These limits may in fact limit the number of males available to fertilize those eggs, and thus reducing the reproductive output all the same. No management plans currently in place in the US serve to preserve the size, age, social structure or natural sex ratios of reef fish stocks (Coleman et al. 2000).

Bag limits and species prohibitions may do little to prevent high rates of mortality of these fishes as bycatch. Adult red grouper may be fished from waters that are too deep for them to survive being brought to the surface and they may be released in bad condition or already dead (Coleman et al. 2000). In addition, new technology such as fish finders and GPS devices have made it very easy for fishers to locate and exploit fish that form aggregations and are site specific and sedentary such as the groupers.

Protection.—In May 2003 as part of the NMFS Red Grouper Rebuilding Plan, measures to further protect the stocks of red grouper were put into effect by the Gulf of Mexico Fishery Management Council. These included reductions in commercial fishing in shallow waters, a shallow water trip limit, a bag limit of two red grouper within a total of five grouper of any species and a minimum size limit of twenty inches total length in South Florida waters. It also proposed a reduction in the deep-water grouper quota (GMFMC 2003). The consensus among specialists of long-lived reef species, including groupers, supports the establishment of no-take reserves as the only effective method of protecting these species (Coleman et al. 1999, 2000).

Red Drum - *Sciaenops ocellatus*

Red Drum: General Description

In the U.S., red drum (Figure 32) occur in the Atlantic Ocean from Massachusetts to Key West and throughout the Gulf of Mexico. Though historically present in Biscayne Bay, they are now considered rare. Adults are generally found offshore and juveniles within the estuary. Red drum is one of the most highly sought of recreational game fishes (FFWCC 2003).

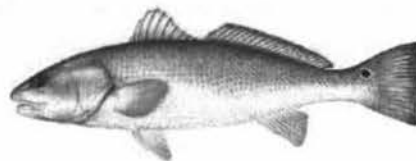


Figure 32. Red drum. Source: FMRI 2003b.

The largest individual ever caught weighed 98 lbs. and measured 59 inches in length. The oldest recorded age for a red drum is 62 years (ASMFC 2005). The Florida record for red drum was a fish 52 lbs 5 oz. Red drum in Florida can reach 25-35 years of age (FFWCC 2003).

Red Drum: Habitat

Adult—The adults of this species occur in open oceanic and gulf waters (FFWCC 2003). Adult red drum migrate seasonally from inshore waters in the spring through fall to warmer deeper offshore waters when surface water temperatures drop in the winter (ASMFC 2005). Trace element analysis of the otoliths (earbones) of red drum showed that those from the northeastern Atlantic coast are a separate stock from those in the Gulf of Mexico. This study also suggests that red drum return to spawn near their natal estuary (Patterson et al. 2004). If this is true, it is not probable that Biscayne Bay is likely to be repopulated by red drum from other areas (Gulf of Mexico).

Juveniles—Juveniles are found in a variety of habitats within estuarine areas: seagrass meadows over muddy and sand bottoms, in tidal freshwater habitats, low salinity reaches of estuaries, mangrove fringe areas and over shell and oyster reefs (ASMFC 2005). The protective cover that mangroves and seagrasses provide make Biscayne Bay a vital nursery area for this species (FFWCC 2003). Juveniles less than 1 year in age move in and out of backwater channels and canals and may remain in the estuary until the age of 4 years. Red drum tend to remain in the waters near where they were spawned. A recapture study of juveniles showed a 50-85% recapture rate within 6 miles of the original release site. The mangroves and seagrasses in the estuary provide detritus as their leaves decompose. This detritus is the basis of the food chain leading up to the shrimps and crabs that juvenile red drum feed on.

Red Drum: Life History

Most of the early life cycle of red drum is spent in nearshore waters. By the age of one year red drum are about 13-14 inches long. They mature at a relatively young age, with males reaching maturity at about two years and four lbs and females at four years and 13 lbs. Spawning may occur between the months of July and December and peak in September or October. Adults are found offshore in aggregations and spawning usually occurs near passes and inlets into the estuary (FFWCC 2003).

Females may produce one million eggs in a single spawn and spawn every three to five days. This results in tens of millions of eggs produced by a single female over the spawning season. Small juveniles feed on copepods and other zooplankton moving on to shrimp and crabs at larger sizes. By the age of two, their diet consists of fish in addition to crabs and shrimp (FFWCC 2003).

Red Drum: Anthropogenic Disturbances

Salinity, Temperature, and Dissolved Oxygen—The different life stages of red drum have different tolerable and optimal salinities (Neill et al. 1990). Eggs are spawned in seawater and larvae move into waters of lower salinities. Larvae are susceptible to changes in salinity and the optimum salinity for them is about 30 ppt. After about 2.5 weeks, the larvae reach a stage where they are less vulnerable to changes in salinity (FFWCC 2003). This period of wider salinity tolerance would coincide with the movement of larvae into estuarine nursery environments. Adults make annual migrations between offshore more saline waters to estuarine fresher water habitats indicating a wider salinity tolerance at this stage. Laboratory tests on juveniles 71-155 mm TL showed them to be able to survive in water with temperatures between 10° C and 33° C but there is evidence that red drum must slowly acclimatize to changes in temperature (Procarione & King, 1993). Sudden drops in temperature are not tolerated by adult fish and they tend to move into warmer, deeper waters in response to cold water temperatures.

The lack of estuarine habitat in Biscayne Bay, including Biscayne N.P., probably played a major role in the failure to re-establish a fishery for the red drum in Bay waters by the State of Florida's Florida Marine

Research Institute. Red drum were "abundant in all seasons" during the late 1800s (Smith 1896; FMRI 1994) when the Bay was a brackish marsh. Subsequently, this species all but disappeared from the Bay by the late 1950s. The State of Florida released over 1.5 million red drum juveniles over a ten-year period, at 12 locations from near the Oleta River State Recreation Area to Card Sound (Serafy et al. 1996, Serafy et al. 1999). It is believed that this effort was largely unsuccessful because juveniles were released into an environment that no longer contained suitable (i.e. consistently brackish) estuarine habitats (Serafy et al. 1996).

Loss of habitat—Loss of habitat is considered one of the most imminent threats to red drum. The coastal development that has occurred in the Miami area over the last century has already led to the loss of nursery habitat such as mangroves and fresh water inlets in Biscayne Bay. Changes in the hydrology of the area has shifted the Bay to an environment less favorable to red drum and attempts to reestablish this species met with failure (Serafy et al. 1996, 1999). Current threats to remaining habitat include dredging, jetty construction, nutrient enrichment through agricultural activities, pollutant discharge from boats, hazardous material spills, alteration of freshwater flows, and further loss of coastal wetland areas to development (ASMFC 2005). Oyster bars are believed to be important habitat for red drum. de Sylva (1976) noted a correlation between the disappearance of oyster bars (due to salinity changes) and loss of Biscayne Bay's drum species. The simultaneous disappearance of red drum and oyster bars in Biscayne Bay is supported by the observations of at least one commercial fisherman who has harvested bait shrimp from Biscayne Bay since the late 1950s (Luznar, personal communication).

Red Drum: Anthropogenic Disturbances—Fishing

Pressure—Red drum are a popular recreationally fished species as they are voracious eaters and strike readily at a variety of bait. Red drum has been fished commercially since at least the 1850's. Since the early 1980's the fishery in the southeastern US has become almost completely recreational, with 90% of total landings by recreational fishers (FFWCC 2003). Currently there is no commercial fishery for red drum in Florida as their sale is prohibited by the Florida Administrative Code.

The recreational fishery consists mostly of the taking of sub-adults ("puppy drum") in estuaries and bays and large trophy fish which must be released due to maximum size limits. The number of these catch and release fish has risen, with a peak of 1.6 million fish in 1995. Because red drum reach a large size before maturity, the fishing of "puppy drum" targets sub-adults in the 1-4 year old range and is what accounts for the highest fishing mortality in red drum (ASMFC 2005).

In the 1970's, the population of red drum in Florida began to decline and red drum disappeared almost entirely from Biscayne Bay (FFWCC 2003). The last stock assessment for red drum was conducted in 2000 and included data up to 1998. Due to the limited data available to base stock assessment measures, stock status is based on spawning potential ratio (SPR) which is a measure of reproductive capability. SPR is expressed as the ratio of all the eggs that could be produced by a mature fish over its lifetime if the stock is fished vs. unfished. Based on the current goal of 40% SPR, it has been concluded that the stock is currently overfished. In this assessment, it was reported that recruitment (fish reaching one year of age) had declined from 1.2 million in 1987 to 200,000 in 1998 in the southern region (Florida to South Carolina) (ASMFC 2005).

Protection—Increased protection measures for red drum were first initiated in 1986. In 1988, commercial harvests in Florida were banned and restrictions on recreational fishing were increased (FFWCC 2003). In

order to achieve 40% SPR, an amendment to the Red Drum Fishery Management Plan was adopted in 2002 imposing stricter size and catch limits. Currently in Florida, the bag limit for red drum is one fish between 18-27 inches per day (ASMFC 2005).

Gray Snapper – *Lutjanus griseus*

Gray Snapper: General Biology

Populations of adult gray snapper (Figure 33) are known from southeastern Brazil, the Caribbean, and the Bahamas to the northern Gulf of Mexico, Bermuda, and North Carolina (Grimes et al. 1982; Robins and Ray 1986; Smith 1997). The subtropical marine ecosystems of South Florida form a prime habitat for an extensive population of this species where adults occur primarily along the reef tract and

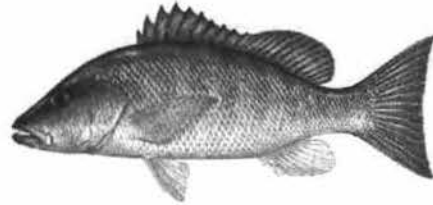


Figure 33. Gray Snapper. Source: FMRI 2003c.

juveniles utilize nursery grounds within coastal bays, including Biscayne Bay. Adults are believed to recruit to the reef from sea grass and mangrove nursery habitats of

Biscayne Bay where they may spend their juvenile phase before migrating to the coral reefs as young adults. The source of larval recruits and extent to which population replenishment relies on upstream populations (e.g. Cuba and the Yucatan) is unknown.

Gray Snapper: Habitat

For gray snapper, Biscayne Bay serves primarily as a juvenile nursery habitat. While mature fish are known to occur within the Bay (e.g. Faunce et al. 2002) spawning takes place elsewhere as ripe and running adults are rarely found within the bay habitats (Crocker 1962, Rutherford et al. 1983). Ault et al.'s (2001) examination of rollerframe trawl and reef-fish visual survey data from studies conducted in Biscayne N.P. indicate that the juvenile stages of gray snapper occur throughout the Bay while the adult stages are largely absent, occurring instead in platform margin reef habitats. In South Florida gray snapper migrate to offshore areas and spawn during the new moon periods from June to September (Starck and Schroeder 1970; Rutherford et al. 1989; Domeier and Colin 1997). The waters off Alligator Reef (Starck 1970) and those near reefs off Marathon (Rutherford et al. 1989) and in the Middle Keys are important known spawning grounds for gray snapper. The resulting offspring have an offshore pelagic larval phase which has been described for laboratory-reared (Richards and Saksena 1980) and wild-caught specimens (Richards et al. 1994).

Gray Snapper: Early Life History

Very little is known of the biology and ecology of larvae and early juveniles of this species. The pelagic larval phase of snappers recruiting to waters adjacent to Biscayne N.P. (e.g. Florida Bay) ranges from ca. 36–42 days (Jones et al. 2001). Evidence of the wide dispersal potential of this stage is supported by the presence of larvae within bay inlets of North Carolina (Hettler and Barker 1993) and the occurrence of juveniles as far north as Massachusetts (Sumner et al. 1911). Gray snapper in such northern extents have presumably been expatriated by the Gulf Stream and do not survive the winter.

Previous attempts to collect snapper larvae within waters adjacent to Biscayne N.P. have resulted in little success. No gray snapper larvae were collected in ichthyoplankton sampling in Florida Bay conducted by Rutherford et al. (1989). Only a few specimens were collected by Powell et al. (1989) or Collins and Finucane

(1984), the youngest of which were actually external to Florida Bay (i.e. offshore in Hawk Channel). Previous work indicates only the latest larval stages were found to enter Florida Bay and Biscayne Bay from offshore Atlantic waters through inter-island channels in the Florida Keys (Jones et al. 2001, Maddox 1997); late stage larvae may also enter the Bay from the Gulf across the southwestern Florida Shelf, but this transport scenario has yet to be sufficiently investigated.

At 10–12 mm SL (Starck and Schroeder 1970 Richards and Saksena 1980) gray snapper settle from the plankton into seagrass meadows in Florida Bay (Starck 1970, Chester and Thayer 1990). Early juveniles are solitary, diurnal feeders that exhibit high site fidelity at this stage. The seagrass beds offer shelter from predation and provide a rich source of small invertebrate prey. After reaching ca. 80 mm SL, fish initiate ontogenetic migrations and aggregate in mangrove prop root habitats and channel edges which offer larger structure for shelter (Starck and Schroeder 1970).

Gray Snapper: Juvenile Nursery

Despite the anthropogenically derived changes to the water quality, habitats, and ecosystem, gray snapper have remained an abundant component of the of Biscayne Bay mangrove prop-root habitat over the last century (Smith, 1896, Serafy et al. 2003). Gray snapper were one of only three fish taxa inhabiting the mangrove prop-root habitats of Biscayne Bay that exhibited significant seasonal differences in densities, which were higher in the warm wet season vs. the cool, dry season (Serafy et al. 2003). However, it is unclear the extent to which the onset of the reproductive season—which coincides with the beginning of the wet season—or seasonally associated ontogenetic migrations were responsible for these patterns.

Serafy et al. (2003) examined their Biscayne Bay visual survey data for evidence of a modal size progression to demonstrate ontogenetic migrations from mangrove to reef habitats. However, no such pattern was found for gray snapper. The authors suggested that the lack of such a pattern was a result of 1) differential fishing pressure on the reef vs. in the mangroves (i.e. the larger, older fish on the reef are quickly harvested), 2) populations of gray snapper expand from mangrove to mangrove and reef habitats rather than shift from mangrove to reef habitats, and 3) data from Starck and Schroeder (1970) suggest that females are more numerous inshore, while males tend to occur offshore.

Gray Snapper: Age & Growth

A number of previous studies have examined age and growth of snappers in the region of South Florida. Initially, scale-based techniques were employed in estimating age and determining growth rates of gray snapper from the Florida Keys and Florida Bay (Croker 1962, Starck and Schroeder 1970). Based on scale-derived aging, Rutherford et al. (1983) concluded that gray snapper in South Florida displayed growth rates of 9 mm SL per month and that ontogenetic migrations to offshore adult habitats occur at 3–4 years of age. Unfortunately, many life history parameters cannot be reliably estimated from scales as these structures are often replaced after loss, are frequently disfigured, and rarely validated for reliability.

More recently, otolith-based methods have been employed as a more reliable alternative to scalebased work. Unfortunately, age (Manooch and Matheson 1981, Johnson et al. 1994) and growth (Johnson et al. 1994) were estimated from otolith annuli prior to validation of annular deposition growth increments. Early works relying on otolith annuli were probably rife with inaccuracies, most likely the result of misinterpretations of subannual growth rings as annual (Claro and Garcia-Arteaga 1994). Marginal increment analysis has only very recently been used to actually validate the annular deposition of growth increments of otoliths in gray snapper from Florida (Burton 2001). In addition, otolith marking methods have been used to validate daily

increment deposition in otoliths of gray (Ahrenholz 2000, Allman and Grimes 2002) and lane snapper (Ahrenholz 2000). Daily increment deposition of a related species, yellowtail snapper, have been validated through laboratory rearing (Lindeman 1997).

Gray Snapper: Otolith Microchemistry

Lara et al. (*in review*) traced the ontogenetic movements of juvenile snappers from the nursery grounds in Florida Bay to adult habitats along the offshore reef tract of the Straits of Florida using otolith microchemistry as natural tags. This study is based on the presence of trace metals and rare earth elements in the otoliths. Preliminary results define a unique suite of elements that distinguish fish residing in Florida Bay as juveniles from fish from other regions, including Biscayne N.P., Dry Tortugas, Lower Florida Keys, and Ten Thousand Islands.

Gray Snapper: Anthropogenic Disturbances - Fishing

Gray snapper comprise a large proportion of the commercial and recreational finfish harvest in the state of Florida. Landings in Florida from commercial harvesting from 1998–2001 averaged 158,757 kg per yr with a value of \$635,000 dollars in 2001. Commercial accumulated landings reported to NOAA SEFSC (April 2005) show total landings of gray snapper in Biscayne Bay (national park and non-national park), and adjacent Card Sound and Barnes Sound between 1997 and 2004 to have been between 4 pounds (\$9) (in 1998) and 404 pounds (\$757) (in 2001). Recreational fishing was responsible for landings of 518,909 - 753,417 kg per yr between 1998 and 2002 (U.S. DOC, 2003). The economic value of the recreational component of the catch is not readily estimated, as it generates indirect, value-added revenue through support industries, e.g. tourism, restaurants, fishing supply and boating stores, dive shops, etc. (Browder et al. 2003).

In Biscayne Bay, gray snapper are one of the most popular game fish, comprising the highest harvest in the recreational fishery. Due primarily to its extreme fighting ability, all sizes of these fishes are highly valued by anglers (Manooch 1984). The recreational fishing effort in South Florida is continually expanding as the greatest number of reported fishing trips to Florida Bay alone, for example, reached an all time high in 2001 (Schmidt et al. 2002). Recreational fishing within Florida Bay along with recreational and commercial fishing within Biscayne Bay and along Florida's reef tract have already affected the size structure of snapper populations (Ault et al. 1998, Faunce et al. 2002). This intensive fishing combined with high rates of other sources of mortality have resulted in more than half of the species of snappers in south Florida being growth overfished (Ault et al. 1998). Ault et al.'s (2001) assessment of the reef fish populations inhabiting Biscayne N.P. indicated that populations of gray snapper were growth overfished.

Conclusions

A comprehensive, historically based account of the fishes inhabiting Biscayne N.P. is lacking because all of the quantitative studies were conducted after a tremendous amount of anthropogenic change had occurred within Biscayne Bay and its surrounding coastal wetlands. Only a limited number of studies examined both the northern and southern portions of the Bay but excluded the adjacent offshore (i.e. reefal) waters (e. g. Berkeley and Campos 1984). The temporal scale of most of the previous studies have been insufficient to accurately evaluate changes in fish community structure on the appropriate, ecological time scale. Also, a number of observations that have been reported to have originated from within the Bay proper have actually been inappropriately combined with datasets from adjacent offshore (i.e. reefal) waters (e.g. Ault et al. 2001).

Many of the estuarine fishes (e.g. the drums of the family Sciaenidae) have been reduced in number, or have totally disappeared with the elimination of the Bay's freshwater and brackish marsh habitats that once bordered the western shoreline, and as oyster bars, especially in northern Biscayne Bay, disappeared. Consequently, for at least the last 30 years, Biscayne Bay's ichthyofauna has been comprised primarily of tropical and temperate marine species -- an expected result of a subtropical estuary turned freshwater-pulsed lagoon. In the mid 1970s de Sylva (1976) pointed out how little quantitative data existed on the bay's fishes and fisheries. This void was partially filled by the Berkeley and Campos (1984) assessment of Biscayne Bay's fishery resources, but this work is now in dire need of updating.

Marine Invertebrates

Spiny Lobster

The Caribbean spiny lobster (Figure 34, *Panulirus argus*) is a species of special concern in south Florida because of its economic importance. Since 1986, spiny lobster has consistently ranked as the first or second most valuable commercial fishery in Florida, alternating with pink shrimp. The dockside value of the commercial lobster fishery in Florida now varies between \$20 and \$30 million/yr (Harper 1995), which does not include ancillary economic benefits (i.e., "multiplier effects") such as the value of the large recreational sport diving fishery for lobster. Each year, over 150,000 people purchase permits to recreationally fish for lobster in south Florida, accounting for ~20% of the total recorded catch.



Figure 34. Spiny Lobster.
Source: FMRI 2003d.

Ecologically, *P. argus* is an important component of the south Florida marine ecosystem for several reasons. It is a locally abundant, large benthic predator of a variety of gastropods, bivalves, crustaceans, echinoderms, and small fishes (Andree 1981, Herrnkind et al. 1988). Its juveniles also fall prey to an enormous variety of even larger predators, comprising a major portion of the diet in many species (e.g., nurse sharks, bonnethead sharks, rays), some of which are important to sport fisheries (e.g., permit, bonefish) and commercial fisheries (e.g., gray snapper, grouper) (Smith and Herrnkind 1992). Lobsters are thus an integral component of the trophic structure in south Florida, both as predators and prey.

The Caribbean spiny lobster is a tropical, marine species that tolerates neither estuarine conditions nor cold waters. Thus, within the continental United States, *P. argus* persists in large numbers only off the south coast of Florida, although small, inconsistent populations occur on rocky reefs within the Gulf Stream's influence off the coast of Georgia, South Carolina, and North Carolina. By far the largest adult populations of *P. argus* and the only nursery areas for the species occur in south Florida, including Biscayne N.P. where a large fraction of the central and eastern portions of the bay serve as a nursery for young lobsters. Several studies of spiny lobster ecology have been conducted in the Biscayne N.P., but most of the research on spiny lobsters in south Florida has taken place in the adjacent Florida Keys ecosystem.

Spiny Lobster: Life History

The Caribbean spiny lobster has a complex life history, involving several distinctly different life stages each requiring a separate marine habitat for completion of its life cycle (Butler and Herrnkind 2001). Adult *P.*

argus, which may live for > 25 yrs, dwell primarily in coral reef environments, taking refuge by day on the reefs and foraging at night in rubble and seagrass habitats up several km from the reef (Cox et al. 1997). Reproductive activities and spawning take place exclusively on the reef, primarily from March – July in Florida. The resultant planktonic larvae are long-lived (estimated 6 – 12 month duration; ~ 11 larval stages), planktotrophic predators of the open ocean realm where they are presumably transported great distances. This is no doubt the reason for their widespread geographic distribution (Brazil to Bermuda) and what is believed to be a pan-Caribbean population with little genetic substructure (Silberman and Walsh 1994, Silberman et al. 1994). Following larval dispersal, the subsequent postlarval stage travels inshore each month on new moon flood tides (Acosta et al. 1997). Those that encounter structurally complex vegetation settle, preferably in clumps of red macroalgae (e.g., *Laurencia* spp.) within hard-bottom habitat, but sometimes in seagrass meadows or among heavily fouled mangrove roots (Marx and Herrnkind 1985, Herrnkind and Butler 1986, Acosta and Butler 1997). The postlarvae then metamorphose into the early benthic juvenile (EBJ) stage and remain hidden and solitary within their settlement habitat for ~ 3 - 4 months (Butler and Herrnkind 1991, Herrnkind and Butler 1994). Later, the juveniles emerge from the macroalgae, become social, and take up daytime refuge in crevice-bearing shelters such as sponges, corals, and solution holes that occur on hard-bottom habitat (Eggleston et al. 1990, Forcucci et al. 1994, Butler et al. 1995, Herrnkind et al. 1997a). Postlarval juveniles initially occupy relatively small home ranges, but at 45 mm CL (carapace length – the standard scientific measure of size in lobster) they become more nomadic (see Butler and Herrnkind 2001). After 1 – 2 years in the shallow, inshore nurseries, the lobsters then migrate offshore to the coral reefs. Lobsters can not be reliably aged, but based on size and estimated rates of growth, spiny lobsters may live for 25 years or so. As adults, mortality from natural sources is low. The ecological processes that naturally limit lobster populations are those that impact juveniles within nursery habitat.

Spiny Lobster: Nursery Habitats

Shallow hard-bottom habitat is the primary nursery for spiny lobster within the Biscayne N.P., as it is throughout south Florida. Hard-bottom (also called: live-bottom, hardgrounds, bedrock outcrops, alcyonarian-sponge communities, nearshore rock-bottom, and algal-dominated hard-bottom; Chiappone 1996) within Biscayne N.P. is typically shallow (< 3m) and is characterized by low relief (< 0.5 m), limestone bedrock overlain by a thin veneer of sediment. As the term “algal-dominated hard-bottom” implies, numerous species of red, green, and brown macroalgae occur there. However, bushy, red macroalgae (primarily *Laurencia* spp.) dominate the algal biomass and serves as the primary settlement habitat for lobster. Sponges, soft corals, and sometimes hard corals are prominent biogenic structural features of hard-bottom habitat and, along with solution holes, are the primary shelters occupied by juvenile and subadult spiny lobster. Massive sponges (e.g., loggerhead sponge, *Speciospongia vesparium*; vase sponge *Ircinia campana*; stinker sponge, *Ircinia felix*, etc.) and a few species of tall, branching octocorals (sea plume, *Pseudopterogorgia* spp.; angular sea whip, *Pterogorgia anceps*) are common, and they provide most of the three-dimensional structure in these otherwise flat seascapes. Hard-bottom habitat – thus the major lobster nursery – is found primarily in the eastern and central portions of Biscayne Bay where it covers a substantial fraction of the seafloor. There are no well developed hard-bottom areas or significant lobster nurseries in western Biscayne Bay (Butler, no date), presumably due to decreased larval transport from oceanic sources, low salinity from freshwater canal discharge, and higher rates of sedimentation from terrigenous sources and coastal development (Rosenberg 1975, Wang et al. 2003). Sponges, octocorals, and hard corals, like juvenile lobsters, are intolerant of these conditions (Field and Butler 1994, Lirman et al. 2003, Biber et al. 2004).

Spiny Lobster: Factors Limiting Juvenile Abundance–Postlarval Supply

The local availability of new recruits (i.e., planktonic postlarvae) transported from outside of Biscayne N.P. ultimately determines the maximum lobster population possible. Large-scale oceanographic processes operating offshore of south Florida, coupled with larval and postlarval planktonic mortality, are primarily responsible for changes in the temporal pattern of supply of lobster postlarvae to coastal nurseries (Acosta et al. 1997, Acosta and Butler 1999, Yeung et al. 2001). Unlike Florida Bay, where a labyrinth of carbonate mud-banks

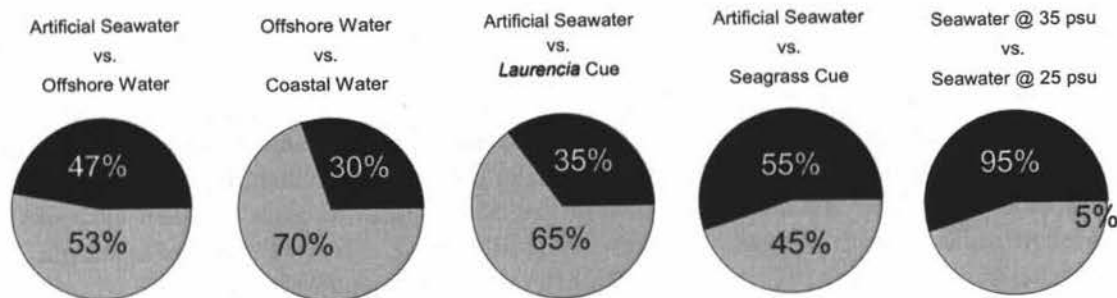
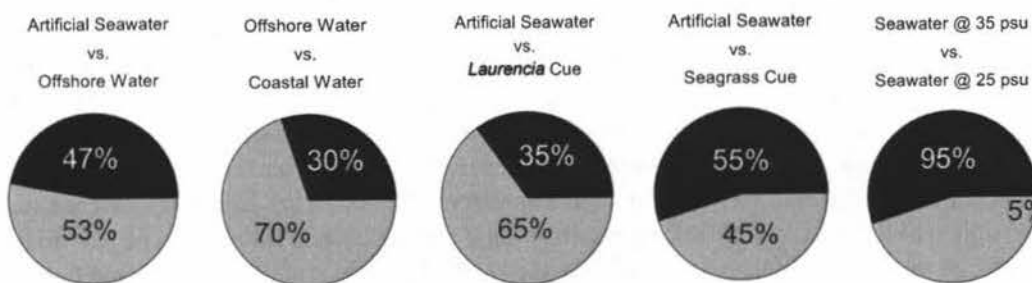


Figure 35. Pie diagrams depicting the results of five separate laboratory experiments in which postlarval *P. argus* were given a choice of two water masses from which to select. The first two pie diagrams show that postlarvae swim toward coastal water cues. The second two pie diagrams show that postlarvae swim toward coastal cues provided by the macroalga *Laurencia*, but not cues produced by the most common seagrass (*Thalassia testudinum*). The last diagram shows the aversion of postlarvae for water of low salinity. N = 22 – 75 per experiment. Unpublished data; Jason Goldstein and Mark Butler, Department of Biological Sciences, Old Dominion University, Norfolk, VA 23529.

restricts the flow of water (Nuttie et al. 2000) and the transport of lobster postlarvae (Field and Butler 1994), the circulation of water and postlarvae in Biscayne Bay is more straightforward. The large passes and channels between the Keys and banks forming the eastern boundary of the bay serve as the major source of tidal exchange with Atlantic waters, with only minor flows through the north-south passes (Pitts 2001, Wang et al. 2003). The result is diminished flow and longer water residence times from east to west in the bay, thus a reduced supply of oceanic larvae in western Biscayne Bay (Cropper et al. 2001, Wang et al. 2003).



postlarvae, Herrnkind (1986) and Butler (1999) found that Biscayne Bay is a "sink" for postlarvae (i.e., there is no net gain or loss of postlarvae to the bay).

Spiny Lobster: Factors Limiting Juvenile Abundance–Predation and Habitat Availability

Following settlement, post-settlement mortality (i.e., predation, disease) takes its toll. Experimental studies indicate that the local abundance of juvenile lobsters is limited in a density-dependent manner by shelter-

imposed demographic bottlenecks that set an upper threshold, below which the juvenile population fluctuates in response to local changes in larval supply (Butler and Herrnkind 1997, Herrnkind et al. 1997a,b). Predation by various species of fish (Smith and Herrnkind 1992, Mintz et al. 1994) and by octopus (Berger and Butler 2001) is normally the most significant source of mortality for juvenile lobsters in Florida. It is estimated that < 5% of the postlarvae that settle survive their first year (Butler et al. 1997, Sharp et al. 2000). For the smallest lobsters (i.e., recently settled postlarvae and EBJ), the availability of red macroalgae is crucial to survival, so they rarely leave it until they are too large to effectively shelter there (Herrnkind and Butler 1986, Butler and Herrnkind 1991, Acosta and Butler 1997). Not only are EBJs sheltered from predators within the bushy algae, their cryptic behavior, asocial nature, and camouflage coloration makes them less visible as well. For larger, crevice-dwelling juvenile lobsters, the risk of predation diminishes significantly when shelters of suitable dimensions are available, and for lobsters dwelling in social aggregations and thus capable of group defense (Eggleston et al. 1990, 1992, Mintz et al. 1994, Smith and Herrnkind 1992, Herrnkind et al. 2001). Therefore, the abundance of hard-bottom with ample stands of *Laurencia* and abundant crevice shelters is characteristic of good nursery habitat within Biscayne N.P. Surveys of juvenile lobster in Biscayne N.P. indicate that they are most abundant in eastern and central Biscayne Bay where their nursery habitat (hard-bottom and seagrass with ample stands of *Laurencia* macroalgae) is most abundant (Eldred et al. 1972, Butler et al. 1992, unpublished data).

Spiny Lobster: Factors Limiting Juvenile Abundance—Food Availability

Postlarval lobsters are the first stage to enter the nearshore waters of Florida Bay, but they are incapable of feeding, living instead off internal energy stores accumulated during the previous larval stages. Food for EBJs does not normally appear to be limiting, because they have access to abundant prey (e.g., copepods, mollusks, shrimp, etc.) that also inhabit their macroalgal settlement habitat (Herrnkind et al. 1988). However, siltation can reduce prey abundance in macroalgae, inducing emigration of EBJs from the food depleted habitat (Marx and Herrnkind 1985, Herrnkind et al. 1988). It is therefore likely that lobsters immigrating into western Biscayne Bay where siltation is greatest, would find the area unsuitable.

Spiny Lobster: Factors Limiting Juvenile Abundance—Movements

Spiny lobsters exhibit a wide range of ontogenetic, reproductive, and episodic population movements that reflect changing ecological conditions of the benthic life stage during ontogeny, and eventual movement to oceanic sites for spawning. These patterns are also seen in *P. argus* within Biscayne N.P. As noted earlier, there is an incremental ontogenetic pattern of movement associated with maturity in which large juvenile and subadult lobsters gradually depart Biscayne Bay and move offshore to occupy patch reefs, rocky crevices, undercut seagrass banks, and the barrier reef itself. During this gradual ontogenetic migration, juvenile *P. argus* use corridors of food-rich habitat, particularly shallow sea grass meadows, within which individuals move about nomadically in a spatial pattern dictated by the location of prey and shelter (Herrnkind 1980, Cox et al. 1997, Briones-Fourzan and Lozano-Alvarez 2001). These nightly movements can be up to tens of kilometers, but more typically involve forays of a few kilometers. Limited mark-recapture evidence suggests that these nomadic movements of adult lobsters results in a net loss of lobsters from Biscayne N.P. to the north and a net gain of adults from the Florida Keys to the south (Lyons et al. 1981, Gregory and Labisky 1986).

Seasonal movements of lobsters in Biscayne N.P. are tied to the reproductive period and thus occur in late winter or early spring just prior to the reproductive season (Herrnkind 1980). During the reproductive season, shifts in habitat use on the reef also occur in which large, dominant males exclude smaller males from prime mating areas on the forereef. The small males move to adjacent patch reefs and other crevice-bearing

structures, resulting in a significant shift to a female dominated sex ratio on the reef (Lyons et al. 1981, Cox et al. 1997).

The localized, brief but spectacular non-reproductive mass single-file offshore "migrations" by *P. argus* reported in the northern Caribbean and the Bahamas are not known to occur in Biscayne N.P., although smaller versions (i.e., with fewer participants) of these same dramatic movements do (Herrknind 1980). These events are associated with evasive movements from areas of disturbance (subject to rapid cooling and high turbulence) to more stable sites (Herrknind 1980). These movements also may also benefit the redistribution of individuals into new habitat, guided by one of the most remarkable navigational capabilities in the animal kingdom. Recent findings by Boles and Lohman (2003) provide compelling evidence that lobsters possess both a magnetic directional compass and a geographic position sense. The latter capability is the first documented for an invertebrate and, combined with their directional sense, grants them an orientation ability that equals or exceeds that of the best known vertebrates (e.g., passenger pigeons and sea turtles).

Spiny Lobster: Factors Limiting Juvenile Abundance–Disease

There are four diseases known to infect *P. argus*, but there are undoubtedly more that have not been discovered (Evans et al. 2000, Porter et al. 2001, Shields and Behringer 2004). Three of the four known diseases were reported from *P. argus* populations in Florida: shell disease (Porter et al. 2001), microsporidiosis (Bach and Beardsley 1976), and PaV1 virus (Shields and Behringer 2004). Shell disease (Iverson and Beardsley 1976) and PaV1 virus (Shields and Behringer 2004) are reported in Biscayne Bay. Shell disease is rarely fatal, but the PaV1 virus is pathogenic and lethal. Most infected lobsters die within 90 days. Methodical sampling for disease in lobsters in south Florida has only been conducted for PaV1 viral infections, and only since its discovery in 1999. The disease is widespread in the south Florida, appearing at about 25% of the sites where lobsters were surveyed, including sites in Biscayne Bay. The prevalence of PaV1 infections in juvenile lobsters has remained around 5% per site (max = 30%/site). The disease is most frequent (mean = 16%) among the smallest crevice-dwelling juveniles (<20mm CL) and its incidence declines with size; few adults (<1%) are affected. Its prevalence in EBJs in nature is unknown, but laboratory evidence suggests that it is likely to be even higher than in larger juveniles. Laboratory experiments indicate that the virus is transmitted most effectively by direct contact with infected individuals, but can also be contracted via ingestion of infected tissue (Behringer 2003).

Spiny Lobster: Population Distribution and Abundance

The lobsters that inhabit Biscayne Bay proper are nearly all juveniles; no reproductive activity has been reported within the bay. As noted earlier, within Biscayne Bay nearly all of the juveniles are found in the eastern and central bay; very few are found in the western bay where habitat and water quality are deleterious to them. Adult lobsters are found primarily on the oceanside portion of Biscayne N.P. to the east of the fringing keys. There they inhabit by day a variety of crevices – rocky outcroppings, undercut seagrass banks, patch reefs, and the barrier reef. At night, adult *P. argus* are found over a wider range of habitats as they forage in rubble zones and in seagrass beds. Densities of crevice-dwelling juveniles on hard-bottom habitat in Florida vary widely, but in prime nursery habitat their numbers can exceed 400 individuals/ha (Forcucci et al. 1994). The density of EBJ can not be easily determined, but based on estimates of mortality (Butler et al 1997, Sharp et al. 2000) must be at least an order of magnitude greater than that of the crevice-dwelling juveniles. Time-series data on crevice-dwelling juvenile abundance within Biscayne N.P. are limited. Data from nine sites surveyed just prior to Hurricane Andrew in 1992, just after the hurricane, and they one year and ten years later suggest a relatively stable population in 1992-93 (Figure 36; Butler, no date). Lobster densities were lower in 2002 but without a more complete data set for the intervening and more recent years it is not possible to determine trends.

Creel survey data on the landings of adult lobsters in the recreational fishery in the area, collected by the National Park Service since 1987 (Todd Kellison, Biscayne National Park, Homestead, FL) show that the mean catch per trip increased from the late 1980's into the late 1990's with a subsequent decline thereafter (Figure 37). However, the size of the lobsters retrieved in the recreational fishery has remained stable (Figure 37). Fishery independent data are needed to unambiguously determine whether any changes in the adult population have occurred over time.

Spiny Lobster: Threats & Management Issues

Potential threats to lobster populations in Biscayne N.P. include: commercial shrimping activities, hurricanes, climate change, and diminished water quality. Commercial shrimping activities, primarily trawling for bait shrimp, are permitted in Biscayne N.P. (Berkeley et al. 1985) and pose a threat to spiny lobsters. Trawling is done primarily within seagrass habitats and juvenile lobsters are caught in trawls as bycatch (Eldred et al. 1972, Berkeley et al. 1985). However, the potential impact of shrimping on lobster recruitment has not been studied.

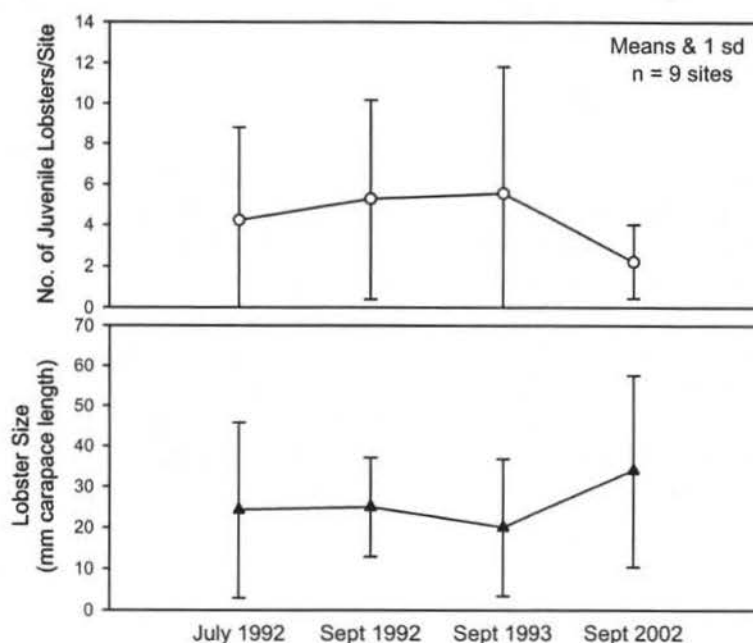


Figure 36. The mean relative abundance (top panel) and size (bottom panel) of juvenile *P. argus* surveyed by divers at 9 sites in Biscayne Bay over a ten year period. Estimates are based on timed catch-per-unit surveys of 1 hr at each site. Source: Butler, unpublished data.

Hurricanes may temporarily impact lobster populations via turbulent transport, local habitat destruction, and freshwater run-off, but their effects are not likely to be long lasting. In fact, following Hurricane Andrew in 1992, the overall abundance of juvenile lobsters in Biscayne Bay was similar to that before the hurricane (Figure 36), although their distributions had shifted in response to movement from the most heavily impacted areas. The effects of global climate change, in particular, global warming on lobster populations in Florida Bay are unknown and probably more complex than one might assume. Geographically heterogeneous and more extreme climatic effects, along with indirect effects on lobster habitat, prey, and predators render simple hypotheses based on thermal stress alone meaningless.

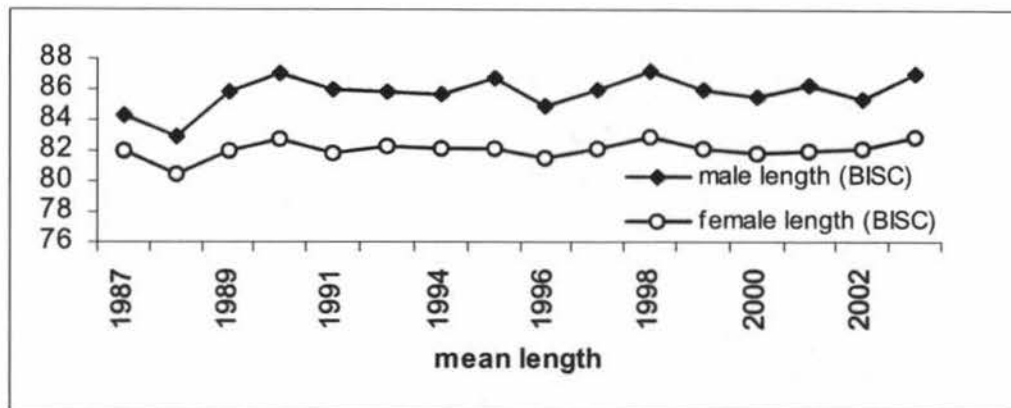


Figure 37. Mean size (carapace length) of lobsters caught in the recreational fishery and landed in BNP from 1987 – 2003. Data from BNP (Todd Kellison).

Anthropogenic impacts on water quality and marine habitats in Biscayne Bay are well documented, severe in some places, and are likely to continue with perhaps unpredictable results (Rosenberg 1975, Long et al. 2002, Finkle and Charlier 2003). This is especially the case in western Biscayne Bay closest to the sources of anthropogenic impacts. Diminished water quality (i.e., eutrophication and chemical contaminants), altered salinity, and nursery habitat change are the gravest threats to the persistence of lobsters in Biscayne N.P. Hard-bottom communities and the lobster populations they sustain have proven to be sensitive indicators of ecosystem change (Butler et al. 1995, Herrnkind et al. 1997a,b). Salinities appreciably different from 35psu kill *P. argus* postlarvae and EBJ (Field and Butler 1994) and are a stressor to larger lobsters, which alter their patterns of movement when salinities change (Butler 2003). It is also feasible that inappropriate salinity may promote PaV1 disease in spiny lobster as it does in other crustaceans (LeMoullac and Haffner 2000). Although the direct impact of inappropriate salinity on lobster are likely to be severe, field studies and simulation modeling suggest that significant effects of eutrophication and salinity change on lobster will also be manifested indirectly through changes in nursery habitat structure and disease epidemiology (Butler 2003, Butler et al in press). For example, significant changes in macroalgal and seagrass communities (i.e., lobster nursery habitat) are projected if nutrient-laden freshwater inputs into Biscayne Bay continue or increase (Biber et al. 2004). Sponge, hard coral, and octocoral abundances and community structure also diminish if salinity changes more than a few psu (Lirman et al. 2003, Lirman and Cropper 2003, Butler, no date). This loss of shelter for larger crevice-dwelling juvenile lobsters is likely to have two consequences: higher

mortality due to predation (assuming predator abundance and their foraging preferences and efficiency are not diminished), and an increased probability of intraspecific encounters and perhaps transmission of the PaV1 virus among lobsters.

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